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A cellular automation model for urban land use simulation

Kwok Hung Lau
RMIT University

Abstract

Conventionally, land use and transport interaction is studied through computer simulation using large-scale integrated land use and transport models. Though comprehensive, most of these models fail to recognise that urban growth is not entirely a global but also a local process. The over-complex and data hungry nature of these models further render them inefficient as tools for strategic planning.

This study attempts to find an alternative modelling approach by developing a land use simulation model using cellular automation (CA). The essence of CA is that simple local actions lead to complex global behavioural patterns. The whole system behaves as a self-organising, self-evolving entity based on some transition rules. The model rests on a conceptual framework in which urban land use and transport interaction is characterised as an outcome of aggregate supply and demand. The framework condenses the myriad factors affecting land use and transport into a few attributes which include accessibility, residential density, property value, and passenger trip volume.

Recognising that urban growth is both a local and a global process, the CA model developed in this study identifies two effects on land use changes: the attribute effect and the gravity effect. The former is considered as a local driving force for change constituted by changing accessibility and other attributes resulting from the interaction of land use and transport at the neighbourhood level. The latter is a universal resistance to change due to inertia and agglomeration of compatible land uses in the vicinity. The combination of these two forces determines local land use changes. Taken together, these local changes constitute the global land use pattern.

Practical use of the CA model will be demonstrated using metropolitan Melbourne as a study area.

Contact author
Kwok Hung Lau
Lecturer, School of Marketing, RMIT University, Level 14,
239 Bourke Street, Melbourne VIC 3000
Tel: (03) 9925 5910
charles.lau@rmit.edu.au

GO BACK TO START SCREEN GO BACK TO INDEX

Introduction

Since Mitchell and Rapkin (1954), who formulate transport demand as a function of land use, the interaction between land use and transport has been widely recognised. Over the years, the relationship between land use and transport has been extensively studied using large-scale mathematical models. Initially, land use and transport were modelled separately with the former as an exogenous factor affecting the latter. While Lowry model (1964) focuses on land use allocation, the conventional four-step models of early transport studies, such as the Chicago Area Transportation Study (1960), mainly looks at traffic volume and distribution. The linkage between land use and transport are more closely examined in the linked land use–transport models used in the 1970s, such as the SELNEC Transport Study (1971, 1972). It is not until the integrated land use–transport models developed in the 1980s, such as LILT (Mackett 1983, 1990, 1991a, b) that the interaction between land use and transport is modelled using a consistent theoretical basis. The integrated models adopt a wide range of theories, such as microeconomic theory, entropy maximisation, and random utility, together with sophisticated techniques, such as logit, probit, and input-output models, to simulate consumer responses to travel costs. Though theoretically more valid, they are often complicated, data-hungry, costly to operate, and time consuming to calibrate. For strategic transportation-land use planning which focuses more on the impacts of transportation on land use development than traffic volume details, an alternative simpler modelling approach is required.

In recent years, some researchers (see for example Batty and Xie 1994, White and Engelen 1993, Roy and Snickars 1996, Wu 1996) have attempted to look at urban form and land use development from a different perspective. They regard city as a self-regulating, self-organising, and self-evolving living entity composed of numerous tiny cells. Urban development is a process of local interactions rather than a global activity. Land use of a local area is assumed to be determined more by the current use of its neighbouring land and other local attributes than some remote global factors. Using a top-down approach with a set of global equations to forecast changes in local land use is therefore considered not entirely representative of reality. In contrast, adopting a bottom-up approach with simple rules to determine local development is regarded as an alternative way to model urban changes. In this respect, cellular automation (CA) – a spatial modelling technique used to simulate spatial dynamics – has been used to simulate dynamic urban systems (see for example Couclelis 1985, Batty and Xie 1994, 1997, White and Engelen 1993, 1997, Wu 1996, Wu and Webster 1998, Yeh and Li 2002). CA works on the principle of self-organisation and continual adaptation. The essence of CA is that local actions lead to complex global behaviours (Batty 2000). Taking this point of view, this paper presents a CA model developed for detailed land use simulation in an urban environment. The model permits scenario testing and can be used as a strategic planning tool to facilitate impact analysis of development proposals or policies.

Cellular Automation and Urban Studies

In general, CA models can be seen as simplified discrete dynamic systems representing reality in time and space using an *n*-dimensional array. In a strict CA, a two-dimensional array is used and a neighbourhood in the form of a 3×3 template is employed to capture the spatial dynamics occurring in the local area of each cell. Within the array the state of each cell changes with time as a function of its previous state and the state of other cells within its neighbourhood based on a set of stated transition rules. The essence of CA models is to ensure that changes in time and space are always generated locally by cells that are strictly adjacent to one another. Any global patterns or centralised order emerged in the system is entirely the result of local actions during the simulation process (Batty 2000).

It is generally agreed that the field of CA was developed by physicist John von Neumann (1966) based on the suggestion of mathematician Stanislaw Ulam (1952) in the late 1940s. Nevertheless, the origin of the idea can be traced back to computer scientist Alan Turing when developing his notion of universal machine which would be self-reproducible through digital computation (Copeland 1999, Batty 2000). However, it was not until mathematician John Conway who developed the famous game 'Life' in the late 1960s which had aroused significant interest that CA became widely known (Gardner 1970). Initially, CA models were used in the study of natural science, such as the modeling of DNA sequences (Burks and Farmer 1984) and cytoskeletal lattice structure (Smith, Watt, and Hameroff 1984). More recently, continuous-valued CA models have also been used to simulate the flow of electricity in a power grid using wave propagation theories (Ostrov and Rucker 1996, Rucker 1999).

In the 1990s, researchers began to use CA models to represent geographical systems to simulate long-term developments in urban form and land use (Batty and Longley 1994, Webster 1996, White and Engelen 1993, Webster and Wu 1999a, b). Focuses of these studies were mainly on revealing the fractal properties of urbanised area and land use structure through dynamic interactions, evolution, and self-organisation as replicated on the CA models. For example, in their study of non-linear urban dynamics, White and Engelen (1993) used CA to model the development of US cities such as Cincinnati and showed how urban form could be modelled through time and how these forms were consistent with fractal geometry and urban density theory. Similarly, Batty and Xie (1994) used CA model to simulate urban growth and form and applied the model to simulate the development of the historical 'cell' city of Savannah, Georgia before developing a more generic model. In the same vein, Clarke, Hoppen, and Gaydos (1997) used a CA simulation model to predict urban growth for the San Francisco Bay Area using observed historical development patterns for calibration. Relating density to development, Wu (1998a, b) used CA to study the intra-metropolitan land use changes in China as well as polycentric urban growth by linking the stability of sub-centres with population density and disutility such as congestion. More recently, Yeh and Li (2002) incorporated density gradient in a CA simulation of urban development for different urban forms and found that high-density development could significantly reduce encroachment on agricultural land and other environmentally sensitive areas.

All these studies can be grouped under the label of macro-scale urban form studies. Their focus is mainly on how the form of a city changes through local interactions (urban morphology) and what properties these forms exhibit in the long run. From a large-scale perspective, these studies revealed that urban form or land use could be measured by a fractal dimension through a natural self-organising procedure during the development process. To date, a large body of literature that includes both theoretical and empirical studies in this aspect has been established (see for example Batty and Longley 1994, Batty and Xie 1994, 1996, Benguigui 1995, Benguigui, Czamanski, Marinov, and Portugali 2000, Cecchini 1996, Longley and Mesev 2000, Mesev, Longley, Batty, and Xie 1995, Semboloni 2000, Webster 1996, White and Engelen 1993).

There are also studies on other aspects of urban dynamics using CA models on a finer scale. For example, White and Engelen (1997) used an integrated model of regional spatial dynamics consisting of a CA-based model to simulate the land use of the island of St. Lucia. In considering the city as a complex, open, and thus self-organising system, Portugali and Benenson (1995) applied a cell-space model (a relaxed CA model) to simulate international migration in the urban process by incorporating social and economic interactions into the transition rule set. Semboloni (1997) developed a CA model (based on a general accounting model derived from the classical economic base theory) as an alternative to the conventional Lowry model. Benati (1997) extended the Hotelling model (1929) of competitive location theory by using a CA model to simulate spatial competition among a group of competitors. In fact, with proper model configuration and formulation of transition rule set, many urban theories can be incorporated into CA models to examine various kinds of urban dynamics (O'Sullivan and Torrens 2000).

As far as studies using CA to model land use changes are concerned, the work of White and Engelen (1993, 1997), White, Engelen, and Uljee (1997), Engelen, Geertman, Smits, and Wessels (1999) and that of Wu (1996, 1998b), Wu and Webster (1998), are most prominent. The modelling approaches adopted by these researchers can be broadly divided into two. White and Engelen (1993, 1997), White, Engelen, and Uljee (1997), and Engelen et al. (1999) focus more on the application of the CA model as a practical aid to strategic land use planning. Their CA models use actual land use plans as input with a relatively large number of cell states to represent the different land use types in reality. The cell states are further divided into two categories to represent changeable land use types and permanent features. A relatively large circular neighbourhood is used to capture local agglomeration and action-at-a-distance effects. The transition rules base only on the proximity of different types of land uses and therefore the models do not require many different data sources to run. Also, variations of their generic CA model in terms of neighbourhood configurations and transition rules in the different studies are limited. Extension of the model is achieved via exogenous controls and linkage to other modules such as input-output models to forecast economic changes.

In comparison, Wu (1996, 1998b), and Wu and Webster (1998) focus more on the theoretical aspects of CA for land use simulation, particularly in relation to decision making, and use their models as tools to explore different research ideas in simulating rural to urban land use transition. Since their studies concern primarily with how human decision affects land use change (referring as rural to urban transition), Wu (1996, 1998b), and Wu and Webster (1998) use only a small number of cell states and a small rectangular neighbourhood in their models. Also the use of satellite image as input, which has a small variation in colour and hue, has limited the land use classification hence the number of cell states. The transition rules they employed, however, are relatively complicated in mathematical formulation. Decision tools and techniques such as fuzzy logic, preference function, and multi-criteria evaluation procedure are introduced to the variants of the generic model to mimic the uncertainties in the human decision-making process. Also, factors other than land uses of neighbouring cells are considered. Therefore, their CA models are good for simulating broad-brush changes, such as rural-urban transition in urban fringe, under different development policies or scenarios where different human decisions can generate entirely different impacts. In short, the CA models of White and Engelen (1993, 1997), White, Engelen, and Uljee (1997), and Engelen et al. (1999) are developed for detailed practical land use planning whereas those of Wu (1996, 1998b), and Wu and Webster (1998) are designed for scenario testing to reflect the impacts of different development decisions.

A Proposed Cellular Automation Model for Urban Land Use Simulation

This study attempts to develop a CA model for urban land use simulation to incorporate the aggregate effect of the interactions between land use and transportation. The myriad forces of urban land use changes are first condensed into two basic types termed attribute and gravity effects respectively. The former is a driving force for change constituted by changing values of local attributes as a result of land use and transport interactions. The latter is a resistance to change due to inertia and agglomeration of compatible land uses in the vicinity. Land use changes at the local level are regarded as the result of a balanced combination of these two forces. Local land use changes collectively constitute the global land use pattern.

In calculating the attribute effect, an aggregate approach is taken to mimic market behaviour based on the economic principle of supply and demand. While recognising the mutual relationships between different variables, such as accessibility and population density, this study does not attempt to model the direct impacts of a particular attribute on the others and vice versa. Instead, the focus is placed on how the aggregate impact of local attributes affects land use distribution in the long run. Therefore, a composite index calculated on the basis of local attribute values is used to represent the overall effect of the different attributes on land use change. In this regard, the concept is similar to that of hedonic analysis (Rosen 1974). Similarly, another index is used to represent agglomeration or gravity effect on land use change. The index can be regarded as the sum of push and pull forces, inertia, agglomeration and competition effects on the center cell exerted by itself and other land uses in the neighbourhood. Potentials of a cell to change from its existing land use to other use types are calculated using a geometric formulation of the two indices. A multi-pass land use allocation algorithm is used to assign land use to individual cells on the basis of the calculated potentials. The general mathematical formulation of the CA model is shown below:

$$ {}^{t+1}P_{z,i} = ({}^{t+1}S_{z,i})^{a} \; ({}^{t+1}C_{z,i})^{b} \; ({}^{t}N_{z,i})^{g} + e \qquad (1) $$

where

${}^{t+1}P_{z,i}$ is the potential of cell i to change to state z at time $t + 1$; z refers to a certain type of land use;

${}^{t+1}S_{z,i}$ is the suitability of cell i for state z at time $t + 1$; with $(0 \leq {}^{t+1}S_{z,i} \leq 1)$;

${}^{t+1}C_{z,i}$ is the planning control (or restriction) on cell i for state z at time $t + 1$; with ${}^{t+1}C_{z,i} \in \{0, 1\}$;

${}^{t}N_{z,i}$ is the neighbourhood effect on cell i at time t for change to state z at time $t + 1$ and ${}^{t}N_{z,i} = {}^{t}A_i \times {}^{t}G_i$ where ${}^{t}G_i = (r_{x,i} +$ å$_j\, w_{j,y,z})$ " j Î $W_{i,j}$ and $j \neq i$;

$W_{i,j}$ is a standard Moore neighbourhood with eight cells j defined around the centre cell i and $j \in \{1, \ldots, 8\}$;

${}^{t}A_i$, termed attribute effect, is an index for cell i at time t which is a weighted sum of normalised values of accessibility, population density, residential property value, and passenger trip volume representing a driving force of land use changes;

${}^{t}G_i$, termed gravity effect, is an index for cell i at time t which is a sum of resistance of cell i to land use change and the push and pull forces exerted by other cells, j, in neighbourhood $W_{i,j}$ representing a retarding force of land use changes;

$r_{x,i}$ is the inertia or resistance of the cell i with state x at time t to land use change;

$w_{j,y,z}$ is the weighting parameter applied to the cells, j, in neighbourhood $W_{i,j}$ which is determined by the forces of attraction or repulsion between the state of the neighbouring cell, y, at time t and the potential state of the centre cell, z, at time $t + 1$ as a result of compatibility or incompatibility of land uses;

a, b and g are parameters expressing the importance of ${}^{t+1}S_{z,i}$, ${}^{t+1}C_{z,i}$, and ${}^{t}N_{z,i}$ in the calculation of the transition potential. They serve as binary switches in the model and have the value of 0 or 1 depending on the availability of the information; and

e is a stochastic disturbance term which explains the variance not accounted for by the model.

This study uses a strict CA model with a 3×3 Moore neighbourhood. It adopts a similar cell state design as that of Engelen et al. (1999) but a totally different formulation of change potential and transition rule. Time unit in the model is one year. The various urban land uses are first collapsed into 10 basic types, which are further divided into two categories: 'function' and 'feature'. Land uses in the former category are changeable whereas those in the latter category are assumed to be permanent but their presence in the neighbourhood affects the change potentials of the center cell. Potentials to change are calculated as a geometric sum of the two indices representing the attribute and the gravity effects respectively. Instead of being written as distance function, as in Engelen et al. (1999), the transition rules of this model are used to calculate the new values of the local attributes as a results of land use changes. The new attribute values, together with the new land uses, are in turn used to calculate the change potentials for the next time period. In calculating the new attribute values, an incremental change approach is adopted such that the attribute values of the center cell will alter whenever a certain number of cells in the neighbourhood have changed their land uses even though the land use of the center cell has remained unchanged. Therefore, changes in the attribute values of the center cell will accumulate over time until a certain threshold is exceeded which triggers a change in land use type. This arrangement mimics the time lag required for the propagation of the impacts. For example, if a new transport facility is introduced in a neighbourhood thereby improving the accessibility of the area, more people may choose to move into the neighbourhood for residence. As a result, population density, residential property value, and passenger trip volume of the whole neighbourhood will gradually increase. Land uses of some of the cells in the neighbourhood will change even though the land use of the centre cell remains unchanged at the beginning. As time goes by, the increased demand for housing will provide enough incentives for additional supply of residential properties in the neighbourhood. This will trigger a land use change of the centre cell in the end if its original use is not residential, provided that the land is suitable for such purpose, and the resistance to change is surmountable. From this perspective, the transition rule set can be seen as an encapsulation of the dynamics of transportation and land use interactions in an aggregate manner. Figure 1 shows schematically the principle of using CA in modelling land use changes in this study. Table 1 shows the specifications of the CA model.

For implementation, the proposed CA model adopts a loose coupling architecture (Fischer, Scholten, and Unwin 1996, Wegner 2000) by using a geographical information systems software MapInfo for spatial data management, operation, and visualisation. A series of programs written in Visual FoxPro are used for the calculation of indices and change potentials, the allocation of cell states based on change potentials, the calculation of performance statistics, and the derivation of attribute values after transition. Import and export of data is done using DBF file as a common file format.

Figure 1 Principle of using CA in modelling land use changes

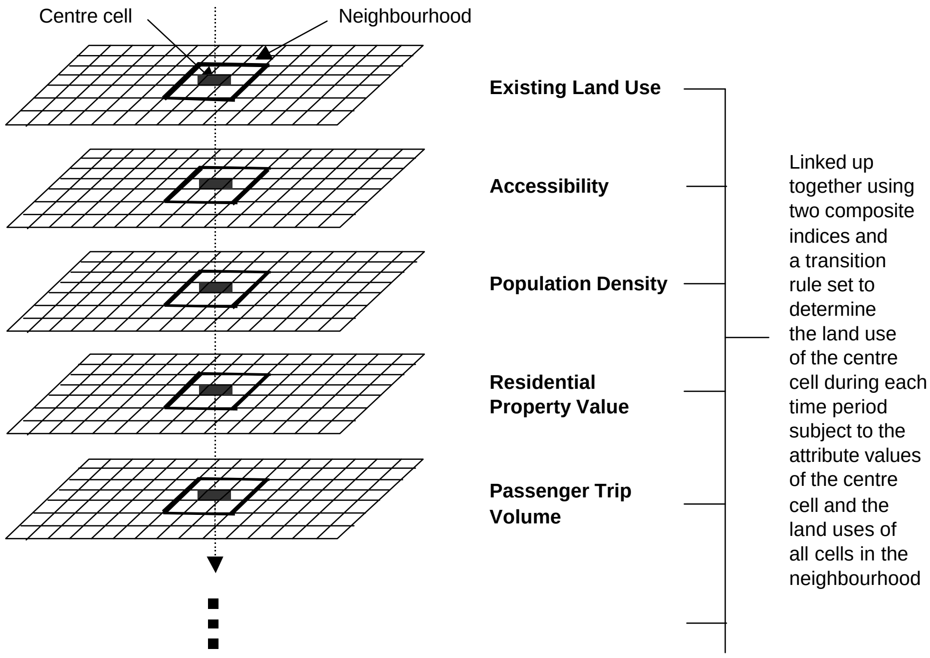


Table 1 Specifications of the proposed CA model

Shape and Size of Cell	Grid, 1 km by 1 km
Shape and Size of Neighbourhood	Rectangular, 3 grids by 3 grids
Number of Cell States	10 cell states representing 10 land use types divided into 'functions' and 'features' Functions Urban Residential (UR) Rural Residential (RR) Business or Commercial (BU) Industrail (IN) Commonwealth Land (CL) Rural (Type 1) (R1) Features Infrastructural Purposes (IP) Public Purposes (PR) Rural (Type 2) (R2) Environmental Purposes (EP)
Effects on Land Use Change Considered	2 effects considered: Attribute Effect and Gravity Effect Attributes (of the centre cell) in the Attribute Effect Accessibility (includes density of road network, availability of public transport and other facilities) Population Density Residential Property Value Passenger Trip Volume Variables in the Gravity Effect Land use of the centre cell Land uses of other cells in the neighbourhood
Transition Rules	Averaging functions to calculate the new attribute values of the centre cell subject to the land use changes of all cells in the neighbourhood
Study Area to which the Model Applied	Melbourne Statistical Division (excluding the Shire of Yarra Ranges where digital land use data is not available), 6,340 sq. km

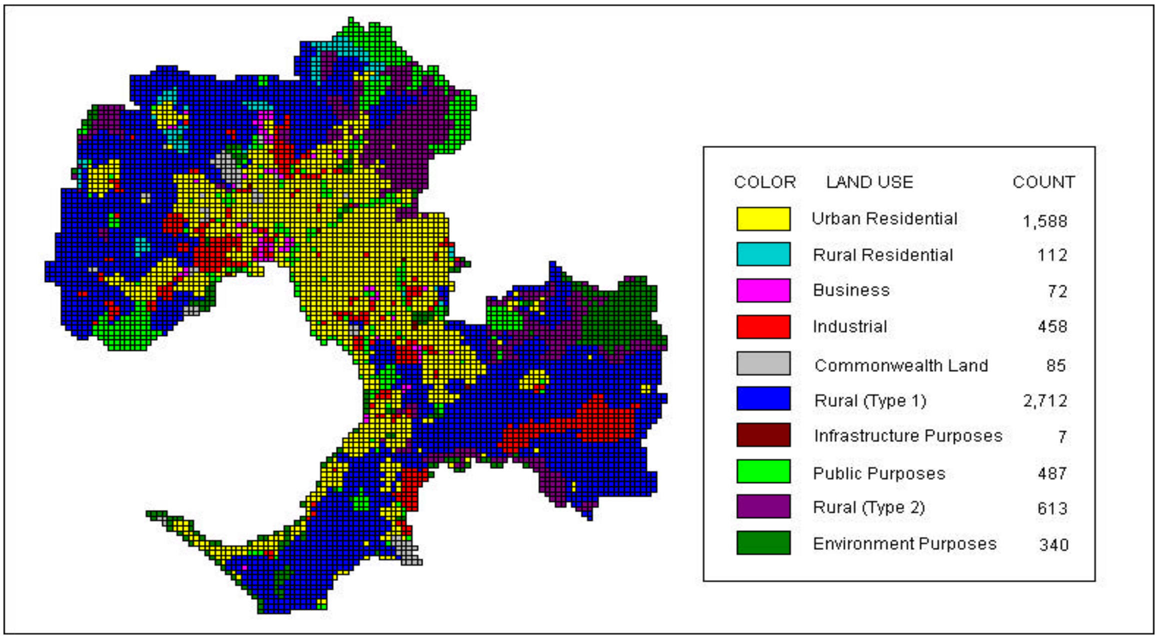
The Case Study of Metropolitan Melbourne

To demonstrate the use of the CA model for land use simulation, Metropolitan Melbourne, defined by the Australian Bureau of Statistics (ABS) as the Melbourne Statistical Division (MSD), is used as a case study area. The MSD covers an area of about 8,830 km^2. Its population in 1996 was 3.14 millions (Australian Bureau of Statistics 1997). Land use information was obtained from the Victorian Department of Infrastructure. As standardised digital land use plans are only available from 2000 onward, the year 2000 land use plan is used as the base year map. Also, due to the absence of digital land use data for the Shire of Yarra Range in the land use plans, the actual size of the study area has been reduced to about 6,340 km^2. Land Victoria, another government department of Victoria, provided the digital road network as well as the residential property transaction prices. Population estimates were obtained from the ABS. The Transport Research Centre of the Royal Melbourne Institute of Technology (RMIT) University provided the Victorian Activity and Travel Survey (VATS) data and other transport related information. Table 2 shows a summary of the databases used in this study. Figure 2 shows the land uses of the study area in the year 2000 classified in 10 basic types.

Table 2 Databases used as inputs for the CA model

Database	Source	Use
Digital planning schemes of Melbourne Statistical Division (MSD)	Victorian Department of Infrastructure (DoI)	To calculate land uses for individual cells in the array of the CA model
Residential land release forecast for MSD	DoI	To prepare one of the control layers for the CA model
Industrial land release forecast for MSD	DoI	To prepare one of the control layers for the CA model
Average residential lot size of MSD	DoI	To calculate residential property values for individual cells in the array of the CA model
Estimated population figures of MSD	Australian Bureau of Statistics (ABS)	To calculate residential densities for individual cells in the array of the CA model
State Digital Road Network (SDRN) for Victoria	Land Victoria (LV)	To calculate accessibility indices for individual cells in the array of the CA model
Residential property transaction prices of Victoria	LV	To calculate property values for individual cells in the array of the CA model
Victorian Activity and Travel Survey (VATS) databases	Transport Research Centre (TRC) at Royal Melbourne Institute of Technology University	To calculate passenger trip volumes for individual cells in the array of the CA model
VATS public transport network databases for MSD	TRC	To calculate accessibility indices for individual cells in the array of the CA model
VATS landmark databases for MSD	TRC	To calculate accessibility indices for individual cells in the array of the CA model

Figure 2 Land use distribution of the study area in year 2000



Using the two composite indices representing the attribute and the gravity effects respectively as discussed earlier, the potentials of each cell in the study area to change to the six different land use types in the 'function' category for the next time period are calculated. A multi-pass land use allocation algorithm is then used to assign land use to each cell based on the calculated potentials. Instead of just ranking all the potentials and selecting the cells with the highest potentials for a particular land use in a single pass, the multi-pass algorithm first checks among the different change potentials of each cell. If the potential land use type (i.e., the type with the highest potential) equals the existing land use type, the state of the cell is kept unchanged. This design gives due emphasis on local characteristics. Instead of comparing all cells at a global level right at the beginning, potentials are compared at local level first before comparing globally. This emphasis on local influence on land use change is more akin to the essence of CA (i.e., local actions result in global pattern). After the first pass, the algorithm selects from all the remaining cells those with potentials to change to a particular land use type and picks the first *n* cells to meet the total number required (the total, *n*, is controlled exogenously). It then returns the unselected cells to the pool and repeats the procedure with another land use type until all land use types are processed. The algorithm also uses additional passes to accommodate controls, such as suitability and planning regulation, and specific conditions, such as one-way conversion. Table 3 shows a comparison of the modelled counts against observed counts in land use distribution of the study area in the year 2001 using the CA model. It can be seen that performance of the model using a multi-pass allocation algorithm is much better than using a single-pass one. Not only the overall accuracy but also the results for minority use types have improved.

Table 3 Modelled land use distribution of the study area in year 2001

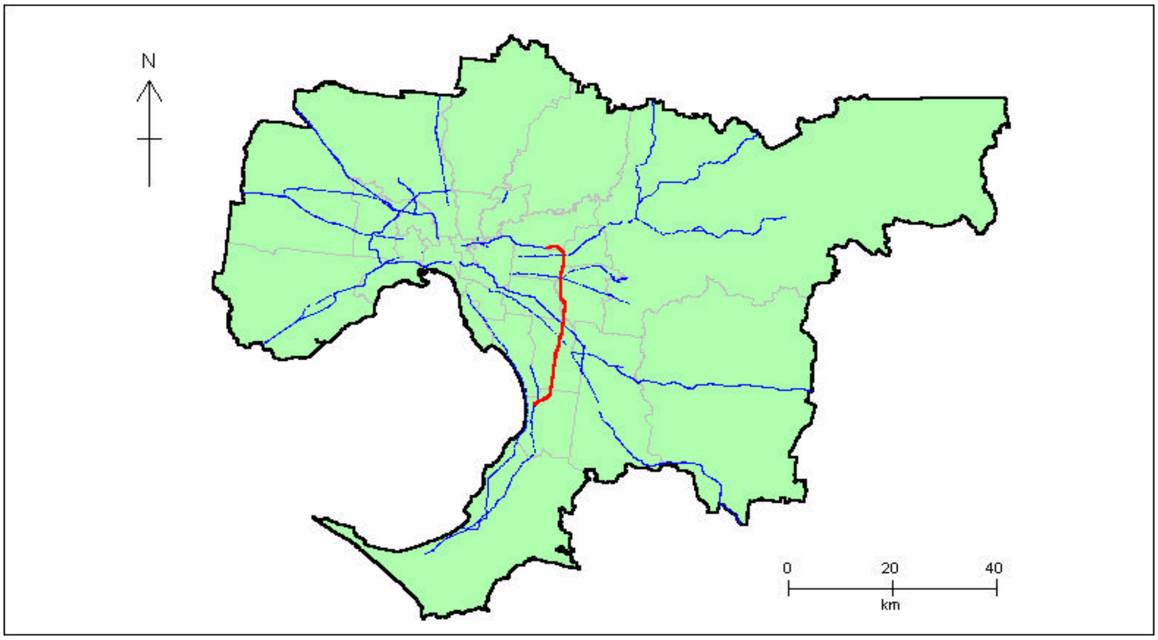
Land Use For Year 2001	Observed Count	Correct Modelled Count Using Attribute and Gravity Effects: Using a Single-Pass Algorithm	Correct Modelled Count Using Attribute and Gravity Effects: Using a Multi-Pass Algorithm
Urban Residential	1,590	1,376 (86.5%)	1,584 (99.6%)
Rural Residential	112	21 (18.8%)	112 (100%)
Business or Commercial	75	4 (5.3%)	71 (94.7%)
Industrial	458	248 (54.1%)	453 (98.9%)
Commomwealth Land	84	2 (2.4%)	84 (100%)
Rural (Type 1)	2,708	2,516 (92.9%)	2,699 (99.5%)
TOTAL	5,027	4,167 (82.9%)	5,003 (99.5%)
Correct Overall Classification		82.9%	99.5%
Chi-Square		359.90	0.32
Joint Information Uncertainty		0.5032	0.9738
Adjusted Kappa		0.7152	0.9921

NOTE: Figure in brackets is the percentage of correct modelled count to actual observation.

To illustrate that the CA model can be used as a strategic planning tool, a scenario of adding a new freeway to the existing road network is tested. The additional freeway is the proposed Scoresby Freeway linking the Eastern Freeway in Nunawading (in the City of Whitehorse) with the Mornington Peninsula Freeway in Seaford (in the Shire of Frankston) (Figure 3). First proposed in 1937, the freeway is planned to be part of the ultimate MSD ring road system skirting the inner and middle suburbs of the city. Recently, the Victorian government has given the green light to the construction of this new freeway of more than 37 km in three stages. Once completed, it is believed that the linkage between the northeastern and the southeastern parts of the city will be greatly enhanced. Another freeway linking the suburbs of Thomastown, Greensborough, and Nunawading, if constructed, will link up the Western Ring Road with the proposed Scoresby Freeway (also named as the Eastern Ring Road) thereby completing the MSD ring road system.

In the CA model, it is assumed that the new freeway will be fully opened to traffic in the year 2005. As a result, accessibility of the catchment area of the new freeway improves which in turn increases the attribute effects of the cells affected. To incorporate this change, the freeway is assumed to be in place in the base year (i.e., 2000) and a new set of accessibility values is calculated. This set of values is compared with the original one (without the new freeway) and the differences are noted. Using the CA model and the original set of attribute values, land uses and attribute values for 2005 are calculated. The set of attribute values for 2005 are then adjusted based on the differences noted earlier on a cell-by-cell basis. Using the set of adjusted attribute values for 2005, land uses for 2011 are then projected by the CA model through self-evolution.

Figure 3 **Major roads in the MSD (blue) and the proposed Scoresby Freeway (red)**



Figures 4 and 5 show the projected land uses for 2011 under a do-nothing scenario and one with the opening of the proposed Scoresby Freeway in 2005 respectively. In comparison with the do-nothing scenario, the most significant change is the further expansion of the industrial development south of the intersection of Princes Highway and the proposed Scoresby Freeway (circled area) indicating that the improved accessibility in the area is vital to its long-term growth. The availability of abundant rural land also permits further expansion of the industrial area with minimum resistance. On the contrary, there is little change in land use in the northern section of the new freeway. This might be explained by the fact that first of all the land use in the northern end of the freeway is largely residential. Improvement in accessibility should attract more people moving to live in the area thereby increasing the residential density and property value in the neighbourhood. These increases will result in a stronger attribute effect. However, since residential land use has already had the highest average attribute effect in comparison with other land uses, further increase in the attribute value will only consolidate the land use and reduce its potential to change to other land use type. Secondly, the massive residential area has a very powerful gravity effect and therefore resists strongly to changes. The green belt (which comprises land use in the 'feature' category) south of Burwood Highway also forbids any further development of any kind. This explains why there is no expansion to the industrial development in the middle section of the new freeway.

Another interesting point to note is the mild change in the commercial development south of the industrial area. Adding a new freeway seems to have little impact on this block as the with- and without-freeway patterns are more or less the same. This can be explained by the fact that commercial land use ranks second based on attribute effect alone. The use type is therefore less sensitive to increase in attribute values when compared with industrial land use. Probably the increase in attribute effect in the neighbourhood as a result of the addition of a freeway is strong enough to increase the potential of change from rural to industrial but not commercial. In other words, in order to promote commercial development, complementary development strategies to provide stronger incentive to increase residential density or property value of the area is needed apart from improved accessibility.

Figure 4 Predicted land use distribution of the study area in year 2011 under a do-nothing scenario

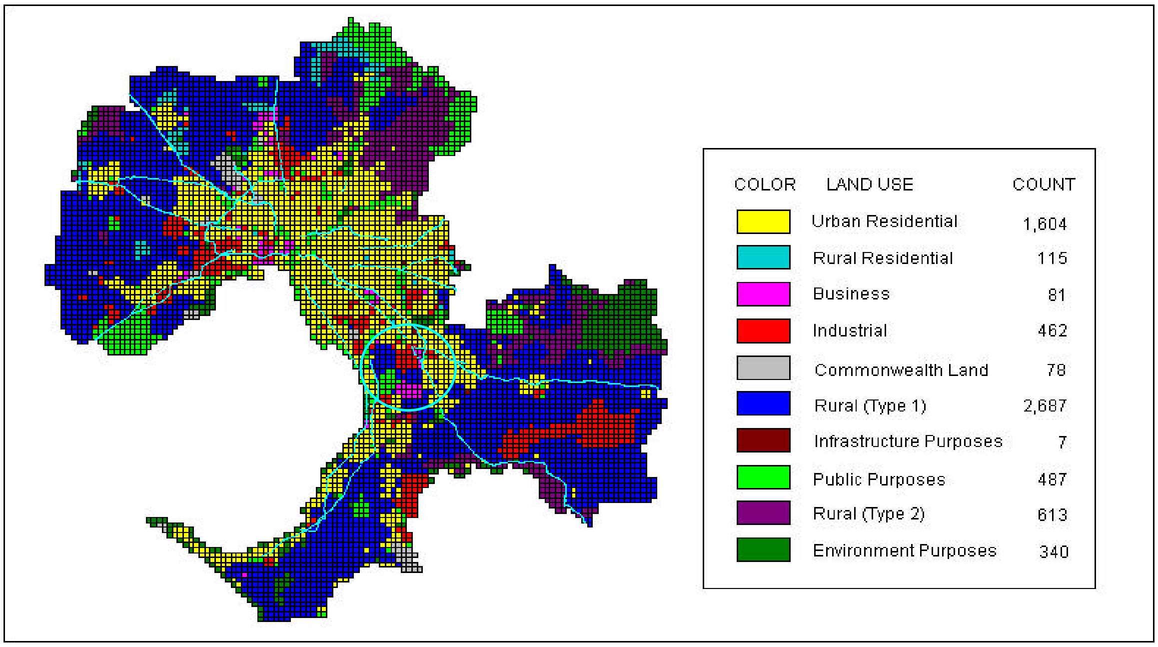
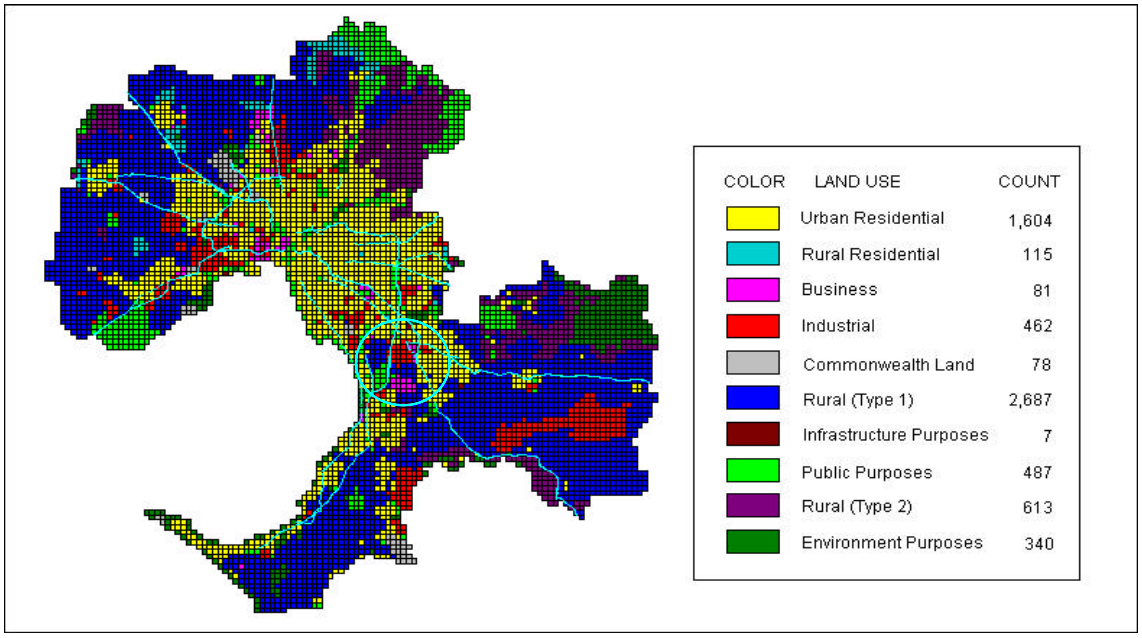


Figure 5 Predicted land use distribution of the study area in year 2011 with the opening of the proposed Scoresby Freeway in 2005



Conclusions

This paper has presented the development of a land use simulation model using cellular automation (CA) which considers urban growth as both a local and a global process. The model condenses the myriad factors affecting land use and transport into a few attributes, which include accessibility, population density, residential property value, and passenger trip volume. It interprets land use change as the result of a balance of two distinctive forces: attribute and gravity effects. The attribute effect can be regarded as a local force specific to the local sphere of attribute values. The gravity effect indicates a resistance to change due to inertia and agglomeration of compatible land uses in the vicinity. Other global forces such as overall demand and supply of different land uses and state population policy can be introduced in the model by means of exogenous controls.

The use of the CA model as a strategic planning tool to facilitate analysis of developmental impacts on land use has been demonstrated using metropolitan Melbourne as a case illustration. A scenario analysis has been conducted using the CA model to investigate the likely land use changes upon the opening of the proposed Scoresby Freeway linking the Eastern Freeway with the Mornington Peninsula Freeway. The result reveals that the proposed Scoresby Freeway will mainly promote the industrial development in the southeastern part of the city as it provides an express route for the freight traffic coming from the north (Tullamarine Airport and Sydney) to bypass the city centre. The volume of freight traffic on the proposed freeway as well as the local roads is expected to increase. By regarding land use changes as a result of the wrestling of two opposing yet complementary forces, gross effects of land use and transport policies can be estimated by assessing their impacts on the two effects without going through a lengthy and complicated modelling procedure. The proposed CA model has the advantages of being simple, flexible, transparent, and requiring much less data to run in comparison with the integrated land use–transport models. Built on a geographic information system platform, the model also allows easy visualisation of output. For strategic planning purposes, the CA model can serve as a handy tool for examining impacts of various transport and land use proposals.

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