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Smart growth and transit-oriented development planning in site selection for a new metro transit station in Taipei, Taiwan

Wann-Ming Wey*

Department of Real Estate and Built Environment, National Taipei University, 151 University Road, San Shia District, New Taipei City 23741, Taiwan

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ABSTRACT

In recent years, the application of transit-oriented development (TOD) concept to urban development has been proposed based on the planning principles of smart growth and sustainable development. The development of appropriate design techniques for the surrounded built environment of TOD has become increasingly important as TOD concepts apply to urban development. The available evidence lends itself to the argument that a combined design strategies and TOD patterns planning approach that promotes the quality of urban built environment will help create active, healthier, and more livable communities. This is an essential element of this research. The TOD design strategies can be proposed by utilizing the supply side prediction methodologies of planning. There has also been an increasing interest in the urban built environment design in the past decade. This interest is motivated by the possibility that design policies associated with the built environment can be used to control, manage, and shape individual activity and behavior. This paper first studies and classifies smart growth principles based on literature review. Then the individual expert's judgments are obtained and utilized to evaluate the relative importance of smart growth principles. Next, the site selection for a new metro transit station in Taipei (Taiwan) is conducted to show the application of our proposed methodological approach. A combined Fuzzy Analytic Hierarchy Process (FAHP) and Data Envelopment Analysis (DEA) model with assurance region approach is applied to select the most suitable station from a given set of possible station sites. Both the selected station and the proposed methodological approach are provided to the public sector.

Introduction

To understand how transportation investments can be consistent with the principles and practices of land-use planning is important to researchers, professionals, and community organizations in the field of urban sustainability. Since the 20th century, the automobile has become the primary mode of transportation. This expansion has brought freedom of movement. It nonetheless has caused urban sprawl which increases travel distance and lowers energy-use efficiency. In order to discourage sprawl and to promote energy efficient development patterns, smart growth principles have been applied to integrate land use and transportation planning. Meanwhile sustainable development, with its dual emphasis on the most recent concerns—development and environment—further promotes the use of transit-oriented development (TOD) as a novel approach to development that focuses land uses around a transit station or within a transit corridor. Most site selection research has therefore focused on facility location efficiency (e.g., Min, 1994; Neufville, 1990; Neufville & Keeney, 1972; Paelinck, 1977); however, research has not provided satisfactory answers for the problem of inefficient decision-making units (DMUs) and a prior specification of input and output weights.

Accordingly, this paper develops an integrated approach to show how the site selection problem found in less-effective DMUs can be solved analytically and how the analyzing procedure requires no prior articulation of preference information. Taking facility location investigation of a new metro transit station in Taipei City (Taiwan) as an example, this paper presents an effective solution approach for the site selection problem. Also, under the proposed approach, the selection process can integrate smart growth principles into a TOD planning in order to evaluate and select a location that provides the greatest potential to serve transit riders in. Taiwan is a small island with a high population density. Due to geographical constraints, only one-third of its land can be used to accommodate people and their activities. Taiwan therefore

* Tel.: +886 2 8674 1111x67428; fax: +886 2 8671 5308.
E-mail address: wmwey@mail.ntpu.edu.tw.

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faces inefficient urban spatial development patterns. As such, Taipei City, the capital of Taiwan, has encountered serious consequences of urban sprawl. Motor vehicle engine exhaust, particularly from motor scooters, was a main source of air pollution before the implementation of an integrated multi-modal transit system in early 1990s. Currently, the public transit utilization rate reaches about 37%. To further increase the public transit ridership, the Taipei City Government is expanding the transit network and; hence, new metro transit stations are needed. The Government requests that the station location decision is made based on a selected expert panel. Also, the decision-making process must incorporate both TOD planning and smart growth principles as well as be rational, transparent, and understandable.

In an effort to meet these requirements, this paper introduces a decision-making model for reaching a group decision. The model is based on a combined Fuzzy Analytic Hierarchical Process (FAHP) and Data Envelopment Analysis with Probabilistic Assurance Region (DEA/AR) approach. Past studies have constructed models in combining the DEA model with the traditional AHP for solving site selection problems (e.g., Shang & Sueyoshi, 1995; Yoshiharu & Kaoru, 2003). This paper reinforces previous studies by incorporating fuzzy logic into the AHP method. In doing so, we are able to deal with approximate (rather than fixed and exact) expert judgment when assessing the relative importance of smart growth principles. Also, we treat the planning principles of smart growth as the criteria for evaluating a given set of point sites. These criteria are: (1) multiple criteria: qualitative and quantitative; (2) tangible and intangible factors in a hierarchical manner; (3) internal and external constrains (i.e., weaknesses and strengths of each possible site) imposed on the evaluation process.

Material and methods

Site selection research

The facility location problem was first investigated by Weber in 1989 (Brandeau & Chiu, 1989). Weber solves the problem concerning optimal placement of a single facility in order to minimize the total travel distance between the facility and a set of spatially distributed customers. Partovi (2006) further presents a strategic solution to the facility location problem. In the Partovi's model, a combined quality function deployment and analytic network process approach is used to consider external and internal criteria that sustain competitive advantage. Facility site selection involves measuring the needs of a new project against the merits of potential locations. The decision process includes a process of identifying, analyzing, evaluating, and selecting one site from a given set of point sites in light of a given objective. The facility site selection therefore is a multi-criteria decision-making which comprises quantitative and qualitative criteria (Ashrafzadeh, Farimah, & Zare, 2012). Such a decision can be of great importance to companies because a facility construction plan is a long-term commitment. It is usually non-reversible and involves huge costs. This is particularly true for the transportation facilities construction planning.

Locations of transportation facilities can strongly influence capital and operating costs. The amount of research effort has been spent on facility site selection (Neufville, 1990; Neufville & Keeney, 1972; Paelinck, 1977). For example, Neufville and Keeney (1972) develop a multi-attribute utility function to evaluate two alternative airport sites near Mexico City. The authors consider the impacts over time when evaluating these two sites. However, their analysis neither assesses potential economic benefits that are associated with each site nor is validated by the sensitivity analysis. Min (1994) then proposes an AHP model that considers cost-benefit trade-offs and validates his model result by conducting a sensitivity analysis; but, as argued by DeWispelare and Sage (1981), the AHP measures are not capable of assessing the location planner's dynamic utility functions. Thus, in order to overcome these modeling problems, Shang and Sueyoshi (1995) integrate the AHP result (based on the expert's subjective judgment) into a DEA model in order to select a flexible manufacturing system. Yoshiharu and Kaoru (2003) also apply a similar approach to explore the relocation of Japanese government organizations outside Tokyo City.

Many studies (e.g., Belton, 1992; Belton & Vickers, 1993; Cook & Kress, 1990; Cook, Kress, & Seiford, 1992; Doyle & Green, 1993; Stewart, 1994, 1996) highlight the relationship between DEA and Multi-Criteria Decision Analysis (MCDA) because, similar to many approaches to multiple criteria analysis, DEA incorporates a process of assigning weights to criteria. In this study, we obtain the ranking result through a weight assignment technique that sets a relative degree of importance for each study criterion. The ranking method has been widely used as an aid to decision making in MCDA studies; in particular, a study (such as the current work) needs to assess the relative importance of a set of elements (or alternatives) with either single or multiple criteria. Various ranking methodologies ranging from the utility theory to the AHP method have been proposed in the literature (see Fishburn, 1988; Keeney, 1982; Keeney & Raiffa, 1976; Sinuany-Stern & Mehrez, 1987). Particularly, the AHP method, introduced by Saaty (1980), is a subjective method because evaluators assign a weight to a criterion based on their own subjective judgment. It is useful for quantifying subjective (or qualitative) judgment. It generates a weight for each decision criterion and determines the relative importance degree of each alternative. Yang, Su, and Hsu (2000) use AHP to generate objective weights against a set of qualitative layout evaluation criteria and determine the relative importance of multiple-objective layout design alternatives, which are adopted directly from the study of Muther (1973). However, the AHP is efficient neither in evaluating a large number of alternatives nor in selecting performance frontiers.

The DEA method assumes equally proportional improvements of all inputs (or outputs). But, this assumption becomes invalid when a preference structure over the improvement of inputs (or outputs) is present when evaluating inefficient DMUs. The unrestricted weight means that some of the inputs (or outputs) may be assigned a weight of zero, especially if DMUs are doing poorly in a particular dimension. This assumption is definitely not true in the present study, in which all the variables contribute in some way to the overall efficiency. To address the DMU inefficiency problem, the AHP method manages inputs and restricts weights, so that these restricted weights can be more feasible. That is, in a combined DEA and AHP approach, the AHP is used first to prioritize and derive weights for predefined criteria. Derived weights were then used to establish the constraints of the DEA model. Such combined approach presents a thorough decision-making process. The subjective approach used in AHP determines weights that reflect evaluators' subjective judgments, while the objective approach used in DEA determines weights based on mathematical modeling. By combining AHP and DEA, we eliminate most of the drawbacks associated with individual methodologies, and thereby yield a more accurate and justifiable result.

In addition, Charnes, Cooper, and Rhodes (1979) point out that the process to generate weights in a traditional DEA model requires improvements in order to increase model efficiency. Accordingly, studies have proposed approaches, such as CCR (Charnes, Cooper & Rhodes)/AR and BCC/AR, in the DEA literature (e.g., Cooper, Seiford, & Tone, 2000; Dyson & Thanassoulis, 1988; Thompson, Singleton, Thrall, & Smith, 1986). These studies suggest that the Data Envelopment Analysis with Probabilistic Assurance Regions (DEA/AR) method can effectively solve the issues caused by free running of