The Diffusion of Transportation Effects In an Urban Network

David Burik

Large urban centers are served by transport networks which consist of a great number of links and nodes. Predicting what the effects of the construction of a proposed link, the abandonment of superfluous elements, or the improvement of existing links will be on the traffic flows over the entire system is currently a time-consuming and expensive undertaking. It is nevertheless, a necessary step for proper investment appraisal.

It is often the case that the amount of available capital will only allow for the completion of a relatively small scale projects. The cost of a full traffic study to assess the impact of several competing proposals is the same no matter the size of the investments. It is often held that the high cost of a full traffic study as a percentage of the cost of a small road investment does not warrant the execution of one. The decision-making process would be better assured of success if a traffic study existed to fully illuminate the unique changes which are induced by each individual proposed link improvement. Any method which would reduce the cost of the study is therefore potentially valuable.

The cost of a traffic study would be reduced in direct proportion to any shrinkage in the size of the network to be considered. It would be a great economy if the effects of an improvement on a single link could be clearly defined to be a subset of the network as a whole. If indeed there is a regional decomposability in transport networks it would be possible to operate a traffic study only for the pertinent region and to argue convincingly that all the effects of a

Mr. Burik is a student at Northwestern University where he has served as President of Alpha Omicron Chapter. *His paper was supported by NSF Grant SOC76-16832, and presented at the Undergraduate Paper Session, Illinois Geographical Society Meeting, Mattoon, April, 1977.*

link improvement have been captured. The cost of the regional traffic study would be lower than that of a full transport study by a constant determined by the proportion of the size of the region to the size of the total network. If there is no regionality in transport networks then a new method must be proposed to lower the cost of a traffic study. It is the purpose of this paper to answer the question, "Is a given network readily decomposable into regions between which there is relatively little interaction?"

A Theory of Network Use

The observation that trips from each single origin are not distributed equally to all destinations is the initial requirement in a search for network regionalization. Based on this criterion it is intuitively appealing to believe that some degree of regionalization occurs in urban networks. The existence of network regionalization is further evidenced by empirically gathered origin-destination matrices which are invariably sparse, indicating that specific origins have a definite discrimination in their choice of destination. What has been lacking to date has been the application of a theory which explains, and the existence of a model which predicts, the extent of this regionalization.

For purposes of a traffic study, a region will be taken to consist of an origin area and a destination area which encompasses a specified percentage of all trip-ends from the origin area. Therefore, to predict the effects of a link improvement, it is not necessary to rerun an assignment algorithm for the entire network, but will suffice to rerun assignments for origin-destination pairs which are in the same region as the proposed link improvement, assuming that all link flows outside of the region are unchanged. It further assumes that the effect on the flow of in-region links from the small percentage of trips which travel outside of a prescribed region, is negligible.

The next logical step is to theoretically explain the existence and definition of regions. For this we employ "Stouffer's Principle" of intervening opportunities:[1] in particular, its applications by Schneider for the Chicago Area Transportation Study.[2] Stouffer found the number of people migrating a given distance to be proportional to opportunities at that distance and inversely proportional to the number of intervening opportunities. Schneider interpreted this to mean that any trip from origin i will have a certain probability $P(S_j)$ of ending in area j.

The equation for this relationship is:

$$V_{ij} = V_i \bullet P(S_j)$$

where V_i represents the total number of origins in area i, and V_{ij} is the number of those trips which have area j as their destination. He discovered that the log of the number of journeys ending in areas closer to i than j is to i was inversely proportional to the number of intervening opportunities between i and j including those within j itself. The number of journeys terminating within j is, therefore, the difference. Schneider's formula is:

$$V_{ij} = V_i(e^{-LV} - e^{-L(V+V_j)})$$

where:

V = the sum of all destinations closer to i than j is to i

V_j = the number of opportunities in area j

L = a factor varying with trip type which was later defined as being the probability that an opportunity will satisfy this traveler when it is offered

Using this formula it is possible to define a region within which more than 99% of all predicted trips from a given origin will have their respective destinations. For the purpose of illustrating this effect, a hypothetical city and road network is specified. The exemplar city is a six level hierarchial city rather loosely based on urban central place theory. The city was assumed to be an isotropic plain so that the necessary links between any origin and destination pair is the shortest-distance, least-cost route. The final assumption was that no higher order place offered lower order services.

Two points, one on the periphery and the other in the center of the city, were chosen as origins. Areas of intervening opportunity were then demarcated for each separate level of service for each zone. Next Schneider's formula was applied using:

V_i = 600 for first order trips

V_i = 500 for second order trips

V_i = 400 for third order trips

V_i = 300 for fourth order trips

V_i = 200 for fifth order trips

V_i - 100 for sixth order trips

L was assumed to equal to one in all cases. The results for the center as origin example (Figure 1) yielded a region (bounded by the broken line) which includes 99.999% of all trip-ends from the origin; but contains only 59.04% of the nodes in the network. The application of the procedure to the peripheral origin resulted in a region (Figure 2) which contains 99.9513% of all trip-ends from the origin; but only 44.58% of the nodes in the network. When aggregating several proximate nodes to create an area, their individual regions may also be compounded to create a composite region. If a link is improved then only the trips with origins and destinations within its specified region need be reappraised with an assignment algorithm.

This exercise has presented a theoretical basis upon which to build an argument in favor of the existence of regionalization in urban transport networks.

Empirical Evidence

Actual empirical data for an existing road network has been examined for evidence of regionalization.[3] The urban area chosen was Bloomington-Normal, twin cities in Central Illinois.

The two main avenues of analysis were:

1) manipulation of an origin - destination matrix to determine if there is any apparent regionalization
2) comparison of complete assignment program runs to to trace the limits of flow variations due to investment on a single link.

Initial inspection of the Bloomington-Normal origin-destination survey revealed that the matrix was a sparse one. Further investigation resulted in the observation that there is a definite regional bias in local trip-making

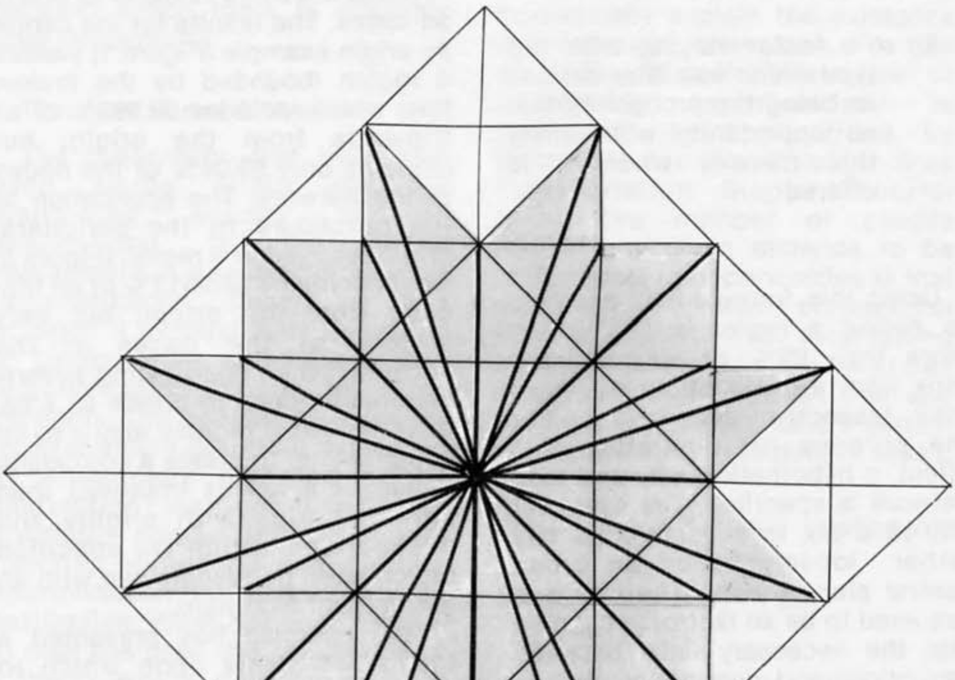

Figure 1
Hypothetical Network, Center as origin Solution

which is determined by location of the origin. On the basis of the origin destination table the city could be divided into a north, central, and south region. Origins in the north region sent trips to the north and central, while avoiding the southern zone. Origins in the southern area limited their trips to destinations in the southern and central area. Central area origins had destinations in all three regions. This behavior is indicitive, but does not ensure that a transport network is regionalized. Factors such as the operating through the speed-flow relationships of links determine whether the preliminary decomposition which is present in the origin-destination table analysis will continue to exist during the operation of a traffic assignment model.

The final check for network regionalization was to operationalize a traffic assignment model for use with the Bloomington-Normal origin-destination and link data. The model chosen was the "Small Network Interactive Traffic Assignment Program" originally written by Levinsohn[4] modified by Prashker[5] and Burik and Ormancioglu.[6] The search for regionalization was made by obtaining the original flow volumes on each link as assigned par the given data. Next, a series of individual links were given higher capacities and the program was rerun. Each new run which included only a single link capacity increase produced a new list of link flow volumes. These new flow volumes were compared to the original ones; significant changes mapped. The end result of this procedure was a mapping of the links which were signficantly effected by a capacity change on each individual specified link. These maps except for a minor discrepancy reinforced the validity of the borders delineated by manipulation of the origin-destination matrix.

It should be noted that in the assignment algorithm used:

total number of hours saved in a network	unit of new capacity on link k	= a	number of new shortest routes	number of trips made on new shortest routes

$$Z_k = ant$$

This means that the only trips which receive a new assignment in any subsequent run of the model after the basic network run, is traffic which, due to the capacity change, now has a new shortest route between its stated origin and destination. This means for our prototype example which has a central section which is relatively highly traveled, that the alteration of a link would have a substantially higher value of nt and therefore, a greater network effect than a perimeter link. A capacity improvement in the north might very well effect shortest routes for trips between northern origins and southern destinations, but the low number of trips which make the journey allow for the decomposition of the network.

CONCLUSION

The fact that network regionalization occurs in as small an urban area as Bloomington-Normal is an encouraging harbinger that the amount of regionalization in large metropolitan transport networks may be very pronounced. It remains to be seen, however, whether these regions will ever be clearly identified and if they shall prove to be of greater economy to transport planning.

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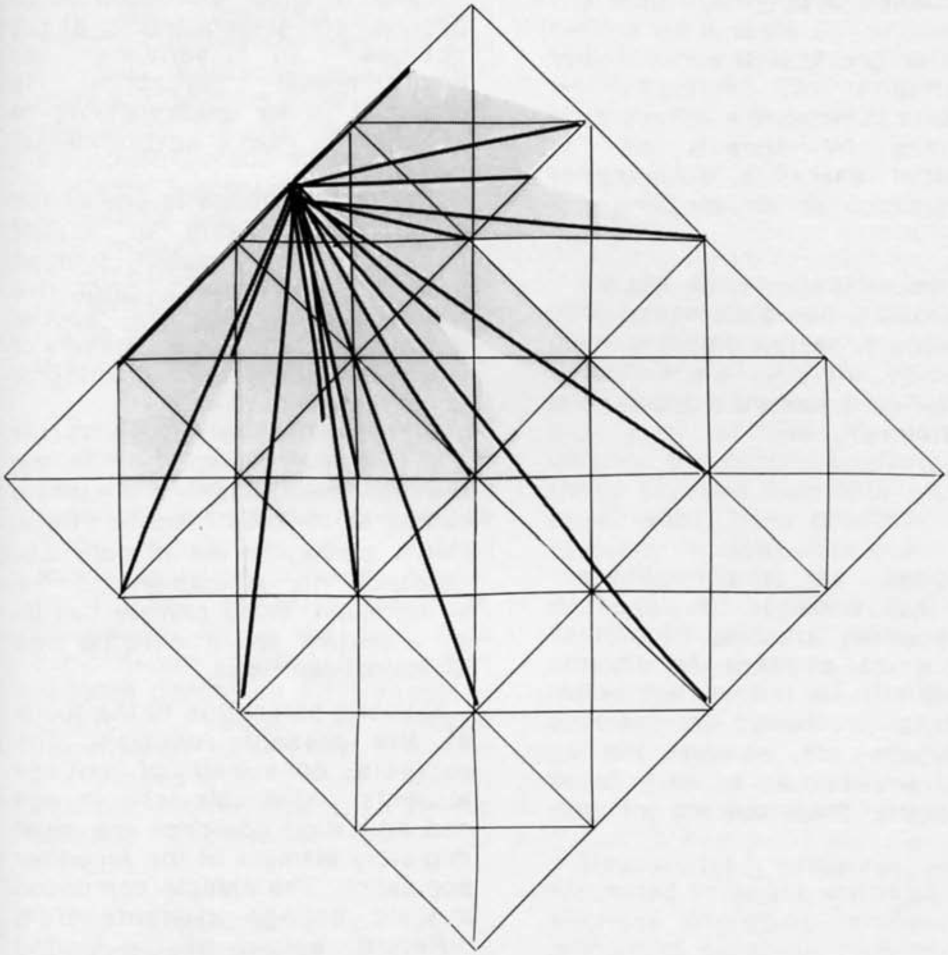

Figure 2
Hypothetical Network, Peripheral Origin Solution