

The Construction of Decision Model for Tourism Disaster Evacuation Based on GIS and Fuzzy Theory

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Abstract—Fuzzy theory provides a rigorous, flexible approach to the problem of defining and computing. Therefore, to facilitate decision-making in geographic information system (GIS), the graph layer indicator and the Takagi Sugeno (TS) fuzzy model have to be integrated. This study explains several versions of the TS fuzzy model based on fuzzy theory and fuzzy operation. An inference model is constructed for GIS by the TS fuzzy model to formulate an integrated TS decision making system (TSDMK). The TSDMK can deal with inexact, linguistic, vague and uncertain data of GIS. The operator assigns most graph layer indicators by intuition. This investigation assesses applications of fuzzy logic for decision-making in GIS based on TSDMK graphs focusing on model-based systems.

Keywords—Geographic information system, tourism industry, fuzzy model, decision-making.

I. INTRODUCTION

GEOGRAPHIC Information System (GIS) digitally records geographical and topographical features and store the data in indexed and overlapped layers. The digital information is then converted into specific data formats and stored in computers to create a database of geographical information. Based on the various demands, the system can support real-time queries and updates on stored information. Moreover, the functions and application fields of GIS include classification, calculation, measurement, overlay analysis, network analysis, digital terrain analysis, proximity analysis, buffer analysis, seek analysis, view-shed analysis and so on. Therefore, GIS has become the most useful decision-support system at present.

Decision support in combined with geographic information

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system (GIS) has become an important issue in public policies throughout the world. More than ever, governments and extensive research are concerned about the safety and resources saving. To achieve these goals, many successful usages of decision-making system in GIS are developed (for example, see Tang et al., 2002; Kumar et al., 2005; She et al., 1999; Seker et al., 2003; Gunes et al., 2000 and the references therein). However, the data used in GIS with uncertainty have to be dealt with carefully because this is of primary importance for a reliable decision-making problem. Regan (2002) advocates that uncertainty broadly has two categories. One is epistemic uncertainty and the other is linguistic uncertainty. The former is uncertainty about a determinate fact, and the latter is uncertainty from nature language with ambiguity and vagueness. Moreover, though the space analysis capacity of GIS is strong, most of the data and knowledge concerning decision-making in GIS contain uncertainties that comprise both categories. How to distinguish and deal with the data under these situations by integrated models are an open area and an expected topic in the near future. The tourism industry directly or indirectly provides 8% of the world's employment opportunities, is worth more than a quintillion USD and is the world's fastest growing industry today (WTTC, 2008). With emergence of sustainable tourism development concepts, tourism industry managers have begun to pay particular attention to natural disasters and their risk to the tourism industry. On October, 2008 in the report on 「Global Sustainable Tourism Criteria」 by The International Union for Conservation of Nature and Natural Resources, IUCN, both security and location were included as part of management criteria. The criteria also required that during the process of land appropriation, environmental impact evaluation and design, special consideration should be given to the environmental impacts of the locality. Hence, this paper proposes the integrated TS decision-making system (TSDMK) which combines TS fuzzy models into GIS space analysis to solve tourism industry Location uncertain problem.

It appears that the uncertainty in data requires appropriate conceptual and analytical tools for successful decisions. An outstanding pioneered work that used the basic ideas and methods of analysis was proposed by Zadeh in 1965. The motivation of this work was the need to simulate the thought

process and judgment of human beings in the analysis of complex systems and decisions. "Fuzzy logic" was introduced as an extension of classical set theory.

Since Zadeh (1965) proposed a linguistic approach, many successful works on industrial and academic fields had been seeking (see Chang and Zadeh, 1972; Zadeh, 1973; Kickert and Mamdani, 1978; Braae and Rutherford, 1979, for example). However, all of them, there is few mathematical theory and systematic design. In 1985, Takagi and Sugeno (1985) proposed a new concept of fuzzy inference system, called the Takagi-Sugeno (T-S) fuzzy model. This kind fuzzy model can combine the flexibility of fuzzy logic theory and the rigorous mathematical analysis tools into a unified framework. Since then, many successful applications of T-S fuzzy model have been proposed (for example, see Chen, 2006; Cococcioni et al., 2006; Hsieh et al., 2006; Zhang et al., 2006 and the references therein). In this type fuzzy model, local dynamics in different state space regions are represented by a set of linear sub-models. The overall model of the system is then a fuzzy "blending" of these linear sub-models. Therefore, an inference model using TS fuzzy scheme is constructed for GIS to formulate an integrated TS decision making system.

Previous studies on Disaster Management focused their efforts strictly on disaster relief and prevention, but neglected to study emergency contingency measures on the rapid evacuation of the general populace to disaster shelters. However, after the 921 earthquake, related studies have attracted a great deal of attention. Once disaster strikes, the planning of emergency measures can be classified into 2 themes: evacuation and division of work. In the first place, the proper evacuation site must be selected, while secondly, workers must be appointed to run the rescue/relief missions. Due the enormity and complexity of the components involved in the planning of emergency measures, this study will focus solely on the analytical solution of the first stage of the emergency measure (evacuation).

This study is organized as follows. First, the disaster shelter and the theoretical basis behind disaster prevention strategies are reviewed. Then the fuzzy set theory and the T-S type fuzzy model are briefly presented to deal with the data of GIS. Consequently, the formulation of T-S decision-making system (TSDMK) is proposed and we discuss why a graphic layer showing of GIS needs a decision-making by TSDMK. Finally, an example of Multi-objective Decision-making for Location of Tourism Disaster Prevention in Hualien is given to demonstrate the proposed approach, and the conclusions are drawn.

II. DISASTER SHELTER

Urban disaster shelters are the only place where the citizens can get reprieve once disaster strikes. However, in Taiwan, where the frequency of natural disasters is rather high, urban shelters have recently gained the public's attention. Especially in population-concentrated and old urban areas, the lack of disaster shelters could increase the difficulty in applying

disaster emergency reaction measures. This is particularly obvious in areas around the train station (city centre) where losses of life and property are prevalent, once earthquakes, floods or fires hit the city. Other problems include the fact that natural calamities cause mass panic and the most citizens will not be able to reach the disaster shelter in time for avoiding the forces of nature. Particular attention needs to be paid on the planning of disaster shelters to ensure that people can quickly reach the shelters and lower losses of life and property.

Currently earthquake disaster shelters can be divided into 3 categories: (1)Emergency Disaster Shelters, (2)Neighborhood Disaster Shelters:, and (3)Urban Shelters.

According to the web statistics of the fire department, in Taiwan Hualien's 13 townships, a total of 179 shelters are being planned shown in Table 1, with most of them allocated within activity centers. However, due to the lack of space, the shelters' capacity is limited; therefore there is a pressing need to restructure those shelters to satisfy the needs of the township citizens. This case study is intended to investigate how to reasonably distribute these shelters to achieve maximum effect and fairness under the limited resources at hand.

TABLE I
CURRENTLY PLANNED DISASTER SHELTERS IN HUALIEN COUNTY

Township	Planned Disaster Shelters	Township	Planned Disaster Shelters	Township	Planned Disaster Shelters
Shioulin Township	11	Fuli Township	13	Rueisuei Township	13
Shincheng Township	14	Fuli Township	14	Guangfu Township	14
Hualien Township	10	Juoshi Township	10	Wanrung Township	14
Jian Township	21	Yuli Township	21		
Shoufeng Township	16	Fengbin Township	8		

III. FUZZY SET THEORY

The traditional characteristic mapping (henceforth called crisp set) takes only two values: 1 if an element belongs to the set; and 0, if it does not. A fuzzy set uses an idea of a membership, rather than being crisp, defined by grade or degree. The normalized fuzzy set A is a set having a membership function which assumes a value between $[0, 1]$. A is usually identified with these membership functions. If x is a possible value of X , then $A(x)$ means its membership degree in the fuzzy set A . Therefore, the value 1 indicates complete membership, while the value 0 indicates complete lack of membership. Intervening values implies intervening grades of membership. That is to say, a crisp set would have membership values limited strictly to the set $\{0, 1\}$, with no intervening values. A definition of fuzzy set is described below.

Definition 1: Let R be a real number set. A fuzzy set \tilde{A} on R is said to be a fuzzy number if the following conditions are satisfied:

(1) $\exists x_0 \in R$, such that $\mu_{\tilde{A}}(x_0) = 1$, and membership function $\mu_{\tilde{A}}(x)$ is piecewise continuous; and

(2) $\forall \alpha \in (0,1]$, $A_\alpha \equiv \{x \mid \mu_{\tilde{A}}(x) \geq \alpha, x \in R\}$ is a convex set on R,

where x_0 is the mean value of \tilde{A} and A_α is a crisp set. The convex set means that $\forall x \in [x_1, x_2]$, $f(x) \geq \min(f(x_1), f(x_2))$.

IV. PROBABILISTIC AND FUZZY UNCERTAINTY

Probability theory is based on classic set theory and on two-valued logic, e.g. yes-or-no or happen-or-not happen statements. It is concerned with the development of a mathematical framework to treat random phenomena. These phenomena occurred in many investigations in which repeated experiments are conducted under essentially the same conditions, but yield different possible outcomes (events) which are not deterministically predictable; the information required for a precise prediction is lacking either due to incompleteness or uncertainties. Instead, the outcomes exhibit certain kinds of statistical regularity that, while the individual outcomes themselves are not predictable, the relative frequency of occurrence of the events can be approximately predicted. Therefore, probabilistic uncertainty pertains to events that have a well-defined, unambiguous meaning. Because the statements of decision-making in GIS can not be well-defined, it will yield an unsatisfactory evaluation for the indicator of graph layer showing. Fuzzy uncertainty, in contrast, pertains to events that have an ill-defined, vague meaning. Fuzzy set theory is based on multiple-valued logic which can evaluate the intermediate value between happening and not-happening. Therefore, we propose the framework of rule-based fuzzy models below to decision-making in GIS.

V. RULE-BASED FUZZY MODEL

In rule-based fuzzy models, knowledge is represented by if-then rules. The rules comprise two parts. One is an antecedent part stating conditions on the input variables and the other is a consequent part formulating the corresponding values of the output variables. Commonly, the case of a single output variable is considered in real applications. The most often used types of rule-based fuzzy models include Mamdani, relational, Tagaki-Sugeno (TS) types etc. In TS type models, the consequent part expresses a (non-)linear relationship between the input and output variables, whereas in Mamdani type models, both antecedent and consequent parts consist of fuzzy statements regarding the variables involved (for more detail, please see reference Mamdani; 1977).

In general, the structure of a typical fuzzy model is shown in Fig. 1. The fuzzification step calculates their membership grades in particular fuzzy sets C^L, C^H of the inputs and the

defined membership function μ_C is provided in Fig. 2. The inference step determines, from the inputs' membership grades μ_C^i , the resulting membership function $\mu_{res}(y)$ of the model output by i ($i = 1, 2, \dots, m$) rules bases. A rule base is described as follows (Hsieh et al., 2006)

R1: IF (x_1 is C^L) AND (x_2 is C^H) THEN ($y = f_1(x)$).

From the resulting membership function $\mu_{res}(y)$, a crisp, numeric output value y^* will be computed in defuzzification step. The value y^* is the effect of the numeric inputs' values x_i .

In this present study, only TS type models will be discussed, because they show effectiveness in decision-making of construction management and it is believed to be utility in GIS for the indicator of graph layer showing. The fuzzy statements hereafter are customarily used with a linguistic nature, e.g. expressing that a certain variable (also called linguistic variables) takes a 'high' or 'low' value. First of all, the T-S fuzzy model can have the form of a set of rules as well as membership functions represented below.

R1: IF (z is F_1) THEN ($r = f_1(z)$),

R2: IF (z is F_2) THEN ($r = f_2(z)$),

⋮

Rm: IF (z is F_m) THEN ($r = f_m(z)$),

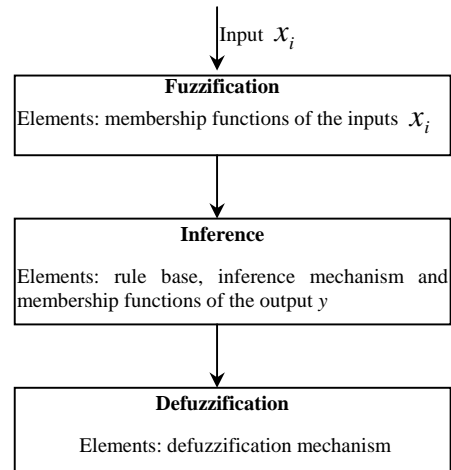


Fig. 1 Structure of a fuzzy model

Then the output can be obtained on the basis of the grade of activation of the particular conclusions $f_i, i = 1, 2, \dots, m$, which is determined by following formula.

$$r = \frac{\sum_{i=1}^m \mu F_i(z) f_i(z)}{\sum_{i=1}^m \mu F_i(z)}$$

Where F_i is the fuzzy set; the function $f_i(z)$ can be nonlinear.

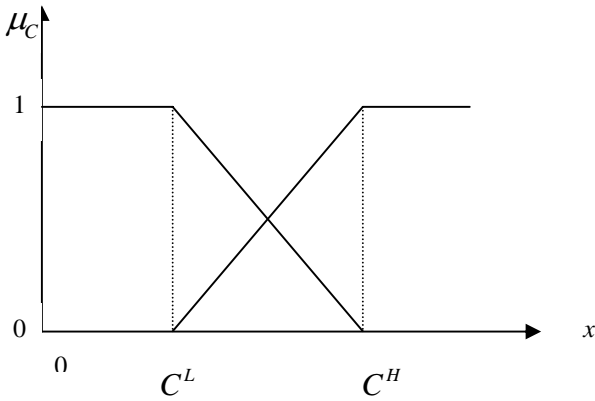


Fig. 2 Fuzzy sets to represent ‘low’ and ‘high’ variables

In the next paragraphs, the mathematical verification and application on the allocation of disaster shelters is proposed and we deal with this GIS application using fuzzy rule-based modeling paradigm.

VI. FUZZY MODELS TO ASSESS DECISION-MAKING IN GIS

Though the space analysis capacity of GIS is strong, it still solves insufficiently on uncertain and deterministic materials in the face of dealing with mass decision problem. Hence, this paper tries through combining with TS fuzzy models to solve uncertain problem while making decision effectively. Unlike traditional modeling, fuzzy rule-based modeling is essentially a multimodel approach in which individual rules are combined to describe the global behavior of the system (Chiang et al., 2004). Therefore, the fuzzy modeling is employed to simplify the decision-making problem in GIS.

The GIS knowledge database of TSDMK is constructed by several sets of if-then (also called antecedent-consequent) rules in TS fuzzy models. The fuzzy knowledge is the database for searching the graphic layer of GIS and the variables in fuzzy rules are formulated in linguistic variables. By fuzzy inference machine, the weighting is determined for showing a suitable graph in GIS. Furthermore, the information format in GIS is recorded to represent a pixel and the description of a pixel results in a fuzzy rule. If there are $m \times n$ pixel in a spatial region, it results in $m \times n$ fuzzy rules before removing the repeats or resemblance sets of rules. Each rule contain above one linguistic variable of the learning resource and learning goal. These data of learning sources and learning goals represent the same location but different graphic layer pixel. The combination of learning sources and learning goals becomes

the fuzzy knowledge map for searching a solution of GIS graphic layers.

The weighting value can be determined by the knowledge base operation of TS fuzzy models. A decision-maker can analyze the suitability for each space and any fuzzy degree. The function of computing weighting in TS fuzzy models can be coded to be a part of system model. The combination of TS fuzzy model and GIS would be effective for GIS database and enforce the ability of special decision-making.

VII. MATHEMATICAL VERIFICATION AND APPLICATION ON THE ALLOCATION OF DISASTER SHELTERS

This section gives a geographical background of the Hualien train station area and presents a case study on the allocation of disaster shelters in the surrounding area. Basing on statistical interpretation and a combination of T-fuzzy and Geographic Information System (GIS) analysis, we could compute the minimum distance from the station and the maximization of serviced shelters.

A. Scope of Study and Analysis of the Locale

Hualien train station is located in the center of the city and situated in the Guo-lien neighborhood (East Longitude 121059’23” North Latitude 23099’20”). The station 2-floor building is built of reinforced concrete. The front station has an area of 7380 square feet, while the rear has an area of 4860 square feet. Bei-huei rail-track and Hua-dong rail-track intersect at this station. According to the 2005 statistics of the Ministry of Transportation, there are on average 6000 people who board trains daily in Hualien train station. To the east of the station lies the Pacific Ocean while Shio-lin township is located on the west. To the north and south are located Shioulin and Jian townships respectively.

VIII. RESULTS DISCUSSION AND CONCLUSION

Hualien has always been a hotspot for tourists. In recent years, the increasing natural disasters have severely affected tourism and economic growth; therefore, how to find a balance point between disaster mitigation and tourism development has become a key question for the county government. Hualien train station is located in the center of the city and is where all tourists congregate. Our study is devoted to solving the issue of crowd dispersal and seeking a rapid course to the shelters once disaster strikes. Through the use of TS fuzzy model integrated with GIS, the TS Decision-making System (TSDMK) effectively provided a spatial analysis of possible shelter targets and pinpointed 3 most suitable shelters: Tzi-chi Hospital, Se-Wei High School, and Chung-hua Elementary School. From the results, we can clearly see that the variables used in determining the most suitable shelter locations include distance from shelters and local population. However, these variables are conditioned by local topography and will affect the time of disaster relief. Additionally, the number of tourists isn’t taken into account; therefore the management of disaster relief requires more manpower and resources in order to provide an exceptional sightseeing environment.

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