<研究論文>

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Comparative Analysis of Urban Public Transportation Systems with Emphasis on Subway-Feeder Bus System

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Abstract

This paper attempts to develop a method which combines a subway system with a feeder bus system in order to increase the efficiency of the performance of the subway system.

The 'feasible region' where a subway system is more desirable than a conventional bus in its travel time for the CBD-bound trip is determined and the service-specification models of the two systems in this region have been formulated and analyzed in an aggregate manner.

The model developed in this study is applied to the Subway Line No. 1 in Seoul. The result obtained in the analysis indicates that the combined system can be guaranteed as a desirable mode in the point of travel time and cost within the feasible region. The concept of the model will lead to a proper assessment of the system's potentials for the choice of an optimal combination of the existing transport technologies.

Ⅰ. Introduction

There exists an urgent and growing need for systematic manageable means for comparison of alternative technologies for application to urban transportation problems. Previous studies on the analyses and comparisons on urban mass transit systems can be seen in [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. These works analyzed a basic and important urban public transportation problem concerning the characteristics and operational aspects of these systems and developed useful concepts and frame-works which permitted a comparison of alternative technologies on the basis of cost and service functions. These, however, did not consider any possibility for increasing the applicability of transport technologies through combining existing transport technologies each other or with any newly developing system. As pointed out in [1, 2, 3, 8], the best transport system for an urban area is likely to be one including more than one mode, and the level of service and areal service coverage for each of these modes is likely to be different.

In this study, a subway-feeder bus system which is an example of many possible combinations of existing transport technologies is proposed as one mode in an effort to expand areal coverage

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and to increase the level of service of a subway system. And an attempt is made to examine under what environment the proposed system can be operated as a desirable mode, compared with a conventional bus system and to what extent this system can improve the urban transportation problems concerning its service attributes such as overall speed of travel, frequency of service, flow capacity, walking distance, etc.

To develop a frame-work for comparison of the performances of the two systems on the basis of service attributes and cost functions, this study concentrates on identifying the region where a subway-feeder bus system is inherently dominant in terms of travel time and on examining the viability together with the physical capacity of the proposed system as a desirable mode from a cost stand-point.

A general approach adopted in this study is basically the same as those of [8, 9]. A circular city is considered as a model city. This research is limited to a CBD-bound trip originated from the outside of city and ended at the CBD located at the center point of city during rush hours. Further limitations are discussed whenever these are needed.

Ⅱ. Determination of Feasible Region for Subway-Feeder Bus System

Ⅱ. 1. Characteristics of Urban Transit Trip

A general pattern of work trip for the CBD-bound commuters by means of urban public transit systems through an urban corridor can be represented as in Fig. 1. In general, the area served by a radial commuter transportation route is approximated either by a segment of a circle or by a rectangle. The former which is typical for radial cities in which each major transport arterial services as a collector for an area widening toward suburbs is chosen in the model. For the segment-shaped service area, the equation of urban population distributions is:

$$P(x) = AXe^{-BX} \tag{1}$$

where A and B are positive parameters, to be the best approximation of the population density P at distance X from the center of the city.

In Fig. 1, walk time from the CBD terminal to commuter's ultimate destination is neglected, because the CBD located at the center of the city is assumed only a point not an area. As mentioned previously, a feeder bus as a possible means of increasing the efficiency of the rail rapid transit system operates on a feeder route between each subway station and a certain area, called 'feasible area' where a subway-feeder system is more 'desirable' mode than the other in case of a CBD-bound trip. The criterion for the determination of 'feasible area' is 'time' that has been a prime factor among many considerable factors in assuming the characteristics of 'economic men' about his attitude to travel activity.

It is, therefore, assumed that each passenger chooses one exclusively between two systems (a conventional bus and a feeder bus connected with a subway) available for his CBD-bound trip at his origin point on the basis of the shortest travel time from his origin to the CBD where both systems terminate. There is, however, a problem that the users of the combined system may hesitate to choose the system in case that they must pay not only the fare of the feeder bus but also that of the subway. But this problem can be solved under a certain condition that is discussed in chapters 3 and 4.

As depicted in Fig. 1, each commuter's travel time can be classified into two portions of time:

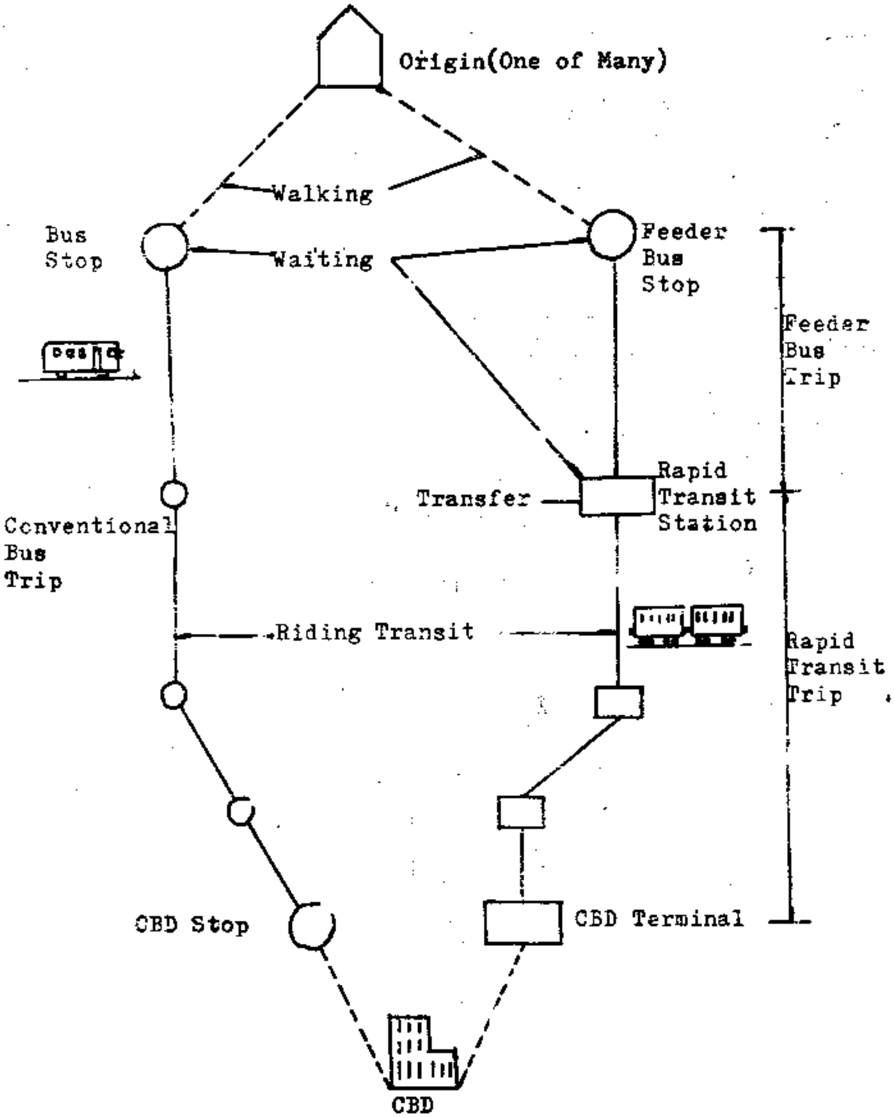

Fig. 1. **Transit Trip Pattern**

one is access time to a vehicle (bus or subway) and the other time on a vehicle. Access time is defined as the sum of walking time from each commuter's origin to the station area (hereafter, the meanings of station and stop are exchangeable), transfer time from the station area to the platform (if required), and waiting time for the vehicle. It depends upon the number of stations per unit length of the route of a feeder or a conventional bus and the number of the routes covering the area (route length per unit area), the frequency of the service and the capacity of the vehicle, the distance between transfer point and platform and facilities installed for convenience for various types of modes in case of rail rapid transit. Typical values for transfer time are usually in the order of magnitude of 60 seconds for pedestrians, 90 seconds for those coming by bus or being drop-off and 120 seconds for park-and-riders. Waiting time for the vehicle at station depends mainly on the headway between consecutive vehicles. When headways are long and vehicles adhere to published schedules, passengers tend to adapt their arrival at the station to that of the serving vehicle. If so, it is the service frequency that dominates the quality of the service. When service is frequent or when passengers have no information about the arrival times of vehicles, they tend to arrive at station at random.

Under such conditions, the expected waiting time, E{W}, is:

$$E\{W\}=\frac{E\{H^2\}}{2E\{H\}}$$
$$=\frac{1}{2}E\{H\}[1+C^2\{H\}] \tag{2}$$

where H=headway of successive vehicles that can be boarded by waiting passengers at station,

W=the waiting time for boarding at station, and

C{H}=the coefficient of variation of H

$=[\mathrm{Var}\{H\}/E^2\{H\}]^{1/2}$.

The above equation was proved in [12]. In fact, the process of headways between vehicles that are available for boarding is complex. It requires specification of the process of headways between all vehicles and the description of the distribution of full vehicles in the route. The occurrence of the vehicles full to capacity at some stop of the route depends in turn on the headway evolution and passenger arrivals at all preceding stops of the route. The formula of expetced waiting time at any point of the route was derived in [13]. This is, however, not the subject of this study. In Eq. (2), the value of C{H} varies within the range of 0 to 1. Assuming headways are regularly spaced and demand for boarding the vehicle is less than capacity to be offered, the value of $\frac{1}{2}$ E{H} is used as the average waiting time at station.

Time on vehicle is defined as time spent on the vehicle from the station where he boards the vehicle to the CBD terminal or to the transfer point. It depends mainly on the number of stations per unit length of the route, maximum speed, acceleration and deceleration rates of the system, dwell time at station, and other factors such as topographical route condition and the variation of traffic flow dependent upon time of day. Without loss of generality, the idealized vehicle travel diagram for the model is depicted in Fig. 2. A simplified expression for time on vehicle is as follows: If a given value of interstation spacing, S_k, which means the distance between k^{th} and $(k+1)^{th}$ stations (The CBD terminal is designated as the First station.), the travel time between k^{th} and $(k+1)^{th}$ stations has a form of

$$T_k=\frac{S_k}{V}+\frac{V}{2}\left(\frac{1}{A}+\frac{1}{B}\right)+t_d \tag{3}$$

where V=constant(or maximum) speed of the vehicle,

A=acceleration rate,

B=deceleration rate, and

t_d=dwell time at station.

It, however, should be noted that t_d would be zero in case that demand for boarding is equal to or greater than capacity at each station. If A=B, then Eq. (3) becomes:

$$T_k=\frac{S_k}{V}+\frac{V}{A}+t_d$$
$$=\frac{S_k}{V}+T_l \tag{4}$$

Thus, cumulative time on vehicle, T_n, from $(n+1)^{th}$ station to the CBD terminal becomes:

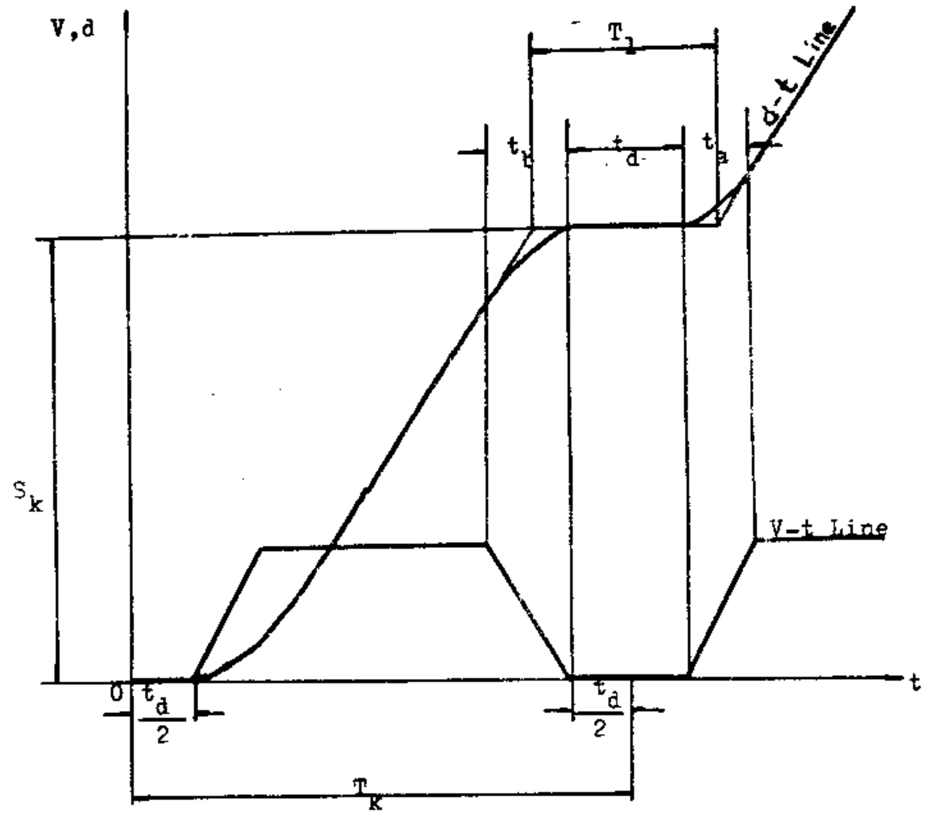

Fig. 2. Distance and Speed vs. Time Diagram of the Vehicle Movement(After Vuchic, 1966)

$$T_v = \sum_{k=1}^{n} T_k = \frac{D_n}{V} + n \cdot T_l \qquad (5)$$

where $D_n = S_1 + S_2 + \cdots\cdots + S_n$, and

n=number of interstation spacings along the route.

Ⅱ. 2. Passenger Shed Line of Subway-Feeder System.

In getting to the nearer station from one's origin point, there are theoritically many ways of access such as direct route, rectangular route, parallel to the transit route and then arc access, etc. Among them, 'direct access' is chosen as the way of access in the model. Here 'passenger shed line' is defined as 'the isochrone line' for the travel via either one station or the other from his origin point to the CBD terminal. As depicted in Fig 3, passenger shed line, R_k, which divides the area between two stations into two parts is derived by equalization of the travel time from any point on the line R_k via the stations k and $k+1$, respectively, to the moment when the vehicle departs from the station k. By using the geometrical relationship for the polar coordinate of which origin point is located at the CBD terminal, each passenger shed line is determined in terms of r from the following general formula for a given set of data (D_k, D_{k+1}, Vs, V_a, T_k, and θ):

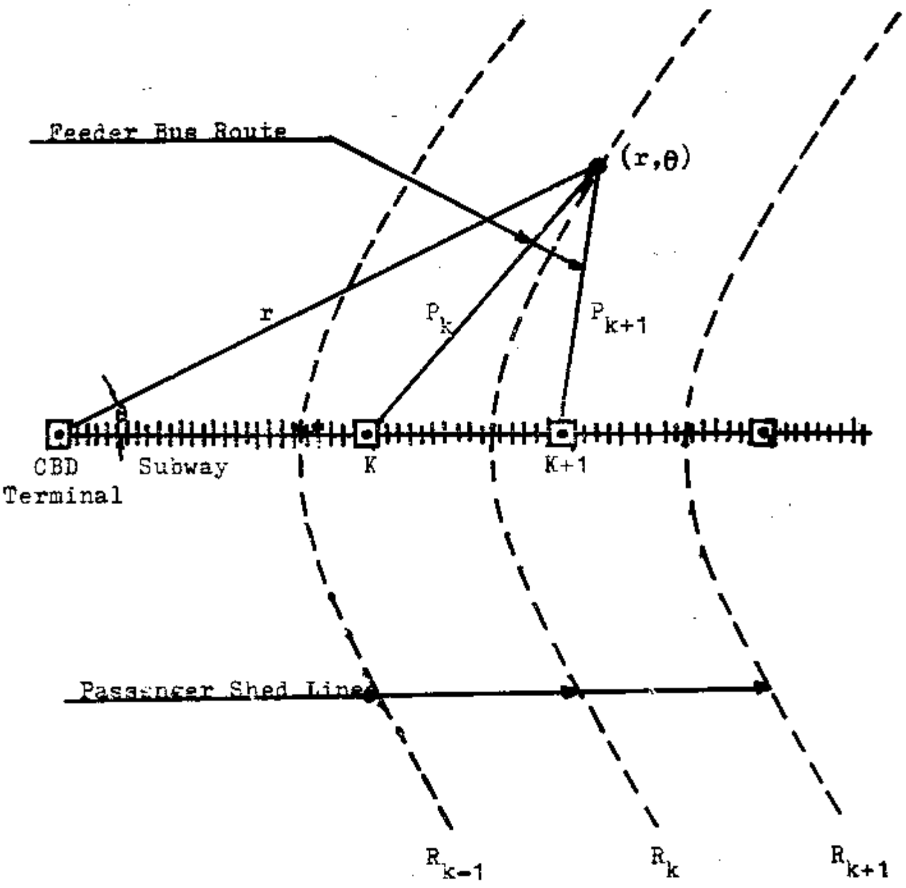

Fig. 3. Passenger Shed Lines of Subway-Feeder System

$$A\cdot r^2+B\cdot r+C=0$$

where $A=4(M+S_k\cos\theta)(M-S_k\cos\theta)$,

$B=4(D_k+D_{k+1})(S_k+M)(S_k-M)\cos\theta$,

$C=M^2\{2(D_{k+1}^2+D_k^2)-M^2\}-(D_{k+1}+D_k)^2S_k^2$,

$M=(S_k/V_s+T_i)/(1/V_f+F)$,

$F=N_f(V_f/A_f+t_{df})$,

V_s=constant speed of subway,

V_f=access speed of feeder bus,

A_f=acceleration rate of feeder bus,

t_{df}=average dwell time of feeder bus at stop, and

N_f=average number of stops per unit length of the feeder route.

For $k=1, 2, \cdots n$, the passenger shed lines of subway-feeder system can be determined step by step as θ increases from 0 to 90 degree.

Ⅱ. 3. Feasible Region for Subway-Feeder System Operation.

The region where the subway-feeder system is preferable to the conventional bus system in travel time for the CBD-bound trip is defined as 'feasible region' and is determined through comparing travel time required by each competing mode. Average walk time to a feeder bus stop is assumed shorter than that of a conventional bus, because the feeder bus can serve more closely to each passenger than the conventional bus and door-to-station service may be offered to the users of the feeder bus in a certain case.

The travel route of a conventional bus is also assumed as direct route as well as that of a feeder bus. This assumption is less realistic in the real world. However, the travel time for the CBD-bound trip in each mode will have a realistic value, if it is adjusted properly through reducing the speeds of the two systems.

The travel time of a conventional bus user, TT_B, is

$$TT_B=\frac{r}{V_B}+N_B\, r\left(\frac{V_B}{A_B}+t_{dB}\right)+\frac{1}{2}H_B+AWT_B \tag{7}$$

The travel time of a subway-feeder bus user via k^{th} subway station, TT_{sf}, has a form of

$$\begin{aligned} TT_{SF}&=\text{Time on Subway}+\text{Time on Feeder Bus}\\ &=\left\{\frac{D_k}{V_S}+(k-1)\left(\frac{V_S}{A_S}+t_{ds}\right)+T_f\right\}+\left\{\frac{P_k}{V_f}+N_f\cdot P_k\left(\frac{V_f}{A_f}+t_{df}\right)+AWT_f\right\}\\ &\quad+\frac{1}{2}(H_s+H_f) \end{aligned} \tag{8}$$

where $V_{B,S}$=constant speeds of a conventional bus and a subway, respectively,
$A_{B,S}$=acceleration rates of each system mentioned above,
$t_{dB,ds}$=average dwell times of each system mentioned above,
$AWT_{B,f}$=average walk times of a conventional bus and a feeder bus
$H_{B,S,f}$=headways of a conventional bus, a subway, and a feeder bus, respectively,
N_B=average number of bus stops per unit length of a conventional bus route,
$P_k=(r^2+D_k^2-2rD_k\cos\theta)^{1/2}$, and
T_f=transfer time at subway station.

In Fig. 4, a closed type of locus surrounding each subway station is produced and the combined system becomes a dominant mode within this region. The area of this region depends upon the technological or operational characteristics of two systems concerning maximum or constant vehicle speed, time for transfer, average walk distance, acceleration or deceleration rate, interstation spacing, dwell time at station, and headway of consecutive vehicles. In Equations (7) and (8), the input data concerning the technological or operational characteristics of two systems except the headways of two systems can be predetermined, if a set of technological and operational options of the systems is given. The reasons why the headway is released from the equations are that it determines the average waiting time of trip-maker's at station and hence influences the attractiveness of transit lines and determines the capacity of a line with the vehicle type. Therefore, the headway of the systems eventually becomes an important factor and furthermore it has a dynamic aspect in determining the area of the region. As shown in Fig. 4, the area of each feasible region at a designated subway station becomes larger and larger as the distance between the CBD and each subway station increases. Because the ratio of time on subway vehicle to total travel time increases and at the same time the effect of the substantial merit of the rail rapid transit system increases. In the next chapter, another criterion for the comparison of the performances of two systems within this region is investigated and the framework for the analysis is formulated.

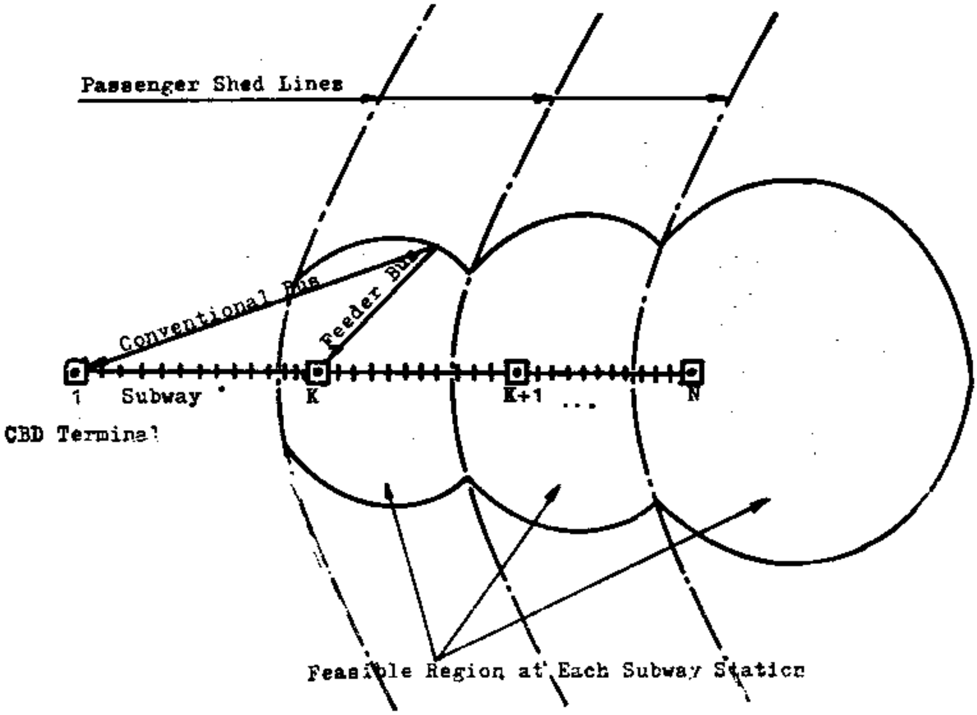

Fig. 4. Feasible Region for Subway-Feeder System Service

Ⅲ. Formulation of the Framework For Comparative Analysis

Ⅲ. 1. Approach to Problem

Although the feasible region where the combined system is dorminant in its travel time is derived in the previous chapter, the problems that the passengers using the combined system for their CBD trips can really be served by better level of service and the operators are willing to or able to operate the systems for those trips in this area are to be examined and analyzed. These depend upon the supply and demand functions as expounded by (14):

$$L=S(V,T) \tag{9}$$

$$V=D(A,L) \tag{10}$$

where L=some measure of level of service,

S=supply or service function,

V=passenger volume in passengers per unit time,

T=vector describing the characteristics of the system,

D=demand function, and

A=non-transportion optation: activity system option.

Here, a transit service function is a schedule of service quality that operator is willing and able to provide a corresponding schedule of passenger flows. The vector T may include service attributes such as transit routes, speed, acceleration, station dwell time, frequency service, seating comfort, ride quality, privacy and safety. Among these, seating comfort, ride quality, privacy and safety are not considered. Thus,

$$L=S(V;\ A, v,\ t_a, f) \qquad (11)$$

where v=cruising speed in the operating context, and

f=frequency of service.

As mentioned in the literature review previously, envelopes of transit service functions developed in [9, 10] are used as a technique for comparing the output spaces of the performances of transit technologies in the feasible region. A service-specification envelope defines the boundaries within which an operator is able to specify transit service for a given technology in predefined circumstance. An envelope is defined on one side by an economic or viability boundary and on the other by a capacity boundary. Two factors, the economic viability limit and the physical capacity limit play a role in constraining an operator's ability to offer transit service, i.e., to use a given technology-headway combination. To portray the service-specification graphically, a level-of-service index which means the overall speed between origin and egress points for characteristic routes in given operating contexts is used.

In the process of formulation of transit service-specification envelopes, the cost of providing transit service and the transit-fare structures should be defined crucially so as to represent the viability boundary of each system more realistically. In estimating the operating cost of urban transit system, some previous works can be seen in [15, 16]. In this study, therefore, it is not studied in detail. So far, the approach has been described and service-specification models of the systems under consideration in the feasible area are formulated in the next chapter.

Ⅲ. 2. Formulation of the Model

In analyzing the level of service and supply function in order to determine the service-specification envelope of the systems, the headway has a vital role. The headway of the systems under considerration will be examined in detail hereafter. This study concentrates on one subway

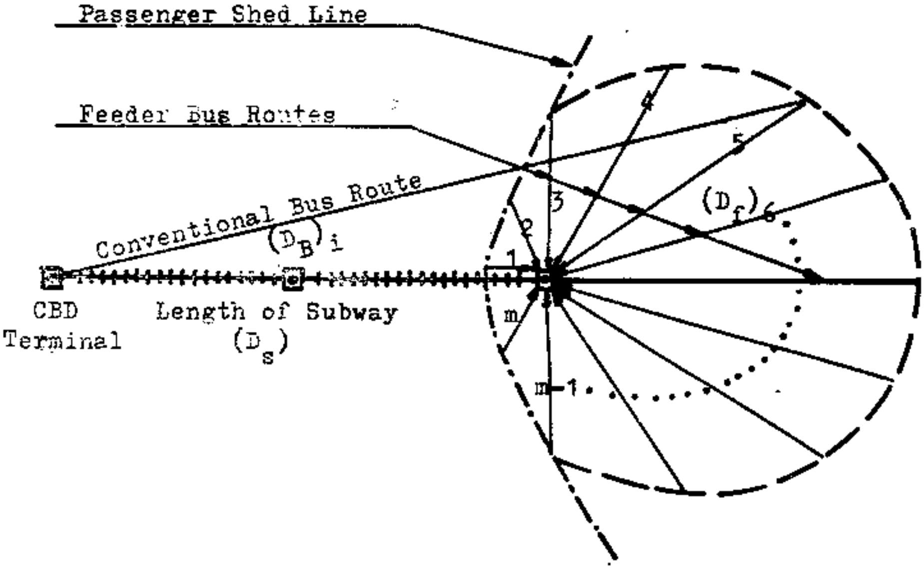

Fig. 5 Study Area with one Station and Feeder Bus System

line having serveral stations along it and is limited to one subway station with its own feeder bus system as shown in Fig. 5. The total number of passengers using the subway-feeder system during a specific time of day is governed by either the capacity of the subway or the capacity of the feeder buses. There are two cases; one is the case that the capacity of the subway is equal to or greater than that of the total feeder buses to be operated, and the other is that the subway is less than that of the feeder buses. In the latter case a queueing situation will occur at the subway station and the expected waiting time at the station will be longer and the level of service will also be decreased. This can be controlled by constraining the number of the feeder bus to be offered properly. In this study, this case is not considered. In the former case, the relationship between the headways of subway and feeder bus becomes as follows:

$$H_S \leqslant \frac{R}{m} \cdot H_f = \alpha \cdot H_f \tag{12}$$

where R=the ratio of the capacity of a subway train to the capacity of a feeder bus,
m=number of feeder bus routes, and
α=R/m.

The value of R should be properly adjusted for the comparison, because this study is limited to one subway station.

The level of service and supply functions of the subway-feeder bus and the conventional bus are calculated as follows:

$$\text{Level of service} = \frac{D_B}{TT_B} \text{ for the conventional bus} \tag{13}$$

$$\text{Level of service} = \frac{D_S + D_f}{TT_{SF}} \text{ for the subway-feeder bus} \tag{14}$$

where D_B=average bus trip distance,
D_s=average subway trip distance (here constant), and
D_f=average feeder bus trip distance.

In case of flat fare structure, supply function consisting of a viability limit and a capacity limit for a given system is formulated below.

For the conventional bus,

$$VL = \frac{(\text{operating cost/km}) \cdot D_B \cdot (60/H_B)}{F_B} \tag{15}$$

$$CL = (1 + R_{sc}) \cdot C_{vB} \cdot (60/H_B) \tag{16}$$

where F_B=flat fare per riding of bus,
R_{sc}=ratio of the number of excessive riders to normal vehicular capacity of bus, and
C_{vB}=normal vehicular capacity of bus.

For the subway-feeder bus, it becomes

$$VL = \frac{(60/H_s)\{(\text{cost/km/train}) \cdot D_s + R(\text{cost/km/veh.}) \cdot D_f\}}{F_{SF}} \tag{17}$$

$$CL = C_{vs} \cdot N_{vs} \cdot (60/H_s) \text{ or} \qquad (18\text{-a})$$

$$= C_{vf} \cdot m \cdot (60/H_f) \qquad (18\text{-b})$$

where $D_f = \sum_{i=1}^{m} D_{fi}/m$,
F_{SF}=flat fare per riding of subway-feeder bus,
C_{vs}=normal vehicular capacity of a subway train,
N^{vs}=number of vehicles in a subway train, and

C_{vf}=normal vehicular capacity of a feeder bus.

Here, Eq. (18-b) is for the case that the total capacity of feeder bus is less than that of a subway train.

So far, the formulas for the determination of the service-specification envelope of the two systems have been derived and according to the procedures described above, the comparative analysis for the systems can be made as demonstrated in the next chapter.

Ⅳ. Case Study

Ⅳ. 1. Assumption and System Service Output.

The framework developed in this study for the comparative analysis of a subway-feeder bus and a convenional bus is applied to Subway Line No. 1 in Seoul, the capital of Korea. In order to estimate the number of passengers in the study area, the population density of East Seoul is calculated by using Eq. (1) in chapter 2 and the regression analysis. The ratio of the expected number of commuters during rush hours (one hour) to the population in the study area is estimated from [17]. The data on the characteristics of the systems and the operating costs are summarized in Table 1. In determining the feasible region, a door-to-station service is applied to the feeder bus users, so instead of assuming a feeder bus stop spacing and its average dwell time, the overall speed of the feeder bus is employed and assumed as 12 km per hour. The average dwell time of the conventional bus at each bus stop during rush hours is assumed as 20 seconds as studied in [18]. The feasible area for the subway-feeder bus operation along the subway line No. 1 is shown in Fig. 6 and as mentioned previously, the study area is limited to the region including the subway station 7 and the service-specification envelope is made for this area. The average trip length of the subway-feeder bus users is approximately 8.0 kms (5.8

Table 1. Data on the Characteristics of the Systems and the Operating Costs

Item	Stop Distance (M)	No. of Stops Per Unit Legth (No./KM)	Average Constant Speed (KPH)	Average Acceleration Rate (KPH/SEC.)	Average Dwell Time at Stop (SEC.)	Average Walk Time (MIN.)	Time Required for Transfer from Feeder Bus to Subway Station (SEC.)	Capacity Per Train or Vehicle Including Standing (NO. OF PASSENGERS)	Operating Costs Per Kilometer (WON)
Subway	800 870 850 1,000 1,340 940	—	50 (40—70)	3.0	30	—	90*	Normal: 936 Rush hours: up to 240% of normal capacity	*** 2,600/Train
Feeder Bus	—	—	12*	—	—	0 (0-1.5)*		25 (15—40)*	70/VEH.*
Conventional Bus	670	1.5	30 (20—50)	2.5*	20	5*	—	80 (60—80)	110/**VEH.

*Assumed data,

**Breakdown for the determination of bus fare of Seoul Metropolis,

***The Government of Republic of Korea (1972), ( ) means the range of the data.

kms-subway route and 2.2 kms-average feeder bus route), and the average trip length from the area to the CBD by a conventional bus is approximetely 7.5 kms. The estimated population in the study area is 320,000 and the number of the potential passengers for the CBD-bound trip during rush hours is estimated as about 9,600. Assuming there are 20 lines of the feeder bus routes in the study area ($\alpha=2$) and also seven routes of the conventional bus evenly spaced through this area, the service-specification envelopes for the systems under consideration in the study area are calculated and shown in Table 2 and Fig. 7. In this study, the flat fare structure is employed, but zonal or distance-based fare rate can be applied by simple change in the equations derived previously.

Ⅳ. 2. Discussion of the Results

The individual service-specification envelope represents the output space of the performance ef the technologies in terms of passenger flow that can be accomodated in the system and in terms of quality of service that can be offered by giving an operator the quarantee at least for a break-even operation of the system. As expected, the quality of service of a subway-feeder bus is superior to that of a conventional bus. Because it has the merits of the speed of the subway system and the door-to-station service of the feeder bus. In this analysis, the estimated potential number of passengers in the study area during rush hours can make the subway-feeder bus more desirable mode in the light of better level of servcie. The subway-feeder bus appears to be well-suited in the study area. The conventional bus also can serve high flows though quality of service is lower than that of the subway-feeder bus and it can serve even relatively low passenger flows. Thus, the application range of the subway-feeder bus can be

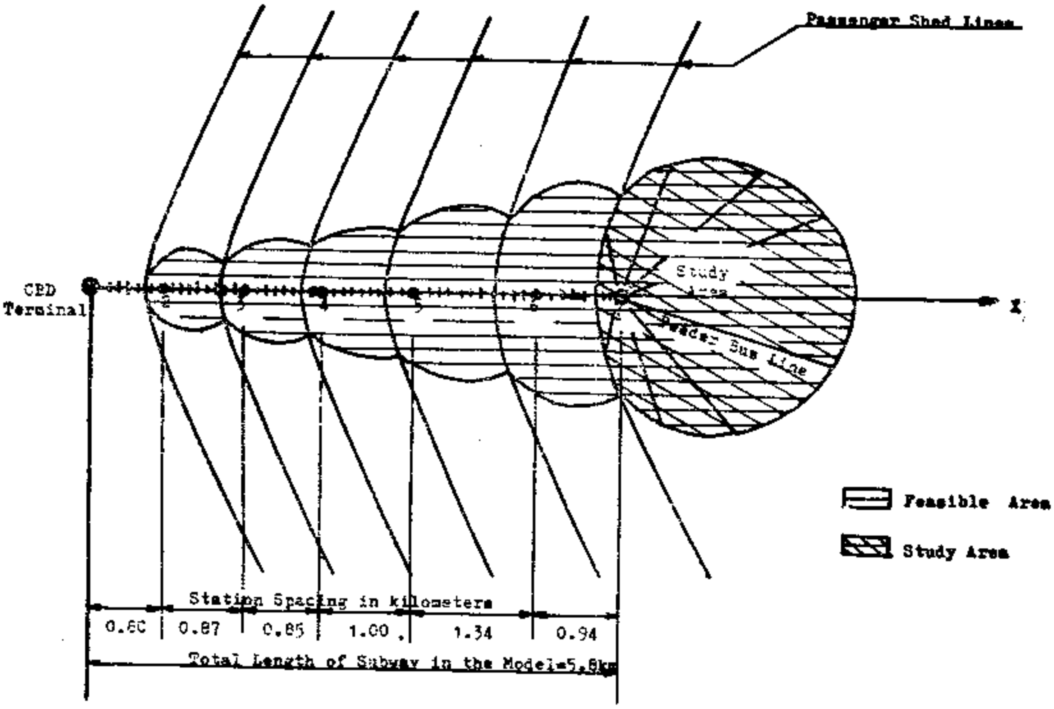

Fig. 6. Feasible Area for Subway-Feeder Bus in East Seoul

Table 2. Data and Assumptions for Service-Specification Envelopes

Technology	Headway		Quality of Service (M/Sec.)	Viability by Fare		Capacity Limit by percent of over-capacity			
	Hs	Hs. (1+1/α)		30 WON	40 WON	0 Percent	25 Percent	50 Percent	100 Percent
	(MIN.)								
Subway-Feeder Bus	2	3.0	5.20	21,240	15,930	28,080	35,109	42,120	56,160
	3	4.5	5.05	14,160	10,620	18,720	23,400	28,080	37,440
	4	6.0	4.92	10,620	7,965	14,040	17,550	21,060	28,080
	5	7.5	4.78	8,496	6,372	11,232	14,040	16,848	22,464
	6	9.0	4.66	7,080	5,310	9,360	11,700	14,040	18,720
	10	15.0	4.22	4,248	3,186	5,616	7,020	8,424	11,232
	15	22.5	3.77	2,832	2,124	3,744	4,680	5,616	7,488
	20	30.0	3.41	2,124	1,593	2,808	3,510	4,212	5,616
	30	45.0	2.86	1,416	1,062	1,872	2,340	2,808	3,744

Technology	Headway		Quality of Service (M/Sec.)	Viability by Fare		Capacity Limit by percentage of over-capacity			
	Hв	—		25 WON	25 WON	50 Percent	0 Percent	25 Percent	50 Percent
	(MIN.)								
Conventional Bus	2.0		4.63	990	6,930	3,600	16,800	21,000	25,200
	3.0		4.55	660	4,620	2,400	11,200	14,000	16,800
	4.5		4.42	440	3,080	1,600	7,467	9,333	11,200
	6.0		4.31	330	2,310	1,200	5,600	7,000	8,400
	7.5		4.20	264	1,848	960	4,480	5,600	6,720
	9.0		4.10	220	1,540	800	3,733	4,667	5,600
	15.0		3.73	132	924	480	2,240	2,800	3,360
	22.5		3.36	88	616	320	1,493	1,867	2,240
	30.0		3.05	66	462	240	1,120	1,400	1,680
	45.0		2.58	44	308	160	747	933	1,120
Remarks				1 route	7 routes	1 route	7 routes		

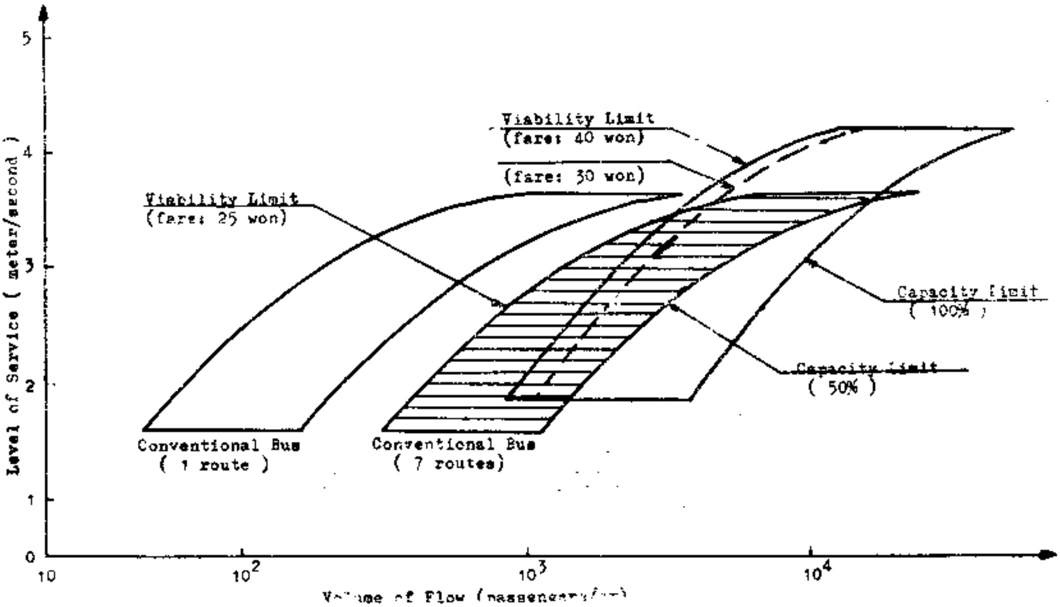

Fig. 7. Services-Specification Envelope of Subway-Feeder System and Conventional Bus System

said to be less flexible. One interesting thing is that if the passenger flow in this area is more than 9, 600 estimated previously, then the subway-feeder bus can be viable at the level of the fare of the subway itself. For this purpose, more up-to-date and detailed data is needed.

V. Conclusions and Further Recommendations

The ultimate goal of this research is to develop a methcd which might help a planner or a decision-maker have an insight into making a possible combination of the existing transportation systems as well as the new modes in the future in order to improve some urban transport problems. In this research, the method for combining the rail-rapid transit with a feeder system to increase the efficiency of the performance of the subway system by expanding its service area has been explored. The service-specification model of the subway-feeder system together with the conventional bus system has been formulated and analyzed in an aggregate manner in order to identify under what circumstances the proposed system could survive in the transportation market and to what extent the system could improve the service level for the users.

The major findings are as follows:

(1) The proposed system, subway-feeder system, can improve the level of service in terms of overall speed in the specific region which is defined as the feasible region;

(2) The operation of the proposed system can be guaranteed from the stand-point of cost, if the travel demand is large enough to meet a break-even point as demonstrated in the case study;

(3) The concept and the procedures of the model provide a deep insight into many interactions in any transportation system, and it will lead to a proper assessment of the system's potentials for real-world problem-solving such as the choice of an optimal combination of the existing transportation systems each other or with the newly developing systems.

The studied model is only developmental. It is limited to one study area having one subway station within a subway route. It is possible to expand the model to whole subway stations within a subway line and then may be to whole area of a city. Furthermore, it is desirable to formulate the model within which all possible system variables between supply and demand interact and the equilibrium state of the systems performance is found. The systems dynamics model [20] may be useful for this purpose.

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