A Theoretical review on urban growth and land use conversion

도시성장과 토지이용전환에 관한 이론적 고찰

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I. Introduction

There are a number of theories on urban growth and land use conversion. Each of them develops the issue from a particular theoretical perspective, but there is a trend to merge, or at least to mix, concepts and perspectives in an attempt to establish a synoptic view. However, there is little agreement on some major subjects related to urban growth and land use conversion theory including a lack of commonly agreed terminology. Many times these terms are also applied interchangeably or interpreted rather freely according to the purpose of the author.

Another viewpoint is that there have been great advances in the last twenty years in the scientific understanding of complex phenomena and a vast increase in the availability of cheap computing power that has helped facilitate this understanding. These have provided urban theorists with a range of new tools for analysing and modelling urban systems. However, due to the geographical complexity of real cities, most urban modelling applications have still failed. This is because they have mostly focused on a limited descriptive analysis of particular attributes of the urban system (Erickson and Lloyd-Jones, 1997).

This study is concerned with analytical and technical factors in using GIS and spatial analysis on urban growth and land use conversion. The study aims at examining related theoretical concepts and existing studies for guiding the present research and suggesting possible solutions and a further research agenda. For this, the study has paid particular attention to several essential elements: unit of analysis; temporal analysis; the application of GIS and spatial analysis; raster or vector based format analysis; transition probability of land use; neighboring land use effects.

Therefore, the study firstly examines theories providing important insights related to the purpose of the study such as land use change theories, California Urban Futures (CUF) Model and Cellular Automata (CA) model. Then existing studies developed to formulate land use and growth management strategies in their regions using the new technologies are reviewed. Finally, this study summarizes major features and some future research directions based on the theories and experimental studies.

II. Urban Modelling

The forecasting, simulation, and prediction of urban growth and land use change are being undertaken within the framework of a dynamic modelling approach. These theories have emerged over the last decade, particularly in complexity theory and in the study of chaos (Batty, 1995).

1. Theories explaining land use change

There are three traditional theories on how to view land use patterns and dynamics; economic theory; sociological theory; and the public interest-oriented approach. Economic theory views land use as a result of economic competition for limited space based on equilibrium theory (Muth, 1969). Sociological theory views land use in the context of urban ecology and social structure (Chapin, 1965). The public interest-oriented approach views land use in the context of health, safety, and general welfare (Kaiser & Weiss, 1970).

These traditional land use theories are connected with theories explaining land use changes. Land use change theories generally focus on the conversion of land from non-urban to urban uses. The land use conversion as usual occurs in the urban fringe, along with urban expansion (Bourne, 1969). These land use change theories have been based on three different approaches: factors affecting land use change, leading actor's behaviour, and process oriented approaches (Chang, 1986).

The approach related to factors affecting land use change is concerned with the causal relationships between land use change regarded as urban growth, and land use change caused by exogenous factors such as proximity between land uses, accessibility to work areas, compatibility between land uses, availability of public facilities, and proximity to ethnic group areas (Chapin, Donnelly, & Weiss, 1962). The studies related to a leading actor's behaviour suggest that the conversion of land use is determined by the decisions of leading actors such as the predevelopment landowner, developer, land speculator, facilitator, local government, and household consumer (Baerwald, 1981). The process oriented approach stresses that the conversion process of land use is a sequence of stages brought about by a series of key decisions which include those of both key decision agents and supporting agents in each stage, and which are influenced by decision factors and local public policies (Kaiser & Weiss, 1970).

A number of land use theories mentioned above have contributed to a better understanding of land use and land use change. These theories can be thought of as an aggregate system of land use and economic activities, or as determinants of city structure based on the difference between the intentions and the behaviour of individuals. They have been the predominant theoretical approaches to the understanding and forecasting of the structure of cities for the last 50 years (Batty, 1994). However, although these theories explain urban expansion and evolving land use patterns, they can hardly serve as tools to simulate, forecast or predict future urban developments. White argues that land use theories are static models and that they assume rational actors interacting in a market which remains in a stable equilibrium state (White and Engelen, 1993).

2. The California Urban Futures (CUF) Model

The California Urban Futures model really shows what this study is interesting in such as the application of GIS and spatial analysis and neighbouring land use effects. The Model is a metropolitan simulation model to provide a framework on how realistic growth and development policies at various levels of government might alter the location, pattern, and intensity of urban development in the fourteen-county Northern California Bay Region (Landis, 1994).

The CUF Model was developed as a planning model "to help planners, elected officials, and citizen groups create and compare alternative land use policies" (Landis, 1995; Kramer, 1996). It is a model which forecasts urbanisation at the regional scale (Landis, 1994). The analytical unit of the CUF Model is Developable Land Units (DLUs). DLUs are generated as the spatial union of multiple GIS layers. DLUs are made up of one-hectare (100m x 100m) grid cells (Landis and Zhang, 1998a).

The CUF Model includes spatial database between 1985 and 1995 as follows: i) local population and employment growth; ii) proximity to regional job centres; iii) site slope; iv) whether the site is within or beyond city boundaries or spheres of influence; v) the uses of surrounding sites; vi) the availability of vacant land; vii) site proximity to freeway interchanges and transit stations; viii) site proximity to major commercial, industrial, and public land uses (Landis and Zhang, 1998a).

The Model is one of the first urban models to utilise GIS technology (Wegener, 1994). The CUF Model incorporates a GIS to "assemble, manage, display, and make available millions of pieces of information describing land development potential" (Landis, 1995:p454). The Model is very complex and extremely "data hungry" (Landis, 1995). The results of the CUF Model simulation present three alternatives for growth policy/ land-use planning for the San Francisco Bay and Sacramento areas (Landis, 1995). The three alternatives are a “Business-as-Usual” scenario, a “Maximum Environmental Protection” scenario, and a “Compact Cities” scenario. This Model also demonstrates evaluation of alternative policies on agricultural protection and zoning at the county, or sub-regional, level.

The CUF Model requires an extensive GIS database because the model is developed to make choices based on the knowledge that planners have (Kramer, 1996). In addition, Landis (1995) explains that the CUF model can be applied at the subregional or county level for local growth planning. Landis and Zhang (1998a, 1998b) extended the database by new data categories such as housing prices, employment growth forecasts distributed to individual DLUs, and major new infrastructure investments. However, the model requires a constant and very knowledgeable interaction to be of use for planners (Kramer, 1996).

3. Cellular Automata (CA) Theory

The cellular automaton approach is to model urban areas and land use temporally and spatially. The Cellular Automata theory is developed to visualise rural to urban transition as a physical process. A cellular automaton is an array of cells, whose states depend on the states of the neighbouring cells (White and Engelen, 1993; Kramer, 1996). Cells of a cellular automaton respond in a mechanical way to surrounding cells. Due to these interactions, cellular automata are considered as discrete dynamic systems with simple construction but complex self-organising behaviour (Clark et al., 1997). Each point in a regular spatial lattice, called a cell, can have any one of a finite number of states. The states of the cells in the lattice are updated according to a local rule. That is, the state of a cell at a given time depends only on its own state one time step previously, and the states of its nearby neighbours at the previous time step. All cells on the lattice are updated synchronously. Thus the state of the entire lattice advances in discrete time steps (White and Engelen, 1993).

The concept of cellular automata was initiated by physicist Stanislaw M. Ulam (1962). John von Neumann (1966) soon used the theory to investigate the logical nature of self-reproducing systems. The research on cellular automata has increased rapidly since John Horton Conway invented the 'Game of Life'. This game became widely known when it was mentioned in an article published by the Scientific American in 1971. The game is played on a field of cells, each of which has eight neighbours (adjacent cells). A cell is either occupied (by an organism) or not. The rules for deriving a generation from the previous one are these: (Conway et al, 1982)

Survivals: If an occupied cell has two or three neighbours, the organism survives to the next generation.

Deaths: If an occupied cell has 0, 1, 4, 5, 6, 7, or 8 occupied neighbours, the organism dies (0, 1 neighbours: of loneliness; 4 thru 8: of overcrowding).

Birth: If an unoccupied cell is surrounded by exactly three occupied neighbours, the organism is a birth cell and becomes occupied (Conway et al, 1982).

A further important step from mathematical theory towards a broad range of applications of cellular automata came with Wolfram's research regarding the universality and complexity in cellular automata (Kramer, 1996). Wolfram concluded that the recognition of the complexity contributed to techniques exploring theoretical issues of the origin, dynamics, and evolution of structures in various fields (Wolfram, 1984).

The dynamic urban modelling approach developed by Batty (1992), White (1993), and Clarke et al (1996) has its main roots in the cellular automata theory (Kramer, 1996). They developed new computational dynamic cellular models of urban growth. Their approach has been described as a new school of urban modelling (Clarke et al, 1997).

Batty and Longley (1994) used a dynamic systems model called "Diffusion-Limited Aggregation"(DLA) to model the growth of an urban area. The model of Batty is based on only two cell states: vacant and occupied. Only vacant cells which are in contact with an occupied cell can be converted to occupied cells. The DLA model was applied to demonstrate the historical growth of Cardiff, Wales, and Savannah, Georgia.

Batty (1994) addressed how the simulation of the suburban development of Amherst in metropolitan Buffalo, New York, might be applied to the growth dynamics of real cities (Batty and Xie 1994b). They had an excellent historical data set of development sites. The model started in 1880 and used the 259 developed sites as 'seeds' from which growth is spawned for the next 110 years. They considered that these seeds already reflect the position of Amherst within the wider urban growth pattern of Buffalo, on existing villages in the rural hinterland and showing the emergent pressures for suburbanisation (Batty and Xie, 1994b).

The model on a Carribean island developed by White is of special interest because it integrates a cellular automaton with a GIS. In the integration of a cellular automaton model and a GIS, the cellular model can take advantage of the detailed GIS database and at the same time undertake spatial analysis, which is not part of GIS. White sees the ultimate goal in building cellular modelling tools into a GIS in order to create a GIS with dynamic capabilities (White and Engelen, 1993). With this vision White comes close to his objective to develop a theory that offers solutions for the local and specific problems of planners and other practitioners (White and Engelen, 1993).

The self modifying cellular automaton urban growth model developed by Clarke et al. (1997) is designed to predict urban growth within a defined study area in order to estimate the impact of urbanisation on the San Francisco Bay area's climate. The model is dynamic and future oriented. It is designed to predict urban growth on a regional basis 100 years into the future. The predictability was necessary in order to evaluate the impact of urban growth on the ecology of the area. The validity of the model is due to a complex GIS based cellular automaton and to rigorous past to present calibration. Making the intensive calibration approach an integral part of the model development is an important new feature of computational cellular automaton urban growth models. Intensive calibrations of the model ensure a high degree of probability with regard to the prediction of future urban growth.

III. Existing studies on land use and urban growth

Existing studies on land use and urban growth have developed rapidly with the advent of GIS and remote sensing technologies. Many metropolitan governmental agencies in the U.S. have begun to formulate land use strategies and growth management strategies in their regions using these new technologies. These studies have been used in a variety of themes such as to estimate land supply and potential for future urban development, to analyse environmental quality issues, to determine changes in vegetation cover, and to investigate potential hazard impacts. Three such projects which were provided to help local governments with timely information on current issues have been identified and are described briefly below.

1. Association of Bay Area Governments (ABAG)

ABAG is owned and operated by the cities and counties of the San Francisco Bay Area. It was established in 1961 to help solve problems in areas such as land use, housing, environmental quality, and economic development. In the ABAG region there are 100 cities and nine counties. More than 6 million people live in this area. Since 1975, ABAG has collected information on current land use and development policies of local governments in this region (ABAG, 1997).

The study, 'Bay Area Futures: where will we live and work?' (ABAG,1997), was produced cooperatively by the San Francisco District Council, ABAG, and the Bay Area Council. The report examines how the region's land use patterns are evolving. Medium altitude air photographs were used to identify land use changes in those areas. The digitised coverages were converted to a grid format with a cell size of one hectare (2.5 acres) (ABAG, 1997).

The first section of the report traces the historical development of the region. It also maps current land uses and identifies land designated for future development. The next four sections examine recent development activity and provide forecasts of future growth in each of four sub-regions: South Bay, West Bay, East Bay, and North Bay. The maps in these sections illustrate relative levels of activity for cities and sub-city (census tract) areas. The maps are colour-coded based on activity per square mile of land area and are intended as a tool for visualizing the geographic distribution of activity. The concluding section examines issues that emerge from the detailed forecasts but are more regional in scope: the affordability of housing and the spatial relationships between housing, jobs, and transportation (ABAG, 1997).

Today's land use changes are typically large-scale housing, commercial, and light-industrial infill projects. The Bay Area's traffic forecast could spur planner or decision makers to develop creative land use strategies to solve these problems. The very scale of the challenges confronting the Bay Area could create the conditions in which imaginative and far-reaching solutions might be realized (ABAG, 1997). Projections 2000, the latest edition, has provided current estimates of the population, employment, income, and households for the San Francisco Bay area from 1995 to 2020 (ABAG, 1999).

2. Twin Cities Metropolitan Council

Today, the Twin Cities is one of the most sprawling major metropolitan areas in the U.S.A. The report, called 'Two Roads Diverge: Analysing Growth Scenarios for the Twin Cities Region' (1999), was prepared by The Centre for Energy and Environment (CEE), Minnesotans for An Energy-Efficient Economy (ME3) and 1000 Friends of Minnesota. The framework of the study uses a 'Sprawling Scenario' and 'Smart Growth Scenario' to describe options for the region's growth from 1995 to 2020. The goals of this study are to apply the scenarios to address the following issues (ME3, 1999a):

How should the region accommodate its inevitable growth?

Can the region grow and retain its unique character at the same time?

What are the costs and benefits to the region of sprawling and smart growth? (ME3, 1999a)

The Sprawling and Smart Growth Scenarios are used not only to analyse growth impacts inside the seven-county metropolitan area but also to analyse growth impacts in the six outlying counties by using St. Michael, Minnesota as a case study (ME3, 1999b).

The study has used Traffic assignment zones (TAZs) and Geographic Information Systems (GIS) software. In addition, the study has used land use layer by interpreting aerial photography to determine land available for development outside the Metropolitan Urbanised Area (ME3, 1999c).

The significant point of the study is to use Traffic assignment zones (TAZs) used in the traffic modelling process as the common geographic unit for data summary. The system of TAZs covers the entire seven-county, Twin Cities metropolitan area. There are 1,165 TAZs assigned in the seven-county Twin Cities metropolitan area (ME3, 1999c).

For these scenarios, the study has used GIS to determine how many new households would be located in each TAZ outside urbanized areas and for the placing of these households to determine the environmental impacts of each scenario (ME3, 1999c).

3. San Diego Association of Governments (SANDAG)

18 cities and the county government make up SANDAG which serves as a forum for regional decision-making. SANDAG has produced both short-range and long-range growth forecasts in the region since 1971. In addition, SANDAG has been developing and enhancing its Geographic Information Systems (GIS) since the 1970s. Complex data sets have been provided to local agencies in a format compatible with GIS (SANDAG, 1998b).

SANDAG's most recent forecasting effort is the 2020 Cities/County Forecast for San Diego Region, with a timescale of 1995-2020. This forecast is based on 1995 land use, population, housing, income, and employment data (SANDAG, 1998b).

The recent Growth Forecast uses two distinct modelling systems: Demographic and Economic Forecasting Model (DEFM) and Urban Development Modelling System (UDM). UDM distributes the regional forecast to smaller geographic areas according to attractions and constraints provided by existing and planned land use policies, transportation networks, and population, housing, and economic concentrations (SANDAG, 1998c).

The 2020 Cities/County Forecast relies heavily on land use characteristics that reflect current or simulated policies of the local jurisdictions. The availability of land for future development depends on the status of existing, planned, and constrained lands. Land use data is collected for 97 planning areas within the San Diego Region and incorporated into SANDAG’s Geographic Information Systems (GIS) database. Data from the 1990 Census is included here in several formats. There is also information about the upcoming 2000 Census (SANDAG, 1999).

All of SANDAG's GIS data bases are in ArcInfo and all information contained in the GIS data sets are generated at scales of 1:24,000 (1" = 2000') and have categorical and positional accuracies associated with the scale (SANDAG, 1998a).

In the early 1990s, SANDAG also developed techniques to utilize remotely sensed data as a cost efficient means of updating land use databases. Satellite images were used to automatically detect land cover changes, to create and update vegetation and road network databases between two years (SANDAG, 1998a).

IV. Review and Discussion

Through above study based on the theories and experimental studies, the main findings can be summarized as follow.

Firstly, much of the research on urban growth theories has been characterised by the use of aggregate level census data. Furthermore, the experimental studies were carried out on the basis of large aerial units (TAZs, census tracts, even jurisdictions). Due to this large scale and the particular way in which area boundaries are defined, smaller and medium size cluster of activity become impossible to identify. Most of the studies are also based on aggregate gross area data which assumes an even spread of population and employment throughout the unit of analysis. In addition, most of the research typically exclude site level information.

Secondly, many of the studies on urban growth theories and existing studies have been limited due to a lack of available data and including longitudinal analysis only rarely. The few existing longitudinal studies typically employ data from two time periods which makes the detection of trends, cycles, or fluctuations in urban development patterns difficult. In addition, most of the research has focused on theoretical and ideological discussion.

Thirdly, much of this body of literature is based on the application of GIS. Despite its recent popularity, GIS has contributed little to methodological innovation in urban analysis. This is because GIS is weak on the analytical capabilities of urban models. The studies mentioned above are still far from making this link between GIS and spatial analysis (Wegener, 1994).

Fourthly, most studies favour using a grid format, cell based raster GIS, because in a planning context, the raster model is a very effective and cheap method of producing land use strategy maps for a number of purposes. In addition, the raster model is best suited to proximity analysis. However, the grid format imposes some limitations on the treatment of land use change. For example, the minimum size for some developments, such as large industrial sites or airports, may be substantially larger than one cell (White and Engelen, 1993).

Fifthly, forecasting of land use change is a necessary and important part of proper land use management. A number of studies on urban growth theories and existing studies have conducted forecasting, simulation, and prediction of urban growth. Clarke et al. (1997) argue that the traditional urbanisation models omit any examination of the physical characteristics of urban expansion. Almost none of these models have examined in detail the rules of the rural to urban transition as a physical process. These models were developed to explain rather than to forecast urbanisation.

Finally, urban growth theories such as Cellular Automata and CUF model are concerned with neighbouring land use effects. As David Adams (1994) pointed out, the potential use and value of any one parcel of land is directly affected by the activity taking place on neighbouring land. Existing studies consider that land use patterns evolve through the effect of the neighbourhood. Cells take on new values depending upon what is in their neighbourhoods and, as this is continually changing, the process of evolution is immediately responsive. In addition, the spatial extent or size of the neighbourhood affects the speed of propagation through the system. Many variants of these neighbourhood effects allow the approach to be made applicable to real problems (Batty, 1994).

V. Conclusion

This review does not purport to provide a comprehensive list of all the research conducted up until now, nor to evaluate all studies in detail. Furthermore, the characterisation of the literature on urban growth theories and existing studies offered here is undoubtedly incomplete. Its categories inevitably partially overlap, and the specific examples presented under each heading can only hint at the broad array of studies that each category subsumes. Nevertheless, the characterisation may prove useful in so far as the categories demonstrate the characteristics of research on urban growth theories and existing studies carried out in the fields of urban planning as relevant to urban fringe growth management.

To conclude, it is hard to divide the mass of literature on urban growth theories and existing studies into clear-cut categories. However, some characteristics can be discovered, as outlined above. Firstly, most of the studies on urban growth theories have been characterised by the use of aggregate level data. However, it will need also to explore smaller or medium size area to identify the pattern of land use change in detail within particular municipal boundaries. This is because it will be helpful for local authorities in managing and monitoring urban fringe areas.

Secondly, most of the research has focused on theoretical and ideological discussion due to a lack of available data. However, it will need to choose data from time periods to make the detection of trends, patterns, or fluctuations in land use change more obvious for practical analysis.

Thirdly, GIS is now a leading tool in the development and application of contemporary urban planning. In the past, people believed that computer technology would provide a technological solution to complex and difficult issues of public policy. Unfortunately, the current techniques and commercially available systems are not entirely satisfactory. The study therefore examined existing approaches and suggests possible solutions and a further research agenda for improving the integration and analysis process.

Fourthly, most studies favour using raster GIS data, because in a planning context, the raster model is in many ways a superior tool in land use identification, particularly over large areas where raster data storage is simpler and more cost effective than vector storage. In addition, the raster model is best suited to proximity analysis. However, the grid format imposes some limitations on the treatment of land use change. This raster model has some restrictions for the representation of residential, commercial, or industrial information because of the discrete nature of socio-economic space, although it is appropriate for representation of spatially continuous surfaces, such as soil types and elevation. Therefore, future study will need also to apply vector-based GIS which is favoured for greater manipulation of single parcels.

Fifthly, a number of studies have developed to explain rather than to forecast urbanisation. Future study will need to develop an analysis of the transition probability of land use, i.e. which areas are most susceptible to land use change. This will be also useful to local government when formulating a plan to protect the lands from future unplanned development.

Finally, many studies, such as CA theory, related to analysis of neighbouring land use have been conducted by using cell based raster GIS. However, the parcel is the ideal unit of analysis for studying land use change because it can have a wide range of information such as parcel numbers, the classification of land category, and the boundaries and ownerships of land parcels. Therefore, future study should also need to focus on cadastral maps used by local government for a number of purposes.

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도시성장과 토지이용전환에 관한 이론적 고찰

김 정 훈

※ 주요단어 : GIS와 공간분석, 토지이용전환, 인접토지이용효과, 토지이용전환 가능성, 도시성장

본 연구의 배경은 지난 20여년동안 컴퓨터 처리능력이 급속히 증가하고, 도시의 복잡한 현상들에 대한 과학적 이해가 더욱 용이하게 됨에 따라 도시성장과 토지이용전환에 관한 이해 정도가 상당히 높아졌다. 특히 GIS와 공간분석기법 등의 발달로 도시성장과 토지이용전환을 분석하고 설명하는 툴이 다양화되고있다.

본 연구의 목적은 토지이용 및 도시성장과 관련한 최근 연구동향과 실제 업무분야에서 수행하고 있는 추세를 조사하여 현재 모델과 사례들의 장단점과 한계점을 제시하고 가능한 해결방안 및 향후 연구 보완방안을 제시하는데 있다. 이와 관련해서 본 연구에서는 특히 도시성장과 토지이용전환 이론에서 최근 기술변화에 따른 분석 요소들의 변화를 살펴보고 중요하다고 판단되는 6가지 요소를 추출하여 각 이론 및 활용사례를 종합적으로 비교 검토하였다.

이 연구에서 중점을 두고 분석한 변수는 분석단위의 규모, 시계열 분석 여부, GIS와 공간분석 활용 여부, 벡터데이터 혹은 래스터 데이터 활용여부, 미래 토지이용변화 예측 여부, 인접토지가 토지이용전환에 미치는 영향 고려 여부이다. 이는 GIS 등 공간정보 처리능력의 향상에 따라 도시시스템을 보는 관점을 다양화하고자 하는 차원에서 수행하였다.

이를 위해 토지이용변화를 설명하는 이론들과 최근에 GIS와 공간분석기법을 이용하여 도시성장 및 토지이용전환을 설명하고자 하는 CUF모델과 CA모델을 살펴보았다. 또한 미국의 대도시들에서 GIS 기술 등을 활용하여 토지이용과 성장관리를 위한 전략을 수립하기 위한 많은 연구들 중에 ABAG, ME3, SANDAG을 사례지역으로 하여 분석요소들을 살펴보았다.

본 연구의 결론부분에서 이상의 요소들에 대해 종합적으로 평가해보고 그 적용상의 문제점과 향후 연구수행시 고려해야 할 부분과 그리고 활용방안 등에 대해 정책적 시사점을 제시하였다.