

Shifts in Activity Centers along the Corridor of the Blue Subway Line in Taipei

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Abstract: Activity centers are areas of strong development of a particular activity, such as residence, employment, or recreation. Understanding shifts in activity centers can help in creating development strategies for subway corridors. This study applied the fuzzy inference system to analyze shifts in activity centers along the blue line of the Taipei subway system (hereafter called the Blue Corridor). Empirical findings indicate that the subway line might weaken residential activities while attracting employment and recreation activities to the newly developed city center. Specifically, residential activities moved away from the city center whereas employment and recreation activities expanded from the existed central business district (CBD) to the eastern suburbs of Taipei. Strategic analysis of the Panchiao station area found that if the commercial and industrial floor space increase by over 350 or 500%, Panchiao station area will be identified as "possibly is an employment center," or "definitely is an employment center," respectively.

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Introduction

Numerous cities have empirically investigated the influence of subway systems on urban development, e.g., San Francisco (Cervero and Landis 1997), Los Angeles (Fejarang 1994), Miami (Gatzlaff and Smith 1993), and so on. Mostly, these investigations have concluded that subway systems significantly influence population, employment, land use, activity distribution, and property prices along subway lines. Effective development strategies can be designed based on empirical investigations. Although the influences of subway systems in Taipei are expected to differ from other cities, they remain poorly understood because Taipei has only had a subway system for eight years. The Taipei subway system represents a new mode of transportation in Taiwan. Most impact studies were conducted before the subway opening, and were based on with and without comparisons, e.g., Lee (1988), Feng and Yang (1989), and Feng and Hsu (1989). Few studies did before and after comparisons on either side of the subway opening; one such example is the study focusing on property prices by Lin and Hwang (2004). Owing to a lack of empirical investigation of the influences of the Taipei subway system, the development

strategies for subway corridors in Taipei were based on incomplete information, creating a risk for the future development of the city.

Understanding the shifts of activity distribution along subway lines can help to direct subway corridor development. Activity centers are characterized by significant activities, e.g., an employment center denotes an area dominated by jobs, employees, office buildings, or manufacturers. The opening of a subway system changes the activity distribution along subway corridors owing to changing the relative accessibility of different areas of the city. City planners consider the development of activity centers along subway lines following subway opening and attempt to develop effective strategies to ensure that developments along subway corridors achieve the desired goals. However, forecasting activity center development is complex because center identification is based on human judgment, which involves multiple criteria and nonlinear interactions. A systematic approach to imitating human judgments thus is required for center identification.

The analysis of activity centers comprises two major tasks: First, creating criteria for evaluating the activity performance of specific areas; second, identifying activity centers based on the criteria performances of specific areas. Three methods (density function, index analysis, and multivariate analysis) were used in previous studies for activity center analysis. Only one criterion is generally applied to density function, such as Feng et al. (1994), to describe the relations between activity densities and locations, which are mostly defined by the distances to the central business district (CBD). Identifying activity centers based on one criterion is inadequate because a specific activity is usually related to multiple characteristics. For example, a residential center can be characterized by high population density, and low population density with median/high residential floor space in the case of a high income community. Identifying residential centers purely based on population density is problematic in the latter case. The index analysis generally applies multiple criteria to evaluate the activity development of a specific area, such as McDonald (1987) and Chang (1990). Using the simple weighting approach or other multiple criteria decision making methods, the criteria performances

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are integrated into one value. Comparing the integrated value with the threshold, which is usually provided by researchers or surveyed from experts, the activity centers then are identified. Because index analysis is rarely used to verify the goodness of fit between model judgments and individual judgments, the main criticism of this method focuses on its validity. The multivariate analysis develops a discrimination function to identify the activity centers through factor analysis, classification analysis and discrimination analysis, such as Chen (1980) and Hwang (1991). The factor analysis transfers multiple criteria into few and independent factors, which are used to describe the performances in specific areas. Based on the factor scores and the center identification of researchers, either directly or using classification analysis, the discrimination function is then calibrated for forecasting. The process of multivariate analysis primarily depends on the crisp statistics and subjective judgment of researchers. Crisp statistics have difficulty in directly describing activity centers owing to the insensitivity and subjectivity of human feelings. For example, although population densities of 100 persons per hectare and 101 persons per hectare may represent two different categories for statistical purposes, in reality few people would perceive any difference between the two owing to the insensitivity of individual feeling; moreover, a density of 100 persons per hectare may be subjectively considered high by researchers and low by other people's feelings. Additionally, the thresholds for discriminating the development level of activity centers generally are determined by researchers or statistical mechanisms (average, mode, discrimination analysis, etc.) and might not accurately reflect people's feelings. The methods of density function and index analysis also suffer from the above-mentioned deficiencies.

To imitate common people's judgments, this study applied the fuzzy inference system to analyze subway station area development. The fuzzy inference system essentially comprises three components: A *rule base*, containing a selection of fuzzy rules, a *database*, which defines the membership functions of linguistic variables used in the fuzzy rules, and a *reasoning mechanism*, which performs the inference based on the rules. For example for a fuzzy rule: *If the population density is high, then the area definitely is a residential center*, the statement between *if* and *then* indicates the premise, and the statement following *then* represents the conclusion. The *population density* in the above-mentioned rule is a linguistic variable defined by some membership functions, which represent different degrees of linguist variables, such as the *high* described in the rule. The fuzzy inference system can circumvent the deficiencies of existing methods for analyzing activity centers via the following mechanisms: First, the premise of the fuzzy rule can use multiple criteria. For example, the premise of the previous example can be changed to: *If the population density is high and the residential floor space is high*, two criteria should be considered. Second, the rule base and membership function are both established via the questionnaire survey of individual judgments, which can be used to establish the goodness of fit between the model judgments and individual judgments. Third, the linguistic variables, other than statistical variables, used in fuzzy rules make the inference process more closely approach the judgment process of individuals. Finally, the linguistic outputs are useful for clearly describing and discussing the decision making process. The reviews of Teodorovic (1999), Bonivento et al. (1998), and Jang and Sun (1995) indicate that the fuzzy inference system is a very promising mathematical approach to modeling problems characterized by subjectivity, ambiguity, and uncertainty, such as identifying activity centers.

This study analyzes the development of activity centers along

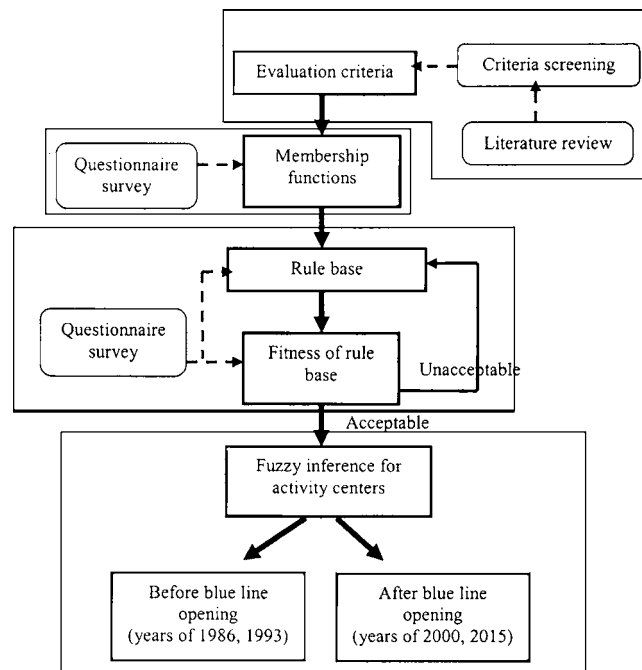


Fig. 1. Analysis approach

the blue line of the Taipei subway system (the Blue Corridor). The development of station areas along the Blue Corridor in both 1986 and 1993 (before subway opening) and in 2000 (after subway opening) was simulated and compared based on the fuzzy inference system. Further, the membership functions and fuzzy rules were generated based on statistical data and a questionnaire survey of subway passengers. Moreover, development in the Panchiao station area was simulated under various land use strategies for achieving the goal of sub-CBD development in 2015 in accordance with city government plans.

The remainder of this paper is organized as follows: The second section describes the developed fuzzy inference system and the next section then discusses the analytical results for applying the inference system to the Blue Corridor and the Panchiao station area. Finally, conclusions and recommendations are presented in the final section.

System

The study approach is illustrated in Fig. 1 and comprises four major parts: Evaluation criteria for activity centers, membership functions for the linguistic variables, fuzzy rules, and fuzzy inference system.

Evaluation Criteria

This study analyzes three types of activity centers: Residential, employment, and recreation. Area with more people, floor space, or trip generation related to a specific activity in a specific area is likely to be a center of that particular activity. Based on the considerations of effective description, interaction with subway and data accessibility, three criteria are applied for each of the center types listed in Table 1 to evaluate the significances of activities for specific areas. Residential centers are identified based on the criteria of population density, residential floor space, and home-based trip generation. Further, employment centers are identified

Table 1. Evaluation Criteria of Types of Centers

Residence	Employment	Recreation
Population density	Employment density	Retail and service employment
Residential floor space	Commercial and industrial floor space	Retail and service floor space
Home-based trip generation	Work trip attraction	Number of super market and department store

using the criteria of employment density, commercial and industrial floor space, and work trip attraction. Finally, recreation centers are identified using the criteria of retail and service employment, retail and service floor space, and number of supermarkets and department stores. Activity significance increases with the criteria value.

For comparing time and space, five criteria are normalized by the average values in Taipei City. For example, the population density of an area is divided by the average population density in Taipei City, i.e., the criterion of population density describes the ratio of the density in a particular area to the average density in Taipei City. The other four normalized criteria are employment density, retail and service employment density, home-based trip generation, and work trip attraction.

Membership Functions

The linguistic degrees of criteria are characterized by membership functions, which were determined from a survey of 40 professional workers involved in urban or transportation planning in Taipei. The respondents included three different employment categories, namely government staff, engineering consultants, and research associates. Since the survey results are too extensive to present here, this work only presents the curve fitting for the criteria of population density. Fig. 2 illustrates the membership functions of three linguistic degrees of the criterion of population density using the ordinary least square method. The membership functions can be used to transfer the crisp statistics into linguistic degrees, which describe people's feelings better than statistics do. Statistics can simultaneously represent multiple linguistic degrees in different grades. For example, in Fig. 2 a population density of 1.0 is considered low in 0.4 grades and medium in 0.7 grades. All

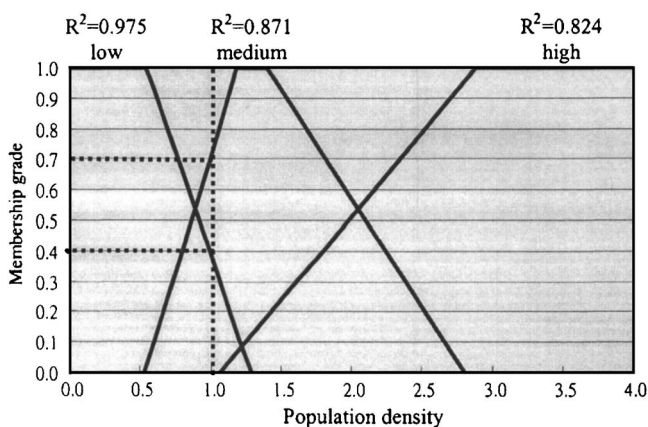


Fig. 2. Membership functions for linguistic degrees of population density

of the membership functions are continuous, except for the criterion of the number of supermarkets and department stores, which have discrete membership grades.

Fig. 2 presents two findings regarding people's feelings. First, people's feelings do not always change with changes in the statistics. For example, the grades of *high* degree are unchanged after the population density of 2.8, and the progression of the membership functions from low, medium, to high does not progress in equal intervals and is not symmetrical in shape. Second, a statistical value might simultaneously represent multiple linguistic degrees in different membership grades. The membership functions for the other eight criteria display the same situations mentioned previously (Hu 2002). The traditional methods of using statistical values for identifying activity centers do not closely reflect human feelings.

Fuzzy Rules

Knowledge is represented using IF-THEN linguistic rules, which describe the logical evolution of the system based on the linguistic variables. For example for the fuzzy rule: *IF the population is high, THEN the area is definitely a residential center*, the statement between IF and THEN is the premise (or antecedent), and the statement after THEN is the conclusion (or consequence). The *population density* in the rule is a linguistic variable (i.e., the evaluation criterion used in this study) described by certain membership functions, which represent different degrees of criteria, such as the *high* in rule.

Fuzzy rule generation begins with a questionnaire survey. Subway passengers over 20 years of age were randomly selected and questioned regarding their impressions of the degree of development for different activities in each subway station area with which they were familiar. A total of 110 passengers were successfully interviewed. Passenger responses for each activity center were graded according to five linguistic degrees: Definitely is a center, possibly is a center, hard to say, possibly is not a center, and definitely is not a center. Sixty subway stations were operating in Taipei by 2002 and were classified via a questionnaire survey. The performance criteria for each subway station area were translated from statistics to linguistic degrees based on the calibrated membership functions.

Finally, the identification of activity centers based on the questionnaire surveys and the linguistic performance criteria were combined to generate fuzzy rules, as shown in Table 2 via the trial-and-error approach. Some advanced and systematic approaches, such as the neural network or genetic algorithm, can be employed in complex cases. Table 2 lists the rule base for identifying residential centers and presents the following findings: First, the criterion of residential floor space dominates the identification of residential centers and presents few trade-off relationships with the other two criteria. It can be concluded that residential floor space is very important for the identification of residential centers. Second, significant trade-off relationships exist between population density and home-based trip generation, meaning these two criteria are interdependent for identifying residential centers. Finally, the progression relationships between premises and conclusions are discrete and irregular. It is difficult to obtain a statistical function that can imitate human judgments. The other two rule bases for identifying employment and recreation centers are contained in Hu (2002).

Table 2. Rule Base for the Recognition of Activity Center (Illustrated by Residential Activity)

Population density	Residential floor space	Home-based trip generation	Conclusion
High	High	High	Definitely is a center
High	High	Medium	
High	High	Low	
Medium	High	High	
Medium	High	Medium	
Low	High	High	
High	Medium	High	Possibly is a center
High	Medium	Medium	
Medium	High	Low	
Medium	Medium	High	
Low	High	Medium	
Low	High	Low	
High	Medium	Low	Hard to say
Medium	Medium	Medium	
Medium	Medium	Low	
Low	Medium	High	
Low	Medium	Medium	
High	Low	High	Possibly is not a center
High	Low	Medium	
High	Low	Low	
Medium	Low	High	
Low	Low	High	
Medium	Low	Medium	Definitely is not a center
Medium	Low	Low	
Low	Medium	Low	
Low	Low	Medium	
Low	Low	Low	

Fuzzy Inference

Based on the fuzzy rules, this study applied the Mamdani fuzzy model (Mamdani and Assilian 1975) to conduct fuzzy inference. The inference process of the Mamdani model is illustrated in the Appendix.

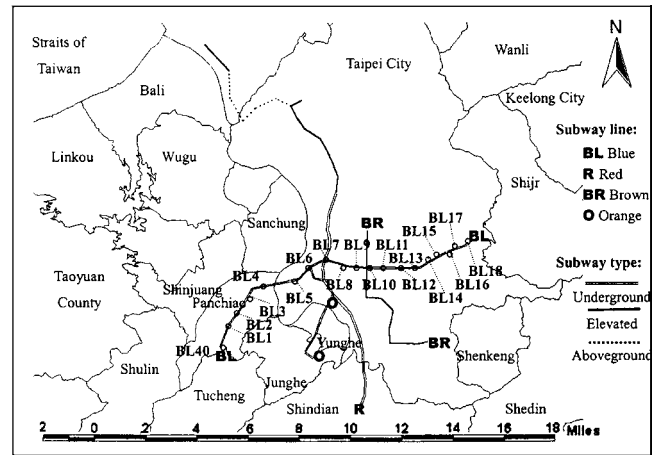
The fitness between the inference conclusions determined by the fuzzy inference system and the real recognition identified via the questionnaire survey should be examined to assess the validity of the study method. The fitness is measured as follows:

$$\text{fitness} = N_s/N \quad (1)$$

where N =total number of subway stations analyzed and N_s =number of subway stations for which the inference conclusions and survey results are the same. The fitness values range between 0 and 1, and the validity of the inference system increases with the fitness value. The fitness of the inference for residential centers is 0.6, whereas that for employment centers is 0.7, and that for recreation centers is 0.68, which represents an acceptable level.

Inferences

This study analyzed activity development for station areas along the Blue Corridor in 1986, 1993, and 2000 using the rule base and membership functions generated previously. Further, the develop-

**Fig. 3.** Network of Taipei's subway system in 2002

ment of the Panchiao station area, the local center of a satellite city along the Blue Corridor, was simulated for the year 2015 assuming different land use development strategies. Fuzzy calculations were performed using *MATLAB* (The Mathworks Inc., Natick, Mass.) fuzzy logic toolbox.

Before and After Comparisons

The blue line of the Taipei subway system, as shown in Fig. 3, presently is 23.9 km long, and acts as a major west-east link for the metropolitan area. This study analyzed 19 station areas for the years 1986, 1993 (before the subway opening), and 2000 (after the subway opening). The evaluation criteria data were sourced from the Taipei City Government (Department of Civil Engineering 1987; Department of Transportation 1989, 2001) and the Industry, Commerce and Service Censuses of 1986, 1991, and 1996, by the Directorate-General of Budget, Accounting and Statistics of the Executive Yuan of Taiwan. This study defined the station areas as the area within a 400 m radius circle around the station, in accordance with the definition used by the planned area of transit-oriented development recommended by previous studies, such as Bernick and Cervero (1997).

Along the Blue Corridor, the present CBD is located around stations BL6 and BL7. Two sub-CBDs are planned for the areas of stations BL2 and BL13, respectively, with the BL13 station area already being well developed. The city center area runs from BL6 to BL13, where BL6–BL8 represent the old city center and the other stations are located in the newly developed city center.

Residential Activity

Fig. 4 shows the shifts in residential activity development. Residential activity weakened during the past 15 years in the station areas from station BL7 (present CBD) to BL13 (sub-CBD under development), which together represent the center of Taipei City. Based on the changes from 1993 to 2000, the subway opening decreased residential activity in the newly developed city center (BL10–BL13). The subway also attracted residential activity back to the old city center (BL7 and BL8) owing to the improved traffic situation. The influence of the subway on residential activity on the western side of the present CBD and the eastern side of the BL 13 was not significant.

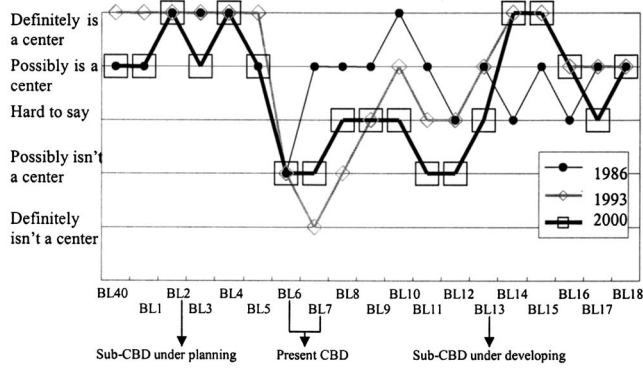


Fig. 4. Inference conclusions of residential activity

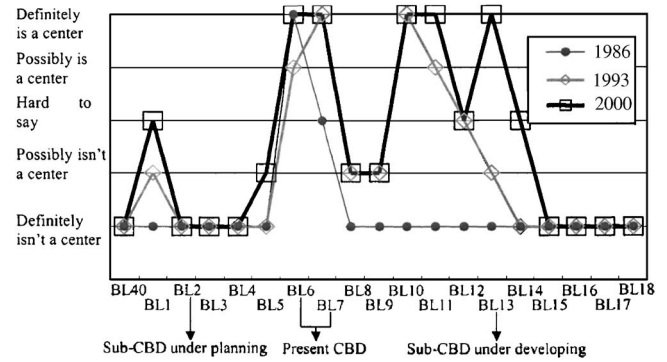


Fig. 6. Inference conclusions of recreation activity

Employment Activity

Fig. 5 shows the development changes for employment activity during the past 15 years. The employment activity strengthened significantly in the city center. Further, the old urban area on the western side of the present CBD maintained a low level of employment activity, and the eastern edge of the city exhibited unstable development during the past 15 years, but overall showed a slight strengthening in employment activity. Based on the changes from 1993 to 2000, the subway opening might increase employment activity in the newly developed city center (BL10 and BL13) and the eastern suburbs (BL15 and BL16). Correspondingly, employment activity was concentrated significantly in the city center, with a simultaneous tendency to expand toward the eastern edge of the city. Because the eastern areas of Taipei have developed only fifteen years, we can infer that the subway can stimulate employment activity in the newly developed urban area.

Recreation Activity

Fig. 6 shows the changes in recreation activity development. Recreation activity along the Blue Corridor exhibited a polycentric structure during the past 15 years. In 1986 only one recreation center was located along the Blue Corridor at the developed CBD (station BL6). Another center then grew from 1993 at station BL10, located on the eastern side of CBD. More recently a third center developed at station BL13, where a sub-CBD is under development, with this development only occurring after the subway opening. Based on the changes from 1993 to 2000, the subway opening enhanced recreation activity at stations BL1, BL11, BL13, and BL14. Since most of the enhanced stations are located

in the eastern city center, we can infer that the recreation centers were originally located at the existed CBD of the city and now are shifting to the newly developed areas.

Forecast and Strategy

Two sub-CBDs, located at stations BL13 (Taipei City Hall) and BL2 (Panchiao), respectively, are planned to ease growth pressure on the present CBD at stations BL6 (Hsimen) and BL7 (Taipei Main Station). The area around station BL13 is currently under development and has already been identified as a significant employment and recreation center, as shown in Figs. 5 and 6. However, the area around Panchiao station continues to be perceived as a residential center with few employment and recreation activities.

To review the land use plan to promote the Panchiao station area as an employment center, the inference system developed here was used to analyze the relationships between floor space and center identification. The employment center was identified based on three criteria, as listed in Table 1: Employment density, commercial and industrial floor space, and work trip attraction. Based on forecasts for the year 2015 from the Taipei City Government (Department of Transportation 2001), this study inferred the center identifications of employment for the Panchiao station area under different increases of commercial and industrial floor space over the existed land use plan. Since increased commercial and industrial floor space also increases the other two criteria (employment density and work trip attraction), this study assumed that all three criteria increased at the same rate. Hu (2002) presents other increase relationships among these three criteria.

Fig. 7 illustrates the inference conclusions for different rates of

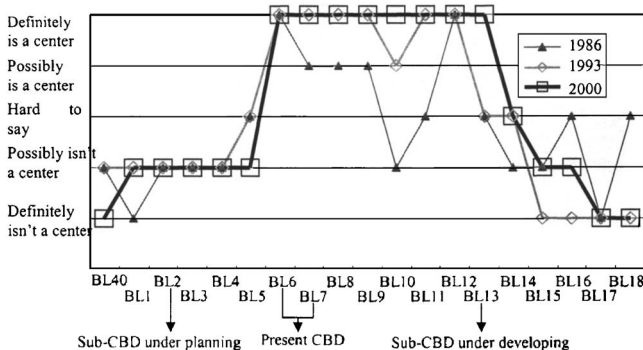


Fig. 5. Inference conclusions of employment activity

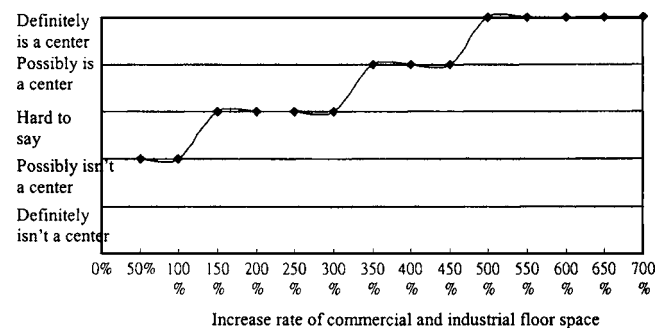


Fig. 7. Strategy analysis of employment activity for Panchiao station area

increases. Fig. 7 shows that the Panchiao station area possibly become an employment center if the rate of increase in commercial and industrial floor space exceeds 350% (about 2.5×10^6 m²), and will definitely become an employment center if the increase in commercial and industrial floor space exceeds 500% ($\sim 3.5 \times 10^6$ m²). Based on the inferred conclusions, this study recommends that city planners should review the land use plan and regulations for the Panchiao station area and increase employment floor space to help achieve the goal of sub-CBD development. Facilities and infrastructures supporting the needs of businesses and employees should also be supplied. The urban structure of three CBDs along the Blue Corridor can disperse activity distribution and enhance transit usage. It is good for Taipei to develop multiple centers on its transit network as a way of promoting sustainable development.

Conclusions

This study applied a fuzzy inference system to analyze activity center development along the Blue Corridor in Taipei. Changes in center development for the 19 station areas were simulated and compared for the years 1986, 1993, and 2000. Strategic analysis was also conducted for the land use plan in the Panchiao station area for 2015. Based on the inference conclusions, the urban development strategies can be well developed.

The present case study reveals three tentative conclusions regarding the development of the station areas along the Blue Corridor after the subway opening. First, the number of residential centers decreased whereas the number of employment and recreation centers increased. Second, residential activity became less significant whereas employment and recreation activity became more significant in the newly developed city center. Third, residential activity moved out of the city center whereas the employment and recreation centers expanded eastward from the CBD to the newly developed urban areas. These three tentative conclusions are identified by fuzzy inference, and further testing is required in subsequent studies. Further, the forecast and strategy analysis for the Panchiao station area in 2015 revealed that if the commercial and industrial floor space increases by over 350%, or over 500%, the Panchiao station area may reach the level of “possibly a center of employment,” or “definitely a center of employment,” respectively. Promoting Panchiao station area as the third CBD is beneficial for developing a transit-based-polycentric structure in Taipei metropolis for achieving sustainable development.

Compared to conventional methods for analyzing activity centers, the fuzzy inference system has three advantages. First, the linguistic variables used in system can express the vagueness and uncertainty of individual opinions. Second, the rule base and membership functions of linguistic variables generated via the questionnaire survey, can avoid subjective bias of researcher. Third, presenting the inference conclusions as linguistic variables makes them easy for the general public to understand, discuss, and apply.

Since the fitness of the fuzzy rules generated in this study is only just passable, the rule validity can be improved by some further effort. First, the survey samples for each station should be increased. A sufficiently large sample can be divided into two parts: for rule generation and fitness examination, respectively. Second, the use of additional linguistic degrees and evaluation criteria can generate plentiful and detailed rules and thus describe the real world more accurately. This study included just three

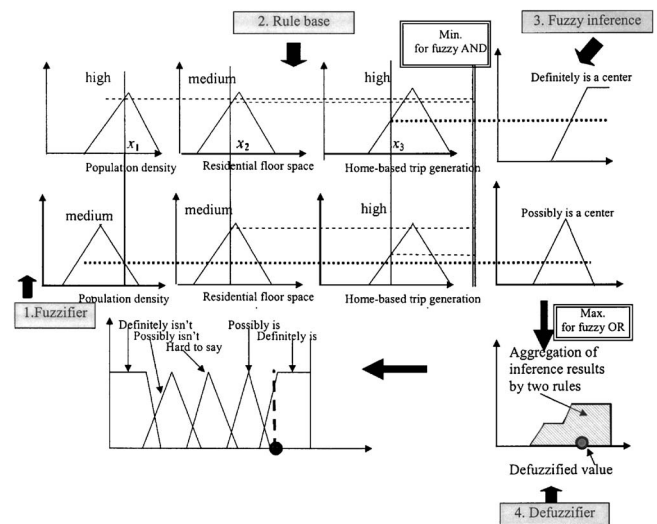


Fig. 8. Mamdani fuzzy inference system illustrated by the inference on residential center

linguistic degrees (low, medium, and high), and three evaluation criteria for each type of activity. Although this simplification is efficient, it may lead to fuzzy rules that are not accurate enough to describe the real world, thus compromising the validity of the rule base. Third, systematic and advanced methods, such as neural networks or genetic algorithms, can be applied to generate fuzzy rules for enhancing the validity and efficiency.

Appendix

Fig. 8 illustrates the Mamdani fuzzy model applied in this study, which is explained as follows.

- The statistical values of criteria should be transformed into linguistic degrees through membership functions. For example in Fig. 8, population density x_1 corresponds to *high* in 0.9 grades or *medium* in 0.4 grades, residential floor space x_2 corresponds to *medium* in 0.85 grades, and home-based trip generation x_3 corresponds to *high* in 0.5 grades.
- Identify the fuzzy rules that are turned on by the linguistic degrees of evaluation criteria. For example in Fig. 8 two rules are turned on:
 - IF population density is high AND residential floor space is medium AND home-based trip generation is high THEN the area definitely is a residential center;
 - IF population density is medium AND residential floor space is medium AND home-based trip generation is high THEN the area possibly is a residential center.
- The fuzzy inference is proceeded by max-min operator. Fig. 8 presents an example:

$$\mu_{\text{definitely is a center}} = \min\{\mu_{\text{high}}(x_1), \mu_{\text{medium}}(x_2), \mu_{\text{high}}(x_3)\} \quad (2)$$

$$\mu_{\text{possibly is a center}} = \min\{\mu_{\text{medium}}(x_1), \mu_{\text{medium}}(x_2), \mu_{\text{high}}(x_3)\} \quad (3)$$

$$\mu_{\text{conclusion}} = \min\{\mu_{\text{definitely is a center}}, \mu_{\text{possibly is a center}}\} \quad (4)$$

where Eqs. (2) and (3) are the fuzzy operator for AND, Eq. (4) is the fuzzy operator for OR, and μ denotes the membership grade or function.

4. The membership function of $\mu_{\text{conclusion}}$ should be defuzzified to produce a crisp value, which then can correspond to a linguistic conclusion. For example in the lower part of Fig. 8, the linguistic conclusion was that the place *definitely is a residential center*. The defuzzification was performed using the center-of-gravity method.

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