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ORIGINAL PAPER

Impact of ubiquitous computing technologies on changing travel and land use patterns

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Abstract This paper utilizes urban growth models to examine future patterns in urban land uses and travel behaviour that may occur during the transition of South Korea's Siheung city into a post-ubiquitous city. In particular, this study adopts the cellular automata and gravity models in order to produce simulated spatial–temporal structures of urban land uses and provide estimates in trip frequencies over time by vehicular travel. Through the application of such models, several findings relevant to the land use planning and urban infrastructure management of Siheung city's transitional phase can be demonstrated. First, predicted changes in urban form are typified through gradual spatial–temporal shifts which, in turn, culminate to produce decentralization and an alternative concentration in polycentric urban land uses. Such findings have a basis in transitional rules which reflect the emphasis of the nation-wide policy of ubiquitous cities on developing a polycentric digital network with higher density living. Additionally, changes in travel behaviour can be shown through estimated increases in short-distance travels and associated decreases in long-distance travels decrease. Accordingly, it is estimated that over time the total travel distance decreased by a range of 18.4 to 21.8 %, with a possible reduction of carbon emission.

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Introduction

Urban growth models have been rigorously used over the past few decades to assist in planning decision-making and urban infrastructure management processes. Models that aid our understanding of population growth, internal migration, as well as the nature of housing and labour markets all play a pivotal role in developing land use strategies which ultimately shape our urban form. More recently, information communication technologies (ICTs) have become increasingly important in the decision-making process behind urban infrastructure provision, management and governance. Recent studies from around the world reveal that ICTs have intensified the spatial division of labour markets, and as a consequence, have dispersed the production function in urban areas. To this extent, it is likely that ICTs will produce particular effects on urban land use patterns and travel behaviour (Yigitcanlar and Teriman 2014; Jang et al. 2011). For instance, office jobs and service works are forecasted to become concentrated in specified urban places (Audirac and Fitzgerald 2003). In many world digital or smart cities, urban land use strategies focus on a compact city model with multi-functional or mixed use within a walkable distance from residential areas (Chhetri et al. 2013). Most of the cases argued that efficient transport mode and ICT networks should be considered as part of the land use planning process. ICTs can accelerate suburbanization, and the role of the CBD becomes less important as ICTs reduce the distance function to enhance accessibility to suburban areas (Sajjad and Iqbal 2012; Kim et al. 2009). The ICT imbedded urban spaces would determine the life and death of cities (Gaspar and Glaeser 1996). For instance, teleworking has become an increasingly popular cause in the death of geographic limits, dispersing employment and population to metropolitan edge and into non-metro regions (Audirac 2005). In this regard, an edge city would appear on the border of the outer city where larger green areas with lower land values may be accessed (Coffey 2000). Urban decentralization therefore pushes forward the post-industrial, informational and networked cities with home office and teleworking infrastructure (Hall 1997).

However, there are uncertainties of changes in urban form and land use patterns in the future informational and ecological cities (Audirac 2005; Audirac and Fitzgerald 2003). Recently, cellular automata (CA) have been extensively used to simulate the process of dynamic land use patterns (Emamgholizadeh et al. 2013; Li and Yeh 2002; Batty et al. 1999) and to generate urban growth scenarios with tentative urban planning strategies (Feng and Liu 2013a, b; White et al. 2009). CA modelling with GIS became a robust and dynamic simulation tool to configure spatial cells and cell states controlled by predefined transition rules. Significantly, conventional methods including binominal logistic regression and principal component analysis have been the subject of criticism on the basis of the bias of spatial autocorrelation among the spatial variables which, in turn, creates difficulties in estimating the magnitude of the effects of spatial variables (Liao et al. 2013; Al-Ahmadi et al. 2009; Al-kheder et al. 2008). Alternatively, the CA models, based on fuzzy logic and artificial intelligence techniques, were effective in addressing such statistical biases. For instance, Feng and Liu (2013a, b) and Al-kheder et al. (2008) developed fuzzy rules based on semantic knowledge of the changes in urban land use and calibrated the land use conversion probabilities for a cell area. Similarly, Kumar et al. (2014) applied artificial neural networks (ANN) for the determination of optimized height of a highway noise barrier as a nonparametric approach with good simulation results. Furthermore, Bangian et al. (2012) tested the optimum post-mining land use for a pit area in open-pit mining through using the fuzzy decision-making method. Feng et al. (2011) pointed out the robustness of CA models with regards to in two relevant aspects. First, CA models present well-defined weights to quantify the contributions of the spatial variables to the land use conversion probability. Secondly, they are applied to eliminate the adverse effects caused by multi-collinearity among the spatial variables.

The two research hypotheses in this study posit that significant changes in both (a) spatial structure and (b) trip patterns will take place in ubiquitous cities. This paper will use a CA model to simulate the spatial structure of ubiquitous city and a gravity model to estimate the changes in the volume of trips in the post-ubiquitous city. The simulation results show whether the changes of urban form and travel patterns are expected with or without the ubiquitous city plan, as well as the magnitude of the expected changes. Finally, the paper will discuss the current ICT implications on the alteration of urban landscape and form. This discussion will operate to inform an analysis of the potential for new developments in current ubiquitous computing technologies to address persistent and chronic urban problems, including urban sprawl, traffic congestion and increasing carbon emissions.

Using a CA and gravity model, this paper will empirically investigate the changes in urban form and travel patterns in Siheung city, South Korea, where the existing land use pattern is similar to a ubiquitous city plan. Siheung city, 30 km from Seoul, Korea, has a total land size of 133.97 km^2 which consists of residential (19.1 %), commercial (1.63 %), industrial (8.21 %) and parks and open space (71.1 %). In 2012, the local population was 399,485. Arc GIS 9.1 and IDRISI Kilimanjaro were used to simulate the changes in its spatial structure. Satellite imagery and digital data were acquired from a number of sources. The Korea Land Information System (KLIS) database, acquired between 2009 and 2010, was used in order to provide data for street network, topology, steep slopes and land uses. Socio-demographic data were derived from the Korean Statistical Information Service (KOSIS) in 2010. The Korean government's Environment Geographic Information System (EGIS) data contained numerous geographic layers such as highways and main roads, rail network and stations, parks and reserves, water bodies and environmental hazards such as soil and air pollution. The study also used the Korean travel database (2009), as provided by the Korea Transport Institute (KOTI). This database contained information on local travel patterns, such as the volume and distance of trips.

Materials and methods

The concept of ubiquitous cities

In recognition of the increasingly important role that ICTs continue to perform in urban and regional planning, many countries have adapted smart technologies as part of smart urban growth strategies. Following Mark Weiser's ubiquitous computing vision (1991), the Korean government proposed a series of new city plans with ubiquitous computing technologies as part of the national agenda. Over the past two decades (1990–2010), Korea has continuously developed innovative city planning strategies based on the national development agendas, which focus on ICTs and ecology as the core of urban planning strategies for the cities' futures. The concept of ubiquitous cities (U-City) has evolved from an informational city, known as a virtual city, to an ICT-driven digital city, and finally, to a ubiquitous city. Castells (1996) defines the space of flow as a new spatial logic of networked society shaped by activities taking place in non-contiguous cities or space of place, but dynamically linked through various technological infrastructures. The ubiquitous urban infrastructure creates a new informational spatial form with economic, technological and social dynamism (Yigitcanlar and Han 2010; Sassen 2001). In this sense, the ubiquitous city can be defined as the ubiquitous computing-based smart city, where receiving and sending information on urban services and infrastructure is more flexible and cost-effective in an integrated manner, hence improving the quality of life and strengthening urban competitiveness (Lee et al. 2008, 2010). Many Asian mega cities such as Seoul, Tokyo and Singapore continue to compete to build the ubiquitous city as a leverage tool for the national economy, as well as creating future urban growth engines (Dabinett 2006).

One of the key characteristics in the ubiquitous city is to provide a multiple-layered planning approach to the master plan in order to coordinate all ubiquitous city services, technologies, infrastructure and management. In this digitally integrated system of planning, the absence of any one layer cannot deliver the ubiquitous city in Korea. By the U-City Planning Act, any citizen can access any U-service anywhere and anytime through any digital network and devices (Lee et al. 2008). More recently, the ubiquitous city is combined with the concept of ecological city so that citizens can access urban information and eco-services anywhere and anytime through ICTs and eco-technologies (EcoTs) embedded in urban infrastructure. The EcoTs include the self-managed carbon emission control, such as an eco-mileage card and the city-wise carbon monitoring system, so as to access the real-time information on a local environmental hazard.

The intelligent U-services such as teleworking, telecommuting, teleconferencing and smart transport are readily available in the ubiquitous city. ICTs- and EcoTs-based ubiquitous computing such as sensing, networking, interfacing, processing and security technologies is vital for the development of a ubiquitous city that provides a variety of services to the public. Sensing technologies aid data production; wired or wireless networking technologies convey data; processing technologies analyse data; interfacing technologies display data; and securities technologies protect privacy and assist in infrastructure management. People can access data from ubiquitous city mobile-built infrastructures such as ICTs embedded cars, robots, smart phones, buildings, conventional infrastructures and other places in the ubiquitous city. Wired or wireless networks carry text, voice and visual data from U-infrastructures (Lee et al. 2008). Ubiquitous cities require big data management centres and portals, where data from U-infrastructures are incorporated into high-quality U-services through the collection, monitoring, inter-correlating, analysis and distribution of real-time urban information (Han and Lee 2013). Private sectors can make profits through information trading, similar to a carbon-trading scheme. The U-City also encourages seamless communication among different pieces of urban infrastructure to automatically provide a safer environment, which results in lower management costs for citizens and governments.

Simulating changes in the spatial structure of ubiquitous cities

A CA model was considered operate as a suitable tool for simulating the spatial structure of a ubiquitous city. Feng et al. (2011) summarized the key benefits of the CA modellings as including: (1) its ability to represent the temporal as well as spatial processes of changes; (2) the flexibility to dynamically update its transition rules; (3) the adaptability to be coupled either loosely or strongly with a GIS; and (4) its spatial visualization capacity to present different scenarios. The spatial transition rules of the CA models are the core element of spatially explicit CA modelling (Clarke et al. 1997; Couclelis 1997; Li and Yeh 2002; Wu 2002; Al-kheder et al. 2008; Liu 2008).

Feng et al. (2011) classified the six categories of the transition rules applied to CA models based on the earlier work from Santé et al. (2010). First, the orthodox rules are based on a stochastic approach which regards the state of a cell as a function of the current state of the cell, as well as the states of its neighbourhood at a previous time (Stevens and Dragicevic 2007). Second, the key driver rules first identify the major factors that attribute to urban growth and the states of the neighbourhood and then compute the land use conversion probability of a cell as a function of transition matrix (He et al. 2006; Almeida et al. 2003; Li and Yeh 2002). Third, the urban form-based rules are applied to generate simulations based on the current urban form and the extrapolation of the urban patterns (Clarke et al. 1997). Fourth, the artificial intelligence-based rules are used to discover urban growth patterns according to mass sample data (Emamgholizadeh et al. 2013; Almeida et al. 2008). Fifth, the fuzzy logic-based rules can be defined by natural languages with explicit meanings (Al-kheder et al. 2008). Finally, the conditional logical operation-based rules refer to transition rules that cannot be grouped into previous five types (Xie 1996).

The CA model based on the urban form-based transition rules was applied to simulate the spatial–temporal changes in urban form of Siheung city, Kyunggi Province, South Korea. The transition rules of the CA model for land use change simulation are automatically generated by optimizing the parameter settings of various spatial proximity variables, land use regulations and ubiquitous city policy. The Visual Basic program was used to code the CA model by assigning read data and application transitional rules. This included checking the conservation area, the number of iteration, t time periods, randomization, as well as computing criteria values, query equations, cell change and increment iteration. We first identified the factors which produce impacts on the changing spatial structure of the Siheung city. Among such factors were the physical constraints of the landscape on urban growth in ubiquitous cities, such as rivers and underground water, steep slopes, agricultural land and conservation areas within wetland and forest. The built environment, such as residential density and path distances to urban centre, main roads and conservation areas, were calibrated. Apart from the spatial and physical land use constraints, institutional factors such as environment laws related to the U-City development, as well as planning strategies such as 'Siheung city plan 2020' and the 'Environment Planning Act' were considered. Institutional constraints include the protection of primary agricultural lands, heritage, forest, military facilities and water catchments. Moore neighbourhood of 3 × 3 cells was used in the model. Each factor was standardized by a fuzzy function based on CA transitional probabilities and rules by a multi-criteria evaluation decision-making process. CA transitional probabilities and rules decide whether or not the state at a cell of space will be converted to higher density.

A state of existing urban form was simulated by CA transitional probabilities and rules. When a cell is selected for a U-City development, a development density should be assigned to that cell. The development density in the size of population is dependent on the distance of such population densities to the urban centre. Thus, density decay functions can be used to determine the development density of a developed cell (Yeh and Li 2002). Urban horizontal extension was simulated after a CA model calibration of the status quo, so as to dispersed unplanned development. The notation refers to the adapted CA model with Clark's negative exponential function of urban population densities to simulating the U-City urban form.

$$D_{xy} = RA\exp\left(-\beta l_{xy}\right)$$
$$= \left(1 + \frac{\gamma - 0.5}{0.5}\alpha\right)A\exp\left(-\beta l_{xy}\right)$$
$$R = 1 + \frac{\gamma - 0.5}{0.5}\alpha$$

where D_{xy} is development density, l_{xy} is distance to centre, A and β are parameters of density decay function, and R is a stochastic factor presenting the uncertainties that may be attributed to ubiquitous city planning or institutional control factors such as land use change in the emergence of urban cells. In this notation, γ is a random number in the range of (0, 1) from a uniform distribution and α is an integer in the range of (0, 10) which controls the effect of the random number.

Simulating changes in the trip patterns of ubiquitous cities

Recently, the concept of accessibility has changed from distance-based physical adjacency to access-time-based quality infrastructure. This results in a decrease in trip distance, energy use and massive land consumption such as greenfield development (Paul 2012). While most of the world's cities encourage citizens to use public transport, they do not intend to accept the responsibility for improving public transport services in terms of accessibility and travel time, due to the higher maintenance cost. Some countries adopted a smart transport linking the public transport network, such as 'real-time' bus information and smart cards, therefore assisting in fostering punctuality. For instance, a bus information system needs sensing and networking technologies attached to each bus, bus stop and depot and along the road network. Information warehouse for data collection and analysis will be a key facility for a ubiquitous city service. The IT centre collects data from buses, bus stops and depots, providing real-time traffic information to citizens. Despite significant improvements in the technological applications to urban infrastructure over the past decade, there are still uncertainties behind the impact of the ubiquitous computing technologies on changing urban form and travel patterns.

Trip patterns before and after the ubiquitous city were simulated using a gravity model, which illustrated the interaction between two locations. Trip generation is positively correlated with the amount of activity at each location, but negatively correlated with distance, time and cost. Even though researchers have pointed out the weaknesses of the gravity model specification, the gravity model appears subsequently more favoured in estimating trip distribution. In general, the gravity models have three types: unconstrained, singly constrained and doubly constrained formulations. In a singly constrained model, a separate value of the parameter is given to each location, while the doubly constrained formulation allows two proportionality parameters are found for each location (Plane and Rogerson 1994). This study adopts a doubly constrained gravity model, with three deterrence functions in the calibration of the fully constrained gravity model. The gravity model is denoted by

$$T_{ij} = P_i \frac{A_j f_{ij} K_{ij}}{\sum_{j-1}^{n} A_j f_{ij} K_{ij}}$$

where, T_{ij} is trips from i to j, P_i is total trips from i as per our generation analysis, A_j is total trips attracted to j as per our generation analysis, f_{ij} is deterrence function (travel cost friction factor), and K_{ij} is calibration parameter.

Here, exponential function is as follows:

$$f_{ij} = \alpha \exp(\beta d_{ij})$$

Inverse power function is as follows:

$$f_{ij} = \alpha \left(d_{ij}^{\beta}\right)$$

Gamma function is as follows:

$$f_{ij} = \alpha \left(d_{ij}^{\beta}\right) \exp(\gamma d_{ij})$$

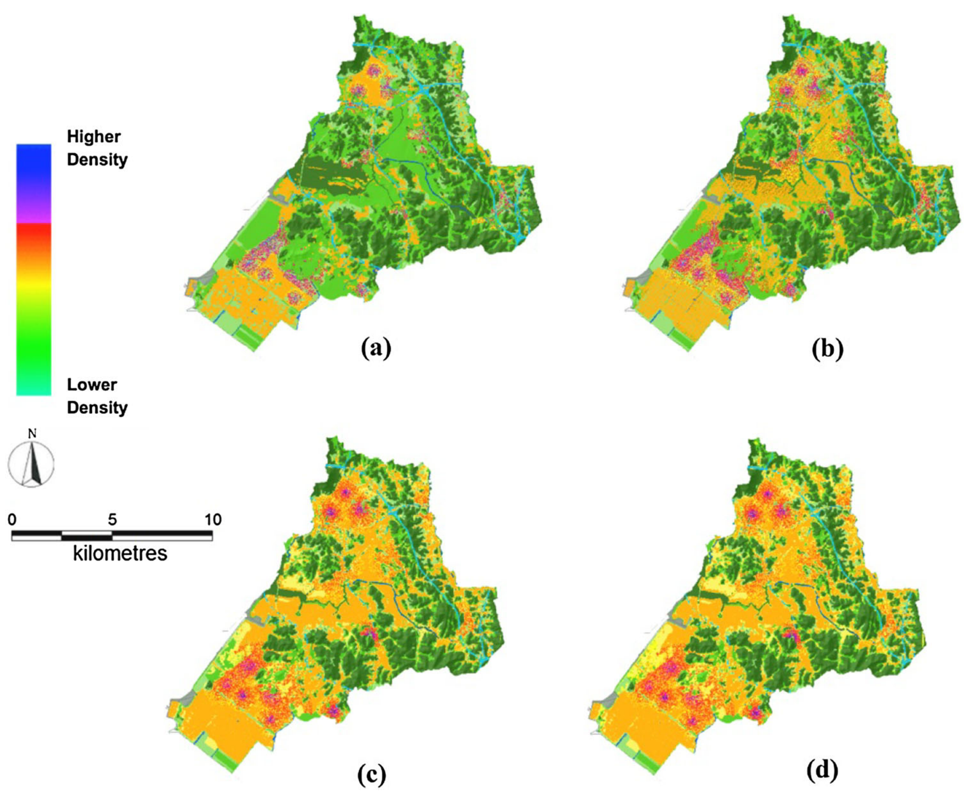
The β parameter expresses the extent to which the volume of trip drops off with increasing distance. The deterrence functions refer to the model distributes the volume of trips to short- or long-distance destinations.

Results and discussion

Simulations of changing urban from

CA model results were obtained based on two scenarios: the existing city spatial structure (before ubiquitous city) and ubiquitous city spatial structure (after ubiquitous city). The parameters of R (0.8), A and β (0.005) at high-density centre, β (0.001) at low-density suburban were obtained from the status quo of calibration and scenarios. Environmental constraints or natural control factors accounted by eco-rules were used with physical environment control factors, in order to apply ubiquitous rules in the simulation of the spatial structure of ubiquitous city. Figures 1 and 2 show two scenarios of changing urban structure in association with urban land use change which are related to its spatial proximity to existing built-up areas and conservation areas. Firstly, Fig. 1 presents the result of the simulation based on the existing city urban form in Siheung. The residential area (yellow) leads to urban sprawl, given the physical constraint of urban growth (e.g. conservation area within wetland and parks). Dispersed unplanned sprawl urban form can bring together unnecessary encroachment on agricultural land, which results in urban sprawl. Sec-

Fig. 1 Existing city spatial structure: a dispersed unplanned sprawl urban form



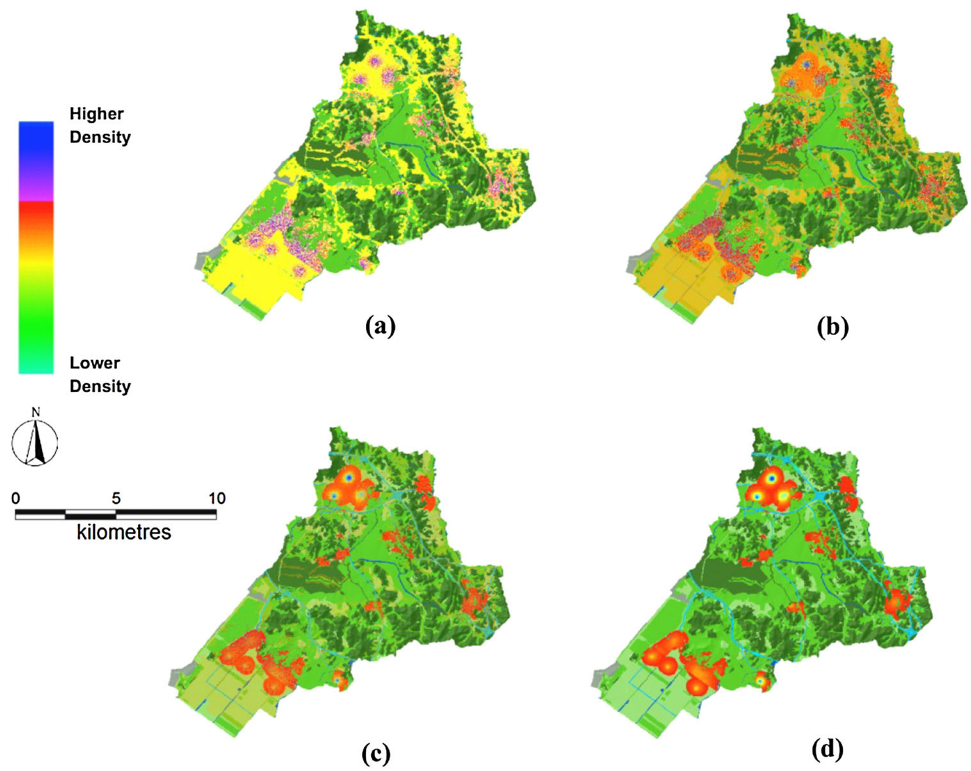


Fig. 2 Ubiquitous city spatial structure: a higher density polycentric compact urban form

ondly, Fig. 2 provides a simulation of ubiquitous city urban form with highly accessible concentrations of people in residential (home) and commercial (work) land use. The series of the CA simulation in Fig. 2 present the compact city urban form where the higher density areas (red spots) increased over time. However, these key growth areas did not lead to further urban sprawl in comparison with the land use change in Fig. 1. The results of urban growth simulation within ubiquitous cities illustrate a compact city model with higher transit services, walkable neighbourhood and U-services accessibility. In regard to the same urban population, the compact urban form can reduce the amount of land needed for population growth, as compared to the existing city spatial form with dispersed unplanned developments.

With ICTs reducing the friction of distance and EcoTs saving energy consumption, greater changes in trip patterns are expected. Time- and energy-sensitive accessibility is more important than distance-sensitive effect in the ubiquitous city. The spatial structure of the ubiquitous city—the decentralized concentrated polycentric, networked and globalized, high-rised and high-density compact urban form and structure—may greatly impact on the trip patterns of a ubiquitous city. Such benefits include more green areas, the saving of energy and shortening travel time and distance.

A compact city with a high-density development offers the opportunity for average trip lengths to be shortened, as well as the fostering of economically viable transport. Higher densities also promote a high level of accessibility for non-motorized modes of transport and enable cities to have a low level of energy use per person in the area of transport (Jang et al. 2011). Similarly, Barter (2000) has demonstrated the extent to which the trip frequency can be dropped by high-density living and therefore easily foster a walkable city or travel by non-motorized vehicles such as a bicycle. Self-contained polycentric neighbourhoods in ubiquitous cities enable citizens to live, work and play within a walkable distance or a bicycle-oriented area, reducing energy consumption. A high-density compact area in the polycentric centre will enhance short-distance trips, encourage walking and bicycle trips and make greater use of a mass transit system in the decentralized concentrated polycentric neighbourhood and networked and globalized centre.

Therefore, great changes in the trip pattern of ubiquitous city are expected. The ubiquitous city may increase traffic demand with the high number of non-motorized vehicles used in a short-distance trips and the level of high public transport use for long-distance journeys. These scenarios in trip patterns were examined in this paper.

Table 1 Estimated trip generation, 2006–2036

Year	2006	2011	2016	2021	2026	2031	2036
Trip	51,056	52,980	54,175	54,192	53,654	52,957	51,658

Unit: thousands trip/day

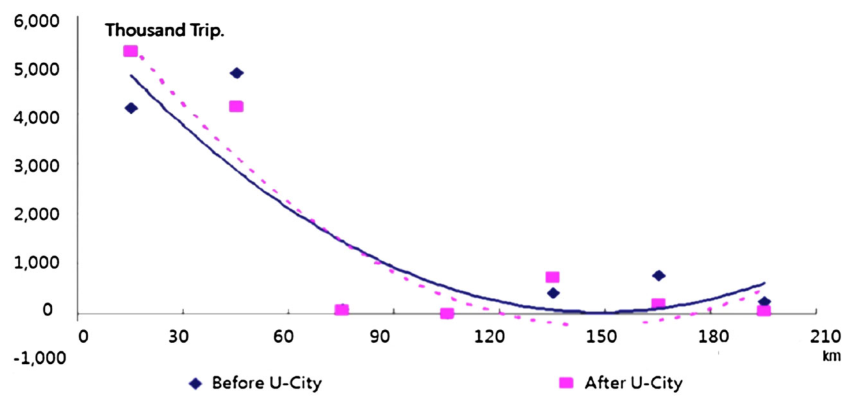


Fig. 3 Estimated trip patterns before/after ubiquitous city in 2011 and 2036

Simulating trip generation after U-City

Under the assumption that the volume of trip generation before and after the ubiquitous city is identical, the paper simulated the difference of trip patterns before and after the ubiquitous city development. The trip generation before and after the ubiquitous city was analysed based on the Korea transport database issued by the Korea Transport Institute (KOTI) in 2009. Trip generation was estimated by PA-based regression model with raw data from 2006. It was estimated that the number of travels will increase from 52,980 trips in 2011 to 53,654 trips in 2026 at the peak and then drop by 51,658 trips in 2036 at the lowest bottom (refer to Table 1).

Trip patterns simulations in 2011 and 2036 were conducted using the Korea transport data (Fig. 3). It is predicted that trip frequencies in the post-ubiquitous city will be greater than before ubiquitous city because of ICTs reducing the friction of distance by scenarios. The model results show that a long-distance trip would be replaced by a short-distance trip after the ubiquitous city. In the ubiquitous city, trips between nearby places were increased, while those of distant places were decreased.

With a decrease of travel distance, one expects energy savings and a reduction in air pollution within the ubiquitous city. In particular, air pollution—even at low levels of motorization—has become a severe problem for dense cities rapidly emerging as an issue in a number of dense Asia cities including Bangkok, Manila, Seoul and Jakarta (Barter 2000). Trip patterns after the implementation of ubiquitous city reduce the travel distance, fuel cost and CO_2 emissions. The model estimation shows that the total travel distance is predicted to decrease by 18.4–21.8 % after ubiquitous city. The total travel distance after the ubiquitous city development decreased from 53,109 to 42,105 thousand km per day (Table 2). Green transport policies are accordingly required to encourage citizens to use bus and mass transit systems instead of private transport. The results of the gravity model are consistent with the CA model simulation of a compact city with a polycentric growth model. In particular, the transit-oriented development (TOD) operates as the preferable land use policy for public transport and non-motorized travel in ubiquitous cities.

The findings show that ICTs induce new trips generated by the emergence of new ubiquitous business activities, home-based work and mobile offices. ICTs improve transportation services in terms of intermodal connectivity (Audirac 2005), just-in-time travel and faster mobility (Castells 1996). Further, urban expansion and decentralization are the synergy between ICTs and automobile. The notion of ‘B2B’ (Business to Business) as well as ‘B2C’ (Business to Customer) has greatly increased the demand for freight mobility with door-to-door delivery services. It is expected that the surge in passengers and freight travels will continue to take place in ubiquitous cities in spite of

Table 2 Impacts of trip patterns after ubiquitous city

Year	Total travel distance (thousands km car/day)			Total gas cost (million won/day)			Total CO_2 emission (thousands kg/day)		
	Before U-City (A)	After U-City (B)	C = B − A	Before U-City (A)	After U-City (B)	C = B − A	Before U-City (A)	After U-City (B)	B − A
2011	228,495	186,390	−42,105	24,646	20,104	−4,542	35,116	28,645	−6,471
2016	235,722	191,441	−44,281	25,425	20,649	−4,776	36,226	29,421	−6,805
2021	242,643	191,612	−51,031	26,172	20,668	−5,504	37,290	29,447	−7,843
2026	243,555	190,446	−53,109	26,270	20,542	−5,728	37,430	29,268	−8,162
2031	240,072	188,251	−51,820	25,895	20,305	−5,589	36,895	28,931	−7,964
2036	234,966	185,552	−49,413	25,344	20,014	−5,530	36,110	28,516	−7,594

the substitution effect of telecommuting for travel (Mokhtarian 1998). Guillwspie (1992) stressed the effect of information on travel generation such as advanced logistics and more frequently involve just-in-time deliveries. In ubiquitous cities, a higher demand of short-distance travel may increase traffic volume not only due to the ICTs driven interaction and concomitant travels, but also due to individual travel behaviours, government green policy and the emergence of new ICT business activities. Changing trip patterns will thus occur as the spatial structure and urban form changed to a compact city in a decentralized concentrated polycentric urban form. Smart working and just-in-time travel via the bus information system could accelerate the change in trip patterns and reduce energy consumption derived from the urban form change.

Conclusion

This paper tested the CA model to simulate the dynamics of urban land use in ubiquitous cities with an 'intelligent' set of the transition rules which are automatically generated and applied in the case study. The results of the simulations revealed that the urban form within ubiquitous cities leads to a compact city form with a decentralized concentrated polycentric model, decentralizing local employment into multiple central places in Siheung. This decentralized concentrated polycentric urban land use based on the institutional transition rules of U-City is a transitional form to better connect to other cities in global networks. The simulations of land use pattern show that the urban growth capacity to meet the needs of local population can be distributed to the key regional centres, while the quantity of parks and open space remains stable. The simulations also show that higher density land use can be accompanied by the implications of ICTs to access urban digital services anywhere and anytime, hence reducing long-distance travels. The CA transition rules within the institutional setting effectively captured the impact of the U-City plan on changing land use. However, the physical constrains and built environment transition rules play a significant role in model simulation. Relatively little research of any kind has been conducted in relation to the ubiquitous cities plan and its impact on changing the current urban form based on the land use transition rule within the physical, environmental and institutional setting. On the other hand, the paper tested whether the simulated compact city model could reduce the volume of intra-urban trips using a doubly constrained gravity model. The results of the gravity model show that short-distance trips to adjunct areas increase, while long-distance trips to outer city decrease. The total travel distance was estimated to decrease by 18.4–21.8 %. The decrease of travel distance could reduce the automobile carbon emission. The finding is also underpinned by the simulation of CA model that closer to existing urban services and infrastructure higher probability the cell converted into a higher density. However, there is a limit of this study to identify the social determinants that affect changes in individual travel behaviours and journey to work patterns.

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