Planning Considerations for Alternative Transit Route Structures

Gregory Lee Thompson

Transit route structures historically have focused on the central business district (CBD), and this orientation is often reinforced by planners wishing to improve transit. Unfortunately, their efforts have not halted the historic decline in transit usage. This result is not surprising. Travel to the CBD generally constitutes a small and declining percentage of the total. It would appear that planners wishing to achieve higher overall transit ridership should instead develop transit route structures oriented to larger and increasing segments of the spectrum of travel within the region.

Network design configurations oriented to this objective exist. They include the grid and timed transfer system concepts. These designs are multi-destination systems, allowing travelers the ability to conveniently get from many points of origin to many points of destination throughout the metropolitan area. With a significantly smaller deficit per passenger trip, they can theoretically attract many more passengers than alternative radial systems. Paradoxically, they may also support a healthier downtown. Examples support this theory.

A characteristic inherent in many of today's transit systems is a degree of disorientation from regional travel patterns. This factor may be partly responsible for transit's poor record of attracting a significant proportion of metropolitan travel, and it appears to result from a widely held assumption that transit systems can serve only downtown oriented work trips. An examination of this downtown orientation, in the context of regional travel patterns, will reveal how it results in transit systems failing to meet the travel needs of today's North American metropolitan areas. It will also suggest alternative assumptions which should underlie transit planning and development programs to achieve greater transit usage.

The downtown oriented transit assumption

The downtown oriented transit assumption prescribes that transit can attract from the automobile only those travelers going to work in the CBD. Its use results in transit and land use proposals designed to speed up transit to the downtown with express buses on freeways or regional rapid transit and to maximize the concentration of office and service employment in the downtown. These types of proposals are probably characteristic of most transit development programs in the United States.

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The apparently widespread use of the downtown oriented transit planning assumption does not mean it is the proper way to maximize transit riding, but rather is an indication of its historical evolution. At one time, most activity and population were located in the central cities, but as developers extended transit lines out from the center cities into undeveloped areas, population moved out along the lines. The result was a radial pattern of transit routes focusing upon the central city like spokes on a wheel, and most travel moved along these routes between the central city and outlying areas.

With the growth of automobile use, activities located in more dispersed configurations. Much downtown activity left for the suburbs, typically leaving service employment to predominate in the CBD (Meyer, Kain, and Wohl 1966). But the transit systems generally remained downtown radial systems, making impossible their use by people wishing to reach the many activities that had relocated from the central cities. Recreational, industrial, and retail activity declined in the downtown, and this was translated into a recreational, factory worker, and shopping traffic decline on transit. The remaining transit traffic became largely service employees making the journey to work.

Planners, observing the transit usage trend, could quickly jump to the conclusion that rush hour riding by downtown oriented service employment workers is the only type of travel that transit can attract. Many major projects and proposals for transit improvement appear to follow this philosophy. A few examples are BART, Washington Metro, rapid transit in Atlanta, and improved bus service in San Diego, St. Louis, Portland, and the San Francisco East Bay area.

**Declining transit ridership**

Unfortunately, the widespread acceptance of this assumption may have severely impaired transit's ability to attract a significant proportion of regional travel. The reason is that most regional travel is not oriented to downtowns in most North American cities. Transit projects focusing exclusively on the downtown may yield impressive transit riding gains to and from the downtown, but they do little to increase transit's importance for most people in metropolitan areas. Predominantly downtown oriented transit development may be the overriding reason why, in spite of unprecedented planning and implementation efforts, ridership declined over the past decade to the point where transit now carries only 2-5 percent of regional travel in many major American cities (Table 1).

**Regional travel characteristics**

The futility of attempting to attract significant regional transit patronage with downtown centered

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**Table 1. Transit modal split declines slightly, 1966-1974**

<table>
<thead>
<tr>
<th>Urbanized area</th>
<th>Population</th>
<th>Annual transit riders</th>
<th>Percent trips by transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>6.5</td>
<td>8.4</td>
<td>138</td>
</tr>
<tr>
<td>Chicago</td>
<td>6.0</td>
<td>6.7</td>
<td>636⁶</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>3.6</td>
<td>4.0</td>
<td>334</td>
</tr>
<tr>
<td>San Francisco</td>
<td>2.4</td>
<td>3.0</td>
<td>219</td>
</tr>
<tr>
<td>Pittsburgh</td>
<td>1.8</td>
<td>1.8</td>
<td>90</td>
</tr>
<tr>
<td>Cleveland</td>
<td>1.8</td>
<td>2.0</td>
<td>96</td>
</tr>
<tr>
<td>Houston</td>
<td>1.1</td>
<td>1.7</td>
<td>32</td>
</tr>
<tr>
<td>Buffalo</td>
<td>1.1</td>
<td>1.1</td>
<td>50</td>
</tr>
<tr>
<td>Dallas</td>
<td>.9</td>
<td>1.3</td>
<td>31</td>
</tr>
<tr>
<td>Seattle</td>
<td>.9</td>
<td>1.2</td>
<td>35</td>
</tr>
</tbody>
</table>

Sources:

* Automotive Safety Foundation, p. 72.
*** American Public Transit Association supplemented by phone calls.
Revenue patronage is for principal transit system for each area, except as noted.
⁶ Includes S.C.R.T.D., Long Beach, and estimate for Santa Monica.
⁷ It appears transfer passengers were included here, inflating figure.
⁸ Includes San Francisco Muni, A.C. Transit, BART, Golden Gate Transit, S.P., Greyhound.
⁹ Includes Cleveland Transit and Shaker Heights.
* Includes SEPTA and PATCO.

† Modal split is calculated by multiplying population by 3 for estimate of total daily trips, and dividing annual transit patronage by 308 for an estimate of daily transit patronage. Daily transit patronage is then divided into daily trips.
Figure 1: Radial System: Connecting all squares to center yields 3Z route miles. The radial assumption, first in regard to reduce passenger assignment, is that in regard to reduce passenger assignment in comparison to the downtown area. So the validity of this assumption would be supported if the distribution would use such linear trips, and if the same proportion of downtown commuters used a multimodal transportation system. It is noted that this is not the case as demonstrated in (a) and (b) in the figure. But it is still a very small proportion of the regional trips that have the larger share of trips. For example, 30 trips from home to work in the downtown (the regional trend is traditionally designed or the same).
A straightforward method for correcting the town's most flawed design is to place another tier of houses on the down-hill sites. This will not only accommodate the steep terrain, but it also makes the town more visually appealing. The town's layout is now more organized and aesthetically pleasing.

Figure 4. Time-transient systems: Several transfers connect many squares together, mathematically transforming all squares.

Figure 5. Grid systems: Connecting all squares together yields 4 route miles.

Figure 6. Grid systems: Connecting all squares together yields 4 route miles.
deficiency without making people transfer between routes is to connect each pair of squares with its own route (Figure 2). This concept will be called the ubiquitous routing method. Unfortunately, the ubiquitous method does not appear realistic because it requires a quantity of service so high that even the most densely populated urban area could not generate enough ridership to support it. It is difficult to imagine passenger loads characteristic of fixed route, scheduled transit on most of the routes. In practice, the only routes which would attract enough patronage to justify them would be those serving the CBD. Economics would then transform a ubiquitous system into a radial system as shown in Figure 1.

However, all squares can be connected with a greatly reduced number of routes if passengers are required to transfer. Two systematic approaches exist for accomplishing this dual objective of high connectivity with minimal routes. Both emphasize transferring. The first presented is the grid routing method.

The grid routing scheme is very straightforward (Figure 3). It consists of two sets of routes. The first includes parallel routes running in a north-south orientation. These routes do not join or cross each other. The second set consists of parallel east-west routes. These do not join or cross each other; but they cross every north-south route, and vice versa. A traveler can get from any square to any other without backhauling (circuitous travel) by transferring no more than once. The grid system offers the connectivity of the ubiquitous system, although a transfer is involved for most trips.

For the transfer concept to work, most routes in a grid system must have frequent service for most of the day. The reason is that a necessary prerequisite for a tolerable transfer is a short wait between vehicles for the transferring passengers. The short waiting time can be achieved through scheduled connections or through frequent service. The former solution cannot be employed on a grid system because of the large number of route intersections. Thus, the grid network must rely on frequent service. It appears that the maximum headway on a grid system should be about ten minutes. With less frequent service, uncertainty about transfer time becomes too much of a burden for transfer passengers (Sullivan 1976, p. 45). They would not likely use the system, leaving on board only those patrons who could both begin and end their trips on the same route. That number would be a very small percentage of the total potential number of trips.

Another multideestination routing method is the timed transfer system (Figure 4). Its advantage over the grid system is that it relies on scheduled connections between routes and does not require the grid system's frequent service on most routes for most of the day. The routes would be laid out to create a manageable number of strategic locations where several routes intersect and where it is possible to schedule connections between all transit vehicles going in both directions on those routes (Typically there would be thirty-minute headways) These points are called timed transfer centers.

A timed transfer center often consists of an off-street platform around which eight to twelve buses can park. Generally, such a center is used on a half-hour cycle. For fifteen to twenty minutes, the platform is deserted; then, passengers begin to appear. Finally, buses appear from all directions and surround the platform which then fills with transferring passengers. In a few minutes, the buses are gone, and all is quiet. This cycle is repeated every thirty minutes.

Relative passenger appeal of different route orientations

The relative passenger appeal of the radial, grid, and timed transfer systems can be tested by considering user disutility in the context of the models. User disutility is the total cost to the user for traveling. It includes out-of-pocket money costs and time spent in travel. Empirical studies on determinants of user disutility have shown time to be the more important variable. A traveler will choose one mode over another largely on the basis of the difference in time required to travel between two points. If the planner knows that a person wishes to travel between two points by one of two possible modes, each having known time components, then he can predict the probability of that person using one mode or the other. This probability is called modal split and is usually expressed as a percentage.

Network design is one of the basic determinants of user disutility characteristics. This will be shown by the application of a modal split model to hypothetical travel situations typical to the network models already presented. The model used will be the A'-Dimensional Logit Model (hereafter referred to as the logit model) which was developed for use in San Diego (Peat, Marwick, Mitchell 1972). It will be used to predict transit modal splits for the radial, grid, and timed transfer transit systems between the following points shown in Figures 1, 3, and 4: case I—A to C; case 2—A to B; and case 3—A to D.

The model uses household income, out-of-pocket costs, line-haul transit travel and auto times, and terminal and access transit and auto times. It yields the transit modal split for trips between home and work. This result can be factored to yield the modal split for all trips.

The following assumptions are used.

1. Auto travel time is based on twenty-five-mile-per-hour speeds (the typical urban automobile speed)
2. Transit travel times are based on twelve-mile-per-
hour speeds (the typical bus system operating speed) 3 Walking time to and from transit is five minutes
4. Total auto terminal time is three minutes
5. Out-of-pocket costs for auto and transit are equal
6. Income level is $S10,000
7. Base- headways are fifteen minutes for the radial, ten minutes for the grid, and thirty minutes for the timed transfer systems
8. The first wait for buses is eight minutes for radial, five minutes for grid, and ten minutes for timed transfer
9. Transfer times are eight minutes for radial, five minutes for grid, and three minutes for timed transfer.

The logit model has been calibrated using San Diego data for two cases: travel to the central city and all other travel. Here, the interest is in generalized travel characteristics, so the latter and more conservative calibration will be used (DeLeuw, Cather 1975, pp. 82-87).

This model, combined with the preceding assumptions for travel between the points described earlier, results in modal splits as shown in Table 2. It is seen that the radial system yields a marginally higher modal split (18 percent) to the CBD, but that the grid and, to a lesser extent, the timed transfer system yield significantly higher modal splits for the other two cases.

The implication of this model application is that the grid and timed transfer systems would yield the highest overall modal split for all trips in an urban area because, in the real world, cases 2 and 3 occur more frequently than case 1. This characteristic is particularly evident if it is assumed in the case of Figure 1 that a traveler cannot transfer at point a in order to travel from A to E. In the example shown in Figure 1, it is indeed possible to transfer at point a, but this type of radial configuration is unusual. More typically, it would not be possible for a traveler to transfer from a route from the west to one to the east without going much closer to the downtown, thus adding mileage to his trip and increasing his overall trip cost.

This characteristic also becomes more evident as the model increases in size and/or if the CBD is skewed to one side. In either situation, the travel costs for making non-CBD trips via a grid or timed transfer system are proportional to those shown in Table 2. However, the circuitry for making many non-CBD trips via the radial system increases rapidly with either situation. Circuitry translates into increased travel costs. Radial modal splits shown as 8 percent and 10 percent for cases 2 and 3 in Table 2 would typically fall to 0, 1, or 2 percent for a much larger model, particularly if the CBD is skewed to one side.

Theoretically then, in a larger urban area with the CBD skewed to one side, and with a typical radial system having difficult transfers between routes, except near or at downtown, modal splits between most pairs of squares would range from 1 to 2 or 3 percent. Only for pairs linked to or through the downtown in a fairly noncircuitous manner would the modal split be higher—from 8 to 20 percent. The average work trip modal split for the entire urban, area might be in the range of 3-5 percent. This would mean a transit modal split of 2-3 percent for all trips." However, for the grid and timed transfer systems, modal splits in the range of 15-20 percent are possible for most pairs of squares throughout the metropolitan area. A theoretical modal split of 15-20 percent for work trips, and 9-12 percent for all trips for the metropolitan area thus seems possible due to the increased connectivity of these multi-destination routing methods.

Therefore, network design and its effect on connectivity can be seen to influence a transit system's ability to attract patronage for a given urban area. Multidestination systems appear to have the ability to attract three to four times more passengers overall than radial systems in similar urban areas.

### Table 2. Transit network design modal split comparisons

<table>
<thead>
<tr>
<th>Type of network design</th>
<th>Line haul distance in miles*</th>
<th>Transfers</th>
<th>Line haul time (minutes)</th>
<th>First wait and access time (minutes)</th>
<th>Work trip transit modal split (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>_</td>
<td>_</td>
</tr>
<tr>
<td>Radial</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Grid</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Timed transfer</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* Square center to square center.
Relative costs of multidestination systems

The deficit from operating most transit systems in North America has increased at a rapid rate during the past decade. Most of these systems are focused on one major destination: the downtown. Policy makers may feel that, because they can barely afford to operate transit systems serving one major destination, they certainly could not afford to operate systems serving many destinations. The inference is that deficits for multidestination systems would be much greater than those for radial systems.

This inference probably is not valid because multidestination systems have less wasteful route duplication. Again, the model can be used to illustrate this point. Typical operating costs based on desired headways can be computed for each routing method. These costs can then be used as a basis for considering what effect additional costs required to meet capacity requirements would have on each routing method, and how these would be balanced by revenue. This analysis will result in a rough estimation for the relative deficit levels of the different routing methods.

Operating costs are a direct function of the number of trips operated over the length of each system for any unit of time, if the following assumptions are met.

1. Every route in each model operates with the same technology (buses are assumed here)
2. Every route in each model operates at the same speed

The number of trips is, in turn, determined by:

1. The desired minimum number of minutes between vehicles passing a given point
2. Where this "policy headway" does not provide sufficient capacity to carry everybody wanting to ride, the additional trips required to accommodate these people.

The model can be used to determine the relative costs for each network based on policy headways. These can be computed by multiplying the number of daily trips for a given policy headway by the number of route miles for each network. The computation results in daily vehicle miles which can then be multiplied by a typical unit cost per vehicle mile ($1.50 assumed here).

The route miles for each of the models are required first. They can be directly measured from the figures. Alternatively, they can be computed for a model of any number of squares to a side with the following formulas:

For radial system
\[ RM = \frac{3}{2} n^2 - w - \frac{1}{2} \]  \hspace{1cm} (1)

For ubiquitous system
\[ RM = 3n^3 - 6n^2 - 2n + 5 \]  \hspace{1cm} (2)

For grid and timed transfer systems
\[ RM = 2n^2 - 2n \]  \hspace{1cm} (3)

Where \( RM = \) route miles, and \( n \) is the number of squares on one side.

Daily trips for a given policy headway are computed by multiplying the number of trips per hour resulting from a given policy headway by the number of operating hours per day, assumed to be eighteen here. For example, a policy headway of ten minutes results in six trips per hour, or 6 x 18 = 108 trips per day.

Table 3 summarizes the operating costs required for the four different transit network designs and expanded versions of them. The expanded model area, more typical of medium-sized urban regions, covers an area of ten miles by ten miles with route spacing every half mile, connecting subareas each a half-mile square. The generalized route mile formulas (1), (2), and (3) were used to generate the route miles for the expanded example. Typical headways for radial, grid, and timed transfer systems are fifteen minutes, ten minutes, and thirty minutes,

### Table 3. Transit network design daily cost comparisons

<table>
<thead>
<tr>
<th>Type of network design</th>
<th>Route miles</th>
<th>Vehicle headways for model Examples</th>
<th>Vehicle headways for expanded Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expanded Examples</td>
<td>10 min.</td>
<td>15 min.</td>
</tr>
<tr>
<td>Radial</td>
<td>32</td>
<td>290</td>
<td>$10,364</td>
</tr>
<tr>
<td>Ubiquitous</td>
<td>220</td>
<td>10,783</td>
<td>71,280</td>
</tr>
<tr>
<td>Grid</td>
<td>40</td>
<td>370</td>
<td>12,960</td>
</tr>
<tr>
<td>Timed transfer</td>
<td>38</td>
<td>370</td>
<td>12,312</td>
</tr>
</tbody>
</table>

\[ a \] All-bus systems assumed; daily operating costs are daily vehicle miles times $1.50 per vehicle mile. \[ b \] Five-mile by five-mile area with one-mile route spacing. \[ c \] Ten-mile by ten-mile area with half-mile route spacing. \[ d \] Calculated from formulas presented in text. \[ e \] Assumed same as grid (see text).
respectively. Thus, in the case of the expanded model, comparable daily operating costs for these three systems are $62,000 for radial, $119,880 for grid, and $39,960 for timed transfer, based on typical policy headways. Based on policy headways alone, one of the multidestination systems would actually cost less to operate than a downtown radial system.

However, policy headways alone do not give an accurate cost picture. Some parts of some routes would likely become overloaded during parts of the day for all three systems. The grid and timed transfer systems would, in particular, most likely have to operate much more frequently than specified by policy headways on the lines serving the downtown. This requirement would also be prevalent during rush hours with the radial system, but to a lesser extent because of the extensive route duplication into the downtown area. Passenger overloads would probably increase the operating daily costs for grid and timed transfer networks in comparison to that of the radial system.

An important consideration, though, is that the grid and timed transfer systems would operate bus trips in addition to those specified by policy headways only as required by passenger demand. Every additional bus would carry a full load, so that added revenues would tend to match added costs. In contrast, the extensive route duplication of the radial system would probably result in many more buses than required by policy headways operating into the downtown area at many times of the day. In addition, the radial system serving just one major and specialized destination would probably be characterized by less off-peak revenue and much less patronage and revenue on the outer parts of the lines. The net result would probably be higher operating costs for a grid or timed transfer system than for a radial system of similar route coverage, but much higher revenues as well, with costs for added services more closely matched to added revenues. There seems little reason to believe that deficits for multi-destination systems would exceed those for radial systems.

**Multidestination systems and land use planning considerations**

Transit networks designed to maximize connectivity have features important to planners from the perspective of land use planning. These features include the evolution of routes with very high passenger volumes and the provision of very high transit accessibility to some areas. These corridors and areas can be complemented with higher density development if such development is desired. However, land use controls can be used to prevent such development if it is not desired, without sacrificing the high quality of transit service.\(^{12}\)

Grid systems typically produce a few routes used very intensively. This characteristic may not be intuitively obvious because the grid system is oriented to dispersed trips. However, main routes result whenever the grid system is superimposed upon an area not having a uniform distribution of land use activity because the few routes serving an area of greater than average activity will receive a large amount of transfer traffic.

The case of a downtown in a region with a grid route structure offers a good example. A grid system typically serves a small downtown with only two routes (Figure 3). A larger downtown will be intersected by, at most, six or eight routes. All transit travel to the downtown from the entire metropolitan area therefore is limited to this small number of routes. As a result, extremely heavy passenger loads may occur on them and they may have to be highly developed in order to cope with the patronage thrust upon them. The patronage may easily be of sufficient magnitude to warrant their conversion to rail.

In contrast, a radial transit system divides downtown-bound patronage among the large number of routes radiating to all parts of the region. No route will carry very much patronage unless:

1. Residential density is extremely high
2. Natural features, such as hills, bays, or rivers, tend to concentrate corridors of residential development which would otherwise spread over large areas
3. The downtown attracts an extremely large amount of travel.

In the context of regional development planning, the grid system opens up interesting options. The passage of tens or hundreds of thousands of passengers every day along one route makes possible the use of that route as a development control tool. Points of transfer with cross routes can be particularly useful spots for transit oriented development. Planners might therefore wish to concentrate much of their efforts for high density development along the entire length of such corridors or at strategic transfer nodes which are potential byproducts of the grid system.

Timed transfer systems have load concentration characteristics similar to those of grid systems. However, any particular area, such as the downtown, does not have as large an impact. Rather, the cumulative addition of passengers to a route serving several important small areas creates heavy corridor patronage.

More importantly, however, the timed transfer centers themselves offer very high transit accessibility and can be integrated with land use planning to achieve maximum independence from the automobile. Typically, any one timed transfer center will be located three to six miles from the next. Thus,
most routes within a radius of one-and-one-half to three miles will focus upon it. If land use planners concentrate trip attractions drawing upon local residents at the timed transfer centers, then transit can be highly useful to the local populace. Transit planners can achieve the same effect by locating timed transfer centers at existing local or regional shopping centers or at older town centers slated for re-vitalization.

Examples

Multidestination transit systems have found limited application in North America, with greater than usual transit usage. While it is beyond the scope of this article to analyze these examples in detail, some points can be made. Toronto has utilized a grid transit orientation since the 1920s. Transit there now carries over 20 percent of all trips in metropolitan Toronto. Over 70 percent of these trips do not cross downtown cords, indicating success in attracting nondowntown travel. The deficit for each passenger trip is about ten cents, much smaller than in most American cities. However, auto ownership, at 375 cars per 1,000 population, is almost as high. In addition, a highly successful rapid transit has evolved incrementally since 1954 from this route network, with the most heavily patronized surface transit routes converted to subway.13

Edmonton, Alberta, began converting its radial bus system to a timed transfer network about 1962. In the late 1960s and early 1970s this process accelerated. The previously declining patronage stabilized and, more recently, has grown faster than population and faster than patronage for systems in other Canadian cities. Transit in Edmonton now carries about 13 percent of all trips in the city, at a deficit per passenger trip of about fifteen cents. Auto ownership is about 425 per 1,000 population. Edmonton's roadway layout is characterized by substantial discontinuities caused by river valleys, ravines, railway yards, an airport, university lands, and industrial tracts.14

Vancouver, British Columbia, has most recently begun implementing timed transfer services as part of a massive program to expand transit to low-density suburban areas. The timed transfer approach is integrated with planning for the staged implementation of light rail transit and with land use planning. Transfer points are implemented in existing or proposed suburban activity centers. Patronage response has been heavy, with per capita rides on transit as high as fifty to sixty (equivalent to about a 5 percent modal split) in low-density suburban areas that had no transit service before 1973.15

Conclusions

The theoretical analysis presented in this article suggests that a multidestination approach is required in the development of transit networks if it is desired for transit to carry a more significant share of metropolitan travel. The examples support this theory, but admittedly, more research needs to be done on this topic. For example, it would be desirable to determine to what extent racial considerations or crime problems inhibit American transit usage, or whether the longer tradition of municipal transit ownership and greater political cohesiveness at the local political level in Canada may lead to higher ridership there.

However, evidence and arguments presented in this article appear strong enough to cause a reassessment of the traditional radial methods for organizing and improving transit services in the United States. This conclusion is emphasized by the fact that some Canadian cities with, by American standards, extremely strong central business districts embrace the idea of multidestination transit. In this context, it seems rather ill-advised for most American cities, with their comparatively weak downtowns, to pursue downtown radial transit development. Alternative multidestination route structures may greatly improve the health of the transit systems, and paradoxically improve the health of the CBD as well.

Author's note

The author gratefully acknowledges the first draft editorial assistance by Rudy Massman of the County of San Diego, Tom Matoff of the San Francisco Municipal Railway, Dr. Imre Quastler of San Diego State University, and Jaswant Kooner of San Diego County, as well as comments and words of encouragement from Dr. Fred Matthews of York University and Peter Dawes of the Canadian Transport Commission.

Notes

1. This summary is generalized from studies in San Diego, the San Francisco bay area, and Denver. This is a small number of examples. However, results from each study are consistent with each other and are consistent with the author's experience in other urban areas. They are also consistent with the comprehensive analysis of Meyer, Kain, and Wohl (1966).

It is likely that a comprehensive survey of metropolitan transportation studies for urban areas throughout the country would produce conclusions very similar to those presented here.

2. In San Diego, a sixteen-zone downtown area accounted for 8 percent of regional trip ends in 1975. This level is forecasted to decline to 5 percent by 1995, in spite of the assumption of a regional rapid transit system focused on the downtown and growth policies designed to encourage recen-tralization. This information is derived from the Comprehensive Planning Organization trip tables for traffic analysis zones. Also, Meyer, Kain, and Wohl (1966, pp. 84-87) discuss the small amount of travel to CBDs and the lack of effect from transit on CBD decline (p. 47). Their major theses seem to be that the CBD is no longer the primary force in most
regions, that its influence will continue to wane, and that, hence, transit is solely CBD-oriented. It is and will remain of no consequence.

The Bay Area Transportation Study revealed that almost half he regional trips were less than twelve minutes long and two-thirds were less than eighteen minutes (Bav Area Transportation Study Commission 1967, p. 28). In San Diego, it was found that more than 50 percent of auto and transit trips were less than twelve minutes long (Peat, Marwick, and Mitchell 1972, pp. 77-78).

"Ubiquitous" transit service is used in a DeLeuw Cather report (1975) to describe a hypothetical transit system allowing direct travel opportunity between all origins and destinations. "Systematic approach" has also been noted by Dr. Brian E. Sullivan, who calls it the "network approach." He contrasts it to the "single route" approach (Sullivan 1976, p. 44). In the single route approach, a transit "system" is a collection of single routes, each established for a unique trade and having little or no interaction with other routes. This is the common North American transit planning approach, and the radial and ubiquitous schemes are examples of it.

Examples of the systematic approach are the grid and timed transfer schemes. This author knows of no other examples, although they may exist. Sullivan makes the following comment on the network approach: The alternative to the single route philosophy is one which views transport services as elements in an interacting network. Each route has its own specific trade, but each, to some extent, feeds traffic to others that the latter would never get. In effect, the Transfer is viewed as an opportunity, not a curse to be avoided at all costs (1976, p. 44).

An example of such a study is Peat, Marwick, Mitchell. Implementation of the N Dimensional Logit Model. Similar studies on modal choice behavior exist in other regions. This income level is used because, at this level and above, modal split is sensitive mostly to transit and auto service factors and not to income. Generally, the average first wait is taken to be half the headway. Half the headway for a timed transfer system is fifteen minutes. However, calibrations of the logit model assumed that patrons waiting for buses on regular thirty-minute headways would perceive their wait to be ten minutes which is used here, because on that long a headway, passengers will not arrive at random, but according to time patterns and schedule. Other planners or those experienced in transit operations have also noted that, for routes with long headways, particularly if they are regular headways, perceived first wait time is less than half the headway. (See DeLeuw. Cather 1975, pp. 77-83.)

The logit model predicts modal split for different modes operating between two points. It assumes there is a certain level of travel between the two points, and that this travel will be distributed among all of the different modes connecting the two points according to the level of service of each mode. If the level of service of one mode is changed, while that for the other modes is held constant, the modal split for all of the modes will change, according to the theory of the model.

The model considers level of service to be composed of several types of time and cost. Time components include time to walk to and from the mode, time spent in waiting for the mode, time spent in parking, and time spent in riding on the mode (this includes time spent in transferring where transfers are involved). Cost components include transit fare or perceived auto operating costs and parking charges. The model also considers the income level of the travelers to partially influence modal split. However, the effect of income on modal split diminishes as income rises, and above about $10,000, has little effect, leaving level of service to be the prime determinant of modal split. The apparent reason for this effect is that at lower income levels, parts of the population are forced to use public transportation because they cannot afford access to an automobile. However, at and above a certain income level, most people can afford either modal choice, and their decision will be based on service offered.

The model was calibrated according to individual trip records from a 1966 home interview survey conducted in San Diego. It was found that one calibration would not replicate modal choice of the time: consequently, two calibrations were used. One is for trips to the CBD. The other is for all other trips. The CBD model will predict a higher transit modal split than the non-CBD model for the same level of service factors.

The logit model is considered by San Diego planners to be one of the best modal split models, although problems are recognized in it. One area of concern is the existence of a CBD and a non-CBD model, for which there is no theoretical justification. One model should handle both cases. (In this article, the non-CBD model is used because it is the more conservative.) Another area of concern is the consideration of transfer time. Most modal split models weight transfer time by a factor between two and three to reflect an assumption of public dislike of transferring the logit model does not.

The point of weighting transfer time in models deserves some discussion in relation to the use of the model in this article. Weighting is probably satisfactory for the typical North American transit case, where the transfer movement or wait is not planned for in design of the system, scheduling, or physical facilities. For example, where two routes intersect, one with a headway of seventeen minutes and the other with a headway of forty minutes, the actual time between the departure of one vehicle and the arrival of the connecting vehicle is different for every trip throughout the day. Passengers wishing to make this transfer can have no confidence in the time they would spend at the transfer point, other than assuming the longest possible time (forty minutes). Few passengers would take advantage of the transfer, and planners in attempting to simulate the movement would be correct in applying a severe penalty. This is a typical North American situation. However, the situation is far different if the transfer is planned for, either by frequent service so the passenger has confidence that the longest possible time spent at the transfer point is tolerable, or by timed transfers, so that the transfer time is constant throughout the day and is known to the passenger. (The presence of physical facilities accommodating transfers is also important, but beyond the scope of this article.) Experience has shown that under these circumstances, passengers will transfer in large numbers (in Toronto, where accommodating transfer passengers is the top planning priority, they account for 70-80 percent of revenue patronage). Under these circumstances, a transfer penalty is probably inappropriate.

The use of this article of the logit model with its non-weighting of transfer times is appropriate for the case of the grid and timed transfer routing schemes, because these are explicitly designed to accommodate transfer movements. However, it would overestimate modal split for the radial routing scheme in cases where transfers are involved. This is not felt to be a problem because the task at hand is to show whether the grid and timed transfer networks attract more patronage than a radial system. If this is shown under circumstances where modal split is overestimated for the radial system, the case against the radial philosophy is even stronger.

10. Where it is used, particularly when combined with high frequency service, transit connectivity is much higher than is typical for radial systems. This characteristic offers an interest-
ing possibility. The passenger appeal of a radial system might be significantly improved by restructuring the routes so that they actually appear as those in Figure 1, and then designing transfer connections and promoting them at places such as point a. These transfers will be attractive only if service on both of the intersecting routes is frequent enough to make a random transfer tolerable. However, if service is frequent enough, a system of this type offers a moderate amount of connectivity.

11. Modal splits for all trips can be obtained by factoring those for work trips. The logit model lists factors (Peat, Warwick, and Mitchell 1972, p. 127) which yield an overall factor of 0.77 for the CBD model and 0.42 for the non-CBD model. The non-CBD model factor appears artificially low because, when the model was calibrated on data from transit trips in San Diego, nonwork travelers by and large could not and did not use transit unless they were destined for the CBD. If transit with high connectivity existed, however, people could use transit for shopping, social, and other purposes to locations in addition to the downtown; and it is likely that their propensity to do so would be similar to their willingness to use transit for those purposes when traveling downtown. A factor of 0.6 was therefore used because it is closer to the downtown factor.

12. Growth has occurred around many Toronto subway stations, but not around others (such as Rosedale). Land use controls make the difference. Transit makes growth possible, but does not cause it.

13. Information on Toronto is from various sources. These include phone conversations with Rod McFale of the Metropolitan Toronto Transportation Plan Review; Thomas E. Parkinson, consultant to the Toronto Transit Commission; and Robert Topp, assistant director of planning for the Toronto Transit Commission. In addition, published material was used (Toronto Transit Commission 1969a, 1969b, and 1974).


15. Information on Vancouver comes from phone conversations with Dr. Brian E. Sullivan, assistant director for the Bureau of Transit Services, Government of British Columbia, and

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