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The Applications of Rough Set Theory in Civil Engineering

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***Abstract*—This paper focuses on the comprehensive review of the literature on applications of rough set theory in Civil Engineering. The relationships between rough set theory and other mathematical methods, such as conventional statistical methods, fuzzy sets, and evidence theory, are briefly introduced. The applications of rough set theory in Civil Engineering are discussed in structure engineering, pavement engineering, traffic engineering, transportation engineering, land management, and water resources management. The great majority of civil engineering applications of rough set theory are based on the rule induction. Recent works on integration of rough set theory with other computing paradigms such as genetic algorithm, fuzzy logic, evidence theory are presented.**

Keywords-rough sets theory, application, civil engineering, structure engineering, pavement engineering, traffic engineering, transportation engineering

I. INTRODUCTION

Rough set theory was originally introduced by Zdzislaw Pawlak in the early 1980's as a theoretical framework for discussion about knowledge. Nowadays it has become one member of artificial intelligence techniques. A rough set provides a representation of a given set using lower and upper approximations when the available information is not sufficient for determining the exact value of the set. The main objective of rough set analysis is to synthesise the approximation of concept from the acquired data. It has been proven that rough set theory has enormous potential in dealing with uncertainties in decision making. During the last decades, rough set theory has received wide attention from all over the world and has been efficiently applied in many domains, such as medicine, finance, business, information science, engineering and social science etc [1].

Since the first case of rough set theory in the area of civil engineering was introduced in 1986 [2], a rapid growth of interest in rough set applications in civil engineering can be lately seen. The applications of rough set theory to solving specific complex problems have been an attractive research topic. This paper reviews the main applications of rough set theory in civil engineering and discusses the development trends of rough set methods and future efforts required. The rest of the paper is organized as follows. The next section outlines the basic concepts of rough set theory. Section III provides brief comparisons between Rough set theory and conventional statistical methods, fuzzy sets and evidence theory. Section IV presents a state-of-the-art review of the literature related to applications of rough set theory in civil engineering, including structure engineering, pavement engineering, traffic engineering, transportation engineering, land management, and water resources management. The final section discusses the application of rough set theory and concludes the paper.

II. COMPARISONS WITH OTHER METHODS

The rough set philosophy is founded on the assumption that with every object of the universe of discourse we associate some information. Objects characterized by the same information are indiscernible in view of the available information about them. The indiscernibility relation generated in this way is the mathematical basis of rough set theory.

Since Pawlak proposed the rough set theory in the early 1980's, the theory has been well studied and currently reached a level of high maturity. The detailed descriptions can be found in the previous studies [3][4][5]. It should be noted that several extensions of the rough set theory have been developed, such as variable precision rough set [6] and dominance-based rough set [7]. Readers can refer to the reference to get more information about the extensions.

To make a clear understanding of the rough set theory, we compare rough set theory with conventional statistical methods, fuzzy sets, evidence theory in the following. The brief description may help to choose appropriate approach before data analysis.

A. Rough Set vs. Statistical Methods

The reference [8] proved that there exists a close connection between rough set theory and the statistical method (ID3) in inductive learning and the main difference between them lies in their attribute selection criteria. Generally, Conventional statistical methods, such as regression analysis, discriminant analysis, are considered as hard data analysis, requiring parameters outside the observed phenomena, or assumption of the probability distribution. However, rough set theory, as a non-parametric technique, does not rely on external parameters or auxiliary model assumptions about data, and can deal with uncertainty and imprecision by utilizing solely the given data and the granularity structure among them [9]. Furthermore, rough set theory can utilize both qualitative and quantitative data and does not have the sample size constraint.

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B. Rough Set vs. Fuzzy Sets

Rough set have often been mentioned in the same breath as fuzzy sets. It is generally accepted that two theories are related but distinct and complementary[10][11]. Both theories are generalizations of classical set theory for modeling vagueness and uncertainty. Rough set theory deals with the indiscernibility among objects which refers to the granularity of knowledge, while fuzzy sets theory handles the ill-definition of the boundary of a class through a continuous generalization of membership functions. Furthermore, rough set theory does not rely on the membership functions like in a fuzzy set. The combinations of two sets, fuzzy rough set and rough fuzzy sets have been proposed to more effectively deal with vagueness and uncertainty.

C. Rough Set vs. Evidence Theory

Evidence theory, also called Dempster-Shafer theory or the theory of belief function, is a generalization of Bayesian theory of subjective judgment. It is one of the methods used to model and manipulate uncertain information. Evidence theory was originated by Arthur P. Dempster's concept of lower and upper probability [12], and extended by Glenn Shafer [13]. The basic representational structure of the theory is belief structure, which consists of a family of subsets called focal elements, with associated individual positive weights summing to one. The primitive numeric measures derived from the belief structure are a dual pair of belief and plausibility functions.

References [14] and [15] described the connection between two theories. In rough set theory there exists a pair of approximation, the lower and upper approximation, while in evidence theory there exists a dual pair of belief and plausibility functions. In some aspects, rough set theory overlaps with evidence theory, but rough set theory uses partitions to specify rough set, lower and upper approximations, and then to capture uncertainty in knowledge representation. In addition, in rough set theory, the basic operation is the intersection of partition, while in evidence theory, the basic operation to combine evidences is the orghogonal sum. However, a more powerful approach can be developed by combing these two theories through expressing belief structures of evidence theory with rough approximation spaces of rough set theory.

From the above comparison between rough set theory and statistical methods, fuzzy sets, evidence theory, we can see that all these methods can handle uncertainty but they have different mechanisms. However, it does not mean rough set are competing with them. In fact, they are independent and complementary. The rough set theory has an overlap with them dealing with imperfect knowledge. Recently, many studies have been conducted in combing rough set with some other mathematical techniques such as fuzzy sets, evidence theory and neural networks.

III. The Applications of Rough Set Theory in Civil Engineering

Over last decades, a great number of rough set applications have been reported in various fields [16], such as in environment engineering, business and finance, industry, medical diagnosis, fault diagnosis, intelligent control systems, pattern recognition, information processing. The reference [17] reported a stated-of-the-art view of the literature related rough set application to economic and financial prediction. Since the reference [18] firstly discussed the potential applications of rough set theory in Civil Engineering, recently, much research has been carried out successfully in applying the theory in Civil Engineering, in particular, in the fields of structure engineering, pavement engineering, traffic engineering, transportation engineering, land management, and water resources management. The diversity of applications is described in the following sections.

A. Structure Engineering

The references [19] and [20] presented a learning expert system based on rough set theory for design knowledge acquisition in the area of structural design of wind bracings in tall buildings. In the learning system, rough set theory was used to generate design rules from examples of decisions made by an expert.

The reference [21] proposed an adaptive expert system for preliminary design of wind bracings in steel skeleton structures by using rough set theory as decision rule generator to deal with the subjective evaluation process. The study, as one of the earliest ones rough set applications in civil engineering, indicated that the proposed system might be an effective design tool.

The reference [22] discusses the application of rough set theory to the acquirement of experiential knowledge contained in diagnostic cases. Rough set theory was applied to cases in which experts diagnosed the damage of bridges, and a minimal-decision algorithm was derived that could make diagnoses equivalent to those of the experts.

B. Pavement Engineering

The reference [23] proposed an effective tool for analysis of pavement management system database by using rough set theory, which helped the pavement engineers discover minimal subsets of condition attributes by the induced decision rules considering the uncertainty and imprecision in the database.

The reference [24] also presented a hybrid approach by combining use of rough set and artificial neural networks in concrete-faulting-performance modeling. In the research, rough set theory played a role of reducing the dimension of the pavement database without loss of information, and the reduced database then became the input of ANNs, which improved the model performances.

The reference [25] applied rough set theory as a tool of pavement management system for maintenance and rehabilitation strategy induction. The testing results proved that the theory could remove redundant records to induce the proper maintenance and rehabilitation strategies.

C. Traffic Engineering

The reference [26] developed an intelligent vehicle-highway system approach by using rough set theory to induce decision rules for driving scenarios along an urban rail corridor that can optimize travel time, energy consumption and passenger comfort.

To deal with the hourly traffic volume, the reference [27] discussed and compared the rough and neo-fuzzy neural networks, and demonstrated that rough and neo-fuzzy neurons are complementary. The practical applications of rough-neural networks, rough-fuzzy neural networks and conventional neural networks were proposed in the case study, where rough-neural and rough-fuzzy neural networks both performed better than conventional neural networks. Rough set theory is introduced to neural networks because it can provide semantics structure by generating upper and lower neurons.

The reference [28] presented an effective way to determine the distribution of probability masses by incorporating rough set theory into the Dempster-Shafer approach of event identification at traffic management center. The application of rough set theory demonstrated its role in determining probability masses for every data reporting source as well as its ability of improving the system's stability.

D. Transportation Engineering

The reference [29] applied rough set theory to analyze relevant characteristics of the various transit systems and identified successful classes of funding by interpreting the outputs in terms of minimal sets, core of attributes and decision rules for performance of public transport schemes.

The reference [30] proposed the rough set approach to analyze the database of urban public transport systems in Europe with 22 cases, which could not be dealt with well by conventional statistic methods because of the small samples. The empirical results provided some interesting insights and the decision rules also indicated some latent structure existing in the database.

The reference [31] proposed an integrated evaluation methodology for complex transport policy analysis, in which Rough set approach was a tool for classifying and identifying the most critical decision attributes and providing hierarchical relationships among attributes through the lower and upper approximations.

The reference [32] reported their attempt to apply rough set theory in activity-based modeling by two case studies and discussed the possibilities and constraints of the rough set application.

The reference [33] demonstrated the feasibility of applying rough set theory to find relationships between personal demographic attributes and long distance travel mode choices. The induced decision rules represented the relationships well and also gave promising prediction results.

The reference [34] presented critical success conditions of collaborative methods by applying rough set theory to identify the success conditions of five urban transport planning projects. The rough set approach dealt with the small sample size in the study and output the rules which represented the knowledge in the datasets.

The reference [35] proposed the rough set approach for accident chains exploration by analyzing accidents in multiple dimensions and modeling the accident occurrence. The study identified the redundant condition attribute and the significant condition attributes, and discovered significant decision rules, which may describe the conditions of different accidents.

The reference [36] also adopted rough set theory to derive rules from heterogeneous accident data. The rules were then used to represent all distinct accident patterns and describe the process of accident occurrences.

E. Water Resources Management

The reference [37] proposed a variable precision rough set model to discover decision rules for water demand prediction by considering factors such as weather conditions, day of the week, and so on. The extended approach used the statistical information inherent in the data to handle incomplete and ambiguous training samples.

The reference [38] reported the rough set-based hybrid fuzzy-neural methodology for industrial wastewater treatment, in which rough set together with GA were used to generate fuzzy rules.

The reference [39] proposed a rough set-based forecast model of hydrologic single element medium and long-term by analyzing the historical annual data.

The reference [40] applied rough set theory to discover operating rules of a Sicilian irrigation purpose reservoir from the historical monthly data.

The reference [41] proposed an approach by combing rough set and GIS techniques to assess groundwater vulnerability characteristics in 18 different counties of South Texas. And the approach showed its advantages of clustering counties with similar vulnerability characteristics.

The reference [42] introduced rough set theory into water affairs dispatchment system by reducing the control regulation with the uncertain information in the water affairs dispatchment.

F. Construction, Land and Environment Management

The reference [43] presented a rough set based geographic knowledge discovery methodology to identify the locations at risk of landslides. The rules consisting of optimal condition attributes represented the knowledge which could be used to make land use decisions about locations.

The reference [44] introduced an exploratory application of Rough set theory to productivity analysis. The induced decision rules were used to estimate equipment productivity.

The reference [45] also provided a rule-based predictive model by rough set theory to deal with the uncertainty existing in geographic characteristics of landslide susceptibility. The results proved better predication of landslide susceptibility by rough set theory than by the evidence theory.

The reference [46] proposed a multicriteria analysis with GIS for territory model to integrate multiple actors of land

management, in which rough set theory helped to compute the homogeneity index among the homogeneous zones.

The reference [47] focused on discovering relationships between physical components of landscape and people's evaluative image with a small sample based on rough set theory.

The reference [48] developed an approach on linking people's perceptions and physical components of sidewalk environments by the combination of factor analysis and rough set theory.

The reference [49] illustrated a practical application to extract important construction safety measures from practices of local construction industry by the use of rough set theory.

IV. CONCLUSIONS

The growing volume of information databases presents opportunities for advanced data analysis techniques. As far as rough set theory has been applied in civil engineering, it seems to have provided convenient and often highly accurate solutions to problems. It can be seen that rough set theory may be a promising alternative method to conventional methods. From the applications of rough set theory in civil engineering described above, and other applications in medicine, information science, economics and business [16] [17], many advantages of rough set theory have been found, which are partly listed as follows:

■ It relies on minimal assumption. That is, it uses only the given information and does not require external information, such as probability in statistical methods and grade of membership in fuzzy sets theory.

■ It deals with the problem of uncertainty and vagueness by approximation sets.

■ It accepts both quantitative and qualitative attributes.

■ It can find out the importance of particular attributes in relationships between objects and decisions.

■ It can reduce redundant information existing in objects and attributes.

■ It discovers important facts hidden in data and expresses them in the natural language of decision rules.

■ It creates models of the most representative objects in particular classes of decisions.

■ It may contribute to the minimization of the time and cost of the decision making process.

However, the great majority of civil engineering applications of rough set theory are based on the decision rule induction. The abilities are limited to employment of the theory to solve a wide range of problems. An important trend for rough set applications in civil engineering is to develop hybrid methods, which incorporate rough set and other computational methods such as neural networks, evidence theory, fuzzy set.

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