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Research paper

Exploring a Last-Mile Solution in High Density Residential Neighborhood for Transit-Oriented Development

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Abstract

Background/Objectives: This study aims at introducing the last-mile transportation system in high density residential neighborhood and estimating impact of last-mile solution on system performance.
Methods/Statistical analysis: The study utilized agent-based model such as multi-agent transport simulation (MATSim) tool. The effect of introducing the minibus assumed in this study was applied to the analysis of public transportation demand and minibus analysis module embedded in MATSim. The minibus module contributes to solving network design problem, estimating the public transport schedule based on fixed public transport demand, providing the number of vehicles needed and the necessary routes.
Findings: This study applied one alternative to provide only minibus as a last mile solution to improve connectivity between land use and transportation. The other alternative was mixing strategy to supply not only new Bus Rapid Transit (BRT) to main trunk road, but also minibus to the high-density neighborhoods. The study area was Sejong City in Korea and was a new administrative capital city. In conclusion, the strategy of introducing the minibus was more effective, especially for applying the BRT to the main trunk road and introducing the minibus to the narrow branch road. The number of passengers, the number of routes and the number of vehicles using BRT and minibus were slightly different according to scenarios. Based on simple revenue and labor cost analysis, the feasibility analysis showed that it was effective to connect the BRT between the neighborhoods in the high-density neighborhood plan as in Korea and to put the minibus between the high-rise residential building and the residential building inside the neighborhood.
Improvements/Applications: Future study suggests that expansion of the entire city of Sejong, consideration of competition between car, minibus and walk modes with different income groups be required.

Keywords: *Last mile, Minibus, Transport and land use connection, High density neighborhood, Agent based model, Transit network design.*

1. Introduction

The relationship between land use and travel behavior has been studied for a long time. Through previous studies for almost two decades, meta-analysis for the relationship has been reported in urban planning journal [1,2]. It emphasizes that traditional cul-de-sac design was transformed to neo traditional design, on which the travel behavior of residents are considered as one of the most important design components. The design scheme is based upon low density of residential environment only with one or two floors' housing and the travel pattern of residents adapted with the environment. Traditionally, most urban areas in U.S. are characterized by low-density housing in suburban area.

In these days, however, metropolitan area becomes higher density and mixed use cities. Especially in Korea, the most common type of residency in cities becomes high-rise multi-dwelling housing. The change of land use can result in the change of travel behavior. Therefore the design of transportation network is made with the consideration of travel behavior compatible with high density neighborhood. In many cities of Korea, however, the transportation network is traditionally designed for low-density development and public transportation service or walk to access transit is not considered well in the planning process. It results in low mode share of public transportation and traffic congestion caused by passenger car during peak hour in high density residential area. For transit-oriented development, access to public transportation should be provided in convenient, comfortable, and efficient way.

This study aims at introducing the last-mile transportation system in high density residential neighborhood and estimating impact of last-mile solution on system performance. The study area is City of Sejong, a newly developed city as an administrative capital of Korea since 2012.Sejong was originally planned for transit oriented development with high density land use. However, the current mode share of public transportation is only 5%, which include bus rapid transit and local bus passengers. One of the reasons for low utilization of public transportation is a relatively long distance to bus stops from home or work place, which requires less than one mile's walk based on users' expectation[4]. In this study, a concept of minibus with non-fixed routes is proposed at Sejong as a last mile solution to poor access to local bus service. It can be well operated even in housing area because of smaller size than normal bus and with demand-responsive schedule. If this kind of new service affects positively on the ridership of public transportation, this scheme can be also applied as last mile transportation service in other areas of high-density neighborhood. Design and operation of mini-bus is simulated by

MATSim which is based upon Agent-based model dealing with the interaction among passenger, minibus, and urban design [3].

This study is organized as follows. Section 2 addresses the methodology proposed in this study after literature review and the input data simulated in MATSim. In Section 3, simulation scenario is presented and the results of simulation are analyzed. Lastly, we summarized the results and suggest the further research.

2. Methodology

2.1. Literature review: Agent-based simulation approach

In many of transportation studies, simulation approach is applied to capture the effect of new transportation service on network performance. Agent-based model is an approach to represent individual's travel choice and well-suited for describing the feedback between land-use and travel behavior, which requires relatively large sets of inputs than the traditional transportation simulation approach. However, thanks to technology development of data collection and analysis, the application of agent-based model has been increasing in transportation and urban studies.

There are several studies on last-mile transportation system using agent-based simulation tools such as MATSim, NetLogo, AnyLogic, and Repast. Zellner et al analyzed the effect of Autonomous Vehicle(AV) shuttle service as last-mile solution using NetLogo[4]. They investigated the change of mode share by the various streetcape design in four neighborhoods of Chicago with different socio-demographic characteristics. NetLogo was also applied in the study on the impact analysis of flexible work hour arrangement, urban concentration, a new bypass and cycle lanes on the duration of commute time, reliability and CO2 emissions [5]. In Netherland, an unmanned automobile operation was simulated using AnyLogic[6]. In New York, Repast was applied to estimate the change of mode share of Bicycle at the micro level of census block for preliminary validation of the policy to promote bicycle usage, which can mitigate traffic congestion and energy usage[7]. In the previous studies, AV shuttle and bicycle were applied in a last-mile solution in urban area which connected from low-density residential area to high-density workplace or business district. If origination of travel demand is a high-density residential area, higher occupancy of automobile such as mini-bus can be a better alternative to AV shuttle with a single ride. Nevertheless, there are only few studies on the implementation of minibus. Network design problem of minibus adoption was tackled in genetic algorithm module within MATSim[8]. The effects of minibus applications in South Africa [9] in 2014 was analyzed as a first trial, and the results of Swiss and other applications were validated in MATSim[10-12].

2.2. Methodology of this Study

In this study, we simulated the minibus as a last-mile solution in high-density residential neighborhood at Sejong using MATSim. MATSim has been developed as an open source based on Java and widely used in various studies. The simulation process of MATSim consists of five modules: initial demand (module 1), simulation (module 2), scoring (module 3), analysis (module 4), and re-planning (module 5), which are optimized through repeated computations[8].It has a co-evolutionary algorithm to optimize the plan for each agent's activity and passage, which executes the agent's plan and searches for new alternatives repeatedly. It is developed to use queue-based traffic simulation for computational efficiency of large-scale scenario analysis.

A last-mile service by mini-bus as proposed in this study is simulated through public transportation demand and minibus analysis module embedded in MATSim. Also we used an enhanced public transportation network with greater efficiency by applying genetic algorithms. In general, it is known that the transit network design is difficult to solve in an analytical way due to the NP-hard problem[13]. However, the minibus module contributes to solving this problem, estimating the public transport schedule based on fixed public transport demand, providing the number of vehicles needed and the necessary routes. Finally, it is possible to estimate revenues from the fixed public transport demand, and estimate the approximate driver's labor cost from the number of vehicles obtained using the agent based model, thus enabling approximate feasibility estimation.

2.3. Study Area and Input Data

The test network is City of Sejong with 250,000 residents in 2017 and more than 20 neighborhoods. For a test network, we select #2-2 neighborhood in dimension of 5 square kilometers and with 20 blocks of 400 square meters. It represents a typical type of high-density residential area in Korea. There is only one route of public transit as shown in figure 1, but full scale of public transportation network will be applied later.

In order to analyze the effect of minibus supply, MATSim's transportation network building process was applied as shown in manual[8]. Transportation network file was made through the following process.

· Extraction of transportation network data from Open Street Map [8, chapter 8]

· Convert to MATSim's road network using JSOM Network Editor [8, chapter 8]

· Simplify transportation network data to save computing time

The network consists of 76 links and 25 nodes and travel diary file is created on the basis of Korean Transport Database (KTDB) data[16]. Based upon these inputs, a plan file for MATSim was constructed through the following process.

· Utilizing macro movement data from Origin Destination (OD) trip table of KTDB

· Subdividing macro OD into block-to-block OD

· In case of departure time, setting up MATSim's plan file at random from 6-10 o'clock in the morning

Travel demand is estimated from the structure of residential building assumed 15 stories on average and six household residing on each floor. Morning peak hour demand from 6 am to 10 am is estimated as 12,000 trips in total.

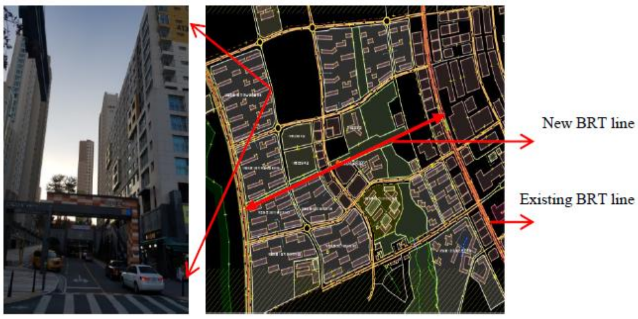

Figure1:.Study area network and test neighbo**rhood**

In Korea, a neighborhood design is mainly planned and executed by Korea Land and Housing Corporation(LH corporation). Following a general guideline, transportation network in a neighborhood is focused on travel demand of passenger car and public transportation network is usually serviced for travel demand between two different neighborhoods[14]. Though it is good for the efficiency of public transportation in low-density residential area, it results in poor service of public transportation in high-density area like Sejong. Figure 2 shows the comparison of public transportation access in two different cities. Left figure shows a light rail stop at Passedena, U.S. as a good example of the linkage of land use and transportation service[15]. Residents of high-rise building make a direct access to light rail from their home. Right figure shows a transfer center of Bus Rapid Transit(BRT) located in test area at Sejong. It is originally designed for a connected travel from car to BRT, which is based on the general guideline of neighborhood design of LH corporation.

	
Source[15, page 3.1]	Transfer center in Sejong City BRT line

Figure2:. Examples of transportation and land use connection

2.4. Scenario

We set up three scenarios to estimate the effect of mini-bus as a new transportation service on network performance. The first one is a public transportation network with only BRT and no mini-bus, on which two routes of BRT are running. The second one is a public transportation network with only mini-bus and without BRT system et al. The third scenario is a public transportation network with two BRT routes and mini-bus operated within a neighborhood to connect a passenger to BRT. Therefore these scenarios are summarized as follows.

- Scenario 1: only BRTs (15 minute interval) on two main trunks
- Scenario 2 : everywhere with minibus only
- Scenario 3: mixed provisions of BRTs (every 15 minutes) for two main trunks and minibus for narrow road

The transportation network is modified to represent the scenarios and the dimension of network is enlarged with 35 nodes and 96 links. Other assumptions for simulation in this study are same as the application in previous studies[8,10]. To get simulation results, we run 100 iterations with each scenario.

3. Results and Discussion

3.1. Simulation Results

The simulations were repeated 100 times to determine if the values reached a stable value. The simulation results are shown in figures 3, 4 and 5. About each scoring function, scenario 1 was stable after 30 and scenarios 2 and 3 were achieved after 20 times. Figure 3 shows an example of scoring function for Scenario 2.

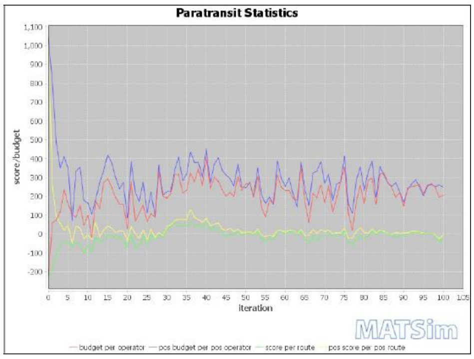

Figure3:. Scoring function for Scenario 2

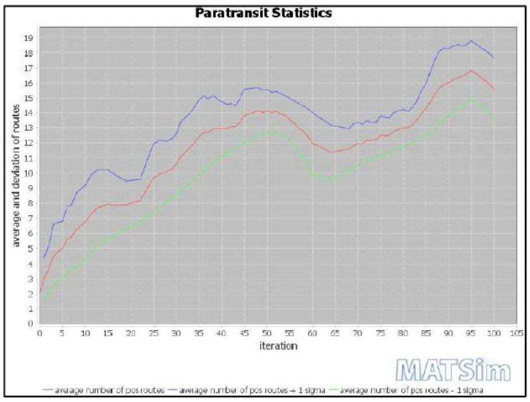

Figure4:.minibus routes distribution for Scenario 3

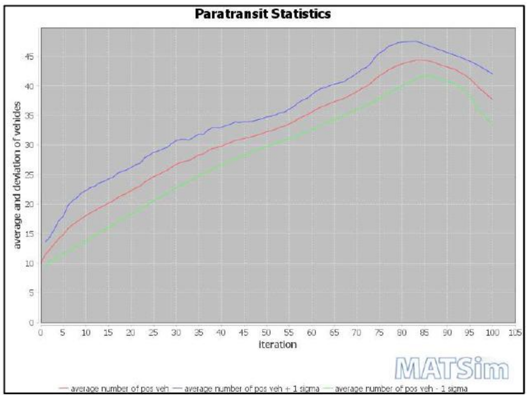

Figure5:.minibus vehicles distribution for Scenario 3

From the results, we estimate the total number of public transport routes, the number of vehicle running, the number of passengers on-board, and the average travel time in each Scenario. Figures 4 and 5 show an example of minibus routes and vehicles distribution for Scenario 3.In Scenario 1, the number of routes is two by BRT and the total number of passengers on board is 14,252 trips. The average travel time of total trips is 46 minutes. In Scenario 2 with only mini-bus, the number of vehicles is about 80 buses on 24 different routes and 20,934 passengers on board. The average travel time is 27 minutes. In Scenario 3, 36 mini-buses are running on 15 routes, the total number of passengers is 25,493 passengers and the average of travel times is 20 minutes.

Table 1 shows the travel time distribution of boarding passengers by scenario. Compared to the results from Scenario 1, ridership of public transportation with mini-bus such as Scenario 2 and Scenario 3 is increasing almost to double. In addition, the average travel time of Scenario 2 and Scenario 3 are also shorter than the average value of Scenario 1. Based on the results, Scenario 3 shows the best performance in terms of ridership of public transportation and the reduction of travel time.

Table 1: Boarding passenger distribution of scenarios

Scenarios	-15min	15-30 min	30 min+	Total trips
S1	6984	1824	5444	14252
S2	13032	2647	5255	20934
S3	16575	2627	6291	25493

To compare the network performance of Scenario 2 to Scenario 3, we choose a set of links with high volume as shown in table 2. On link 4333 and link 2423, the highest traffic volumes are assigned during morning peak in Scenario 2. However, the assigned volumes of the links in Scenario 3 are very small as shown in table 2. It is also observed in Link 3233 with high volume in Scenario 2 and zero volume in Scenario 3. Other links include 2322, 1314, and 1323 have low volume assigned in Scenario 2 and high volume in Scenario 3. From the results, we conclude that a design of min-bus operation should be considered not only the level of service that passenger experienced by introducing a new service but also the network performance such as traffic volume of critical links.

Table 2: Representative selected link volumes for scenarios 2 and 3

Link No.	8-9 hour Scenario S2	Morning Scenario S2	8-9 hour Scenario S3	Morning Scenario S3
4333	85	315	8	14
2423	84	406	40	226
2322	30	162	55	305
1314	60	322	14	54
3233	39	177	-	-
1323	15	50	121	601

Note: the numbers are the count of minibus vehicles

3.2. Discussions

This study assumed fixed travel demand for minibus, determined the public transportation schedule, and eventually, the required number of vehicles. The approximate transportation revenue is 7.5 million dollars per year assuming bus fare of $1 per tour and two tours per day. The number of vehicles required was estimated to be between 36 through 80. Assuming a driver per vehicle and assuming an annual labor cost of $50,000 per driver, the total labor cost is about between 3 through 4 million dollars. Since BRT construction and operation is a major transportation social overhead capital, it is supposed to operate with government support. Under these assumptions, additional profitability analysis can be performed by adding various scenarios of labor costs and operating costs. The simple feasibility analysis showed that it was effective to connect the BRT between the neighborhoods in the high-density neighborhood plan and to put the minibus between the high-rise residential building and the residential building inside the neighborhood. Nonetheless, there is a need for future research through realistic assumptions as follows.

First, public transportation demand is not fixed but equilibrium through competition with other modes. The most important thing is to compete for service between private cars, walks and minibuses, and it is necessary to re-estimate the demand for mini buses and the number of vehicles assuming the competition between three modes.

Second, it is necessary to consider the market segmentation of public transportation users. In other words, characteristics of the income class and the characteristics of the age group should be considered. Therefore, for mode competition and market segmentation, input data of various parameters of agent based model should be recalibrated through Stated Preference and Revealed Preference survey data.

Third, the target area of this study is limited to one neighborhood. In the future, it will be possible to derive research results for the entire city of Sejong.

4. Conclusion

It is important to design neighborhoods that have high connectivity between land use and transportation in areas with high densities such as Korea. In this study, we analyzed the effect of last mile solution on direct entrance of minibus to a high density housing complex where it is difficult to enter a large bus to increase the advantage. The analysis showed that it was effective to connect the BRT between the neighborhoods in the high-density neighborhood plan as in Korea and to put the minibus between the high-rise residential building and the residential building inside the neighborhood.

The study area was Sejong City in Korea and the new administrative capital. The simulation techniques of the study utilized agent-based models. The minibus was considered a mode of transportation to the high-density neighborhoods. This study applied one alternative to provide minibus as a last mile solution to improve connectivity between land use and transportation, and the other alternative to supply Bus Rapid Transit to the main trunk road and minibus to the narrow branch road. In conclusion, the strategy of introducing the minibus was more effective than that of the only minibus provision, especially for applying the BRT to the trunk road and introducing the minibus to the branch road.

This study was limited by spatial and methodological scope. Therefore, it will be a more realistic analysis to consider expansion of the entire city of Sejong, in the future, consideration of private car, interaction between walk mode and minibus, interaction between minibus and street cape design, and interaction with other trip purposes. Also, characteristics of the income class and the characteristics of the age group should be considered. Various parameters of agent based model should be recalibrated through Stated Preference and Revealed Preference survey data.

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