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Comparison of Fuzzy-AHP and AHP in a spatial multi-criteria decision making model for urban land-use planning

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ABSTRACT

Modern planning theories encourage approaches that consider all stakeholders with a variety of discourse values to avoid political and manipulative decisions. In the last decade, application of quantitative approaches such as multi-criteria decision making techniques in land suitability procedures has increased, which allows handling heterogeneous data. The majority of these applications mainly used decision-making techniques to rank the priority of predefined management options or planning scenarios. The presented study, however, shows how spatial decision-making can be used not only to rank the priority of options and performing scenario analysis, but also to provide insight into the spatial extent of the alternatives. This is particularly helpful in situation where political transitions in regard to urban planning policies leave local decision-makers with considerable room for discretion. To achieve this, the study compares the results of two quantitative techniques (analytical hierarchy procedure (AHP) and Fuzzy AHP) in defining the extent of land-use zones at a large scale urban planning scenario. The presented approach also adds a new dimension to the comparative analysis of applying these techniques in urban planning by considering the scale and purpose of the decision-making. The result demonstrates that in the early stage of the planning process, when identifying development options as a focal point is required, simplified methods can be sufficient. In this situation, selecting more sophisticated techniques will not necessarily generate different outcomes. However, when planning requires identifying the spatial extent of the preferred development area, considering the intersection area suggested by both methods will be ideal.

1. Introduction

Urban planning analysis involves the consideration of a number of factors, including natural system constraints, compatibility with existing land uses, existing land use policies, and the availability of community facilities. The suitability techniques analyse the interaction between location, development actions, and environmental elements to classify the units of observation according to their suitability for a particular use (Collins, Steiner, & Rushman, 2001; Kalogirou, 2002; Keshavarzi & Heidari, 2010; Malczewski, 2004). In reality, not all the conflicting objectives due to economic development, community or conservation interests are always taken into consideration, which could lead to political and manipulative decisions (Albrechts & Denayer, 2001; Hillier, 2002). To avoid this, planners are encouraged to adjust their 'tool-kits' or mindsets to the changing needs and challenges of democratic society (Albrechts & Denayer, 2001; Hillier, 2002). Modern planning theories such as communicative planning and actor-network theory focus on the fact that effective planning decisions should essentially consider all participants with a variety of discourse types and values (Hillier, 2002). This encourages approaches for integrating very heterogeneous data, making them available to the various stakeholders to allow them to make more informed and less subjective decisions (Greene, Luther, Devillers, & Eddy, 2010).

In the 1960s, the first multi-criteria decision making (MCDM) techniques emerged to alleviate difficulties in accommodating diverse opinions and handling large amounts of complex

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information in the decision-making process (Zopounidis & Doumpos, 2002; Zopounidis & Pardalos, 2010). These capabilities have encouraged planners to combine MCDM with other planning tools such as geographical information system (GIS).

Multi-criteria decision making involves a multi-stage process of (i) defining objectives, (ii) choosing the criteria to measure the objectives, (iii) specifying alternatives, (iv) assigning weights to the criteria, and (v) applying the appropriate mathematical algorithm for ranking alternatives. MCDM allows to accommodate the need for unbiased integration of modern planning objectives for independent identification and ranking of the most suitable planning solutions (Ananda & Herath, 2009; Herath & Prato, 2006; Mosadeghi, Tomlinson, Mirfenderesk, & Warnken, 2009). These spatial MCDM techniques are capable of improving the transparency and analytic rigour of the land use decisions (Dunning, Ross, & Merkhofer, 2000; Hajkowicz & Collins, 2006). Practical applications of such spatial MCDM techniques have become more widespread in land suitability studies (e.g. Arciniegas, Janssen, & Omtzigt, 2011; Chang, Parvathinathan, & Breeden, 2008; Chen, Yu, & Khan, 2010; Greene et al., 2010; Kordi & Brandt, 2012). Recent study, however, shows application of MCDM techniques in identifying the extent of future land-use zones at local scale are rare (Mosadeghi, Warnken, Tomlinson, & Mirfenderesk, 2013). The majority of previous MCDM applications are at national, or regional scales and they mainly focus on using MCDM to rank the priority of predefined management options or planning scenarios (see e.g. Ananda & Herath, 2003, 2008; Bryan, Grandgirard, & Ward, 2009; Hajkowicz, 2002, 2008; Hajkowicz and McDonald, 2006; Kodikara, 2008; Qureshi & Harrison, 2003; Xevi & Khan, 2005). Spatial MCDM, however, can be used not only to rank the priority of options and performing scenario analysis, but also to provide insight into the spatial extent of the alternatives (Arciniegas et al., 2011). This capability can assist local land use planners in identifying land-use zones for future urban development. It can be particularly useful in situations where planning instruments do not provide prescriptive guideline for local planning decisions. Therefore, presented approach here tries to encourage local governments to use more systematic approach to assist planners in integrating all environmental, social, economic, and political matters through a non-bias procedure. This study also examines the outcomes differences in applying two different techniques namely the AHP and Fuzzy AHP. As a result, it highlights the need for planners and decision-makers to make informed decisions about their choice of MCDM technique.

Several MCDM techniques have been proposed for combining with GIS analysis [e.g. ELECTRE-TRI in Joerin (2001); Ordered Weighted Averaging (OWA) in Malczewski (2006); Compromise programming in Baja, Chapman, and Dragovich (2006); goal programming in Janssen, Herwijnen, Stewart, and Aerts (2008); and analytical hierarchy procedure (AHP)]. The AHP is one of the most commonly MCDM technique incorporated into GIS-based suitability procedures (e.g. Ananda & Herath, 2008; Chang et al., 2008; Chen et al., 2010; Kordi & Brandt, 2012; Marinoni, 2004; Svoray, Bar Kutiel, & Bannet, 2005; Thapa & Murayama, 2008).

The popular AHP-based land-use suitability analyses have been criticized for their need for exact numerical values to express the strength of stakeholders' preferences (Chang et al., 2008; Deng, 1999; Kordi & Brandt, 2012; Mikhailov, 2003; Mosadeghi, Warnken, Tomlinson, & Mirfenderesk, 2013; Wang & Chen, 2008). Such exact pair-wise comparison judgments may be impossible to determine and therefore arbitrary in many practical situations in urban environments with uncertainties arising from climate change, global economic crises or immigration policies and local population growth rates.

Advanced MCDM methods including ELECTRE, PROMETHEE, MAUT, Fuzzy set theory, and Random set theory provide more sophisticated algorithms to process uncertain or inaccurate information (Figueira, Greco, Roy, & Slowinski, 2010; Lahdelma, Makkonen, & Salminen, 2009; Zhang & Achari, 2010). The Fuzzy Set theory techniques are considered the most common techniques for dealing with imprecise and uncertain problems (Chen, 2005; Chen, Wood, Linstead, & Maltby, 2011; Dermirel, Demirel, & Kahraman, 2009; Janssen, Krol, Schielen, & Hoekstra, 2010; Keshavarzi & Heidari, 2010; Kordi & Brandt, 2012; Sui, 1992; Mosadeghi, Warnken, Tomlinson, & Mirfenderesk, 2013; Zarghami, Szidarovszky, & Ardakanian, 2008; Zhang & Achari, 2010). Most of the empirical studies however have applied Fuzzy techniques without a comparative analysis to investigate whether using more sophisticated techniques like Fuzzy AHP will truly make a significant difference compare to conventional AHP. On the other hand, the few studies that have done comparative analysis in land suitability applications (e.g. Elaalem, 2013; Elaalem, Comber, & Fisher, 2010; Ertuğrul & Karakaşoğlu, 2008; Hajkowicz, Young, Wheeler, MacDonald, & Young, 2000; Kordi & Brandt, 2012; Quadros, Koppe, Strieder, & Costa, 2006) have mainly focused on arithmetic aspects such as differences in criteria weights, option rankings, or the effects of introducing uncertainty into their models. This need for comparative analyses carries an even greater imperative in the context of applying spatial MCDM methods to real-world urban planning decisions, where transparency and simplicity of the decision-making model is a key element during consultation with the stakeholders. Accordingly, the presented research uses a case study to compare the outcomes of Analytical Hierarchy Process (AHP) and Fuzzy AHP in urban land use planning for the northeast Gold Coast located in Queensland on the east coast of Australia. In addition to the criteria ranking differences and sensitivity analysis, this study compares the spatial extent of the most preferred development locations suggested by both models. In other words, the comparative analysis in our study focuses more on the purpose of the application itself rather than just the technical aspects of the methods being used.

2. Case Study: planning context and area

This work compares the outcomes of different MCDM techniques in the context of urban expansion along a major transport corridor between the two largest cities in south-east Queensland; the Gold Coast and Brisbane. Much of the Gold Coast's southern areas are either already developed or designated as low residential density buffer areas adjoining a World Heritage Conservation Area and elevated terrain. The region's population growth in recent years has raised the need to identify new areas for future urban development. One of the potential development areas is the northeast of the Gold Coast that covers 17,250 hectares of coastal lowlands bounded by Logan River to the north, the Pacific Motorway (M1) to the west, and southern Moreton Bay to the east (Fig. 1).

The main land formation dominating this area is a coastal plain with agriculture, notably sugar cane, as the main economic activity in the area. In addition, extraction industries, aquaculture and tourism all play an important part in the economic growth of this region. The study area also contains a wide range of natural resources which, in combination with the area's strategic location and large agricultural land holdings, highlighted its exposition to a long history of major development pressures.

In 2012, a change in the State's Government prompted a major reform of the current coastal management and planning framework to revitalize an economy that had been stifled by a subdued global outlook and considerable local debts. The pre-2012 coastal planning system was built on a hierarchical layer of instruments guided by (a) management principles defined in a central document, the State Coastal Management Plan, and (b) detailed provisions in a set of regional coastal plans that contained maps of boundaries for 'coastal management district' areas. These provided direct links