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Intelligent timetable evaluation using fuzzy AHP

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ABSTRACT

There is a substantial body of empirical literature that establishes the benefits of customer satisfaction for enterprises. Among different available options to present our service, selecting the best choice in the customers' eyes is a vital decision.

Developing appropriate passenger train schedules is counted as one of the major managerial concerns in transportation environment. Although different algorithms have been developed to create predictive schedules for a fleet of passenger trains using different performance indicators, selecting the best one embraces some ambiguities and uncertainties. That is because a one-dimensional objective function may not be sufficient for responding customer concerns.

The main objective of this paper is to propose an approach within the fuzzy AHP framework for tackling the complexity of multidimensional service evaluations, where "sum of weighted waiting times", "average of unit waiting time" and "maximum ratio of waiting time to journey time" of a schedule are evaluated and the ultimate judgment on goodness of the schedule is made via the aggregation of the performance measures used. The study is based on the knowledge of certain managers and experts in IRC (Iran Railways Corporation) who are aware of available complexities in train scheduling and have been dealing with customers for several years.

1. Introduction

Train scheduling system is an important function of operations management systems of rail transport which has a significant effect on achieving the maximum profit through planning and offering transportation services to meet customers' requirements. The train scheduling problem is complex when engines, crews and wagons are incorporated into a single planning frame work science various constraints and objectives should be taken into considerations simultaneously. Hence, time tabling problem is an optimization problem whose complexity has been acknowledged in various publications such as Carey and Lockwood (1995), Higgins, Kozan, and Ferreira (1997), Isaai and Singh (2001a), Jovanovic and Harker (1991), Sahin (1999). However, appropriate decision support systems can be used to generate predictive schedules of trains. In such a process, an acceptable solution created in a reasonable time and with a convenient interaction between the user and the scheduling tool appears to be preferred to the optimum solution found after a long calculation time. Mathematical programming, simulation, and artificial intelligence techniques can be considered as the main approaches to solve train scheduling problems in addition to the manual method. To evaluate produced time tables, a number of different criteria have been used in studying train scheduling problems. In Isaai (2000), Isaai classified different criteria to delay-based performance measures and cost-based performance measures. Delay-based performance measures are usually functions of delays imposed on trains involved. Various delay-based measures have been used in different theoretical and practical experiences such as potential risk delays and actual delays (Ferreira & Higgins, 1996; Higgins, Kozan, & Ferreira, 1996), total delays (loss time) (Abramson, Mills, & Perkins, 1993; Iida, 1988), total weighted delays (Jovanovic & Harker, 1991; Szpigel, 1973), minimum delay with respect to the original time table (Chiu, Chou, Lee, Leung, & Leung, 1996) and minimum-changes with respect to the original timetable (Chiu et al., 1996). Cost-based performance measures concern with scheduling decisions affecting a number of cost items that are linked with productivity and profitability of a rail transport company. Such items may be directly or indirectly reflected in the objective function of the optimization model and can be categorized to crew costs (Jovanovic & Harker, 1991), rolling stock value (Jovanovic & Harker, 1991), shipment transit time (Beckmann, McGuire, & Winstin, 1956), and fuel consumption (Cai & Goh, 1994; Carey, 1974, 1994; Carey & Lockwood, 1995). Isaai and Singh (2001a) introduced three performance measures to evaluate and compare the generated schedules. One of the three is the "sum of weighted waiting times" (SWWTs), which is commonly used. The literature survey shows that the spread of delays amongst trains is also important in the eyes of human expert schedulers.

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Minimizing total waiting times does not necessarily mean that the spread of delays is appropriate. Therefore "average of unit waiting time" (AUWT) and "maximum ratio of waiting time to journey time" (MRWJ) have been designed where the schedule with minimum value of the selected measure is desired. For a produced schedule of trains, AUWT represents the average of unit waiting time to minimum traveling time for each train; minimum travel time is travel time excluding waiting times imposed to resolve train conflicts. It is possible to have good a timetable in terms of AUWT in which a train is scheduled with long delays in favor of the others. To avoid such cases MRWJ has been developed. It is used to reduce the biggest ratio of waiting time to journey time, which represents delays imposed on the train bearing longest delays in proportion to its travel time. The above performance measures have been mathematically introduced in Isaai (2000).

To satisfy these three criteria Isaai and Singh developed and compared three intelligent algorithms: Constraint-Based Heuristic (CBH), HeuSa and HeuTS (Isaai & Singh, 2000, 2001b, Isaai, 2007) which outperformed manual timetables created by human experts in terms of SWWT, AUWT and MRWJ. Assume that few timetables are produced for services along the same route, and quality (goodness) of each timetable varies with performance measure considered; the question is "how should experts rank the schedules where a multidimensional approach is adopted and the three measures used are taken into account all together. The reason is that each measure covers limited aspects of schedule goodness. Furthermore, in the real world, the outcomes of timetables are not of the same value in the eyes of customers and the improvement of one criterion, which is represented by the crisp data in scheduling model, means a subjective concept in terms of customers' satisfaction.

To cope with the ambiguity of subjective concept in timetable evaluation and identify the most appropriate schedule, a fuzzy approach is introduced in this paper.

Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. In fuzzy set theory with fuzzy logic, the set membership values can range (inclusively) between 0 and 1; the degree of truth of a statement in fuzzy logic is not constrained to the two truth values {true (1), false (0)} as in classic predicate logic.

To the best of authors' knowledge, no fuzzy logic method has been reported on the evaluation of train timetables. This paper aims at investigating a fuzzy viewpoint for dealing with vagueness existing in timetable evaluation. AHP technique is used to structure expert knowledge on relative values of criteria and timetables being evaluated. A fuzzy AHP model will be proposed for timetable evaluation.

The paper is organized in five sections. Section 2 presents some general knowledge about multi-attribute decision making techniques used for prioritization. Section 3 includes a summary of the basics of fuzzy sets and numbers and defines the basic steps of the fuzzy AHP method used in the proposed model. Section 4 proposes the application of fuzzy AHP for time table evaluation and finally Section 5 presents the conclusions.

2. Multi attribute decision making techniques

In order to assess a set of decision alternatives with respect to different criteria with different scale types, Multi-attribute decision making (MADM) techniques have been used. The ability to use such criteria and evaluate the alternatives using the same scale, i.e. priority, is the significant advantage of these techniques to the traditional ones. Another important advantage is potentials of MADM techniques in analyzing both qualitative and quantitative evaluation criteria. The most frequent employed techniques in this field are TOPSIS, outranking, and AHP.

The concept of TOPSIS is based on choosing an alternative which should have the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal one (Yasin Ates, Cevik, Kahraman, Gülbay, & Erdogan, 2006).

The outranking idea is based on choosing actions which are preferred to the others by systematically comparing them on each criterion (Martel, D'avignon, & Couillard, 1986; Siskos, Lochard, & Lombard, 1984; Takeda, 1982).

The most popular technique, AHP, was developed by Saaty in 1980. This technique first separates the complex problem being studied into a hierarchical system of elements. In the next step, pair-wise comparisons of elements in each hierarchy are done using a nominal scale. Therefore, to represent the comparative weights among various elements of a certain hierarchy the eigenvector of the matrix is extracted. Then, in order to establish a comparison matrix, comparison results are quantified. Finally, in order to appraise the consistency ratio of the comparative matrix and to decide to accept or reject the information, the Eigen-value is used. To generate precious information about decision maker's preference, pair-wise comparison is usually employed. So, there would be no need for judging the measurement scale for each criterion/attribute (Tunc Bozbura, Beskese, & Kahraman, 2007).

Using a hierarchical structure of the goal, criteria and alternatives appears to be a proper way of prioritizing train timetables, therefore, and crisp values fail to represent human expert judgments of goodness; therefore, a fuzzy AHP technique has been developed in this research work to work out the final priority of timetable alternatives.

3. Fuzzy AHP

For the first time, fuzzy set theory was introduced by Zadeh in 1965. He aimed to deal with imprecision and vagueness of human concepts (Beskese, Kahraman, & Irani, 2004). Fuzzy set theory has the precious capability of representing indistinct data. Another remarkable capability of fuzzy set theory is that it lets mathematical operations and programming to be applied on its domain (Zimmermann, 1994).

In the literature, triangular and trapezoidal fuzzy numbers that are the special forms of fuzzy numbers are usually used to capture the vagueness of the parameters related to the topic. The arithmetic operations of these fuzzy number types are explained in Appendix A. In this work, triangular fuzzy numbers (TFNs) are used to consider the fuzziness of measurements and evaluation.

Fuzzy AHP methodology is designed for decision making problems and selecting the best of alternatives by integrating the concept of fuzzy set theory and hierarchical structure analysis. Certain characteristics of fuzzy methodology and AHP empower the decision maker to incorporate both their knowledge, which is mainly qualitative, and quantitative information into the decision model. Decision makers usually feel more confident to give interval judgments rather than fixed value judgments. In this approach, triangular fuzzy numbers are used for the preferences of one criterion over another, and then the extent analysis method is used to calculate the synthetic extent value of the pair-wise comparison.

Since 1983 when Van Laarhoven and Pedrycz presented the earliest work in fuzzy AHP, many surveys have been done around this topic and different approaches have been suggested. In this work, Chang's extent analysis method is preferred; the steps of this approach are relatively easier than the other fuzzy AHP approaches and they are similar to the conventional AHP. The basics of the extent analysis method on fuzzy AHP are introduced in the following.

Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set, and $U = \{u_1, u_2, \ldots, u_m\}$ be a goal set. According to Chang's extent analysis (Chang, 1992, 1996), each object is taken and extent analysis for each goal, gi, is performed, respectively.