A METHOD FOR DESIGNING BUS ROUTES NETWORK AND PRESENTING THE INFORMATIONS OF BUS ROUTES

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abstract: This paper proposes a visual system of bus route information. This system is composed of two devisions. The first is to plan and determine bus routes in a city road network. The last is that bus routes are displayed for the convenience of bus users.

1. INTRODUCTION

Bus system can provide network services, complement the rapid transit system in a big city, and be the main transportation system in a small city.
When there is a change in the OD trip pattern in a city, the bus route network, which has ben operated, should be modified to meet the new demand pattern. Installing a rapid transit system, such as a subway, will cause such a change in OD trip pattern. It is important to have a rational network of bus routes in order to deal with these changes in demand, to increase the usefulness for bus passengers and the operating efficiency. But often bus routes was developed unsystematically over a long period of time, so it is now necessary to develop a scientific and rational system for planning bus route network in order to improve present bus systems.

2. PREVIOUS WORKS

In bus route network planning, such are to be considered as the design of bus route network operated, the frequency of services of the routes, and the schedules of starting times and bus operations. We should consider passengers choices among many routes on the same road section. Lamplin(1967) has developed an approximate method for passenger choice among many routes by adding some fixed passing point in advance.
As for the schedule of the starting time, Friedman(1975) formulated a mathematical programming method to determine the departure time so as to minimize the waiting time of passengers. Jackson(1972) proposed a computer simulation method to calculate the schedules of buses operating on several bus routes. Gerrard(1972) has developed a computer simulation method to calculate the schedules of buses on the branches of bus route network. Rapp(1972) showed an evaluation method for alternative bus routes by the use of Graphic display in computer execution. Barsey(1979) has formulated its policy of applying market analysis techniques to bring the bus services into line with passenger demand.
The design of bus routes is the first step of bus route network planning. The bus routes are often designed by specially trained parsonnel. There is no previous work on the systematic design of bus route network.

3. PRINCIPLE OF DESIGNING BUS ROUTES

In general, bus routes should be as simple as possible and carry all passengers without transfer that they directly travel to their destinations for the convenience of passengers. We, therefore, should find all possible routes in designing bus route network. Routes should individually carry passengers as many as possible. It is, therefore, desirable to select such routes that carry the largest number of possible passengers.
In the road network of a big city, there are a large number of bus routes possible to be instaled. We, however, can not estimate how many possible routes there should be to

carry all passengers without transfer. On the other hand, it is impossible for us to record all the possible routes and to order according to passenger demand owing to the limited capacity and computation time to be spent in computer execution. This article shows an efficient method to decrease the number of alternative bus routes for bus route network planning.

4. MODEL FOR BUS ROUTE NETWORK PLANNING

The model proposed here could be used to help install rational bus route network. The model is composed of three submodels for the determination of alternative routes, reducing the number of of alternative routes and the determination of frequencies on individual routes(see Figure 1).
The first submodel searches systematically for all the possible routes which have the origin and destination nodes at terminals subject to limits on the length, shape of routes and number of turns at intersections, and selects some alternative routes which carry all passengers without transfer(see Figure 2).

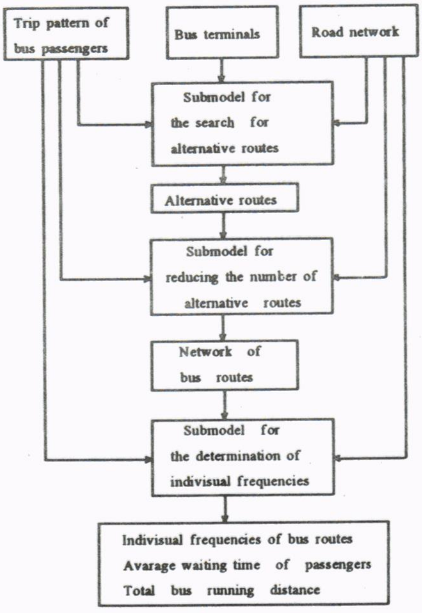

Figure 1. The flow chart of the model

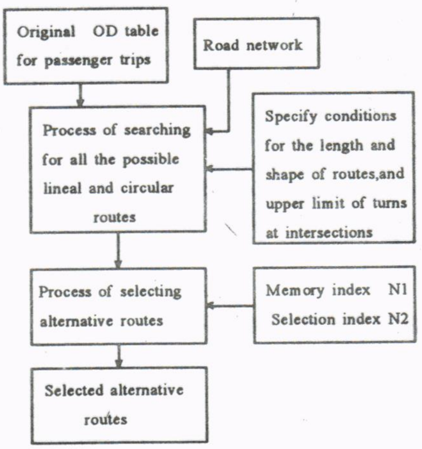

Figure 2. The flow chart of the first submodel

The submodel uses two indices for selecting routes. One is the memory index, the other is the selection index. The combination of these indices gives various sets of alternative routes. The network of alternative routes selected by the first submodel is too large and complicated for passengers to choose in a big city.
Some of the selected routes have partial resemblance to others. The resembling routes which have less passenger demand is to be eliminated for the efficiency of bus operation. In the real situation, it is not always necessary to carry all passengers without transfer. The second submodel, therefore, eliminates, step by step, the least needed routes until percentage of transfer passengers reaches a certain figure, so that there remains only the indispensable and important routes to carry passengers(see Figure 3). The least needed route is found to have the minimum number of passenger demand per link. The percentage of transfer passengers should be determined according to the scale of a city and its passenger demand.
The third submodel estimates individual frequencies of routes, waiting time of passengers and total bus running distance (see Figure 4). It is efficient for bus operation that the total bus running time of passengers is as short as possible.

It is said that designing bus service should be to fit the passengers demand taking account of the fact that the demand will vary with the service offered and the fare charged. Many city have fixed flat fare, so we can do without taking account of it.
Passengers arrive at bus stops at random and they get on buses which come early. Therefore, the passengers choices among routes are proportional to frequencies. Services should be closely attend to passenger needs.

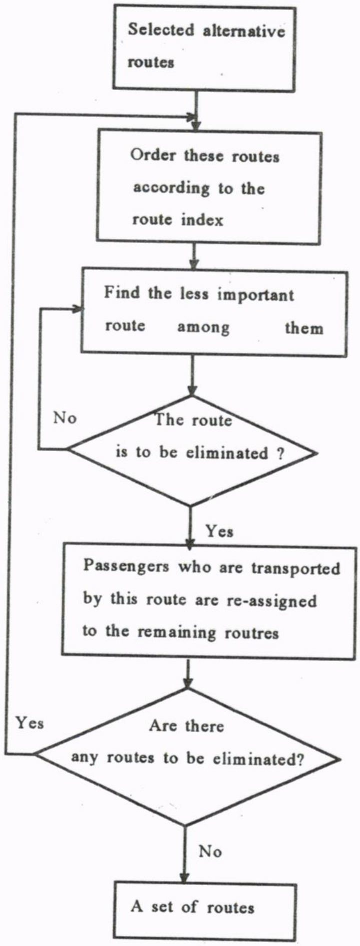

Figure 3. The second Submodel

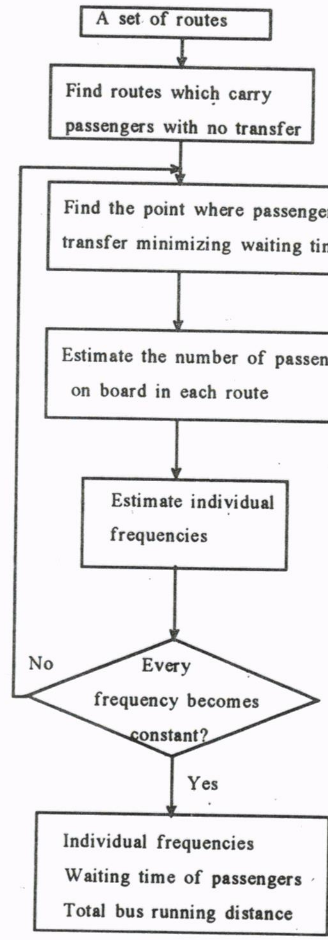

Figure 4. The third Submodel

In estimating frequencies we must consider both passengers who can travel without transfer and those who are obliged to transfer. Passengers who must transfer use another route transferring at a node where the sum of the frequencies of routes to be used is maximized, which means that passenger travel minimizing the waiting time on the route.
There are many transportation systems passengers can use. In the model only one mode of transportation system, which is the bus system, is considered. In general many bus stops are located on a road section. A node is identified as a set of some bus stops, and it is where the trips originate and end. The model is applied to a city which has a grid pattern road network like Kyoto city. The road network forms a grid pattern in the center of the city. The dummy nodes and dummy links, which do not exist in the real road network, are shown as circles and dotted

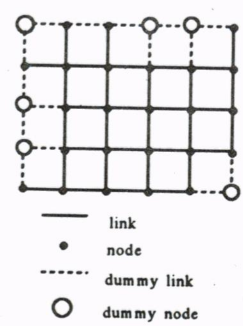

Figure 5. Road network

lines respectively(see Figure 5). The length of every link is supposed to be equal.

4.1 Search for Alternative Routes

The systematic search for alternative routes is the main part of the model. The submodel is composed of two processes, searching for and selecting alternative routes as shown in Figure 2.
We can find a lot of complicated routes which have many turns at intersection, but these routes are too difficult for passengers to understand and choose when they travel for the first time. Therefore, the routes should be as simple as possible. Very long routes are hard to operate at a satisfactory level of service. Very short routes cause loss time at turning point of terminals. It is, therefore, desirable that the length of routes has restrictions and the upper limit of turning left or right should be less than four times.
In the model, two kinds of routes are considered. One is circular (or loop). The other is lineal(or shuttle route). The circular and lineal routes operate in both directions. The lineal routes pass between two terminals by the shortest path. The circular routes have, at least, one terminal and their shapes are rectangular or square.

4.2 Searching for Possible Routes

We should find, at first, all the possible routes according to a given road network. The search for lineal routes is carried out, step by step, subject to the limits of the number of right or left turns, so that the nodes passed through by the route are stored in the memories of computer. The search for circular routes is carried out, step by step, to decide the four turning points. When a route passes through some dummy nodes, it is not memoried nor selected. When a route is as same as any route which is already found, it is never selected again.

4.3 Selecting Alternative Routes

We can get all possible routes by the above process. We should find and select possible direct routes for the convenience of passengers, but we can not estimate how many direct routes there would be. Although a large road network has a large number of possible direct routes, the number of routes should be as small as possible so that passengers can easily choose. We should select such routes that have large passenger demand per link. Owing to the limited capacity of computer, it is impossible to memory all possible routes in the order of possible passenger demand in a large road network. It is, therefore, necessary to select alternative routes among the possible routes by a step by step method as shown in Figure 6.

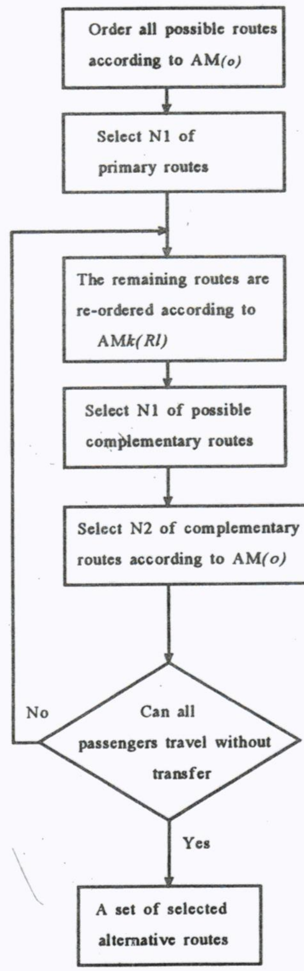

Figure 6.Select alternative routes

The principle of the method used here is, at first, to select some number N1 of primary routes which individually carry the larger number of passengers per link. When N1 is not large enough for passengers to be carried without transfer, there remains passengers who must transfer using the other routes selected so far. Then we select some complement routes which carry these passengers. It is also impossible for us to estimate how many complement routes there would be. Therefore the complement routes is to be selected step by step. The method is to select further routes(n2 in each step) so that eventually a set of routes is found for which no passengers has to transfer.
In the process of selecting alternative routes, the following items are defined. The

original OD(origin/destination) table, $Mij(o)$, is the initially given OD trips for bus passengers. The residual OD table, $Mij(R_1)$, is the OD trips in the l-th step for passengers who would have to transfer using only routes already selected. The possible number of passengers, $AMk(R_1)$, for the k-th route is the number of possible OD trips per link, which the k-th route individually carries in the residual OD table of l-th step. The possible number of passengers, $AMk(o)$, is the number of possible OD trips per link, which the k-th route individually carry in the original OD table.The process carried out in each step are as follows as shown in Table 1;

Step0: Order all (say N) possible routes according to the size of $AMk(o)$ and select best top n1 (= n say). These are called the primary routes (i.e. $a_1,a_2,...,a_n$) and are stored in the computer.

Step1: Calculate the residual OD table R_1 , reorder remaining possible routes(a_{n+1} to a_n) according to $AMk(R_1)$, and select the best top n1(to save only N1 remaining possible routes in memory of computer). This is called the first group of possible complementary routes. From this group, select the best top N2(= m say) according to $AMk(o)$. These are called the first group of selected complementary routes(i.e. $b_1',b_2',..., b_m'$).

Step2: Calculate the residual OD table R_2 (by subtracting trips made by the primary and complementary routes selected so far), reorder remaining possible routes (b_{m+1}' to b_n' and b_{n+1} to b_{N-n}) according to $AMk(R_2)$, and select the best top N1. This is called the second group of possible complementary routes(i.e. $c_1',c_2',..,c_m'$).

Table 1 Possible routes listed in order of $AMk(o)$ and $AMk(Rl)$

step	Step0	Step1	Step2	Step3
routes	Primary routes	First complement routes	Second complement routes	Third complement routes
	$AMk(o)$	$AMk(R_1)$	$AMk(R_2)$	$AMk(R_3)$
	a_1			
	a_2			
	·			
	·			
possible	·			
routes	a_n			
	a_{n+1}	b_1		
	·	b_2	c_1	
or	·	b_m	c_2	d_1
	·	·	c_m	d_2
	a_{2n}	b_n	·	d_m
possible	a_{2n+1}	b_{n+1}	·	·
complement	·	·	·	·
routes	·	·	c_n	·
	·	·	c_{n+1}	d_n
	·	·	·	d_{n+1}
	·	·	·	·
	·	·	·	·
	a_N	b_{N-n}	c_{N-n-m}	d_{N-n-2m}
reordered		b_1'	c_1'	d_1'
group		b_2'	c_2'	d_2'
according		b_m'	c_m'	d_m'
to		b_{m+1}'	c_{m+1}'	d_{m+1}'
$AMk(o)$		·	·	·
		·	·	·
		b_n'	c_n'	d_n'

Step3: Calculate the residual OD table R_3 and so on.
When N1 and N2 are small, we would iterate the step of selecting complementary routes

many times (say p) if there would be many complementary routes to be selected. We, at least, get $N1+pN2$ of selected routes. Many iterations cause the increase of computation time of computer. When N2 is large, we would have many resembling routes and selected alternative routes and the number of selected routes will increase. When we would like to have a small number of selected alternative routes, we should chose a small N1 of memory index.

5. CASE STUDY IN A SIMPLIFIED NETWORK OF A CITY

A simplified road network is shown in Figure 7. The existing bus terminals and garages are shown as double circles. The minimum length of the lineal and circular routes are 4 and 8, and the maximum length of them are 11 and 18 respectively.
When the indices of N1 and N2 are 200 and 3 respectively, there are 251 alternative routes selected which carry all passengers without transfer. There are about one thousand of possible routes according to the road network. The number of selected alternative routes is much smaller than that of possible routes.

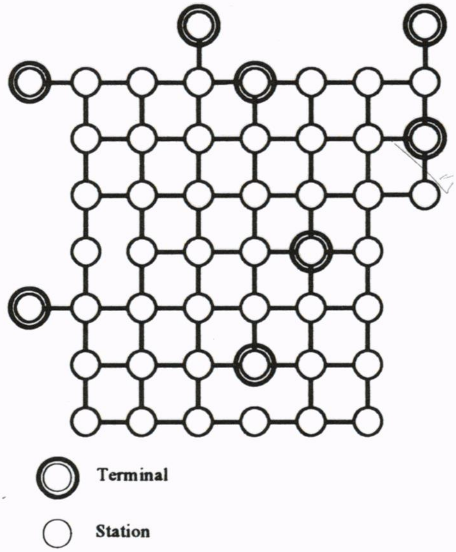

Figure 7. Simplified road network of a city

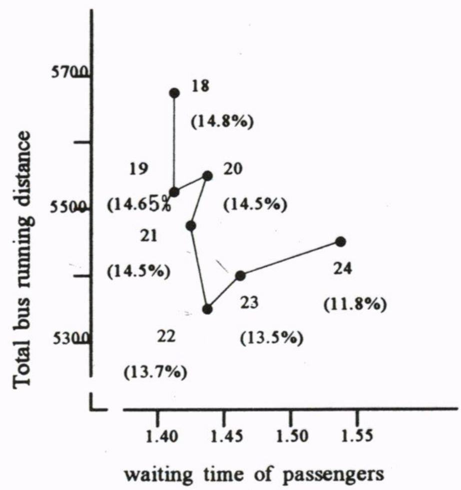

Figure 8. Total bus running distance and waiting time of passengers

We would like to estimate how a bus route network can be simplified when the total bus running distance is minimized. It is, therefore, supposed that, at most, 15% passengers of al OD trips should transfer one time but no passengers transfer two times. The number of alternative routes has reduced to 18 when the 15% passengers would be obliged to transfer. This number is smaller than the number of existing bus routes in the city. When the percentage decreases, the number of remaining routes and the waiting time of passengers increase in Figure 8 which shows the relation between the total bus running distance and the waiting time of passengers in brackets. The optimal number of routes is 22 when the total bus running distance is minimized. The individual frequency of each route is estimated from 3 to 21 per hour and the average number of passengers on board is 48.8 per bus. The bus authority would be able to operate an efficient service, taking these numbers into consideration.

6. DISPLAY MANY INFORMATIONS OF BUS ROUTES

In order to increase the usefulness of a bus system, it is important to establish the system for displaying and presenting many informations of bus routes to bus users wherever they are not only at a bus stop but also at home. The system can provide bus users the informations of suitable bus routes among many bus routes whether they want to go to their destinations as early as possible, as cheap as possible or as comfortable as possible. When bus users can get these informations on computer network at home, this system is the useful system for bus users and a bus system.

People want to know how to use a bus with a cheaper fare, as early as possible, as comfortably as possible and as exactly as possible when they go to their destination. So it is important for bus users that bus routes are easily used and found on the base of the four criteria that the fare is cheaper, the route used is shorter, it is comfortable in bus and that they can reach their destination early. Comfotability , exact of time, shortest and cheapness are estimated by the number of passengers in bus, the waiting time for a bus, the shortest route from the departure bus station to their destination bus stop respectively.

6.1 Setting the Order of Four Criteria

There is different importance on the four criteria among bus users. So the system asks a person to order the importance of them. When he want to go to a destination as early as possible , the criterion of shortestness is to be selected as the first important item. The second and third important criteria are selected on a personal computer, and the order of the four criteria is made identified.
As there exists different value of time among persons, when one want to know both cheap and early route, he must choose either the cheapest route or the earliest route. The system does not show which is better.

6.2 Output Data

All possible routes between a departure stop and a destination one are selected and displayed on the CRT of a personal computer. One of the best route for the four criteria which a person chose is displayed when he needs.The four best routes are simultaneously displayed if need.
Many informations are shown on the CRT of a computer, such as the number of a displayed route, the total number of possible routes combining between a departure one and a destination one, a name of the departure bus station, a name of the destination bus station, a name of a transfer bus station if exists and a waiting time for a bus at a bus station.

6.3 How to Display the Found Routes

6.3.1 Station
The departure station , destination station and the transfer one are shown on the CRT screen by the color of blue, green and red , respectively. Other stations are shown by the color of grey.

6.3.2 Bus Route
A route is shown by a line or a dotted line between two nodes. A direct route is displayed as the dotted lines from the beginning node to the departure station, lines from the departure one to the destination one and the dotted lines from the destination one to the ending node of the route.
A transfer route is displayed by a color, for instance green, as the doted thin lines from the beginning node of the first route to the departure station, the bold dotted lines from the departure one to a transfer one, the bold dotted lines from the transfer one to the destination one by another color, for instance blue and another kind of thin dotted lines from the destination to the ending node of the second route.

7. CONCLUSION

There have been many bus route network planing studies whose aims have been to design bus routes rationally. Most studies required the alternative routes developed by the experiences of bus authorities and specialists to be supplied as input. In this paper the submodel for the search for alternative routes was proposed in order to discover systematically the alternative routes. Even when there is limited computation time, it is possible for us to search for and select alternative routes which carry all passengers without transfer among a large number of possible routes in a big city. The submodel will enable us to design systematically all possible alternative routes with no inspiration nor experience, we can easily obtain the desired rational bus route network for real situation. The system can provide bus users the informations of suitable bus routes among many bus routes. When bus users can get these informations on computer network at home, this system is the useful system for bus users and a bus system.

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