FRAMEWORK OF ROUTE SELECTION IN BUS NETWORK DESIGN

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The purpose of this study is to establish a framework of route selection in bus network design, based on the proposed functional description and evaluation system. In the proposed framework, the network is classified into residential, activity, and transfer nodes. Routes connecting the transfer nodes serve as the regional system, and other routes constitute the local systems. The evaluation system designed is capable of reflecting both the connectivity of transfer nodes and the accessibility of the residential and activity nodes. To establish the priority of route selection, several attributes were tested against transit use at the neighborhood level. The level of transit service was the sole dominant factor in the traveler's determination of mode choice. Furthermore, the employment activity nodes were significantly correlated with route performance. If the work trips and route performance are given prior consideration, employment serves as a good index during the process of network development. If the provision of accesses to other activities is taken into consideration, employment can also serve as a good indication by connecting those activity nodes to the other elements of the network. This framework will be especially useful when it is integrated in a heuristic algorithm for optimization of network design. A case study was carried out to demonstrate the use of this framework in four stages of bus network development in the Denver area.

•BUSES have long been recognized as the transit mode most suitable for serving cities of moderate size. The advantages of bus transit include the flexibility that enables management to make proper route changes when necessary. Ironically, the bus route configurations in most cities have remained almost unchanged since the bus was substituted for trolleys in the 1950s. Only in recent years has the importance of a large-scale reevaluation and change of bus routes been realized.

Many studies on network design have been carried out since then. Basically, there are two approaches to dealing with the network design: (a) the application of mixed-integer programming (1) and (b) the development of heuristic searches (2). Among these efforts, the integer programming approach is still not capable of dealing with networks of realistic size, and the heuristic approach has yet to obtain an acceptable optimization algorithm.

The computer programs capable of making long-range plans for the transit systems have been developed and applied to the daily planning practice (3). These programs, however, are designed primarily for simulating the networks, projecting the demands, and evaluating the level of service: in other words, for analyzing rather than for constructing networks. The problem of developing priorities remains unsolved.

This study attempts to provide planners with a framework for route selection in network design. The proposed framework includes a functional description of various elements of the network, a comprehensive evaluation system for the individual route and the entire network, and a priority algorithm for indicating development priority. It provides the planners a clear view of the network structure and allows them to develop and specify alternatives for network design. In particular, the framework helps planners to integrate routes of various functions into a network and to reach a balance between generating revenues and providing access.

Data were collected and analyzed at the district level (63 districts in the case study area in contrast to 120 census tracts in the same area). In the network, each district was represented by a residential node, and activity centers were identified and designated as activity nodes. Bus routes thus developed represent transit corridors rather than the exact locations of routes.

PROFILE OF TRANSIT USERS

A better understanding of the characteristics of transit users would help planners in network design. In the past, the trip-makers' socioeconomic backgrounds were believed to be the most important determinants for their modal choice behaviors. It is only in recent years that the importance of the system characteristics of transit modes in the modal choice decision has been realized (4). Among the socioeconomic characteristics, family income and automobile ownership are considered to be the most important factors, and the system characteristics are often represented by the level of service.

A survey conducted in 1970 in the Denver area (5) showed that 69.4 percent of transit users were female riders, and the 1970 census showed that only 51.35 percent of the general population of the city of Denver were female. The age profile showed that senior citizens (age over 65) accounted for 12 percent in transit users in contrast to 7.74 percent in the general population. Transit users also have generally lower incomes than the average Denver resident. Almost 42 percent of transit-user households had incomes between \$3,000 and \$6,000, and 21 percent had incomes of less than \$3,000. In total, 81 percent of transit-user households had incomes less than \$9,000. In comparison, half of the general households in the city of Denver had incomes less than \$9,654.

Another survey conducted in 1970 (6) revealed similar results. In addition to providing the information on the rider's sex, age, and income, the San Diego survey showed that less than 57 percent of transit-rider households had an automobile in 1970 and that 78 percent of the general households had one in 1966. When asked if there was an automobile available for the trip being taken, 84.4 percent of the transit users replied negatively. From these results, it is obvious that the transit captives account for a rather high percentage of today's transit users. But it does not mean that socioeconomic characteristics are the dominant factors in the modal choice decision. As a matter of fact, the following study shows that level of service is the only significant factor in determining the percentage of transit users at the district level.

An index for the level of service was designed to reflect both the schedule frequency and transit routing:

$$S_i = \sum_{k=1}^{K} A_{ki} B_k \sum_{n=1}^{N} A_{kn} D_{in} \tag{1}$$

where

S_i = index for the level of transit service of district i,
A_{ki} = percentage of area served by transit route k in district i,
B_k = frequency index for route k, and
D_{in} = number of trips originated in district i and terminated in destrict n.

In addition to the service index, four socioeconomic factors were chosen for the test of transit use. These four factors are percentage of (a) residents over 65 years old, (b) households with incomes below the fifteenth percentile, (c) households without an automobile, and (d) minority residents, including people with Spanish surnames, blacks, and other nonwhites. Origin-destination information and socioeconomic data for each destrict were obtained from the Denver Regional Council of Governments and the city and county of Denver; 25 districts were excluded from the test because of the lack of data or the lack of transit service.

Results of the correlation tests indicated that the service index was correlated to the transit use. The correlation coefficient between them was 0.758. In comparison, all of the four socioeconomic factors had much lower correlation coefficients with the transit use (Table 1).

To calculate the percentage of transit use for each district, three regression equations with one, two, and three independent variables respectively were used:

$$T_i = 0.805 + 0.021\ X_i \tag{2}$$

$$T_i = 0.336 + 0.020\ X_i + 0.015\ Y_i \tag{3}$$

$$T_i = -0.382 + 0.018\ X_i + 0.019\ Y_i + 0.068\ Z_i \tag{4}$$

where

T_i = percentage of transit use in district i,
$X_i = S_i$ = index of transit service in district i,
Y_i = percentage of minority residents in district i, and
Z_i = percentage of senior citizens in district i.

The coefficients of determination R^2 for these three regression equations are 0.575, 0.632, and 0.656 respectively.

From the test, it is concluded that the level of transit service is far more important than the socioeconomic factors in determining transit use. This finding was confirmed by an attitudinal survey conducted in Denver (5, 7). It showed that, among those people not using public transit, 31.4 percent cited routing problems, and another 25.5 percent cited problems relating to bus scheduling.

DESCRIPTION OF NETWORK

The bus network is composed of two elements: nodes and links. Links are the segments of bus routes, and nodes represent the points where bus routes terminate or intersect. In the general procedure of network description, routes are identified first with nodes and then determined by the terminals and intersections of routes. For this study, however, an opposite approach is adopted. All potential nodes are identified first. Routes are then laid out to link nodes into a network.

Bus networks transport people from their residences to activity centers and among

Table 1. Correlation analysis.

Variable	Transit Use	Income Level	No Automobile	Minority Resident	Over 65 Years
Income level	0.3580				
No automobile	0.4787	0.9310			
Minority resident	0.2911	0.6942	0.5529		
Over 65 years	0.3829	0.1690	0.3305	-0.3115	
Transit service	0.7586	0.1886	0.3635	0.0705	0.4416

activity centers. Two types of nodes, activity and residential nodes, are considered separately in this study. Activity nodes are those areas where social or economic activities concentrate, and residential nodes are the centroids of residential areas. Some of the activity nodes are further designated as major transfer nodes, and this will be given special attention in this study.

Activity and Residential Nodes

Activity nodes can be further divided into two categories: employment nodes and nodes for shopping, social-recreational, health care, and cultural activities. According to transit surveys (6, 8), transit service has primarily been used for home-based work trips. If the bus service is designed specifically for this purpose, employment nodes should be given priority consideration in selecting activity nodes. However, a substantial percentage of households in American cities do not own an automobile (9). For these transit captives, public transit is the only alternative, other than walking, for trips of all purposes. When bus service is provided from this point of view, many activity nodes besides employment nodes have to be taken into consideration. For instance, to provide access to health care facilities, hospitals, especially those that are involved in social welfare programs and that cluster together to become major medical centers, should be designed as nodes. Other activity nodes in the network could include regional shopping centers, sports stadiums and coliseums, art museums and performing centers, zoos and parks, and other areas that are of regional importance.

The number of nodes should be kept relatively small so that the analysis will be easy to handle. If the number of nodes becomes too big, it might be desirable to group nodes into several categories and to assign a priority to each of them. Only those nodes in the category with the highest priority are considered in the early stages. Other nodes are taken into consideration subsequently when the network gradually develops.

When the activity nodes cluster to form a strip, it is called an activity corridor. Activity nodes are at one end, and bus routes lead through the residential areas and terminate either at another activity node or at a residential node. The division of the service area into residential zones is based on two considerations:

1. The size of zones should not be so large that each zone loses its identity and uniformity of socioeconomic characteristics, and
2. The number of residential zones should not be so large that the size of networks exceeds the capacity of the analytical tool.

Many existing divisions of zones can be used for network design. Among them, the census tract is one of the most familiar and available divisions. In cities where origin-destination surveys have been conducted, the traffic zone provides another division for use. Other divisions, such as neighborhoods and communities used in the neighborhood analysis, are also useful. In the case study area, there are 120 census tracts, 234 traffic zones, and 63 neighborhoods. Neighborhoods were used as the unit for residential zones in this report. The centroids of residential zones represent only the existence of zones and do not provide accurate locations for buses to pass by. Consequently, the locations of centroids are relatively unimportant and are considered variable during the analysis.

Major Transfer Nodes

The major transfer node plays a dual role in network design. As a bus center, it is the terminus and intersection of bus routes that serve the surrounding neighborhoods and local activity nodes; as a transfer point, it provides the local residents easy access to other subregions in the metropolitan area. These transfer nodes should be located in the area of major traffic attraction and should have easy access both to local neighborhoods and to other transfer nodes. In recent years, the development of intense activity centers, which provide many diverse activities for the local communities, has attracted much attention. These intense activity centers are, of course, ideal locations for transfer nodes. Other transfer nodes could be located in local employment centers or major shopping centers. The design for these transfer nodes should be stressed to provide easy transfer facilities and comfortable waiting spaces.

Another consideration in selecting major transfer nodes involves the geographical relationship among all transfer nodes of the entire network. Ideally, these transfer nodes should be scattered around the service area to provide the optimum accessibility for the entire area. In practice, however, the specific urban form for each service area turns out to be the predominant factor in arranging the transfer nodes.

Classification of Bus Routes

Bus routes are conventionally classified into radial routes, crosstown routes, and feeder lines according to their geographical relationship with the central business district. For network design, however, this classification has not been found appropriate for several reasons. First, the traditional classification envisions the CBD as the only node of regional importance and does not distinguish other activity nodes from the residential nodes. As a matter of fact, the solely dominant role of the CBD in the urban structure has been substantially reduced because of suburbanization and decentralization of business industry in the past two decades. Therefore, it would be more realistic to treat the CBD as one of the activity nodes and make a distinction between activity nodes and residential nodes. Second, the traditional classification does not reflect the different functions that various types of bus routes provide. Urban street systems have long been classified according to their respective functions; bus routes have not. To provide satisfactory service to the public and to revive the declining transit industry, the same concept of functional classification should be applied to the bus network design.

We propose that bus routes be classified into the following categories according to the nature of nodes along the routes:

1. Bus routes that connect two major transfer nodes,
2. Routes that serve an activity corridor,
3. Routes that connect two activity nodes, and
4. Routes that extend from one activity node into the residential areas.

The routes in the first category form a framework for the regional system, and those in the other three categories constitute local networks.

EVALUATION OF NETWORK

The criteria for a good network are difficult to define. For instance, Lampkin and Saalmans (2) and Wren (10) state that a good transportation network should not have too many routes, require too many transfers, and meander excessively. Stating the criteria as such, however, is impractical unless a quantifiable measure for them can be defined and easily adopted into the objective function. According to Miller (11), the assessment process for the transportation system should include

1. Establishing the major objectives that are to be optimized,
2. Listing all performance attributes that are relevant to the objectives, and
3. Selecting a physical performance measure for each attribute.

In the following sections, objectives and performance attributes for bus service are discussed, and measurements for the bus network are proposed.

Characteristics of Bus Network

An intraurban bus network can be distinguished from other transportation networks in many aspects. The flexibility of the bus operation makes it different from a guideway transportation system; almost all streets that are physically suitable for bus operation can be developed as bus routes. However, except for a few newly innovated concepts of bus operation, such as dial-a-bus, buses are operated on the basis of fixed routes and fixed schedules. When the direct route connection is not available, the unavoidable transfer and waiting would reduce bus use substantially. The number of transfers should, therefore, be watched closely during the process of network design.

For those people who have an automobile of their own, buses are considered as an alternative. Because of this competitive nature between buses and automobiles, the relative advantages of each mode should be able to be revealed from the network measurements. And because a majority of bus companies in American cities have been purchased by the local authorities and subsidized by the public in recent years, a fair and uniform coverage of bus service among all neighborhoods is often required by the local authorities. A good measurement of the network should, therefore, reflect the coverage of service and the discrepancies of the coverage.

Among the guidelines proposed in 1958 by the National Committee on Urban Transportation (12) for measuring the transit service, some, such as the directness and density of routes, were particularly relevant to network design. Since then, more measures have been proposed based on various objectives. The area of coverage, number of transfers, and degree of accessibility are among the measures that are often used in the objective function for optimizing network design. For this study, an objective function including operating revenue, accessibility for residential nodes, and connectivity for transfer nodes is used during network development. Operating revenue is directly affected by the ridership and can be easily measured by the number of passengers per bus mile (kilometer). The measures for the accessibility and connectivity, however, are much more complex. Accessibility has been interpreted quite diversely among transportation planners, and many different measures have been proposed (13). However, connectivity, a concept that originated from the graph theory and that is widely used by the geographer, is rather unfamiliar to many planners. In this study, both accessibility and connectivity will be defined from the geographical point of view. Some modifications are made to meet the requirements that emerged from the previous discussions.

Network Measurements in Graph Theory

Graph theory has long been used by transportation geographers to describe the structure of networks. The aggregate geometrical patterns of the network are measured by indexes with a single number; the relations between elements are measured by matrices. The aggregate indexes are most meaningful for comparing two networks or for describing the various stages of network development (14). Werner et al. (15) reported that these indexes failed to discriminate the networks that have the same numbers of nodes and links but significantly different structures. However, the measurement matrices, which are capable of pinpointing the weaknesses of networks, are most useful in the person-machine interactive type of network design. Three of these matrices used in this study are described below.

C is the connection matrix, where element c_{ij} indicates the connectivity between nodes i and j. $c_{ij} = 1$ shows that nodes i and j are directly connected; $c_{ij} = 0$ indicates the absence of connection. C can be multiplied by itself to produce a new matrix C^2, where element c_{ij}^2 indicates the existence of the two-linkage path between nodes i and j. A further generalization of this concept indicates that the n-linkage paths between nodes can be represented by C^n. The accessibility matrix T is then defined as the sum of C and its powers:

$$T = C + C^2 + C^3 + \dots + C^n \qquad (5)$$

where n is the network diameter that is defined as the minimum number of linkages required to connect the two nodes that are the greatest distance apart on the network. T has been used to describe various transportation networks; e.g., Garrison (16) used it to study the Interstate Highway System in the southeastern United States.

The elements of the shortest path matrix D indicate the number of linkages of the shortest path between all pairs of nodes in a network. D can be generated by successively powering C. Originally, all cells in the matrix without the direct connection are recorded as 0. Other cells are recorded as 1. If any new non-0 element occurs after each iteration of powering, the power of that iteration is entered into the corresponding cell in D. D is completed after all 0 elements, except those in the main diagonal, are eliminated.

The major concern of the graph theory is the presence or absence of links between nodes. Sometimes, however, it takes into consideration the characteristics of individual routes. When this is the case, networks are treated as the valued graphs. Instead of the number of linkages, the actual measurement of route characteristics appears in cells of the matrices. Under some systematic procedures, matrices of the valued graphs can be powered to produce the information needed.

C, T, and D matrices are useful when the transfers are of concern; however, the matrices of valued graphs provide information when travel time, either absolute travel time or the relative time to the automobile, is under consideration.

Proposed Measures of Network Design

The proposed measures for the network design include

1. The gamma index, the ratio of the actual number of links to the maximum possible number of links in the network, and the connection matrix for measuring the connectivity of transfer nodes; and
2. T, D, and a relative traveling distance matrix R for measuring the accessibility of residential and activity nodes.

The element r_{ij} in R is the ratio of the distance traveled by bus to that traveled by automobile from district i to j.

ANALYSIS OF PRIORITY FOR ROUTE SELECTION

The performance of routes is tested against attributes associated with the nodes along each route. Precedent analysis of transit use at the district level indicated that the level of transit service was the solely dominant factor in determining the percentage of transit uses. Socioeconomic factors turned out to have little effect on transit use. Based on this finding, it was suggested that the data on trip generation and trip distribution alone could provide enough information for network design at the district level. In this study, the employment numbers at the activity nodes along each route were tested as the primary index for establishing the priority for route selection.

Methods

Because the number of routes is relatively small, nonparametric methods were used in the analysis. The Wilcoxon rank sum test (17) was used to distinguish the performance differences between two types of routes, and the Kendall rank correlation test was used to test the correlation between two attributes.

Data used for the analysis were obtained from a passenger census (18) conducted in

1973 by the Denver Metro Transit (DMT). At the time of survey, there were 26 regular routes, served by DMT, which could be further broken down into 37 links. Information on total passengers, total bus trips, average passengers per trip, route miles (kilometers), and passengers per mile (kilometer) are compiled for each route. Based on this information, an overall rating is then calculated according to the following equation (19):

$$R_i = \frac{100}{2} \times \left(\frac{P_i}{\sum_n P_n} \times \frac{\sum_n Q_n}{Q_i} + \frac{P_i}{\sum_n P_n} \times \frac{\sum_n M_n}{M_i} \right) \qquad (6)$$

where

R_i = overall rating for link i,
P_i = number of passengers for link i,
Q_i = number of trips for link i, and
M_i = route miles (kilometers) for link i.

The number of passengers per mile (kilometer) is another index that has been used often in measuring the route performance. Ranks of links according to these two indexes were then used for the Wilcoxon and Kendall tests.

Distinctions Among Various Types of Bus Links

Among the 37 regular links, only 9 of them were not connected to the Denver CBD. Excluding the route that served only the downtown area and the Mile-High Shuttle, which connected the CBD to parking lots around the Mile-High Stadium, there were 26 radial links. The Wilcoxon rank sum test (Table 2) shows that for the overall rating there is a significant difference between radial and crosstown links. (In Tables 2 through 6, M and N are the sample sizes of the two categories tested; T, T_1, and T_2 are the sums of the ranks of the category with the smaller sample size; and T_u and T_e are the critical values for T, T_1, and T_2 when the level of significance is p.) Measures of the passengers per mile (kilometer) are also significantly different for the two types of links (Table 3). The results are not surprising because the Denver CBD still is the most important employment center in the Denver metropolitan area. Moreover, because the Denver CBD has been the only major transfer point in the existing bus network, many people ride buses to downtown just to transfer to the other buses.

What is more interesting in this study is the difference between the links that connect two employment centers and the links that extend from employment centers to residential areas. In the case of DMT, among the 28 radial links that have the CBD at one end, 9 have another employment center at the other end of the link, and the remaining 19 links are extended to residential areas. The rank sum tests (Table 4) suggest that there are significant differences between these two types of links. For the 9 crosstown links that do not connect with the CBD, the difference also exists as given in Table 5.

Among the DMT links, link 3 is the only one that is qualified as the corridor route according to the previous definition. This link has the highest overall rating score but the second highest number of passengers per mile (kilometer).

The passenger profiles, which show the number of passengers on board during the morning peak hours along the routes, indicated more differences among the various types of bus routes. Figure 1a shows the profile of a route extending from the CBD to the residential areas in northeastern Denver. The dotted curve indicates that the outbound buses are almost empty. Figure 1b shows the route that goes from the CBD along the Broadway Street corridor. The profile shows that the numbers of passengers getting on and off the buses are quite uniformly distributed along the route for both the outbound

Table 2. Wilcoxon rank sum test for overall ratings.

Crosstown			Radial		
Link	Score	Rank	Link	Score	Rank
9	103	16	3	168.5	1
15	93	17	4E	129	7
17	37	30	4W	81	25
18	15.5	34	5E	133	6
19	106.5	4	5W	77.5	27
20	34.5	31.5	6E	110	12
55	34.5	31.5	6W	90	19
73	88	21	8E	135.5	5
80	8	35	8W	89.5	20
Total		220.0	13E	150.5	4
			13W	105	15
			14	167	2
			23	21	33
			28W	79.5	26
			40	119	11
			50E	87.5	22
			50W	127	9
			60S	119.5	10
			60N	41.5	29
			64E	160.5	3
			64W	110	12.5
			75E	71	28
			75W	83.5	24
			75Y	90	18
			84	84	23
			28E	128.5	8

Note: $M = 9$, $N = 26$, $T_u = 214$, $T_e = 110$, $p = 0.05$, $T = 220$, $T > T_u$.

Table 3. Wilcoxon rank sum test for passengers per mile.

Crosstown			Radial		
Link	Passengers/ Mile	Rank	Link	Passengers/ Mile	Rank
9	2.45	24	3	4.73	2
15	2.36	26	4E	2.75	21
17	1.14	31	4W	3.15	15.5
18	0.44	34	5E	3.68	8
19	2.93	18	5W	2.53	22
20	0.73	33	6E	3.28	12
55	1.15	30	6W	2.87	19
73	2.20	28	8E	3.33	11
80	0.19	35	8W	3.17	13.5
Total		259	13E	4.60	3
			13W	3.66	9
			14	4.12	6
			23	0.80	32
			28W	2.44	25
			40	3.17	13.5
			50E	3.52	10
			50W	3.71	7
			60S	3.05	17
			60N	1.26	29
			64E	4.75	1
			64W	4.23	4
			75E	2.77	20
			75W	2.49	23
			75Y	3.15	15.5
			84	2.22	27
			28E	4.19	5

Note: $M = 9$, $N = 26$, $T_u = 95$, $T_e = 259$, $p = 0.01$, $T = 259$, $T = T_e$. 1 mile = 1.6 km.

Table 4. Wilcoxon rank sum test for radial links connecting CBD and employment centers.

	Overall Rating		Passengers/Mile	
Link	Score	Rank	Number	Rank
64E	160.5	3	4.75	1
13E	150.5	4	4.60	3
5E	133	6	3.68	8
50E	87.5	19	3.52	10
8E	135.5	5	3.33	11
6E	110	12.5	3.28	12
3	168.5	1	4.73	2
64W	110	12.5	4.23	4
14	167	2	4.12	6

Note: $M = 9$, $N = 19$, $T_u = 182$, $T_e = 79$, $p = 0.01$, $T_1 = 65 < T_e$, $T_2 = 57 < T_e$. 1 mile = 1.6 km.

Table 5. Wilcoxon rank sum test for crosstown links.

Employment to Employment					Employment to Residential				
	Overall Rating		Passengers/Mile			Overall Rating		Passengers/Mile	
Link	Score	Rank	Number	Rank	Link	Score	Rank	Number	Rank
9	103	2	2.45	2	17	37	5	1.14	6
15	93	3	2.36	3	18	15.5	8	0.44	8
19	106.5	1	2.93	1	20	34.5	6.5	0.73	7
Total		6		6	55	34.5	6.5	1.15	5
					73	88	4	2.20	4
					80	8	9	0.19	9

Note: $M = 3$, $N = 6$, $T_u = 24$, $T_e = 6$, $p = 0.02$, $T_1 = 6 = T_2 = 6 = T_e$. 1 mile = 1.6 km.

Figure 1. Passengers on board for three types of bus routes.

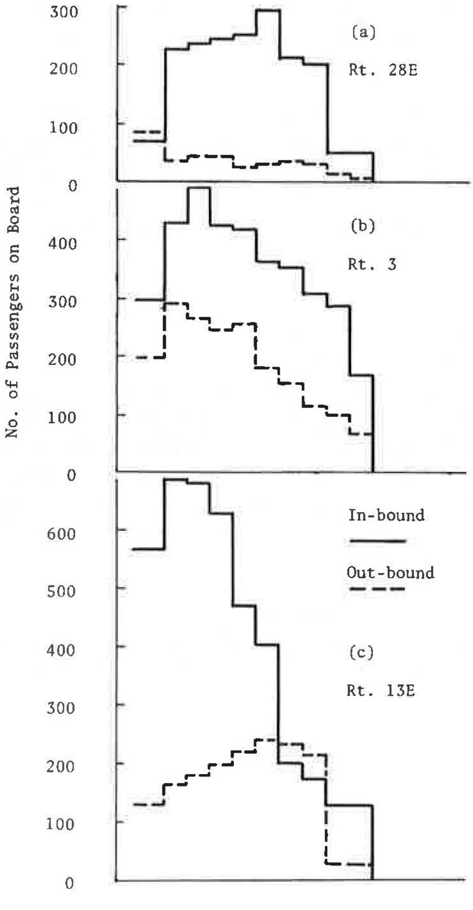


Table 6. Kendall rank correlation test.

	Passengers/Mile		Overall Rating		Employment	
Link	Number	Rank	Score	Rank	Number	Rank
64E	4.75	1	160.5	1	82,582	1
13E	4.60	2	150.5	2	78,887	2
5E	3.68	3	133	4	75,685	3
50E	3.52	4	87.5	7	72,342	5
8E	3.33	5	135.5	3	74,017	4
9	2.45	6	103	5	13,152	7
15	2.36	7	93	6	16,836	6

Note: 1 mile = 1.6 km.

and inbound trips. Figure 1c shows the profile of the route that serves between the Denver CBD and the University of Colorado Medical Center area, which is the third largest employment center in the metropolitan area. The number of passengers on outbound trips, although not so impressive as the number on inbound trips, is still rather high.

Employment as Priority Index

Intuitively, the bus route will have a better performance score if it has larger employment centers at both ends of the route. The results of the Kendall rank correlation test verify this assumption. For those routes that connected two activity nodes, the total employment numbers of the employment nodes were summed and used as the test index. In Table 6, three ranks were assigned to each link according to the overall ratings, the number of passengers per mile (kilometer), and the employment numbers. Griffin's (20) graphical method was used to carry out the Kendall test, as given in Table 7.

The overall ratings and employment number are significantly correlated at the 5 percent level. The correlation between employment number and passengers per mile (kilometer) is even better; $p = 0.01$. The test results suggest that the number of employment centers along the route is a good indicator for the priority index in the network design. However, no similar relations were found for the routes that extend into residential areas.

Regional System and Accessibility of Network

The form of a transportation system significantly affects the levels of accessibility throughout the metropolitan area. The level of accessibility in turn stimulates the community growth and helps shape the urban form. If the desirable urban form in American cities is to strengthen and revitalize the CBD and to develop the intensive activity centers in the outlying parts of the metropolitan area (21), a regional transit system that provides easy accessibility to the CBD and to activity centers should be developed with great care. In the context of this study, this regional system can be formed by connecting major transfer nodes.

In conclusion, bus routes should be classified into four categories: routes connecting transfer nodes, routes serving the activity corridor, routes connecting the activity centers, and routes extending from the activity centers to residential areas. Development priority should be in this order.

CASE STUDY

Study Area

The study area (Figure 2) is roughly bounded by I-225 to the east, I-70 to the north, I-25 and Santa Fe Drive to the west, and Colo-88 to the south. It covers approximately two-thirds of the city and county of Denver, most of the cities of Aurora and Englewood, and all of Cherry Hill Village. The Denver CBD is located at the northwestern corner of the study area. Also included in the area are most of the important employment centers in the Denver metropolitan area. In 1970, the total population in the area was 435,544, and the employment number was 283,685.

Major Transit Nodes

The internal origin-destination data (Figure 2) revealed that the Denver CBD, Cherry

Table 7. Griffin's graphical method.

Treatment	Item						
	Rank						
1 (passengers/mile)	1	2	3	5	4	7	6
Control (employment)	1	2	3	4	5	6	7
2 (overall ratings)	1	2	4	3	7	6	5
	Intersection			k	n	e	d
1	2			4	7	21	1
2	4			8	7	21	1

Note: 1 mile = 1.6 km.

Figure 2. Study area and internal origin-destination data.

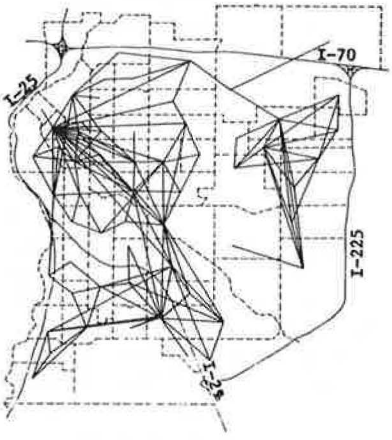


Figure 3. Residential districts, activity centers, and corridor in study area.

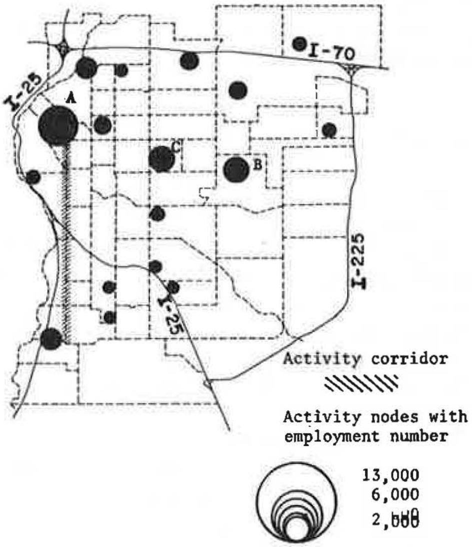
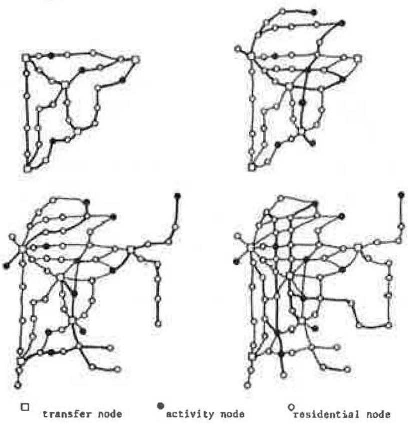


Figure 4. Network development in case study.



Creek, Englewood, South Colorado Boulevard, and Aurora were the five local traffic focuses. In addition to four of these five areas with the exclusion of the old Aurora CBD, the Denver Regional Council of Governments designated three more areas, including the newly proposed Aurora Community Center, as the intense activity center for future development. For simplicity, five existing traffic focuses as indicated by the origin-destination data were designated as transfer nodes.

Activity Nodes and Residential Nodes

In this case study, the total employment number per traffic zone was used as the criteria for designating activity nodes. In the study area, there were 63 zones that had an employment number of 2,000 or more. The adjacent zones were combined into 22 employment centers and one employment corridor (Figure 3). The largest 3 among these 22 centers were the Denver CBD, Lowry Air Force Base, and the University of Colorado Medical Center (A, B, and C respectively in Figure 3). The corridor was located along Broadway, extending from the Denver CBD south to Englewood. Among the 22 employment nodes, 3 were health care centers, and 1 was the airport.

For the residential nodes, the study area was divided into 63 districts or neighborhoods; each of them was represented by a residential node. The boundaries of these neighborhoods are also shown in Figure 3.

Network Development

The case study is restricted to the consideration of providing service for the work trips. The employment numbers of activity nodes were used as the priority index for the route selection. The first stage of the network development is primarily concerned with the regional system. Figure 4 shows that, if five routes are designated, each of five transfer nodes could have direct bus connections to the other four transfer nodes. This fact was reflected by a gamma index of 1.0 and a connectivity of the identity matrix I. Coincidentally, one of these five routes also served the only corridor in the study area.

The next stage involved the selection of the routes to connect activity nodes. Five of these routes were selected on the basis of employment numbers. The resulting accessibility matrix showed that 22 neighborhoods in the area had no bus service available. The number of districts without bus service was decreased to three by adding five routes in the next stage. All five routes could be specified as residential routes. In the last stage, when four more routes were added, all neighborhoods were served at least by one bus route. The last stage, however, was for the improvement of neighborhood accessibility rather than for the provision of uniform coverage. These four stages of development are also shown in Figure 4.

CONCLUSION

The framework is intended as a macrolevel model to help planners in determining transit corridors in network design. As such, it provides planners with an easy tool to specify and design preliminary alternatives on a rational basis.

One of the objectives of the study is to test the hypothesis of using the employment numbers of activity centers as the priority index in the network development. A functional description of the network structure and a comprehensive evaluation system were first developed. The functional description was designed to clarify the network structure and to integrate routes of various functions into a single system. The evaluation system was developed to help the planners reach a balance among various objectives of development.

Based on the new description and evaluation system, the planners can thus develop networks according to their own strategies in either providing service for work trips only or providing service for trips of all purposes.

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