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Optimizing urban land use allocation for planners and real estate developers

Afsana Haque [a,*], Yasushi Asami [b,1]

[a] Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh
[b] Department of Urban Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

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ABSTRACT

In this paper, we use genetic algorithm based optimization models for urban land use allocation. We consider a multi-objective function for the planners, which simultaneously maximizes land prices and reduces incompatibility among adjacent land uses for an area. Land price of each and every plot of real estate developer is also optimized in response to the rules set by city development authorities. The differences in opinions of these two stakeholders are highlighted for a case study area of Bangladesh. The ultimate goal is to look for a computationally easy and efficient tool for generating and evaluating feasible land use plans to facilitate the allocation decision.

1. Introduction

The decision-making process for urban land use allocation has always been complicated. The increased involvement of stakeholders and the multiplicity of their interests and priorities are gradually adding to this complexity. As such, the satisfaction with any allocation decision can vary widely across stakeholders engaged in the process. However, the complexity of the decision-making process also arises from the inclusion of multiple, conflicting, and often non-linear and/or non-additive objectives. Unlike most other forms of resource allocation, land use allocation gives rise to the need to address spatial dependencies among neighboring land uses.

Cities that use arbitrary and less developed land use planning instruments face a particular developmental challenge. This is particularly true of large cities in developing countries. In these cases, market forces exploit the loopholes in development control regulations and even try to dictate land use planning decisions at the expense of planning objectives.

Given the complexities of the urban land allocation problem, we considered two main classes of stakeholders: the government planner and the developer/land owner. There may be other important stakeholder groups, namely, environmentalists, conservationists and so on. But in our study we selected the government planner and the developer/land owner who are the groups predominantly facing each other in confrontation over urban land use allocation.

Naturally, real estate developers and private land owners (hereafter, developers/land owners) are driven by profit-making objectives. They often disagree with planners, environmentalists, and other relevant professionals with regard to the optimization of public interest from the development. Conventional government rules and regulations (e.g., relating to density zoning, purchase and transfer of development rights, financial incentives/disincentives for certain kinds of development, regulatory and educational approaches) encouraging socially beneficial land development are unfortunately found to be inadequate for dealing with the interests of the different stakeholders involved. Planners/practitioners, who work with limited logistics, struggle in setting goal values and generating alternative solutions. The result is poor land management and the uncontrolled and haphazard growth of cities.

For this study, we used the genetic algorithm (GA) based four separate optimization models: two single-objective and one multi-objective optimization problems for the government planner, and a single-objective optimization problem for the land developer. These are restricted by some general constraints. Using these four decision support frameworks (i.e., four optimization models) we have tried to address the critical differences between

* Corresponding author. Tel.: +880 1819 817879.
E-mail addresses: afsanaurp@gmail.com, afsanahaque@urp.buet.ac.bd (A. Haque), asami@csis.u-tokyo.ac.jp (Y. Asami).
[1] Tel./fax: +81 3 5841 6226.

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the thoughts of planners and land developers in the land allocation problem. In addition, our optimization models provide a computationally tractable and useful decision support system for planners. Our model optimization approach does not require any goal value.

2. Optimization approach to land use allocation problem

The complexities of land use allocation have commonly been solved in a number ways through optimization approaches; these are set out in the literature. The approaches try to achieve varying degrees of detail, both in terms of setting the objectives and the constraints. A number of studies (Aerts & Heuvelink, 2002; Berke & Godschalk, 2006; Jiang-Ping & Qun, 2009; Ligmann-Zielinska, Church, & Jankowski, 2005; Stewart, Janssen, & Herwijnen, 2004) have commonly dealt with objectives like maximizing land use compactness, improving compatibility among neighboring land uses, ensuring suitability of land units for land uses, identifying per capita demand for land uses, and so on. Experience suggests that too much detail in setting the objectives and constraints to provide realistic solutions generally makes the model computationally intractable, more narrowly defined, and therefore less useful (Gabriel, Faria, & Moglen, 2006).

Efforts have therefore been made to produce computationally tractable solutions by using various optimization techniques like linear programming (Aerts, Eisinger, Heuvelink, & Stewart, 2003a; Moah & Kanaroglou, 2009), simulated annealing (Aerts, Herwijnen, & Stewart, 2003b; Stewart et al., 2004), genetic algorithm (Aerts, Herwijnen, Janssen, & Stewart, 2005; Haque & Asami, 2011), particle swarm optimization (Shifa, Jianhua, Feng, & Yan, 2011; Masoomi, Mesgari, & Hamrah, 2012). These studies have explored new techniques which are more robust, capable of generating feasible alternatives, and deal with different conflicting objectives, which by their construction sometimes show spatial dependencies and non-additive features; they can also handle large scale data and be used interactively for optimization and design (Stewart et al., 2004).

The models discussed earlier introduce the decision variable as a binary one: deciding whether or not to allocate a particular activity to a specific site. With a few exceptions, these models deal with land that is of agricultural importance, areas of high natural value, or areas with vacant/open urban space, which are subject to change under policy recommendations. The models are limited in their ability to capture the vertical growth of urban areas, or the mixed uses of buildings in the urban landscape. Ligmann-Zielinska et al. (2005) addressed and encouraged mixed land use development for urban sustainability by considering new development, redevelopment, and land use compatibility and accessibility; however the vertical dimension still remained overlooked. The reason for this might stem from the contextual difference and therefore the unavailability of micro-scale data for the large areas concerned. The researchers employed binary decision variables and solved multi-objective spatial optimization models for allocation objectives of varying degrees of importance. The model was tested on a hypothetical case of 400 raster cells.

Another common feature of the above mentioned studies is that they use multiple objectives and combine them into one objective using different weightings to find the trade-off solutions. Ligmann-Zielinska, Church, and Jankowski (2008) argued that the weighting technique is very unlikely to generate a significantly different land use arrangement that might help different stakeholders. However, though they presumed/acknowledged that different stakeholders will search for different solutions according to their particular objectives, they did not focus on the different objectives of stakeholders. In fact, we find that there have been very limited efforts to find alternative allocation decisions that consider the differing interests of more than one party. But the objective analysis of multiple stakeholders' interests at an early stage of decision making is indispensable for realistic and more acceptable land use planning and management.

Gabriel et al. (2006) have provided some useful insights in this context. They considered four main classes of stakeholders: the government planner, the environmentalist, the conservationist, and the land developer. Their objectives, which related to compactness, imperviousness change,[2] environmentally sensitive areas, and profit making, are restricted by land growth and zoning. The resulting models have both linear and quadratic objective functions subject to linear and binary constraints and are applied in the context of an illustrative example to a GIS-based dataset for Montgomery County, Maryland. The process necessitates that all those involved in the decision-making process should formulate explicit and quantifiable descriptions of their goals and constraints.

As a contrast, we have used the genetic algorithm (GA) based optimization model to take two sets of objective functions into account: one for the government planner and the other for the land developer. In the first set (a) the land price of the area concerned is maximized, (b) incompatibility between adjacent land uses is reduced, and (c) a trade-off model is developed that considers both (a) and (b) for the planners. On the other hand, in the second set, (d) the land price of each and every plot of developer/owner is optimized in response to the rules set by city development authorities. Some general constraints are placed on both sets of objective functions. Notably, while objectives (a), (b) and (c) were used in Haque and Asami (2011), they are extended in the current research by the introduction of a new constraint set. Haque and Asami (2011) allowed one and only one land use for each plot while the present work allows different activities on the same land. The marked point of departure for this research is the consideration of the developer's perspective, as in objective (d), while allocating urban land uses in an area. Using land price objectives, namely objectives (a) and (d), we generated significantly different land use arrangements for government planners and developers, and highlighted some interesting differences between their approaches.

The current study is important in several other ways. First, following the principles of new urbanism, it allows mixed uses of multistoried buildings and therefore includes a continuous decision variable. Haque and Asami (2011) employed a continuous decision variable, but were restricted to only one land use for each plot while optimization problems were being solved. We have found no other objective function in the literature with a continuous decision variable while solving the land use allocation problem. Second, our parcel-based rather than pixel-based modeling approach is more realistic and appropriate to the real world land development setting. Our models were applied over 1471 plots of varied shapes and sizes in the case study area. Third, we believe our non-linear representations of objective functions are more representative of the real world scenarios. The price function reflects the complexity of the urban land market, while the compatibility function captures the complexity of the land development setting. Fourth, the constraint including "coefficient of change allowed" provides a useful means of accounting for planners where they can evaluate the strategic decision for redevelopment and other relevant policies prior to practical application. It gives an approximation of the costs incurred by communities once somebody (e.g., the planners) wants to develop an already built-up area from scratch. Fifth, our optimization approach assumes that neither

[2] Imperviousness measure is an index of urban impact. Once the level of imperviousness increases, the streams that the impervious area drains experience negative impacts like increased high flows, decreased base flows, thermal shocks, and greater nutrient and pollutant loads (Gabriel et al., 2006).