

A Framework of Large-Scale Virtual City Simulation with Land-Use Model

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Abstract—Digital twin for city simulation is a technology that replicates real city infrastructure and predicts the future of cities through various analysis and simulations. In this paper, we propose an integrated virtual city model that utilizes the prediction data of the land-use model and the agent-based transport model. The land-use simulation model is a spatially explicit and integrated socioeconomic modeling approach that aims to predict the long-term impact of land-use and change in various management planning policy scenarios. The proposed virtual city simulation platform predicts changes in urban space demand and population movement, and simulates urban policy scenarios to compare and evaluate the results.

Keywords— Modeling and Simulation, Agent based Modeling, Smart City, Digital Twin, Land-Use Model

I. INTRODUCTION

Most large cities face various urban problems such as housing problems, traffic congestion, lack of parking spaces, and air pollution that negatively affect the safety and environment of citizens and threaten the sustainability and competitiveness of cities in the long term. Many cities are trying to solve urban problems through a “Smart City” that combine ICT technology to effectively utilize existing urban infrastructure and improve the quality of life of citizens, the sustainability and the competitiveness of the city. As a field of smart city, city simulation using digital twins is nowadays becoming the focus of attention of an increasing number of researchers.

Digital twins for city simulation digitally replicate real-world objects and systems, enabling effective operation, rapid feedback, and future prediction of real-world phenomena through various analysis and simulations. Agent-based modeling (ABM) presented in [1] is a simulation modeling technique utilized to simulate cities and calculate city changes. Modeling and simulation of agent-based urban societies uses computationally intensive methods to analyze social phenomena and uses large-scale objects to simulate complex social processes ([2], [3]).

City simulation using digital twins utilizes virtual digital twin cities to help realize smart cities through real-time monitoring, operation and forecasting, but has limitations in long-term forecasting.

Because digital twins implement current objects and systems in the real world as virtual digital twins, acquire real-

time data, and perform analysis and simulation, it is difficult to maintain high reliability and accuracy when predicting dynamic changes in a city for a long period of time.

In this paper, we propose virtual city simulation model is an integrated model for land-use scenario simulations by coupling land-use and transportation effects.

A land-use simulation model is a spatially explicit and integrated socio-economic modeling approach that aims to predict the long-term impacts of land-use and change in various management-planning-policy scenarios.

An integrated virtual city model that leverages the interactive predicted data of land-use model and transport model can predict long-term demand for city services such as transportation facilities and residential space.

The rest of the paper is organized as follows. First, we give an overview of a land-use model and an agent-based transport model respectively. In Section 4, we propose an integrated virtual city simulation platform. Section 5 addresses the results of the proposed model. Finally, we provide concluding remarks on our scheme in section 6.

II. DELTA LAND-USE MODEL

The land-use model is a socio-economic modeling approach to produce results by simulating the impact of urban development, planning, and policies on urban development in advance.

DELTA is a land-use model developed by David Simmonds Consultancy Ltd. of Cambridge, UK in 1995, and aims to predict changes in accessibility according to the interrelationship between land-use model and transport model over time ([4]). After being first applied to Edinburgh, Scotland, it is one of the representative integrated land-use models that have been used in many cities.

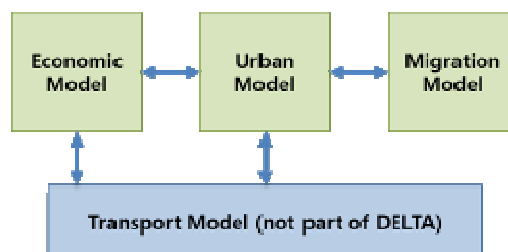


Figure 1. The structure of the DELTA land-use model

As shown in Figure 1, DELTA consists of a transport model, an economic model, an urban model, and a migration model. The transport models are not included in Delta, but are usually linked to specialized modeling packages.

The urban model consists of five sub-models which predict the location of households and occupations within a detailed modeled area.

The development(D) sub-model estimates the total amount of development and predicts the operation of the development process. The employment(E) sub-model calculates labor demand by sector and predicts the supply of workers in consideration of employment status and commuting patterns. The location(L) sub-model predicts the location of households and occupations, by considering changes in housing supply, changes in accessibility, transport-related changes in the local environment, area quality, and the rent of space. The transition(T) sub-model predicts demographic changes such as household composition, conversion and dissolution rates. The area quality(A) sub-model implements the hypothesis that the inhabitants of an area affect their characteristics and influence the places to live over time. The name DELTA was created as an acronym for these five sub-models.

The delta land-use model clearly divides cities into physical spaces and activities, and allows agents to economically determine the physical spaces in which to conduct social activities. In other words, DELTA model determines the residence of an agent by considering changes in socioeconomic characteristics, accessibility, and price according to the life cycle.

III. AGENT BASED TRANSPORT MODEL

The virtual city transport model in Figure 2 implements a decision model for the agent's behaviors and destinations to simulate their movements ([5]). Citizen agents are classified by occupation and autonomously perform actions such as going to work, commuting to school, shopping, visiting relatives, visiting hospitals, and shopping according to the probability of action by occupation.

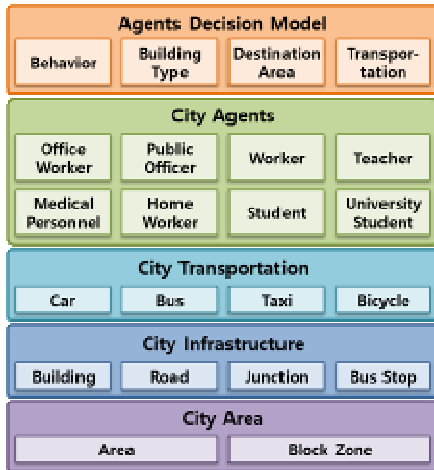


Figure 2. Agent based transport model

The destination of the agent is determined by the gravity model in the trip distribution sub-model. The gravity model is a concept that the exchange of trip between two places is proportional to the product of the amount of activity in the two places and is inversely proportional to the inconvenience of trip. In this paper, we use the double constrained gravity model, in which the distribution of movement for each zone is calculated by the following equation.

$$t_{ij} = \frac{k_i k_j P_i A_j}{f(Z_{ij})} \quad (1)$$

where,

$$k_i = \frac{f(Z_{ij})}{\sum_j k_j A_j}$$

$$k_j = \frac{f(Z_{ij})}{\sum_i k_i P_i}$$

P_i = number of trips produced from zone i

A_j = number of trips attracted to zone j

$f(Z_{ij})$ = impedance function (travel time, distance, cost)

Trip production and trip attraction of traffic zones are calculated using socio-economic indicators such as the number of residents, number of households, and number of workers. The trip distribution sub-model builds the trip distribution between zones by distributing the trip production and trip attraction in the transport network.

Once the agent's destination is determined, the transportation decision sub-model determines the mode of transport by considering distance, presence or absence of transport, and route.

IV. PROPOSED VIRTUAL CITY SIMULATION PLATFORM

The virtual city model aims at an integrated socio-economic modeling to predict the long-term impact of changes in urban components by the city management, planning, and policy.

To achieve this goal, the city model combines the interaction of the land-use model with the transport model using multi-agent simulation.

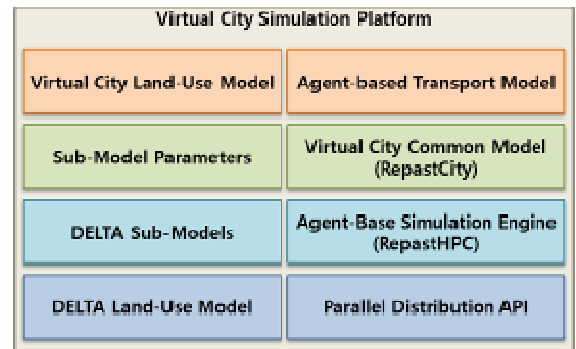


Figure 3. The Proposed Virtual City Simulation Platform

As shown in Figure 4, the integrated city model is driven by linking the land-use model and the transport model to simulate

the circular relationship implemented with the flow of data. The most basic relationship between subsystems in the integrated city model is the circular relationship between land-use and transport. Through this relationship, the integrated model allows the agent to consider location attractiveness, location cost, travel cost, and accessibility together, and selects the location of residence and the destination of behavior. In particular, the integrated model enables prediction of future urban spatial structure changes by simulating the process of continuously changing land-use patterns and movement patterns by repeatedly influencing the spatial distribution of new activities and the spatial distribution of accessibility.

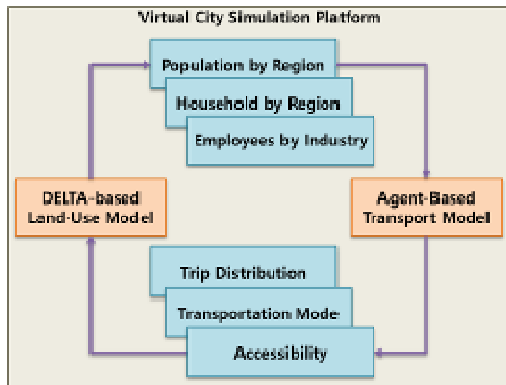


Figure 4. The data flow in the proposed Platform

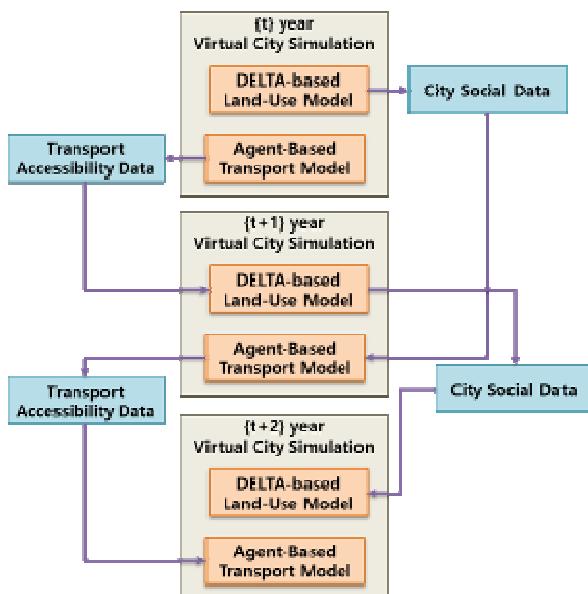


Figure 5. The simulation flow in the proposed platform

The integrated model is driven by linking the land-use model and the transport model to simulate the cyclical relationship between land-use and transport over time. In the integration model, this circular relationship is implemented as a data flow. When the spatial distribution (time t) data of the activity is given as input data of the traffic model, the traffic

model provides the spatial distribution of accessibility as output data. The result of the transport model becomes the input data of the land-use model again, and the spatial distribution (time $t+1$) of the new activity is provided through the selection process of the activity location. This process is repeated until the target year (time $t+n$).

V. VIRTUAL SEJONG CITY MODEL

In this paper, we implement Sejong City as a virtual city on the integrated virtual city simulation platform.

In order to build a virtual Sejong City, we use public data and administrative data such as building information, road network, traffic network, and citizen data. Figure 6 shows the constructed virtual Sejong infrastructure data on the map.

- 424,865 agents(citizens)
- 32,635 buildings
- 8,229 roads and 3,233 junctions
- 175 bus lines and 2,057 bus stops

In the land-use model, we constructed data and parameters such as the number of populations, household type, location cost by spatial analysis unit, and accessibility (trip time, distance, cost) between zones in Sejong City and surrounding cities.

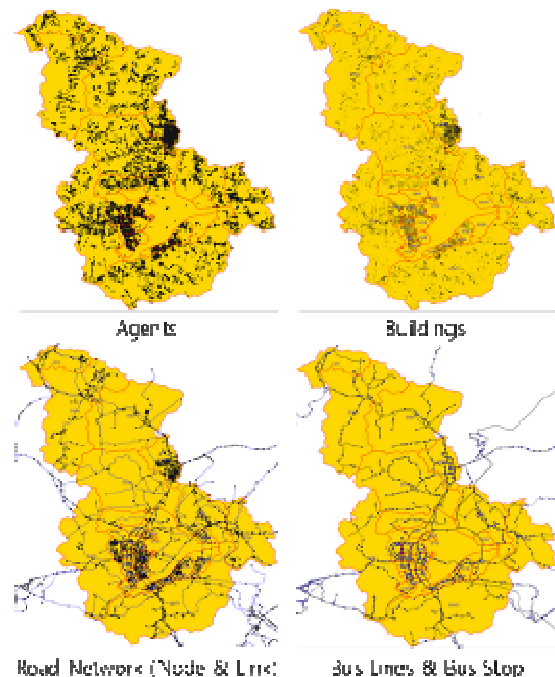


Figure 6. Infrastructure in virtual Sejong City model

After applying the urban integration model applied to Sejong City, we performed a simulation of the influence and effect of large commercial facilities on the city. Figure 7 and 8 present changes in population movement and transport within cities before (scenario 1) and after (scenario 2) large commercial facilities. The simulation results showed that when large commercial facilities are located in a specific area, the population of that area increases by up to 1.5 times, and

carbon emission increases by up to 1.2 times due to the increase of personal vehicle traffic.

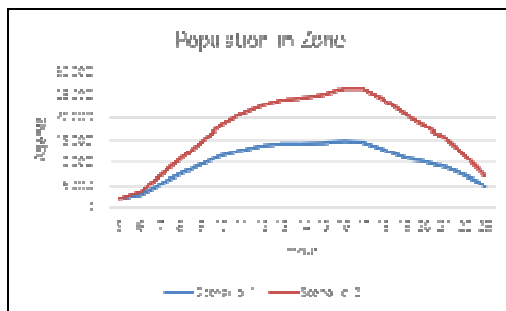


Figure 7. Simulation result (population)

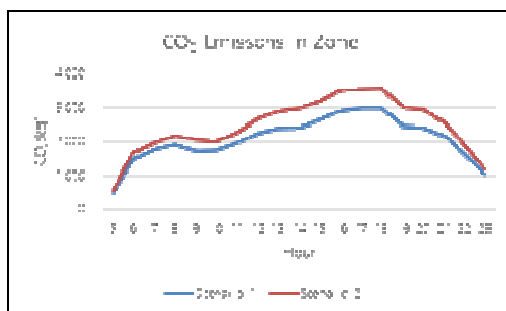


Figure 8. Simulation result (CO₂ Emissions)

VI. CONCLUSIONS

Using digital twins that replicate the physical city to create a virtual city, we can simulate urban planning before implementation. In this paper, we proposed an integrated virtual city model that utilizes the prediction data of the land-use model and the agent-based transport model to predict long-term changes in urban space and population movement.

The integrated virtual city model can be exploited for the purpose of supporting efficient decision-making of urban and transport policies to seek desirable urban development.

As a future work, we plan to validate the simulation results of urban future policy scenarios.

ACKNOWLEDGMENT

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