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A Conceptual Approach of Measuring Spatial Walkability Index for Light-Rail Transit System

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Abstract: Light-rail transit is an example of transit services that is growing to become one of the key components in enhancing city's livability. Every trip begins and ends with pedestrian travel making it important to have a walkable environment around the stations. Most of local governments do have their own criteria or guidelines in planning and designing a walkable city. It includes many aspects such as connectivity, comfort, convenience, etc. In recent years, there is a significant increase of interests on walkability of the transit stations. Many studies had demonstrated how walkability can be quantified statistically. This study will discuss a conceptual approach for measuring a spatial walkability for light-rail transit services in Kuala Lumpur by using the analytical network process in multi-criteria decision analysis. This method aggregates the people's preferences on walkable environment by assigning a weighting factor. The aggregated weightage will be integrated into geographical information system platform for further spatial analysis. The final result will be a spatial walkability index representing the station's walkability that can be later used for future planning for the city or future development of the transit services.

Key words: Pedestrian, multi-criteria decision analysis, analytical network process, geographical information system, network analysis, aggregates

INTRODUCTION

Pedestrianisation is growing to become one of the most essential aspects in a sustainable development of a city. It has become an indicator in measuring city livability. The key component of pedestrianisation is the walkability concept. Apart from promoting healthy lifestyle, many governments in this world have started to become ambitious in getting ranked on the world most livable cities. Malaysia is not an exception as the government is very committed in growing the country, especially Kuala Lumpur as one of the world's most livable cities.

However, walkability is never been easy to be measured. Various studies had demonstrated how they can be quantified. True to its name, the footpath should be assessed by using multiple criteria analysis instead of a single criterion. The footpath itself is built or planned by considering various aspects and most definitely a platform that is capable in handling multiple criteria in spatial and aspatial environment efficiently. One of the famous methods is geographical information system based multi criteria decision analysis or can be simply called GIS-MCDA or spatial MCDA. This study discusses how the MCDA decision rules can be implemented in modelling walkability by using GIS analysis as a platform. The decision rules include several criteria of walkability. Each criterion will be spatially analysed and then modelled into a criterion map that will further represent a Spatial Walkability Index (SWI).

Walkability

Definition: Walking is considered as the oldest mode of transportation on Earth. Centuries ago, people travel from one place to another simply by walking. Due to that reason, the footpath has always been considered as one of the fundamentals in transportation planning. Early European cities were said to be developed with pedestrian access for people to walk through the buildings and around them (Southworth and Joseph, 2013). During that time, spaces between the buildings were provided with a comfortable walking area for people. The government at that time even set a limitation or barrier to which extent a car can enter the city. Most of the time, cars were allowed to enter the city only to deliver goods to the shops. It is stated that people at that time love walking, since footpath were more comfortable as the buildings shielded them from hot weather. As time goes by walking is still considered as the basic mode of transportation as every trip is started and ended by walking. It is important to

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have good walking routes for people to walk on them. One of the widely used terms associated with study of footpath level of service is walkability. It can be defined as the friendliness of an area to walking activities. Walkability is becoming a global priority as many governments began to have a careful consideration in planning for a better walking environment. Walkability defines the comfort level of the pedestrian environment. It is a growing concern in urban development as it is closely related to the sustainable development. If the built footpath environment could not provide a convenient walking experience for the people, how can it promote sustainable lifestyles? To reach a walkability status, a footpath should be able to allow people to get to a destination comfortably. Not only that the footpath should connect the facilities which people wanted to go such as shops, schools, parks, etc.

Now a days, transit service, Light-Rail Transits (LRT) in particular are becoming the main purpose of people to walk. Growing demand and usage of public transportation forced transit stations to have better access, especially by foots for people to reach it. They walk to the station, ride the LRT and then walk again to their destinations such as workplace, shopping area and home. This introduces the Transit-Oriented Development (TOD) concept which is meant to enhance the transit ridership with the urban land use are designed to maximize the access to the transits (Bernick and Cervero, 1997). A TOD city has a transit station as its center. Typically, TOD has 400-800 m development area which seldom referred as the appropriate scale representing the people's walking distance. TOD is gaining much interest in designing a better urban transportation system that is capable of reducing the traffic problems. It is believed to support the efficiency of urban mobility. It can be either the new construction or redevelopment of the existing transit facilities (Abdul *et al*., 2015).

TOD has been used in many cities in this world to cope with urban sprawl and improve the transit patronage. For example, most of the United Kingdom's (UK) major cities grew out of the rail stations. Aside from London which is very popular as TOD city, Edinburgh, a capital of Scotland also had its city centered on its Edinburgh Waverly station. This station is a hub of trains to and from all over UK. The station itself is connected to one of the city's shopping mall which is the princes street mall. Not only that it is surrounded by the city's shopping area along the princes street, the royal mile which houses the city's tourist attractions such as St. Giles Cathedral and the Edinburgh Castle and even the university quarter. Most of the European cities were also similarly designed such as Berlin, Prague, Rome, etc.

MATERIALS AND METHODS

Criteria for measuring walkability: It has been a great challenge for local government to develop a walkable city. Many criteria need to be included. Most developed cities do have their own guidelines and policy in planning for a footpath that suit their personal needs. There are many factors that affect the comfort level of a footpath such that it attracts people to walk on it like safety, weather, connected facilities, etc. Transport for London had developed one of the most comprehensive criteria for walkable environment. It is known as 5C's and is one of the most applied criteria in many literatures, namely.

Connectivity: The footpath should be linked, interfaced, joined, attached and networked.

Convenience: The footpath is appropriate, useful, proper, suitable and time-saving.

Comfort: Travelling using footpath is easy, pleasant, protected, relaxed, sheltered and untroubled.

Conviviality: It should promotes entertaining, lively, pleasant and sociable journey.

Conspicuous: The footpath should be obvious, clear, discernible, distinct and perceptible.

Measuring walkability: Measuring walkability is certainly not an easy procedure. Besides having to consider more than one criterion, it is also important to recognize people's perspectives on walkability. Although, the planning authority does have their own view of developing a walkable city but the public might have their own opinion on this matter. Thus, measuring walkability should never be just a desk procedure but it must include a methodology that has an ability in translating people's opinions analytically.

Various studies had demonstrated how a questionnaire survey to the pedestrians can be very useful in understanding the walkability. It is vital to understand people's perception on the pedestrian instead of relying on theory only. In the end, it is the public user who should be satisfied. A study done in Kuala Lumpur illustrates the usage of questionnaire survey to determine the pedestrian's satisfaction on their walking experience (Zakaria and Ujang, 2015). The study listed three most walkable areas in Kuala Lumpur and distributed 150 questionnaires to each area asking the respondent's opinion on the connectivity, accessibility and safety of the pedestrian. The relationship of the three aspects is then analysed using person correlation and then interpreted using Dancey and Reidy's Rule of Thumb.

The survey questionnaire method is sometimes doubtful due to its unreliability, since it is dependent on people's perception. There are uncertainties that people might be inclined to their own preferences. Thus, the measure of walkability was improved by incorporating a qualitative approach. Instead of just analysing the survey questionnaires statistically, many studies had demonstrated the possibility of incorporating spatial analysis and modelling the walkability (Cambra, 2012; Joo and Jun, 2011; Wey and Chiu, 2013). Cambra (2012) suggested that the screening and the scoring methods can be used in assessing footpath walkability. The former aims to interview people on issues related to pedestrian while the latter aims to understand it quantitatively by ranking the concerns related to each respondent group.

RESULTS AND DISCUSSION

Geographical information system analysis: Geographical Information System (GIS) is a very powerful platform for mapping purposes. GIS is not only for display purposes but for spatial analysis as well. Network analysis had been used by many to not only visualise the walkability but also analyse it in a geographic environment (Morar *et al.*, 2014). Network analysis provides a more precise analysis as it runs through the network. Many notable liveable cities in this world implemented network analysis to spatially analyse their transportation system. In Melbourne, the network analysis is used to create efficient access of the public transportation system with the job density location as the reference. The job density is considered as the demand together with the residential density. The accessibility is measured by using the time taken by walking to the job location from the transits along the pedestrian network routes.

Another study in Alexandria demonstrated the implementation of network analysis using buffer and service area analysis in measuring the accessibility of the bus stops (Foda and Osman, 2010). It used the actual pedestrian network to index the accessibility of the bus stop. The accessibility is measured from the service area analysis of bus stops with 1.3 m sec^{-1} as the walking speed, 400 m walking distance and 5 min cut-off walking time. The end results of the study are the index and isochrones maps showing the accessibility of the bus stops. This study also indicates the possibility of indexing the accessibility by dividing the total area covered by the travelling distance cut off with the circular buffer distance of the stops.

Spatial multi criteria decision analysis: As walkability involved many criteria to be assessed, there has been a growth in implementing the multi-criteria decision methods instead of traditional single criteria analysis. Instead of focusing solely on accessibility, the evaluation of walkability includes safety, comfort level, pleasantness, connectivity to amenities, etc. The vast number of criteria to be assessed forced better model to deal with them. Bernal (2013) had developed the Pedestrian Environment Data Scan (PEDS) to quantify the qualitative aspects of walkability. The factors evaluated include design, safety; traffic and physical barriers, amenities, multi-modal transportation system and public alleys, vacant and abandon spaces. Each factor is mapped in vector format before being assessed using PEDS. The procedure is somewhat similar to the classic network routing analysis. The simple network routing analysis did not prioritise the nodes or lines in the model. The analysis strictly used distance-based analysis to obtain the optimal alternatives.

Spatial-MCDA is still growing till date. There are many literatures that implement the method not only for sustainability assessment but for spatial or geographical problems as well (Ha *et al.*, 2011). While GIS aids a decision to be made by analysing possible alternatives based on multiple factors, MCDA provides rules for aggregation of the criteria in ranking of the alternatives (Greene *et al.*, 2011; Malczewski and Rinner, 2015). The Spatial-MCDA is not simply viewed as a quantitative optimization to find a solution but it is a principle for analysing or aiding a decision to be made. There are various methodologies to aggregate the criteria in ranking the alternatives such as Analytical Hierarchical Process (AHP) and Analytical Network Process (ANP). Although, the former was widely used in many Spatial-MCDA based studies, ANP is essentially better as it is more realistic in representing the real-world problem.

Analytical network process: ANP is also known as a generalization of AHP (Saaty and Vargas, 2006). Unlike hierarchical AHP, ANP is influenced by network containing clusters and nodes. It still uses the same pairwise comparison concept as AHP did to rank priorities but the interaction between the elements is now considered inter-dependently aside from dependent. The hierarchy of the clusters is disregarded as elements of high-level might be influenced by the low-level one. ANP pointed out that not only alternatives depend on the criteria but criteria also depend on alternatives. Moreover, there is high possibility that criteria are interdependent to each other as well.

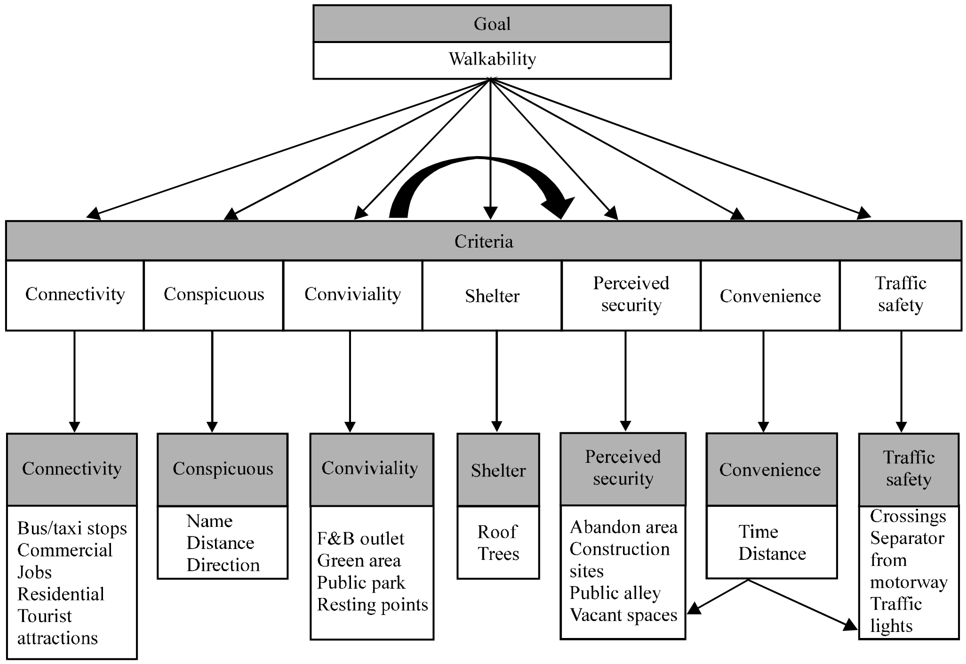

Fig. 1: Analytical network process decision model

It is essential to have the criteria prioritised or weighted as it will illustrate the better walkability model. It is a known fact that each of criteria differs to each other. Some criteria might be more important than the other and vice versa. The weights or priority of walkability criteria can be obtained by using various methods such as ranking, rating, trade-off analysis and pairwise comparison (Malczewski and Rinner, 2015). As mentioned previously, the weights will reflect the importance of an aspect in the modelling. There were many literatures suggested the implementation of pairwise comparison method in walkability assessment.

As ANP is relatively new in transportation studies, there is a growth of interest in implementing ANP to assess the walkability of TOD. ANP had been used by many to understand the relationship between the technical requirements and pedestrian needs for planning and designing purposes. Wey and Chiu (2013) stated that ANP is combined with house of quality matrix in order to address the walkability issue of MRT stations in the New Taipei City, Taiwan. The study developed a weighting system that will rank the criteria of a friendly-pedestrian environment that will later be used to measure the level of service of the pedestrian.

A related study on two train stations in Seoul was made in Seoul station and Jongno3 station (Ha *et al*., 2011; Joo and Jun, 2011). The survey questionnaires implementing ANP comparison were used to obtain the weightage of the factors influencing pedestrian-friendly environment which include comfort, safety, connectivity and street design. The weights of each criterion were normalised before visualised in a map form. The study used weightage summation method to evaluate the walkability. The simple additive weightage is known to produce maps or models showing the walkability level of a city.

Spatial walkability index: Although, the walkability index is considered as a good method in measuring walkability but with the aid of GIS, it could have been better. The key word in GIS is spatial and having the index to be developed spatially will give a better representation of walkability in geographical manner. The development of the Spatial Walkability Index (SWI) will consist of four main stages. First, the ANP Decision Model will be built followed by pairwise comparison for each criterion in the model. The result of questionnaires will be analysed to establish criterion weight. Further, analysis in GIS environment will require weights to be represented as attributes of respective criteria. Network analysis with criterion weights will be performed to analyse the walkability. Finally, the walkability index of the stations will be ranked to identify the most and least walkable station.

Analytical network process decision model: In this study, the ANP decision model consists of three layers of goal, criteria and sub-criteria as shows in Fig. 1. The model involves a relationship between the goal and criteria and criteria and its respective sub-criteria. To show the dependencies of the 5C's in creating a walkable environment, an inner interdependency is established in the criteria cluster. As many literatures indicate that convenience (time and distance) of walking depends on the comfort criteria, a link connecting their sub-criteria is established to show their outer interdependencies.

Pairwise comparison method for survey questionnaire: A measure of walkability requires a precise judgment in deriving the degree of importance of each criterion involved. As mentioned earlier, most literature used survey questionnaire for this purpose. Most of the time, the questionnaire asked people to select their preferred criteria. One of the methods in selecting choices is by pairwise comparison of each criterion. This method requires people to give preference between two choices and then give the intensity level of their preferences. Pairwise comparison is rarely used as it is quite complicated. This method must be planned thoroughly with the human tendency in making judgments. Human brain's capacity has a limit in dealing with comparisons. However, pairwise comparison is still one of the precise methods in aggregating preferences. This is how ANP works. After the criteria are modelled dependently and inter-dependently to each other their degree of importance will be aggregated using pairwise comparison method.

The differences between normal questionnaire and ANP questionnaire is that it will ask the respondent to choose their preferred choice between a pair of criteria. Let's say, there are four criteria to be aggregated there will be seven pairs to be compared. Unlike normal questionnaire it will simply ask the respondent to rank their choices from one to four. By pairwise comparison, the criteria will be ranked better instead of selecting four, the method listed two at times to be chosen. For aggregating preferences, ANP requires the score to reflect the intensity of the choice. Thus, the score of choices will aid in deriving weightage for each criteria that is very useful in measuring walkability. This weightage can be integrated with GIS for further spatial analysis.

Determination of weightage for each criterion: The results of ANP survey will be processed and analysed to determine the weights or degree of importance for each criterion. The process will be done by using ANP software, superdecision©. The general process in the software is described in Fig. 2.

ANP uses supermatrix to synthesis the priorities parallel to Markov chain process (Malczewski and Rinner, 2015). The supermatrix is a two dimensional matrix

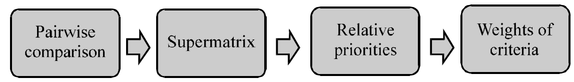

Fig. 2: Procedure of determining the weightage in analytical network process

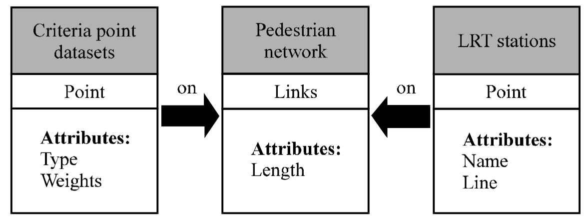

Fig. 3: Network model with relationship between each datasets for analysis

reflecting the dependencies on the network between clusters and elements. It consists of submatrix representing a set of relationships between the elements in the network. The relative priorities are obtained from the eigenvectors of the matrix. The process began with pairwise comparison of nodes that produce an unweighted supermatrix showing their influences on each other. The relative importance of the clusters is represented in a cluster matrix which its products with an unweighted supermatrix will produce a weighted supermatrix. The power in a weighted supermatrix will be raised to form a limit supermatrix. These values will be normalized or synthesized to obtain the relative priorities which is always referred to as weights of criteria.

Integrating weightage derived from anp into GIS Model to develop a spatial walkability index: ANP-derived weightage will be used to indicate the walkability of an area in GIS Model. This explains the term Spatial Walkability Index. Instead of displaying the criteria with their weightage on the map, it can be included as the attributes of the criteria for further analysis. As discussed in section A, GIS network analysis can be a very useful platform in assessing walkability. The SWI of LRT stations could be established by using the analysis on the impedance either the distance or time travelled through the network from demand points to the central facility. It requires the network dataset to be modelled first as the analysis will be performed in vector (Fig. 3). Analysis can then be performed exploring the effect of using a range of covering distance or 'isochrones'. This analysis uses Dijkstra's algorithm to find the shortest route between any two points in the network. It also can be used to create a set of polygon representing the coverage area for the LRT stations within a range of specified distances. The service areas generated can give insight into the catchment area of each station as shaped by the pedestrian network.

During the analysis, the point datasets of the walkability criteria will act as the 'added cost'. The weightage will become decisive factors for the analysis when the analyst chooses a route to establish service area of the station. A higher weightage will reflect a better choice of route. The output of the analysis would be the total Euclidean distance that can be travelled in the catchment area of each station. The distance then will be divided by the TOD distance cut off which is 400 m to produce an index of the walkability of the LRT stations. The index of each station will be ranked accordingly to identify the most walkable LRT transit in KL. Then, the score will be ranked to determine the most and least walkable station.

CONCLUSION

This is an ongoing study attempting to apply ANP model to weight the five listed criteria of walkability. The survey questionnaires have been distributed to the general public and experts as part of the research methodology to derive the weight of each criterion. The weights will be added as attributes to each criterion that will be represented as vector data model. The weights of the criteria will act as the 'added cost' when the network analysis is performed. The euclidean distance covered by the LRT stations will be divided by the TOD distance cut off which is 400 m to produce an index of the walkability to the LRT stations. The index of each station will be ranked accordingly to identify the most and least walkable LRT transit in KL.

The expected outcome of this study is a spatial walkability index of the LRT stations. The index will indicate the walkability of LRT stations and whether they complement the TOD concept. It also can be used as a guide for future planning for development of transit stations not only in KL but also in other cities having similar demographic as KL.

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