URBAN LAND USE MODELS FOR SUSTAINABLE FUTURES*

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1. Introduction

Urban land use is the use to which urban land is put as a result of the complex web of interactions related to both internal and external relationships within the confines of the existing institutions. From micro level changes at the decision maker, e.g., changes that affect everyday patterns of trips, and medium level changes at the urban level, e.g., suburbanization, to macro level changes at the regional or higher levels, e.g., change in economic base, a large body of phenomena is effective on the use of a piece of urban land. Change in urban land use is also a function of times required for changes in different realms such as buildings, activities or trips[1)]. Thus efforts to predict urban land use will produce no more than a simple representation of a continuously changing complex phenomenon. Looking at a snapshot of this complex phenomenon, one might see residences, industries, and groceries or supermarkets located in relation to each other, together making up a land use pattern. Related to this, a relatively early study elicit two kinds of hierarchical actions directly related to land use development, i.e., priming and secondary actions[2)]. Priming actions are associated with large-scale actions such as the routes of major roads, major industrial facilities etc. Secondary actions, which are triggered by the primary actions, are generally small in scale, but consist most of the "bulk" development in an urban area. Two effects of priming actions on land development are given as structuring effect on land development and timing effect on the sequence of events[2)] (p. 376). Thus, every development decision has an incremental effect on the system of activities as well as the system of movements in the city within a lapse of time characterized with the priming action itself. In this regard, land development in an urban area involves many complex actions, in most of the instances, in relation to other actions, thus it represents an evolution rather than equilibrium.

An important factor governing this land use pattern is accessibility, which is the collection of opportunities reachable from a location. Hansen[3)], using data from Washington D.C. area, have showed that land use of an area is highly dependent on the accessibility of the location of the land. There are three generic groups of accessibility computations each of which can be employed in different settings, e.g., aggregate and disaggregate settings. Physical interpretations of accessibility relied generally on Newtonian distance decay with the decay parameter to be estimated from the origin-destination matrices or graph theoretic formulation of the urban networks and using the connectivity deriving accessibility of different locations. Economical interpretations relied on the utility concept, which relied on either consumer surplus in utility or total utility that should be derived from one location by exploiting discrete choice framework. Space-time geographic conceptualizations utilized the Hägerstrand constraints that limit individuals to prisms containing different opportunities.

Models so far proposed for predicting urban land use can be approached in three waves of development that are aggregate spatial-interaction models, utility maximizing models and activity based or cellular automata based simulation models[4)]. The first wave find its breeding area in the backdrop supplied by the Lowry Model[5)]; in other words, these models generally represent modifications over the Lowry-Garin framework[6)]. For example, early models, TOMM[7)], PLUM[8)], , ITLUP- DRAM-EMPAL-METROPILUS[9)], LILT[10)], IRPUD[11)] are models anatomically resembling the Lowry-Garin framework. The second wave of development is benefited primarily from the development of the discrete choice theory based on utility maximization principle[12)], and from the theoretical adaptation made by Anas[13)] on zonal aggregation of behaviors of decision making units.. MEPLAN[14)] and TRANUS[15)] are two models which use utility maximization resolution in addition to the reliance on the Input-Output framework[16)]. Other models that can be mentioned as typical second wave models are BASS/CUF[17)], MUSSA[18)], RURBAN[19)], CATLAS[20)], URBANSIM[21)], IMREL[22)], TILT[23)]. The last wave is more associated with paradigmatic shifts in closely related urban transportation planning from the realm of trip-based perspective to activity-based perspective and the emphatic change focusing broadly on sustainability issues - more particularly on sustainability issues surrounding environmental quality and energy. It is also supplemented with the developments in computing and information technologies. All together, developments so far achieved in the field indicate improvements in general problem areas indicated by Lee[24)]. Generally, urban models encompass at least two sub-systems to simulate: land use and transportation, among which there is a cyclic relationship through accessibility-product of transportation system given land use distribution, and distribution of activities-product of land use system given transportation system, that act as intermediaries between two sub-systems. The models that tightly integrates these two sub-systems are regarded as "unified", models that loosely integrates the two sub-systems, as a collection of sub-modules with independent internal functionings, are regarded as "composite" models [25)]. The

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difference between two model systems turns significant when dynamism is to be incorporated into the models. Composite models by having modules functioning independently can represent dynamism, which is difficult to be represented in unified models.

2. Motivation

Lately, sustainability has become a hotbed of studies trumpeting worries concerning the increasing odds of depletion of natural resources and the pervasive environmental effects of human activities. Of these, a substantial portion is devoted to the urban realm, which has been the integral part of virtually all aspects of economic, social, and administrative activities. Given the available technology, the urban areas are critically dependent on non-renewable fossil fuels as energy sources. Moreover, considering prospects of the business-as-usual practices, depletion of fossil fuels in the foreseeable future is likely. Equally or more importantly, the carbon content of fossil fuels has adverse effects on the global warming phenomenon, which is covering a good deal of media attention nowadays, e.g., see special report by weekly news magazine Time[26)]. In addition, pollutants such as NOx, VOC, and HC, end-products of either the reactions among gases emitted from various sources and the atmospheric gases impose health problems on human populations either directly or indirectly through other means, e.g., food chain. As evidenced in the historical trends of basic statistics[27)-28)], increasing dependence on fossil fuels indicates that sustainability, both in the environment and natural resources, cannot be achieved without sustainability in the urban areas. Historical accounts of today's developed countries show us that energy use and environmental pollution increased tremendously through the industrialization of the 19th and the early 20th centuries. Currently, this increasing trend is continuing through what we know as the post-industrialization era. On distinguishing features of this development, we may say that the industrialization period is characterized with the emergence of motorization, while the post-industrialization era is characterized by the proliferation of automobile-oriented systems of production-distribution-consumption-disposal, and resultant life styles with ever increasing and diversified consumption of natural resources and non-renewable energy.

Urban forms has various effects on the uses of motorized and non-motorized travel modes[28)–31)]. Dieleman *et al.*[32)] report that defining the relationships between urban forms or land use composition and the mode of travel as well as vehicle kilometers traveled is a complicated task as very diverse sets of factors come into play: firstly, travelers hold different personal and household attributes, income, household composition, and participation in the workforce, which have strong impacts on mobility and modes employed; secondly, residential location, residential environment and the transportation services the residential location is endowed with affect travel behavior; and thirdly, trip purpose, space-time constraints and land use affect the chaining of trips, which strongly affects mode(s) utilized[32) pp. 507-508].

It is generally recognized that motorized transportation, especially automobile transportation have caused air pollution, high energy consumption, and adverse effects on urban land use such as uneven urban development, which have become the main problem areas of studies concentrating on sustainable development. Heavy use of automobiles in low density urban areas is closely related to the phenomenon termed as automobile dependency. One reason for automobile dependency is the urban sprawl. Because, in low density and sprawled urban areas, public transit facilities remain in poor accessibility to most residents; contrary to the public transit, automobile is flexible and offers increased accessibility and mobility (Figure 1). Mainly, commuter trips in these urban areas are highly dependent on automobiles. This phenomenon is seen in developed countries in line with the suburban development which is associated with low density, bedroom communities. In this regard, planners in recent years have sought to contain suburban sprawl and its negative social, economic, and environmental effects some of which are given above[33)]. It is expected that increases in energy shortage and air pollution will require actions to reduce motorized transport of people and cargo.

3. Basics of a land use model and a short general critique

In this section, we will discuss the underlying structures of different traditions of land use models and their correspondence with sustainability considerations as a critique. Contextually- and generally- urban land use models constitute one part of the more broad integrated land use transportation models, which generally assumes endogeneity of the two closely interrelated realms of interest, transportation and land use. Thus, the core of the integrated land use transportation models hosts the functioning of the transportation system with its demand and supply counteracting and the simulation system of distribution and intensity of the land uses. To this core, generally, demographics (, regional economics, government policies and transportation system supply the bulk of exogeneous information[34)]; from this core we generally expect to have estimates about stocks (such as buildings), flows (such as trip interchanges) and impacts on the environmental system (such as emissions). The land use simulation system is dependent on the accessibility inputs from its counterpart designed for simulating the transportation system. Regarding this, trip times between two points in urban space, webbing of ways of access are crucial in determining the type and intensity of land use, thus any land use model. Besides many other factors are included in the land use models such as rents, locational amenities, etc. However one has to note significant variation in terms of theoretical background, modeling techniques, land uses simulated, factors included, among the models used. Explanatory power, theoretical soundness and comprehensiveness of land use models have already been studied by other researchers, thus in the remaining of this section, we confines ourselves to supply a generic critique of the models regarding their responsiveness to the sustainability considerations.

A bird's eye view of most of the operational models[25)] might reveal that different model elements are standardized to be compatible with the core sub-systems of transportation and land use, e.g., zones, links. However, unless the urban land use models are designed and operationalized at the micro level of detail, many issues related to the energy use (e.g., energy consumed by buildings) or environmental issues related to nebulous biotopes (e.g., green space continuity) will be uncompatible with the coarse areas of simulation, and remain unchecked in the face of policy development regarding sustainability. From another viewpoint, none of the land use models are not adequate to address policies or planning decisions that are considered to be less-traffic generating, thus more sustainable in terms of the arguments presented above. For example, mixed-land use requires a high level spatial resolution, which, however, is not sufficient for mixed-land uses to breed. The development of the mixed land uses requires planning objectives embedded into the model procedures effectively. Similarly, transit-oriented development, as its name indicates, emphasizes high density land development around the terminal areas or access points. On another footing, representation of the land market in tandem with the planning institutions which implicitly might embrace a multitude of measures directed to sustainability concerns is still not effectively addressed.

4. Conclusions

Currently, urban areas face a multitude of problems related to degradation of air, land and water resources, and increased energy consumption. They have become the hinges by which worries on urban sustainability have been expressed. To address urban sustainability, however, there is a need for an emphatic change in estimation techniques. Acknowledging this need, we have offered a discussion and a critique on how sustainability is important and can find its place in land use models. To do so, we mine through different traditions of land use models. Urban land use models have been evolving to more complex and fines-grained future models. Yet, sustainability remains unchecked even in the face of growing public concern about the environment, energy and natural resources, and biodiversity. Critique outlined above inevitably give rise to a legitimate questioning of the raison d'être of the current land use models as useful tools for public policy development for sustainable futures, which is strongly needed nowadays. Thus evaluation of land use models should be reinstituted to make the model development efforts more directed toward sustainability considerations.

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