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GIS-MCDA based cycling paths planning: a case study in Singapore

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ABSTRACT

Cycling has been recognized as one of the solutions to urban transportation challenges. In 2013, Singapore has announced the National Cycling Plan to significantly increase the cycling infrastructure and promote cycling across the entire country by 2030. Given Singapore's land constraints, planning the most effective cycling network is critical. Moreover, there has been growing pressure to incorporate public participation in planning decisions. In order to achieve ideal planning outcomes and greater transparency in planning, multiple criteria and the perspectives of different stakeholders need to be considered. This paper proposes a Geographical Information System-based multi-criteria decision analysis (GIS-MCDA) framework for the support of cycling paths planning in Singapore. It is positioned to address the lacuna in the literature that is dominated by western-centric case studies and a fixation on only infrastructural and objective factors in the planning of cycling paths. The proposed cycling paths planning support framework will be implemented in Woodlands Planning Area (WPA). The primary research questions are about where to build cycling paths in WPA and whether/how the cycling paths to be built will change based on different stakeholders' preferences. The cycling paths planning support framework is able to incorporate different stakeholders' preferences into various scenarios, hence can improve the engagement between stakeholders and contribute to greater transparency in Singapore's cycling paths planning. The limitations and further applications of the framework is also discussed.

1. Introduction

Cities today face many urban challenges associated with high population density. Transportation is one such challenge that leads to problems of congestion and air pollution, especially with burgeoning private car usage. In many cities, transport is also the top contributor of air pollutants such as carbon monoxide, nitrogen oxides, benzene and ground-level ozone (Krzyzanowski et al., 2005). Hence, urban transportation has repercussions on both the environment and public health, and consequently the sustainability and liveability of cities.

Active mobility, which main modes are walking and cycling, has been touted as one of the solutions to urban transportation challenges as it simultaneously promotes sustainability, health, safety and quality of life in cities (Neun, 2013). Infrastructure for active mobility requires much lesser land compared to motorized transportation, freeing up more land for the development of amenities for the community (Centre for Liveable Cities & Urban Land Institute, 2014). The decrease in demand for motorized transportation will reduce the air and noise pollution in cities and contribute to a higher quality of life. Active mobility is also more affordable and environmentally friendly than motorized transportation. Due to the significant benefits that walking and cycling bring about, many cities in both developed and developing countries have been planning for walkable and bikeable cities.

Cycling is probably the most sustainable urban transport mode (Pucher & Buehler, 2017). Accordingly, Singapore's 2013 Land Use Plan announced the National Cycling Plan (NCP) to promote cycling, with the vision of providing ‘a cyclist-friendly, well-connected network providing safe and healthy cycling for all’ (LTA, 2013; MND, 2013). Off-road cycling path networks will be expanded to all Housing and Development Board (HDB) towns to enable residents to cycle to key transport nodes and amenities as well as inter-town routes to connect various towns to the Central Business District (CBD) (LTA, 2013).

With the announcement of the NCP, cycling paths will gradually be built in Singapore, necessitating methods that can facilitate the planning of effective cycling paths. This paper proposes a Geographic Information Systems (GIS)-based path planning support framework that incorporates multiple criteria to address the questions of where to build cycling paths, and secondarily, whether and how the preferred cycling paths will change based on different stakeholders' preferences, in order to support the cycling paths planning process. The perspectives of three key groups of stakeholders, including public, transport experts and the government planners, are examined and GIS-MCDA is utilized in the case study of WPA in Singapore. In addition, the limitations and implications of the paths planning support framework are also discussed.

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Table 1
Criteria considered in the evaluation of the cycling planning problem.
Sources: McClintock, 1992; Larsen & El-Geneidy, 2011; Koh & Wong, 2013a; Meng et al., 2014.

No.	Criterion	Rationale
1	Slope	A smaller slope angle reduces physical exertion of cycling and can encourage more people to cycle.
2	Pedestrian traffic	Areas with high pedestrian traffic increases possibility of collision and conflict and hinders cycling momentum.
3	Distance from major roads with high traffic	Greater distance from major roads can reduce exposure to the real and perceived dangers of vehicular traffic and to vehicular emissions.
4	Proximity to educational institutions	Enables cycling to educational institutions for short-distance trips or last-mile commute.
5	Proximity to retail developments	Enables cycling to retail developments for short-distance trips or mid-trip errands.
6	Proximity to employment zones	Enables cycling to employment zones for short-distance trips or last-mile commute.
7	Proximity to community amenities	Enables cycling to community facilities for short-distance trips or last-mile commute.
8	Proximity to MRT/LRT stations	Enables cycling to MRT/LRT stations to allow transfers between transport modes and promote cycling as a first- and last-mile transport for long-distance trips.
9	Proximity to bus stops	Enables cycling to bus stops to allow transfers between transport modes and promote cycling as a first- and last-mile transport for long-distance trips.

2. Background of research

Cycling has gained traction in cities as a form of accessibility-based transport mode that promotes sustainability and liveability. One strand in cycling planning literature is the evaluation of cycling networks. The purpose of the evaluation is to give each segment of the cycling network a rating in terms of its friendliness for cycling, which helps policy-makers to identify bicycle-friendly routes and segments requiring improvements. Many evaluation methods exist and each takes into account different criteria. One of the first methods was the Bicycle Safety Index Rating that related cycling safety to the physical features and operational conditions of the roadway (Davis, 1987). The Bicycle Level of Service (BLOS) method, developed by the Transportation Research Board, is used in the United States for evaluating the suitability of roads and streets for cycling, and incorporates factors like roadway width, traffic volume, ground surface conditions and vehicle speeds. Most of these methods evaluate the bicycle-friendliness of cycling networks based on safety, especially with regard to infrastructure conditions and ignore other factors that affect the bicycle-friendliness of cycling networks, such as comfort and convenience. Furthermore, most of these methods focus solely on road conditions in determining bicycle-friendliness, which are more suitable for the western context where many cities have on-road bicycle lanes. These methods are less relevant for Singapore, which has a policy focus on off-road cycling paths.

Another strand in cycling planning research approaches the issue from the demand side, elucidating the factors that increase cycling demand (Koh & Wong, 2013a; McClintock, 1992; Winters, Davidson, Kao, & Teschke, 2011). The premise is that by understanding the needs of cyclists, cycling infrastructure can be designed to be more attractive to them, hence promoting higher cycling levels. Some factors identified by Winters et al. (2011) include safety, ease of cycling, pleasant route conditions and integration with transit. A recent research by Van Cauwenberg et al. (2018) noted that traffic safety appeared to be the most important concern of adults' cyclists compared to road design, maintenance, connectivity, aesthetics etc. In Singapore's context, Koh and Wong (2013a) found that security, traffic accident risk, crowded walkway/roadway and stairs/slope are the most important factors for cyclists, which planners should prioritize. Other factors include amount of detours, number of road crossings, comfort, scenery and having shops along routes (Koh & Wong, 2013a). Methods, such as the Latent Demand Score model, have been developed to simulate demand on the cycling network based on its provision of such factors (Landis & Toole, 1996).

There have been limited studies on planning where to build cycling infrastructure, which has only begun to emerge in recent years. Rybarczyk and Wu (2010) proposed a comprehensive bicycle planning methodology, using GIS and MCDA to evaluate the quality of bicycle facilities by integrating supply- and demand-based criteria. Larsen, Patterson, and El-Geneidy (2013) proposed a method using GIS to combine five indicators – number of observed and potential cycling journeys, priority segments identified by cyclists, location of cycling collisions and discontinuities in current cycling network – into a grid cell model that identifies priority locations for new cycling infrastructure.

The existing cycling network planning field lacks research in the Asian, and more specifically, Singaporean context of off-road cycling paths. The existing evaluation of cycling networks is also largely limited to objective and infrastructural factors. With growing recognition that multiple factors contribute to people's willingness to cycle and that the importance of each factor is highly subjective and personal, a GIS-MCDA framework that incorporates participatory methods proposed in this paper can provide novel research outcomes.

3. Methods

3.1. Evaluating optimal locations for cycling paths

A list of criteria to be evaluated in the planning of new cycling paths is derived by reviewing the related literatures (Buehler & Dill, 2016; McClintock, 1992; Larsen & El-Geneidy, 2011; Koh & Wong, 2013a; Meng, Koh, Wong, & Zhong, 2014; 2016; Bicycle Network, n.d.), cycling planning guidelines from other cities (Bicycle Network, n.d.; Department of Transport, 2014; National Transport Authority, 2011) as well as e-mail correspondences with avid cyclists in Singapore. The preliminary criteria are then narrowed down to those relevant to Singapore's context and only criteria that affect the optimality of where to build the cycling network are included. The former consideration eliminates criteria pertaining to seasonal climates or on-road cycling. The latter consideration adheres to the scope of this research, which focuses primarily on the spatial location of the paths and does not consider other (albeit important) aspects of cycling infrastructure such as bicycle parking facilities and directional signages. The criteria also have to be mappable in the raster data format. Table 1 presents the nine criteria derived from the primary and secondary research and the rationale for their inclusion in the planning of cycling paths in Singapore.

In order to derive a more holistic cycling network that caters to the needs and preferences of different stakeholders, questionnaires are conducted with three key stakeholder groups, i.e., the public, the transport expert and the government planner.

Respondents are asked to rank the relative importance of the criteria on a Likert-type scale between 1 and 7, with 1 being least important and 7 being most important. The Likert-type scale is chosen over the more rigorous pairwise comparison method as it is less time-consuming and thus more respondents can be reached. Although the pairwise comparison method has the advantage of representing trade-offs between criteria more effectively, it is more challenging to implement (Saaty, 1988). The time needed to complete a survey with the Likert-type scale is much shorter than for the pairwise comparison method, and this