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A fuzzy integer-nonlinear programming approach for creating a flexible just-in-time location-aware service in a mobile environment

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ABSTRACT

This study provides a timely and flexible location-aware service (LAS) to mobile users in a dynamic environment. Few previous studies have examined similar concepts. In the proposed methodology, the inaccuracy of user positioning and the uncertainty of manual service preparation are considered and modeled by using fuzzy numbers. These numbers are used as inputs to establish a fuzzy integer-nonlinear programming model applied in identifying the most suitable service location and path. A required service is prepared immediately before a user reaches the recommended service location. To manage simultaneous requests from multiple users, the concepts of fuzzy modeling, route planning, and parallel machine scheduling are combined. Thus, the proposed LAS can distribute multiple users among service locations, thereby enabling users to avoid unnecessary waiting, which is a major problem associated with existing LASs. To assess the effectiveness of the proposed methodology, two experiments were conducted in small areas in Taichung City and Taipei City, Taiwan. The experimental results revealed that the waiting times of users were substantially reduced, increasing the average satisfaction level. However, improving the accuracy of user positioning does not necessarily facilitate achieving a high average satisfaction level.

1. Introduction

Location-aware service (LAS) has recently received a considerable amount of attention in the context of ambient intelligence (AmI), mainly because of the prevalence of cell phones and applications. An LAS, or location-based service, provides relevant information and services to a user through interpretation of the user's location and other contextual elements [7,12]. LAS systems have been applied to online social networking [1,24], instant personal recommendation [5,19,21], and other areas. A different research field that is similarly critical is to provide ubiquitous services to users regardless of their location [6].

The objective of this study was to create a flexible just-in-time LAS for mobile users in a ubiquitous environment. This is not an easy task because of the uncertainties of such an environment. The first source of uncertainty is the interpretation of a user's needs. Because few options can be provided to a user with his or her cell phone, confirming a user's needs is difficult. To address this difficulty, Kotsakis and Ketselidis [17] suggested using linguistic terms to describe a user's subjective feelings. Similarly, Anagnostopoulos and Hadjiefthymiades [3] represented a user's context by using variables assuming fuzzy values.

The second source of uncertainty is the detection of a user's position. According to Virrantaus et al. [22], LASs are supported by the processing of geographic information system data. To increase certainty, mathematical modeling, optimization, simulation, statistics, fuzzy modeling, cellular automata, knowledge-based systems, fractal analysis, neural computing, spatial multimedia, visualization, and genetic programming are applied. Astrain et al. [4] established a fuzzy inference system to estimate the location of a user. The inputs of the fuzzy inference system are Wi-Fi signal strengths in specific zones, which are expressed in linguistic terms. The output from the fuzzy inference system facilitates associating the user with a specific zone and establishing membership. Such a positioning method is common for indoor LAS applications (e.g., Alonso et al. [2], Chen et al. [8], and Hernández et al. [15]). The positioning accuracy is approximately 2.0–2.5 m [4]. For outdoor LAS applications, users are usually positioned using the Global Positioning System (GPS) applications installed on their cell phones. This positioning method is also subject to inaccuracy; the detection error may be as high as 20 m. To examine this inaccuracy, Lin and Chen [19] estimated the position of a user by using a fuzzy set. The travel time between two locations was calculated as a fuzzy value. Chen and Wu [11] evaluated the timeliness of a path by using a fuzzy value. By comparing the timeliness values of different paths, the

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just-in-time path and service location can be recommended to a user.

The third source of uncertainty is the determination of a user's preferences and is addressed using fuzzy logic. Mateo et al. [20] established a set of fuzzy inference rules to recommend the most suitable nearby restaurant to a user by evaluating the user's needs. Anagnostopoulos and Hadjiefthymiades [3] applied a similar approach to classify the contexts and activities of multiple users by comparing their routines. Recently, Chen et al. [12] recommended a parking station that most closely fitted a user's needs by establishing fuzzy inference to compare alternatives.

This study involved developing a flexible just-in-time LAS in which

(1) there are multiple service locations along the route, from the starting point to the destination of a user;
(2) "just-in-time" means that the required service is ready exactly when a user reaches the recommended service location [10]; and
(3) "flexible" means that users are provided with a choice of multiple service locations.

The remainder of this paper is organized as follows. First, the concepts of a fuzzy just-in-time service location and path in a ubiquitous service network are defined. To identify the fuzzy just-in-time service location and path for a user, a fuzzy integer-nonlinear programming (FINLP) problem was formulated and solved, as detailed in Section 2. To manage simultaneous requests from multiple users, the FINLP model is extended by incorporating the concept of parallel machine scheduling, as discussed in Section 3. The application of the proposed methodology is illustrated using an example. In addition, to elaborate the effectiveness of the proposed methodology, Section 4 presents the results of two experiments conducted in small areas in two cities. Finally, Section 5 offers the conclusion and provides directions for future research.

2. Literature review

Existing LASs used for similar purposes have exhibited the following problems:

(1) In some LASs [3,10,11,18,19], fuzzy parameters are defined and established fuzzy models are used to address various uncertainties. However, defuzzification is applied before deriving the final results, reducing the flexibility of the recommendation. In addition, defuzzification is a subjective process. Results vary according to the defuzzification method used, and there is no absolute rule for determining which defuzzification method is the most suitable for any given purpose.
(2) In theory, identifying the just-in-time service location and path is an NP-hard problem [14]. In a complex traffic network with multiple service locations, the problem is considerably difficult.
(3) Most existing LAS systems do not consider simultaneous requests from more than one user. These systems manage only individual incoming requests. However, multiple requests can be considered simultaneously to improve results.

Graph models have also been applied to LAS systems. For example, in Duckham and Kulik [14] and other studies, graphs have been used to represent a geographic space. Duckham and Kulik also summarized the advantages of using a graph model over the Cartesian plane. In [16], to secure the location of a user from a location-based service, an anonymizer constructed a graph, with each graph vertex representing a query. If two users fell in each other's rectangles, their queries (and the corresponding vertices) were connected. Existing graph models have been generally used to model the location and movement of a user; however, in such models, other problems, such as the preparation of service on a service location and the distribution of users to several service locations, have rarely been assessed simultaneously.

To address some of these problems, the following actions were taken in the proposed methodology:

(1) A FINLP model is established to facilitate solving the fuzzy just-in-time service location and path problem. In one instance, to facilitate constructing new municipal incinerators, Chang and Wei [5] solved a multiobjective FINLP problem by using a genetic algorithm. Saad et al. [21] addressed a multiobjective FINLP problem in which only the objective functions were fuzzy. To solve the problem, the objective functions were defuzzified and their weighted sum was then optimized. Zandhessami et al. [25] established a multiobjective FINLP model with piecewise linear membership functions to minimize the total transportation costs in a multiechelon supply chain. The problem was converted into a goal programming problem to maximize the satisfaction level of the fuzzy target. Lin and Chen [19] defuzzified a FINLP problem by using the center-of-gravity method before deriving the optimal solution. Rather than defuzzifying the model, several just-in-time service locations with different memberships are derived, generating a flexible recommendation. In addition, because membership ranges between 0 and 1, it is an appropriate and objective parameter for expressing the suitability of a just-in-time service location or path.
(2) The FINLP model is then extended to address the case of multiple simultaneous users. The concepts of fuzzy modeling, route planning, and parallel machine scheduling are combined, constituting an innovative approach in this field.

Table 1 summarizes the differences between the proposed methodology and existing methods. Kotsakis and Ketselidis [17] revealed that modeling a user's preferences by using linguistic terms is a promising strategy. On the basis of such linguistic terms, various fuzzy inference rules can be directly applied to make recommendations [4,13]. Furthermore, traffic flow statistics can be incorporated into fuzzy inference rules, as demonstrated by Chen et al. [12]. Chen and Wu [11] also indicated that just-in-time (or timeliness) is a vital performance measure for LAS systems. Lin and

Table 1
Differences between the proposed methodology and some existing methods.

Reference	Method type	Result type	Optimized?	Flexibility of the recommendation	Consider simultaneous multiple users?
Kotsakis and Ketselidis [20]	Linguistic modeling	Crisp	No	Low	No
Astrain et al. [4]	Fuzzy inference rules	Fuzzy	No	High	No
Hernández et al. [17]	Fuzzy inference rules	Fuzzy	No	High	No
Chen et al. [14]	Fuzzy inference rules	Crisp	No	Low	No
Chen and Wu [13]	Integer nonlinear programming	Crisp	Yes	Low	No
Lin and Chen [22]	Fuzzy integer nonlinear programming	Crisp	Yes	Low	No
The proposed methodology	Fuzzy integer nonlinear programming	Fuzzy	Yes	High	Yes