論文の内容の要旨

Neighborhood scale optimization for density, transportation, land use and the natural support systems towards an efficient urban form

（効率的な都市形成に向けての密度、交通、土地利用、自然システムの地区単位での最適化）

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ABSTRACT

The process of urbanization differs in different parts of the world. Whereas, cities in the developing world are growing at a rapid pace primarily due to the rural urban migration, cities in the developed world are facing different patterns of growth namely suburban sprawl. The size and organization of the cities itself lead to wastage of physical resources needed to support it and damage of its own and its hinterland's environment. Besides, environmental concerns such as air and water pollution, etc. are featuring seriously in the minds of the urban policy makers for the first time. Thus, traditional urban land use and transportation planning process is not enough to plan for our future cities where sustainability would be the key, requiring the intervention of multi-disciplinary approaches.

Travel Demand management (TDM) and Transit-oriented development (TOD) has been the focus of sustainable urban transportation research for the last few decades. Numerous studies have recognized the importance of enhancing transit connectivity at the city scale and at the same time increasing development density and mixed-use development at the neighborhood scale to enhance transit usage. Enhancing development density at the neighborhood scale not only promotes modal shift towards transit use but also increases the modal share of walking and bicycle use for different trip purposes whereas, mixed-use development at the neighborhood scale has a profound influence on the urban

structure and form thus effecting location choice by households which in turn influences trip generation and distribution. Increasing development density within the urban area also reduces urban sprawl and suburbanization thus increasing land use efficiency.

Development density of a particular neighborhood can be enhanced either through increasing the built-up area percentage or through increasing the height of existing buildings or a combination of both. Neighborhood environmental concerns such as amount of open area, parks and greens becomes the decisive factor for increasing the built-up area percentage whereas, people's preference for living or working in high rise buildings and construction cost becomes the decisive factors in increasing building height. This is where the TDM design problem is converted to a multi-criteria planning and design problem at the neighborhood level. This is referred as the land use design problem (LDP) in literature and the resulting mathematical formulation is a multi-objective optimization problem. Finally, the land use design problem could be further extended to take into considerations city level design targets for natural support systems such as parks and greens, agriculture, water bodies etc. thus incorporating concerns for urban food security and livability into the urban land use transportation planning process.

The basic objective of this research is to model the interaction between urban land use, building floor area density, population density, transportation and the natural support systems and provide an integrated analytical planning model for urban scale application. The specific objectives are as follows:

- Comprehensive analysis of how built environment characteristics influence modal choice at the neighborhood level for different trip purposes.
- Incorporating a proactive component in the urban land use transportation planning process in form of an optimization model at the neighborhood scale to evaluate neighborhood planning targets.
- Integration of the different model components such as residential location choice, trip generation, trip distribution, modal choice and neighborhood optimization for city scale simulation.

- Development and application of the models for Nagoya.
- Estimating, evaluating and proposing long terms plans for urban structural modifications towards our vision an efficient urban form for Nagoya using the modeling framework developed in this research thus attaining reduction in total travel cost, travel time and CO_2 emission levels in the process.

The present model utilizes an integrated modeling approach using multi-objective optimization to reconcile the trade-offs among various urban planning and environmental parameters at the neighborhood scale and simultaneously simulating the land use, building use and transport dynamics, both at the neighborhood and city scale using aggregate models such as the multiple regression models for trip generation and attraction, discrete choice models such as the logit model for modal split and a multi-objective optimization model for land use and building use plan generation. The sub-models developed could also be applied independently or in combination to evaluate other planning targets at the city or neighborhood scale.

At first, the case study area, Nagoya city is introduced. The city is then divided into zones or neighborhood for the development of our model. Then, detailed databases were developed for each neighborhood on demographic, built environment, trip and network characteristics. In the next step, linear multiple regression models were developed for different trip purposes using neighborhood parameter estimates like total floor area for building categories, area for land use categories, population etc for predicting trip production and attraction from the neighborhoods. For trip distribution, the standard gravity model formulation was adopted and calibrated for Nagoya.

In the next step, modal split models were developed for 6 broad trip purposes in Nagoya. The modal split model adopted in our study is a post trip distribution modal split model based on the discrete choice framework. We adopted a two stage model with a binary choice at each stage. The first stage (Level 1) explained the mode choices between slow and fast mode and the second stage (Level 2) explained the mode choices between car and transit mode. A comprehensive set of built environment characteristics at both the trip origin and destination were evaluated to determine the influence of built form on modal choice.

The next model developed is the neighborhood regeneration model. Based on TDM planning objectives, neighborhood environmental concerns and economic efficiency four objectives were formulated: maximizing transit use; maximizing walking and bicycle use; minimizing built-up area coverage; and minimizing total transport cost. The decision variables used in the model were average building height, neighborhood building floor area density and % of existing buildings to be demolished for reconstruction. Five types of constraints were used in the development of the model. The first constraint is the lower bound of building floor area density. This constraint is set by considering the existing density of the building categories. The second constraint is the upper and lower bounds on percent of buildings to be demolished. This constraint is set by considering the percent of buildings which have reached the end of their service life (lower bound) and feasible percent of buildings that could be demolished (upper bound). The third constraint is the upper and lower bounds on average building height. This constraint is set by considering the existing average building height of the building categories (lower bound) and people’s preference for living and working in high-rise buildings (upper bound). The fourth constraint is the upper and lower bounds on total cost of building construction. This constraint is set as 0 (lower bound) and cost benefit achieved by minimization of transportation cost (upper bound). The fifth constraint is the lower bound on land use savings. (Built-up area decrease due to higher density reconstruction) This constraint is set by considering the land use design target. Seven building categories are investigated in our model. The model planning period was fixed as 5 years which is usually also the period between subsequent PT surveys undertaken in Nagoya. Another general assumption in our model is that service life of buildings in Japan is 30 years. All economic and environmental benefits are also evaluated over the same period. Considering Nagoya’s case, we assumed additional floor area demand for a building category to be absorbed within the existing land use for that building category which would actually make the reconstruction activity profitable for developers. One limitation of our optimization approach is that, neighborhood density at trip origin is only considered for modification whereas; modal split is affected by both neighborhood densities at trip origin and trip destination. To address this issue we have used an iterative approach for neighborhood optimization. The resulting optimization problem is a nonlinear, non-convex programming model. Premium Solver Version 7 software was used for optimization and the method employed was 'Standard Interval Global'. Even though, minimizing total transportation cost has been used as the primary objective, minimizing transport CO_2 emission or total CO2 emission from both transportation and the building sector could also be also used as an objective function in this model.

In the next step, a residential location choice model for rented multi family housing location choice and a multiple regression model for estimating new demand for commercial floor area in the different neighborhoods were estimated.

Finally, the model framework was applied to Nagoya. The simulation framework is developed at the beginning. Then, baseline estimates were obtained for trip characteristics for all the neighborhoods in Nagoya. The next step involved selection of neighborhoods for application of the neighborhood regeneration model based on our planning targets. The neighborhood regeneration model was then applied to 66 neighborhoods. Three objective functions within the neighborhood regeneration model, minimizing total transportation cost, minimizing transport CO_2 emission and minimizing total CO2 emission from both transportation and building sector was evaluated separately using three sets of calculations for the 66 neighborhoods selected for regeneration. Finally, estimates for trip characteristics and built environment characteristics were obtained along with related costs and benefits for all the selected neighborhoods for regeneration for the three different evaluated objectives.

The following general conclusions could be drawn from the present research.

Neighborhood built environment characteristics play an effective role in determining travel behavior of the population. However, their effect on mode choices at the neighborhood level not only varies according to the mode but also according to the trip purpose. Thus, adopting ad-hoc decisions to modify built environment characteristics at the neighborhood level may result in unexpected effects. For example, increasing residential density at a zone to increase modal share of transit use may actually result in decrease of transit rider ship due to modal shift to slow modes such as bicycle or walking. Thus, the effect though beneficial may result in unexpected complications like underutilized transit infrastructure.

Neighborhood built environment characteristics at trip origin was found to be more effective in influencing probability of choosing slow mode than neighborhood density at trip destination. However, for transit mode choice, neighborhood density at trip destination is more effective than neighborhood density at trip origin. Thus, it would be more effective to increase business and commercial density at transit destinations to increase transit mode choice.

Built environment characteristics and particularly, development density of a particular neighborhood can be enhanced to improve the modal share of slow and transit modes. However, actual physical barriers, like limited plot size for high rise development or due to the existing age of buildings which may be relatively new and people's willingness to change, the effective improvement in density may be insufficient to influence significant changes in modal choice. Thus, long term planning targets for improving the development density at the neighborhood level should be adopted.

Environmental concerns such as amount of open area, parks and greens at the neighborhood level and CO_2 emission both at the neighborhood and city scale from the transportation and building sector, amount of land area required for natural support systems for agriculture, forestry etc, could be evaluated as fixed values or as decision variables using the present modeling approach.

Finally, the present modeling approach could be utilized to generate a more efficient urban form in terms of travel time, travel cost as well as CO_2 emissions as was demonstrated in the case of the model application in Nagoya city.

An analytical model for integrated planning at neighborhood scale and transportation planning at the city scale has been left unexplored due to the complexity of the interactions between these two design problems. The present modeling approach can be one of the useful tools for planning for TDM and TOD, allowing planners and decision makers to make more informed choices about F.A.R. (Floor area ratio) and B.A.R. (Building area ratio) regulations, construction of new transit lines and design policies for changes needed within the neighborhoods in terms of land use, building use, building floor area and density.