

The Application of Dynamic Network Process to Environment Planning Support Systems

Wann-Ming Wey

Abstract—In recent years, in addition to face the external threats such as energy shortages and climate change, traffic congestion and environmental pollution have become anxious problems for many cities. Considering private automobile-oriented urban development had produced many negative environmental and social impacts, the transit-oriented development (TOD) has been considered as a sustainable urban model. TOD encourages public transport combined with friendly walking and cycling environment designs, however, non-motorized modes help improving human health, energy saving, and reducing carbon emissions. Due to environmental changes often affect the planners' decision-making; this research applies dynamic network process (DNP) which includes the time dependent concept to promoting friendly walking and cycling environmental designs as an advanced planning support system for environment improvements.

This research aims to discuss what kinds of design strategies can improve a friendly walking and cycling environment under TOD. First of all, we collate and analyze environment designing factors by reviewing the relevant literatures as well as divide into three aspects of "safety", "convenience", and "amenity" from fifteen environment designing factors. Furthermore, we utilize fuzzy Delphi Technique (FDT) expert questionnaire to filter out the more important designing criteria for the study case. Finally, we utilized DNP expert questionnaire to obtain the weights changes at different time points for each design criterion. Based on the changing trends of each criterion weight, we are able to develop appropriate designing strategies as the reference for planners to allocate resources in a dynamic environment. In order to illustrate the approach we propose in this research, Taipei city as one example has been used as an empirical study, and the results are in depth analyzed to explain the application of our proposed approach.

Keywords—Environment Planning Support Systems, Walking and Cycling, Transit-oriented Development (TOD), Dynamic Network Process (DNP).

I. INTRODUCTION

THE planning and designing for walking and cycling environment under Transit-oriented Development (TOD) is an important issue especially in a new developing city. Walking and cycling is an active, environmentally friendly mode of travel, that can encompass distances long enough to efficiently cover many urban and suburban trips. TOD planning gives us an idea that urban design factors and a pedestrian-friendly design are positive planning factors in reducing automobile use through the reduction of automobile traffic speed and enhancing pedestrian accessibility to a transit

center [1]. Walking and cycling advocacy groups, community-level organizations, local jurisdictions, and public agencies have promoted walking and cycling at multiple levels. In USA, at the federal level, the Intermodal Surface Transportation Efficiency Act (ISTEA), and its successor, the Transportation Equity Act of the 21st Century (TEA-21), have increased public funding of non-motorized transportation infrastructure, including pedestrian and bicycle lanes and other cycling facilities. The significance of proximity to trail strongly suggests that adding continuous and protected facilities near residential areas and securing neighborhood access to them can yield increases in walking and cycling [2]. Survey reports support this finding, with almost half of the respondents, including both cyclists and non-cyclists, stating that more trails and bike lanes in their neighborhood would help them bicycle, or bicycle more. Cycling is also significantly related to reported transit use, implying potentially effective ways to promote both cycling and transit use for physically active travel.

This study applies the time dependent Analytic Network Process (ANP) to forecast the planning and designing trend of walking and cycling environment under TOD in Taipei City of Taiwan for adjusting the resources allocation for future public policies use. When historical data are lacking and when a broad spectrum of social impact is involved, the ANP, with the capacity to manage dependence and feedback among the factors, can serve as a tool to forecast outcomes by using expert judgment. They are obtained from the limit supermatrix of the ANP that represents forecasts for the next period.

The main aim of the paper is to propose a methodological framework for analyzing environment planning focused on walking and cycling environment under TOD. Many specific factors of the environment planning can be modeled and analyzed by ANP/DNP methods. Some specific features as "safety", "convenience", and "amenity" from environment designing factors are analyzed by ANP/DNP methods and combined in a general forecasting model in this study.

II. OBJECTIVES

This study examines the relationship between walking and cycling and the built environment using new data on walking and cycling behavior, detailed GIS-based measures of land use and infrastructure, and advanced DNP methodology. It considers both objectively and subjectively measured data on the built environment that is directly linked to the respondent's household locations, and thereby captures potential correlates of walking and cycling in a comprehensive yet disaggregated manner. The study employs measurable and modifiable

environmental variables, not composite indices or factors, to facilitate the interpretation of results and their translation into policy and implementation strategies. Models estimate the likelihood of walking and cycling to identify particular environmental attributes (measured subjectively and objectively) that explain people's decision to walk and bicycle in their neighborhood, controlling for socio-demographic factors.

III. METHODS

According to Korpela and Tuominen [3], the five drawbacks of traditional forecasting methods are: (i) a need for explanatory variables to be mostly expressed in quantitative terms, (ii) not considering the development of new relationships among variables and possible changes in trends, (iii) an assumption of the dimension on which the prediction takes place is autonomous, (iv) the forecasts are based on past data, and (v) being both deterministic and structurally stable, leading to errors in forecasting. The AHP is an expert judgment approach [4] and can avoid such drawbacks. Moreover, the AHP provides a systematic procedure to deal with quantifiable and intangible criteria, which is different from traditional judgmental forecasts, such as a consumer survey or the Delphi technique. It converts judgment, experience, and expertise into quantitative data through pairwise comparisons. The ANP is a generalization of the AHP and can handle dependence and feedback among elements/factors and clusters. Although the AHP and ANP have been applied to many areas, we will concentrate on three key arguments so that their utilization in forecasting is clear.

Some possible uses of the AHP/ANP for forecasting-related applications are divided into two main categories of forecasting-related application [5]. There are four areas, i.e., evaluating forecasting methodology, combining forecasts, prediction of future events, and assessment of future performance, in the second category. The essence of these areas is based on the priorities obtained from the AHP and ANP such that the priorities or weights of alternatives can be determined. From this viewpoint, the AHP and ANP here are much like the roles of MCDM for ranking and selecting. However, the advantages of the AHP and ANP over other MCDM methods are in dealing with quantifiable and intangible criteria in which expert judgment is easily imbedded. Of course, handling dependence and feedback among factors is another contribution of the ANP.

The first category, including three areas of expert-opinion forecasting, adjustment of other forecasting methods, and hybrid forecasting with other forecasting methods, is the major role of the AHP and ANP for forecasting. The first area is most important for making a forecast by collecting expert opinions. However, the second and the third are used for assisting other methods in making a forecast.

The ANP Procedure for Forecasting

The newly developed ANP possesses the ability to handle a complicated situation with flexibility and comprehension [6]

and can manipulate tangible and intangible factors [7]. Therefore, while the prediction of printer sales volume is limited by many conditions, this research hopes to employ expert judgment to construct an ANP model to obtain the forecast value of the sales volume of printers in Taiwan. In the following, we will modify the ANP procedure for our forecasting and investigate some issues of using the model.

This study mainly refers to Niemira and Saaty [6] and Yuksel [8] in terms of the steps they propose for the calculation analyses of the ANP and AHP. Although Korpela and Tuominen [3] proposed three basic steps for demand forecasting by the AHP, a slight modification in [9] regarding the procedure of the ANP makes it clearer for forecasting by illustrating the following six steps.

- Step 1. Clarify the goal of the forecasting problem and list some related clusters and their elements.
- Step 2. Take a questionnaire survey from experts to establish a preliminary network for forecasting.
- Step 3. Perform expanded pair-wise comparisons and obtain relative priorities of clusters and their elements in the network.
- Step 4. Construct a supermatrix and compute the limiting priorities.
- Step 5. Process the forecasting outcome.
- Step 6. Execute sensitivity analysis of important parameters.

Sensitivity analysis is the study of how the optimal solution responds to changes in the input parameters or the elements in the network. It is a technique for systematically changing the input parameters of the elements to see whether the final selection is stable to changes in the inputs. Some important elements or clusters are chosen for analysis to see the possible change of the final outcome. One special interest is to see whether these changes alter the order of the final outcome by the ANP [10].

Now that the comprehensive steps have been illustrated, we demonstrate the procedure through an empirical study in Taiwan.

IV. AN EMPIRICAL STUDY AND FINDINGS

This section presents an illustration of the developed decision procedure based on an empirical example of a walking and cycling under the TOD in Taipei City, Taiwan. Fig. 1 shows the empirical study location of Xinyi District in Taipei City. In order to illustrate the use and advantages of the proposed model combined with ANP approach in the assessment of pedestrian walkability and bicycle environment under TOD, we use the empirical example as a case study adopted from the TOD project of Xinyi District in Taipei City (Fig. 2).

The foregoing events suggested to us that it was a good opportunity to do another forecasting exercise to determine when the walking and cycling environment criteria considerations under TOD would begin to turnaround from this latest recession. Our forecasting effort addressed the timing of the expected trend by seeking to answer the question "What is

the most likely period in the future when the important criteria resurgence will occur?" By this, we implicitly mean a recovery from the trough that will eventually be confirmed by the planners. As traditional forecasters we based the forecast on our general knowledge and expertise. We did not seek precision with regard to the projected rate of the expansion but rather general accuracy.

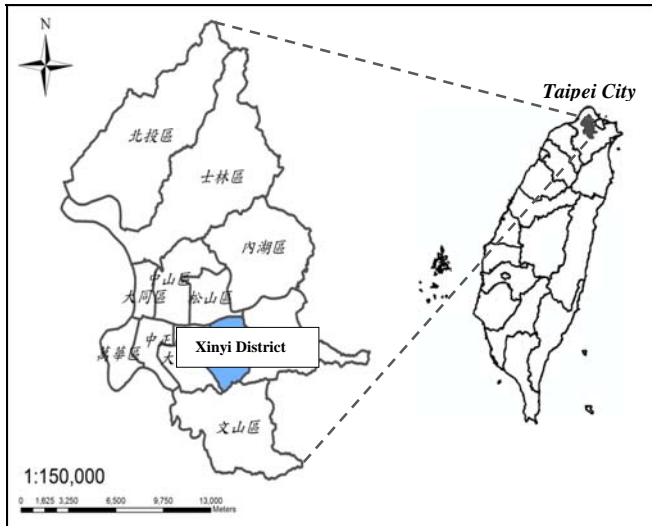


Fig. 1 Location of Taipei City in Taiwan

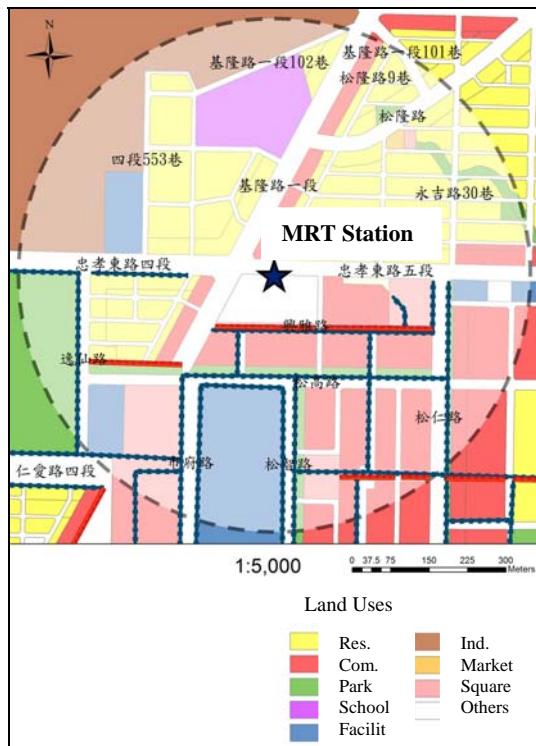


Fig. 2 Study Area Map (Xinyi District)

Modeling the Problem

The ANP was tried to be used to model the problem in this research, with the problem of interest here being decomposed as a hierarchy and network with feedback from the alternatives

to the primary factors. An overview of the model structure is stated as follows. The factors/criteria are grouped into clusters in the model. For example, in the top cluster there are the primary factors that represented the forces or major influences driving the walking and cycling environment criteria under TOD: "C1. Exclusive right of way", "C2. Obstacle reduction on lane", "C3. Pavement stability promotion", "C4. Continuity to destination", "C5. Accessibility to destination", and "C6. Service and direction facility." With regard to the choice of these criteria the model captured the implicit and emerging understanding of the experts involved in the study. The alternatives consist of the possible time periods during which the trends might occur based on the situation as of 2013 (preliminary exercises had been conducted during October and November, 2013): Within 0-7 years (i.e., 2020), and 7-17 years (i.e., 2030). The purpose of the model is to establish priorities for the time periods. In this study the priority for a time period is interpreted as the likelihood of the walking and cycling environment criteria turnaround under TOD occurring during that time period.

The criteria in the foregoing discussion have been included in the DNP model. Priorities were derived for all the criteria in the model by making judgments about them using the pairwise comparison process of the ANP. Judgments are based on the Fundamental Scale of the AHP for dominance: 1-Equal, 3-Moderate, 5-Strong, 7-Very Strong, 9-Extreme [11]. Numbers in between these values, including decimals, are allowed as well. Priorities are then obtained from a pairwise comparison matrix by raising the matrix of judgments to large powers until its columns are equal, or nearly so.

The Criteria Weights Determined by DNP Approach

We investigate the criteria weights changes via the DNP approach through 2013, 2020, and 2030 time periods. From the experts interview, the criteria weights changes were determined shown as Table I and Fig. 3. We can also see that "C1. Exclusive right of way" is the most important criteria among them but decreasing along the time change, "C2. Obstacle reduction on lane" is increasing along with the ranking, "C3. Pavement stability promotion" seems to be the least important criteria among all the considered ones, "C4. Continuity to destination" is increasing and then decreasing on the ranking, "C5. Accessibility to destination" is increasing then stable then, and finally, "C6. Service and direction facility" is the modest rank all the time.

TABLE I
THE CRITERIA WEIGHTS CHANGE AND RANKING WITH TIME DEPENDENCE

we	2013	Rank	2020	Rank	2030	Rank
C1. Exclusive right of way	0.426	1	0.394	1	0.259	1
C2. Obstacle reduction on lane	0.124	5	0.109	4	0.168	2
C3. Pavement stability promotion	0.055	6	0.059	6	0.130	6
C4. Continuity to destination	0.127	4	0.177	2	0.152	4
C5. Accessibility to destination	0.129	3	0.102	5	0.138	5
C6. Service and direction facility	0.139	2	0.160	3	0.153	3

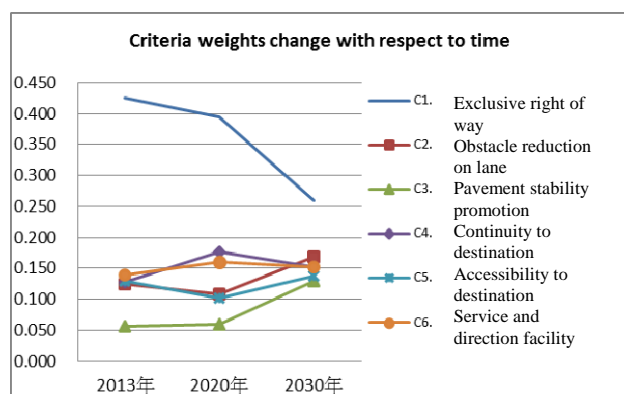


Fig. 3 The trend of criteria weights change with time dependence

V. DISCUSSION

For the priorities of the criteria in terms of the time periods, so far we have written about comparisons of criteria about the comparisons for likelihood of the time periods. Now we turn to the comparisons of the dominance of the criteria with respect to the time periods. There could be 3 such tables of comparisons, one for each time period derived from Table I. We illustrate these in Table I for the importance of the criteria in the 2013 time period. The question here is: "Which criterion is more likely to be dominant (has greater influence) in giving rise to walking and cycling environment under TOD in 2013 and other years time period?" C 1. Exclusive right of way was felt to be very strongly more dominant, so a '7' was thus entered for the judgment, with '1/7' in the transpose position. Similar questions were posed for the remaining pairs. The resulting priorities from Table I indicate that for a walking and cycling environment under TOD to occur within about 20 years from the time the prediction was made in 2013, C 1. Exclusive right of way appears to be the most important criterion with 42.6% of the priority while C3. Pavement stability promotion is much less important with 5.5% of the priority. The results from the three sets of comparisons of the criteria with respect to the time periods are illustrated in Fig. 3.

VI. CONCLUSION

Our findings perhaps have the greatest implications for new-town development. Like most rapidly growing cities, Taipei City's periphery is rapidly being carved up into new subdivisions and tract housing. To promote active transportation (i.e., walking and cycling), particular attention

should be given to street designs and layouts that create dense networks with high connectivity. Grid-street patterns and the platting of land into small blocks produce dense, highly connected networks. And, following the traditional patterns of the older, built-up parts of the city - specifically, compact, mixed-use development - is likely also important in encouraging non-motorized travel.

As cities of the developing world increasingly mimic the car-oriented settlement patterns of modern cities, there becomes a greater likelihood that the same kinds of congestion problems associated with physical inactivity in the United States and other car-based societies will arise. One study found that Chinese men averaged a weight gain of 1.82 kg within a year for every car they purchased versus a weight loss of 0.57 kg for each bicycle acquired [12]. The public health implications of rapidly growing cities becoming more automobile-oriented in their designs need to be seriously weighed.

REFERENCES

- [1] Wey, Wann-Ming and Chiu, Yin-Hao, 2013. "Assessing the Walkability of Pedestrian Environment under the Transit-oriented Development", *Habitat International*, Vol. 38, pp. 106-118.
- [2] Cervero, R., Sarmiento, O. L., Jacoby, E., Gomez, L. F., and Neiman, A., 2009. Influences of Built Environments on Walking and Cycling: Lessons from Bogotá. *International Journal of Sustainable Transportation*, 3(4), 203-226.
- [3] J. Korpela, M. Tuominen, Inventory forecasting with a multiple criteria decision tool, *International Journal of Production Economics* 45 (1-3) (1996) 159-168.
- [4] A.R. Blair, R. Nachtmann, J.E. Olson, T.L. Saaty, Forecasting the exchange rates: an expert judgment approach, *Socio-Economic Planning Sciences* 21(6) (1987) 363-369.
- [5] Hsu-Shih Shih, E. Stanley Lee, Shun-Hsiang Chuang, Chiau-Ching Chen, A forecasting decision on the sales volume of printers in Taiwan: An exploitation of the Analytic Network Process, *Computers and Mathematics with Applications* 64 (2012) 1545-1556.
- [6] M.P. Niemira, T.L. Saaty, An analytic network process model for financial-crisis forecasting, *International Journal of Forecasting* 20 (4) (2004) 573-587.
- [7] J. Korpela, M. Tuominen, Inventory forecasting with a multiple criteria decision tool, *International Journal of Production Economics* 45 (1-3) (1996) 159-168.
- [8] S. Yuksel, An integrated forecasting approach to hotel demand, *Mathematical and Computer Modelling* 46 (7-8) (2007) 1063-1070.
- [9] T.L. Saaty, *Theory and Applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Cost, and Risks*, RWS Publications, Pittsburgh, 2005.
- [10] T.L. Saaty, *Decision Making with Dependence and Feedback: The Analytic Network Process*, RWS Publications, Pittsburgh, 1996.
- [11] Saaty T.L. *Fundamentals of decision making and priority theory with the analytic hierarchy process*. Pittsburgh, Pennsylvania: RWS Publications; 2006.
- [12] Bell A, Ge K, Popkin B. 2002. The road to obesity or the path to preservation: Motorized transportation and obesity in China. *Obesity Research* 10(4):277-283.