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Review

Fuzzy Sets Applications in Civil Engineering Basic Areas

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ABSTRACT

Civil engineering is a professional engineering discipline that deals with the design, construction, and maintenance of the physical and naturally built environment, including works like roads, bridges, canals, dams, and buildings. This paper presents some Fuzzy Logic (FL) applications in civil engeering discipline and shows the potential of facilities of FL in this area. The potential role of fuzzy sets in analysing system and human uncertainty is investigated in the paper. The main finding of this inquiry is FL applications used in different areas of civil engeering discipline with success. Once developed, the fuzzy logic models can be used for further monitoring activities, as a management tool.

Keywords: *Fuzzy Sets, Civil Engineering*

İnşaat Mühendisliğinin Ana Konularında Bulanık Küme Uygulamaları

ÖZET

İnşaat mühendisliği, yollar, köprüler, kanallar, barajlar ve yapılar gibi işleri içeren fiziksel ve doğal yapılı çevrenin tasarım, inşa ve bakımı ile uğraşan profesyonel bir mühendislik disiplinidir. Bu çalışma inşaat mühendisliği disiplini içindeki bazı Bulanık Mantık uygulamalarını ve bu alandaki BM'ın potansiyel imkanlarını sunmaktadır. Çalışmada, bulanık mantığın sistem ve insan belirsizliği analizindeki potansiyel rolü araştırılmıştır. Bu incelemenin ana bulgusu, Bulanık Mantık uygulamalarının inşaat mühendisliği disiplininin çeşitli alanlarında başarı ile kullanıldığının tespiti olmuştur. Bir kez geliştirildiklerinde, bulanık mantık modelleri daha çok izleme faaliyetleri için bir yönetim aracı olarak kullanılabilirler.

Anahtar Kelimeler: *Bulanık Kümeler, İnşaat Mühendisliği*

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I. INTRODUCTION

CIVIL engineering is a professional engineering discipline that deals with the design, construction, and maintenance of the physical and naturally built environment, including works like roads, bridges, canals, dams, and buildings [1][2][3]. It is traditionally broken into several sub-disciplines including architectural engineering, environmental engineering, geotechnical engineering, control engineering, structural engineering, earthquake engineering, transportation engineering, forensic engineering, municipal or urban engineering, water resources engineering, materials engineering, wastewater engineering, offshore engineering, facade engineering, quantity surveying, coastal engineering [4], construction surveying, and construction engineering [5]. Civil engineering takes place in the public sector from municipal through to national governments, and in the private sector from individual homeowners through to international companies.

Artificial Intelligence (AI) is the intelligence exhibited by machines or software. It is also the name of the academic field of study which studies how to create computers and computer software that are capable of intelligent behavior. AI research is divided by several technical issues. Some artificial intelligence subfields focus on the solution of specific problems. Others focus on one of several possible approaches or on the use of a particular tool or towards the accomplishment of particular applications. One of the subfields is Fuzzy Logic (FL) [6].

Fuzzy Logic is embodied in a Fuzzy Inference System (FIS) that produces outputs for given inputs by mathematical operations onmembership functions and "IF preconditions THEN consequences" rules. Since themembership functions for a precondition variable usually have gentle edges and neighboring ones overlap, several rules in a fuzzy inference system's rule base may have preconditions matching inputs to some degree and collectively impact outputs. Zadeh pointed out that the guiding principle of fuzzy logic is to exploit the tolerance for imprecision, uncertainty, and partial truth to achieve tractability, robustness, and low solution cost [7]. Fuzzy logic has been applied to many complex problems in construction, such as contractor prequalification for surety bonding [8], evaluation of alternative technology [9], minimum bid markup determination [10], estimating haulers' travel time [11], and project risk assessment [7-12]. Therefore, fuzzy logic appears potentially useful for modeling.

Engineering field acts as platform for the application of fuzzy concepts. It's known that civil engineering field is fundamentally different from other disciplines. It means that the theories never fully satisfy the problem considered. This is because, the civil engineering project is complex and usually large in nature: hence, there will be almost no chance to test the prototype compared to other disciplines. As result, there is uncertainty in application of theoretical solutions. More over, civil engineering problems are constraint satisfaction problems. Fuzzy concepts provide an easy way of dealing with complex problems, because it can be built with fuzzy models containing vagueness and impreciseness in knowledge representation. Hence, it is suited for applications where the ability to model real world design problem in precise mathematical form is difficult [13]

Civil engineering is an art, the practise of which requires the use of scientific knowledge as a basic tool. The engineer has to use considerable judgement in setting up and interpreting his scientific calculations and in making decisions based upon incomplete information. Because a very high safety level is required in civil engineering structures the uncertainty associated with the application of scientific calculations is very crudely and conservatively estimated using traditional methods. Current reliability theory enables a discussion of random parameter uncertainty but in civil engineering,

system uncertainty and the possibility of human error is extremely important and must be included in any reliability calculations [14].

Also by integrating Fuzzy concepts with Genetic Algorithms (GA) or Genetic Programming (GP) and Neural Networks (NN), the complex problems can be more efficiently and effectively solved in order to arrive at optimal soln.

II. METHOD

For the aim of fuzzy logic aplications' provides in civil engineering discipline; there have been made a literature invistigation on different sub-branches of civil engineering. Because of civil engineering is a very large area, this invistigations' scope is determined on the some papers in the Science Situation Index. The research method used for this paper was to launch a comprehensive review of the related literature from 2002 to 2015. The selection of literature was mainly based on the top quality journals in civil engineering and other related fields, which include: Computers and Structures, Computers & Industrial Engineering, Automation in Construction, Expert Systems with Applications, Advances in Engineering Software, International Journal of Sustainable Built Environment, Engineering Geology, Applied Mathematical Modelling, Engineering Structures, Structural Safety, Engineering Failure Analysis, Applied Mathematical Modelling, Information Sciences, Safety Science, Engineering Applications of Artificial Intelligence, Control Engineering Practice, Procedia Computer Science, Minerals Engineering, Acta Mechanica Solida Sinica, Scientia Iranica, Transactions A: Civil Engineering, Applied Soft Computing, Journal of Hydrology, Catena, Journal of Hydro-environment Research, Science of the Total Environment, Transportation Research, Procedia Engineering, Journal of Materials Processing Technology, Engineering Geology, Measurement, Soil Dynamics and Earthquake Engineering, Advances in Space Research, Tunnelling and Underground Space Technology, Journal of Rock Mech Geotech Eng., International Journal of Mining Science and Technology, Res Chem Intermed, Materials Science (Medžiagotyra), Construction and Building Materials, Materials and Design, Computational Materials Science, International Journal of Project Management, Applied Soft Computing. Keywords for searching were "construction", "civil engineering", "dam", "tunnel", "harbor", "bridge" atc. and "fuzzy set," "fuzzy logic," "fuzzy control," and other hybrid fuzzy techniques. These terms were well known of having been used in writing papers on fuzzy techniques. Each studies' aims, methods and findigs are expressed in the result part. An evaluation about the study has made in the conclusion part.

III. RESULTS

In general, civil engineering is concerned with the overall interface of human created fixed projects with the greater world. General civil engineers work closely with surveyors and specialized civil engineers to design grading, drainage, pavement, water supply, sewer service, dams, electric and communications supply. General civil engineering is also referred to as site engineering, a branch of civil engineering that primarily focuses on converting a tract of land from one usage to another. Civil engineers apply the principles of geotechnical engineering, structural engineering, environmental engineering, transportation engineering and construction engineering to residential, commercial,

industrial and public works projects of all sizes and levels of construction. Some findigs of different fuzzy set invistigations about 11 main sub-branches of civil engineering are given below.

A. BRIDGE ENGINEERING

Bridge engineers help vehicles and pedestrians cross rivers, valleys, roads and other obstacles. They are civil engineers who specializes in bridge design and construction. Some design new bridges, while others inspect and plan the rehabilitation of older ones. They work as project managers overseeing the actual bridge construction process. Typically, these engineers are employed by heavy construction and highway construction companies, design and consulting firms and government transportation agencies. A bridge engineer may build a variety of bridges, including cable, truss, arch and suspension bridges, for example. He or she will prepare plans, specifications and cost estimates and, during planning and design, will consider what type of bridge will best meet the needs of the area and how the selected building site will support it. He or she will perform load rating and stress analysis calculations to ensure that the structure can stand up to the weight it will bear and the environmental stresses of the site. This engineer also must take into account local and regional building codes and requirements [15]

D. Degrauwe, G. De Roeck, G. Lombaert's study has the name of Uncertainty quantification in the damage assessment of a cable-stayed bridge by means of fuzzy numbers Cables offer interesting possibilities in bridge design, but are rather susceptible to damage. Since damage in a cable changes its natural vibration frequency, it can be assessed with a vibration-based finite element updating procedure. However, the natural frequency of a cable is also influenced by the temperature, and the measured frequencies are prone to measurement errors. Therefore, it is useful to check the sensitivity of the identified damage with respect to these factors. This paper presents a methodology based on fuzzy numbers to investigate the propagation of measurement errors and uncertainty on the structural temperature throughout the updating procedure [16].

A fuzzy group decision making approach for bridge risk assessment is the name of the study of Ying-Ming Wang, Taha M.S. Elhag. This paper proposes a fuzzy group decision making (FGDM) approach for bridge risk assessment. The FGDM approach allows decision makers (DMs) to evaluate bridge risk factors using linguistic terms such as Certain, Very High, High, Slightly High, Medium, Slightly Low, Low, Very Low or None rather than precise numerical values, allows them to express their opinions independently, and also provides two alternative algorithms to aggregate the assessments of multiple bridge risk factors, one of which offers a rapid assessment and the other one leads to an exact assessment. A case study is investigated using the FGDM approach to illustrate its applications in bridge risk assessment. It is shown that the FGDM approach offers a flexible, practical and effective way of modelling bridge risks [17].

Fuzzy AHP approach for selecting the suitable bridge construction method is Nang-Fei Pan' study. Selecting an appropriate bridge construction method is essential for the success of bridge construction projects. The Analytical Hierarchy Process (AHP) method has been widely used for solving multi-criteria decision-making problems. However, the conventional AHP method is incapable of handling the uncertainty and vagueness involving the mapping of one's preference to an exact number or ratio. This paper presents a fuzzy AHP model to overcome this problem. The proposed approach employs triangular and trapezoidal fuzzy numbers and the α-cut concept to deal with the imprecision inherent to the process of subjective judgment. A case study that evaluates bridge construction methods is presented to illustrate the use of the model and to demonstrate the capability of the model [18].

A fuzzy integrated methodology for evaluating conceptual bridge design, is H. Malekly, S. Meysam Mousavi, H. Hashemi'es invistigation. Choosing the most suitable superstructure is vital for the success of a small to medium-span highway bridge design. Numerous attributes must be considered and evaluated in terms of many different conflicting criteria in the conceptual design of a bridge, leading to a large set of subjective or ambiguous data. Furthermore, integrating experts' knowledge and experiences to make appropriate decisions is a commonly used method. In order to solve this problem, project managers and design engineers need to evaluate their initiative designs carefully and make accurate decisions. For this reason, a systematic decision process for selecting the best design idea by means of a novel integrated optimization-based methodology is proposed. In the first phase, Quality Function Deployment (QFD) is employed for translating the project requirements into design requirements. In the second phase, Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is utilized to select the best superstructure as an alternative, based on the weighted criteria achieved from the first phase. In this study the rating values regarding to each alternative and criteria throughout the phases are described in a fuzzy environment by means of linguistic variables. Finally, a case study is provided to illustrate the implementation process of the integrated methodology for bridge superstructure design. For this purpose, an expert team has been formed to collect and verify the expectations of the project, which located in Tehran, Iran. The results demonstrated that the proposed methodology could be successfully applied in the highway bridge projects as a useful tool to facilitate decision making [19].

Fuzzy modeling of combined effect of winter road maintenance and cyclic loading on concrete slab bridge, is P. Štemberk, W.R.L. da Silva, J. Sy´ korová, J. Bartová's research. The reinforced-concrete slab road bridges in their simplest form are used as a cost-effective solution for local infrastructure in various parts of the world. Since the reinforced concrete slab is the load-carrying element whose upper surface is directly exposed to both road traffic and weather, the integrity of the upper layer of the concrete slab becomes the decisive factor for estimation of durability of these bridges. This paper presents a fuzzy-logic based approach to estimation of stiffness reduction of concrete in the compressed zone of the cross section which takes into account the combined effect of the cyclic loading, freeze–thawing and chloride contamination. The fuzzy logic is used for derivation of numerical relations from available experimental data on the three relevant effects, which can be readily implemented in or used with existing finite element codes. The proposed approach is demonstrated in an example of a model bridge subjected to moderate road traffic and mountainous climatic conditions [20].

Nizar Markiz, Ahmad Jrade's work is Integrating a fuzzy-logic decision support system with bridge information modelling and cost estimation at conceptual design stage of concrete box-girder bridges. Integrating 3D bridge information modelling (BrIM) with construction technologies had inspired many researchers for the past decade. In this study, research objectives are intended to demonstrate the viability of integrating a 3D computer-aided design (3D-CAD) model with a structural analysis application and bridge cost estimation framework without compromising interoperability matters. An integrated model that relates a fuzzy logic decision support system with cost estimation for concrete box-girder bridges is presented. Model development methodology comprises an integrated preliminary cost estimation system (IPCES), and complex quality functions and deployment of a multi-criteria decision making (MCDM) approach. An actual case project is used to validate and illustrate model corresponding estimating capabilities. The proposed model is engineered to enhance existing techniques implemented by bridge stakeholders and designers to prepare cost estimates at the conceptual design stage by taking into consideration box-girder bridge project site preparations, substructure, and superstructure. The proposed model is anticipated to be of major significance to

designers and its contribution resides into the integration of BrIM technologies with cost estimation approaches [21].

B. DAM ENGINEERING

Water resources engineering is concerned with the collection and management of water (as a natural resource). As a discipline it therefore combines hydrology, environmental science, meteorology, geology, conservation, and resource management. This area of civil engineering relates to the prediction and management of both the quality and the quantity of water in both underground (aquifers) and above ground (lakes, rivers, and streams) resources. Water resource engineers analyze and model very small to very large areas of the earth to predict the amount and content of water as it flows into, through, or out of a facility. Although the actual design of the facility may be left to other engineers.

Gao Hongmei, Wang Zhihua, Jin Dandan, Chen Guoxinga, Jing Liping's inquiries is Fuzzy evaluation on seismic behavior of reservoir dams during the 2008 Wenchuan earthquake, China. The post-earthquake rapid risk evaluation on the reservoir dams plays an important role in the emergency danger disposal and reinforcement. The fuzzy Data Envelopment Analysis/Assurance Region (DEA/AR) approach was introduced evaluating the seismic behavior of reservoir dams, in which the seismic risk of dam site, the structure characteristics of reservoir dam, and pre-earthquake state of dams were taken as input variables; in the meantime the seismic crack, leakage and deformation of dams induced by the earthquake were taken as output variables. The proposed DEA/AR approach was adopted to evaluate the seismic behavior of 19 reservoir dams suffered from Wenchuan earthquake in Luojiang County, Sichuan Province. The input and output variable values all originated from the post-earthquake field investigation data. And the weight values of DEA/AR model were determined by the entropy weight method which was able to avoid the interference from subjective consciousness. The evaluation results on the seismic behavior obtained from DEA/AR approach were mainly consistent with those from the experts in the field, which verified that the approach was valid and rational. The proposed DEA/AR approach was based on the objective data and the cognitive ability of the model self to give the evaluation results, which was adaptive for the situation that the seismic behaviors of the reservoir dams were not easy to distinguish. A rankingmethod was recommended to judge the order of quality of seismic behavior of the evaluated reservoir dams. The ranking results could serve for the post-earthquake emergency disposal and reinforcement [22].

Shape optimal design of arch dams using an adaptive neuro-fuzzy inference system and improved particle swarm optimization is D. Hamidian, S.M. Seyedpoor's quest. An efficient methodology is proposed to find the optimal shape of arch dams including fluid–structure interaction subject to earthquake ground motion. In order to reduce the computational cost of optimization process, an adaptive neuro-fuzzy inference system (ANFIS) is built to predict the dam effective response instead of directly evaluating it by a time-consuming finite element analysis (FEA). The presented ANFIS is compared with a widespread neural network termed back propagation neural network (BPNN) and it appears a better performance generality for estimating the dam response. The optimization task is implemented using an improved version of particle swarm optimization (PSO) named here as IPSO. In order to assess the effectiveness of the proposed methodology, the optimization of a real world arch dam is performed via both IPSO–ANFIS and PSO– BPNN approaches. The numerical results

demonstrate the computational advantages of the proposed IPSO–ANFIS for optimal design of arch dams when compared with the PSO–BPNN approach [23].

Vesna Rankovic´, Nenad Grujovic´, Dejan Divac, Nikola Milivojevic´, Aleksandar Novakovic's esseys name is Modelling of dam behaviour based on neuro-fuzzy identification. The radial displacement of one or several points of the dam is an important time-varying behaviour indicator and it is a nonlinear function of hydrostatic pressure, temperature and other unexpected unknown causes. Nonlinear system identification is becoming an important tool which can be used to time-varying behaviour modelling of engineering structures. Identification and prediction of complex nonlinear structural behaviour are complex tasks for which non-parametric models are often used. The objective of this study is to develop a neuro-fuzzy identification model to predict the radial displacement of the arch dam. The ANFIS (adaptive network-based fuzzy inference system) models were developed and tested using experimental data collected during 11 years. Comparing the values predicted by the ANFIS with the experimental data indicates that soft computing models provide accurate results. These models can be applied for prediction of displacement in further studies [24].

F. Salazar, M.A. Toledo, E. Oñate, R. Morán's search is An empirical comparison of machine learning techniques for dam behaviour modelling. Predictive models are essential in dam safety assessment. Both deterministic and statistical models applied in the day-to-day practice have demonstrated to be useful, although they show relevant limitations at the same time. On another note, powerful learning algorithms have been developed in the field of machine learning (ML), which have been applied to solve practical problems. The work aims at testing the prediction capability of some state-of-the-art algorithms to model dam behaviour, in terms of displacements and leakage. Models based on random forests (RF), boosted regression trees (BRT), neural networks (NN), support vector machines (SVM) and multivariate adaptive regression splines (MARS) are fitted to predict 14 target variables. Prediction accuracy is compared with the conventional statistical model, which shows poorer performance on average. BRT models stand out as the most accurate overall, followed by NN and RF. It was also verified that the model fit can be improved by removing the records of the first years of dam functioning from the training set [25].

Yao Ji, Guo H. Huang, Wei Sun' investigation is Risk assessment of hydropower stations through an integrated fuzzy entropy-weight multiple criteria decision making method: A case study of the Xiangxi River. An integrated fuzzy entropy-weight multiple criteria decision making (IFEMCDM) method was proposed and applied to risk assessment of hydropower stations in the Xiangxi River. The IFEMCDM integrates the fuzzy set theory, the entropy weight method and the multiple criteria decision making method within a risk assessment framework. It can quantify uncertainties presented in fuzzy sets and assess multi-criteria decision problems in a more objective manner through avoiding subjective effects on the weights. The detailed computational procedures were provided to illustrate the integration process of the above methods. The performance of IFEMCDM was analyzed in terms of relative closeness and a-cut levels. The comprehensive assessment results demonstrated that, all of the ten hydropower stations can be divided into four degree ranges in accordance with the relative closeness. Most of the hydropower stations along the Gaolan River and the Gufu River would have lower risk. Decision makers can conduct flexible and variable response programs for the ten hydropower stations under different a-cut levels. The application of the IFEMCDM revealed its superiority in solving complicated multi-criteria assessment problems more objectively under fuzzy uncertainty. This study was the first application of the IFEMCDM model to risk assessment of hydropower stations, which indicated that it can also be applied to other environmental problems under uncertainties [26]

Interval risk analysis for gravity dam instability is Huaizhi Su, Zhiping Wen's paper. Fuzziness and randomness are two inseparable uncertainty attributes of most factors influencing stability of gravity dam. Moreover, there is a fuzzy transition from stability status into failure status. Risk analysis and fuzzy mathematics are conducted to evaluate the stability problems of gravity dams, where the process of stability failure is studied as a fuzzy event. Membership functions are used to describe the extent of stability failure risk for gravity dams. The fuzziness of both the design parameters and failure criterion are accordingly eliminated through a transformation by use of the concept of the Level Set. Corresponding analysis procedures are then provided to calculate the fuzzy risk and its probability of the stability failure for gravity dams. Based on a real dam section, a detailed example is further provided to illustrate the proposed risk analysis approach. The results show that it is feasible to apply the present method to analyze the fuzzy risk of stability failure for gravity dams. The modeling approach is sound and the findings do improve the current understanding of this important problem. The conventional risk is a determinate value but the proposed fuzzy risk is an interval value. The obtained conclusions can reflect more reasonably the actual dam engineering [27].

C. RAILWAY ENGINEERING

Transportation engineering is concerned with moving people and goods efficiently, safely, and in a manner conducive to a vibrant community. This involves specifying, designing, constructing, and maintaining transportation infrastructure which includes streets, canals, highways, rail systems, airports, ports, and mass transit. It includes areas such as transportation design, transportation planning, traffic engineering, some aspects of urban engineering, queueing theory, pavement engineering, Intelligent Transportation System (ITS), and infrastructure management.

A fuzzy railroad blocking model with genetic algorithm solution approach for Iranian railways is Masoud Yaghini, Mohsen Momeni, Mohammadreza Sarmadi, Masoud Seyedabadi, Mohammad M. Khoshraftar's probe. In the railway, the fright car classification takes place in the terminals. This classification always imposes a remarkable delay to the movement of the cars from origin to destination. To reduce car handling, it is necessary to group various shipments together with respect to their destination in the railroad blocking plan. In this paper, for the first time, a railroad blocking model with fuzzy travel costs is proposed. In the model, the preferred fuzzy paths are determined by a fuzzy shortest path method. Then, the fuzzy model is transformed into a classic railroad blocking model. The real-life blocking problems are very large with many variables and constraints, and modeling and solving them using commercially available software is very time consuming. Therefore, a solution method based on genetic algorithm is developed. To evaluate the performance of the solution method, several simulated problems are tested and the solutions of genetic algorithm are compared with those of the CPLEX software. The results reveal the algorithm has promising accuracy and computing speed for solving the railroad blocking problem. As a case study, the proposed model for creating the Iranian railway blocking plan is utilized. Iran railways can significantly diminish the some costs and save the time in delivering the loads [28].

Min An, Yao Chen, Chris J. Baker's exploration is A fuzzy reasoning and fuzzy-analytical hierarchy process based approach to the process of railway risk information: A railway risk management system. Risk management is becoming increasingly important for railway companies in order to safeguard their passengers and employees while improving safety and reducing maintenance costs. However, in many circumstances, the application of probabilistic risk analysis tools may not give satisfactory results because the risk data are incomplete or there is a high level of uncertainty involved in the risk data. This article presents the development of a risk management system for railway risk analysis

using fuzzy reasoning approach and fuzzy analytical hierarchy decision making process. In the system, fuzzy reasoning approach (FRA) is employed to estimate the risk level of each hazardous event in terms of failure frequency, consequence severity and consequence probability. This allows imprecision or approximate information in the risk analysis process. Fuzzy analytical hierarchy process (fuzzy-AHP) technique is then incorporated into the risk model to use its advantage in determining the relative importance of the risk contributions so that the risk assessment can be progressed from hazardous event level to hazard group level and finally to railway system level. This risk assessment system can evaluate both qualitative and quantitative risk data and information associated with a railway system effectively and efficiently, which will provide railway risk analysts, managers and engineers with a method and tool to improve their safety management of railway systems and set safety standards. A case study on risk assessment of shunting at Hammersmith depot is used to illustrate the application of the proposed risk assessment system [29].

Aggregation of group fuzzy risk information in the railway risk decision making process is the name of Min An, Yong Qin, Li Min Jia, Yao Chen's work. Railway risk assessment is a hierarchical process where risk information obtained at lower levels may be used for risk assessment at higher levels. Fuzzy analytical hierarchy process (FAHP) is widely used in risk decision making process to solve imprecise hierarchical problems where the risk data are incomplete or there is a high level of uncertainty involved in the risk data, particularly, in the process of railway safety and risk decision making. However, the application of FAHP in risk decision making the risk analysts often face the circumstances where a large number of pairwise comparison matrices have to be established by expert knowledge and engineering judgements. There may be a lack of confidence that all comparisons associated with a railway system are completely justified in a rigorous way. This is particularly true when a complex railway system needs to be analysed or when subjective judgements should be involved. This paper presents a modified FAHP approach that employs fuzzy multiplicative consistency method for the establishment of pairwise comparison matrices in risk decision making analysis. The use of the proposed method yields a higher level of confidence that all of comparisons associated with the system are justified. In the meanwhile, the workload in determining the consistency of the judgements can be reduced significantly. A case example is used to demonstrate the proposed methodology. The results indicate that by using the proposed method, risks associated with a railway system can be assessed effectively and efficiently, and more reliable and accurate results can be obtained [30].

A fuzzy knowledge-based system for railway traffic control is Alexander Fay's investigation. Modern train traffic systems have to ful®ll high requirements on service reliability and availability. This becomes especially important with competitive transport markets. Train operators can only meet these requirements by quickly developing an efficient action in case of traffic disturbances. This paper describes a dispatching support system for use in railway operation control systems. It also contains expert knowledge in fuzzy rules of the ``IF-THEN" type. Various methods have been proposed for the representation of this kind of knowledge and for reasoning on this base. Expert systems can gain significant success by incorporating fuzzy knowledge and a graphical means of description. The paper describes a Fuzzy Petri Net notion that combines the graphical power of Petri Nets and the capabilities of Fuzzy Sets to model rule-based expert knowledge in a decision support system. Using this approach, a knowledge base is easy to design, analyze, test, enhance, and maintain. An assistant system for train traffic control is presented, and the advantages of this Fuzzy Petri Net notion are shown in the context of application in train traffic control decision support [31].

A high speed railway control system based on the fuzzy control method is the name of W.Y. Liu, J.G. Han, X.N. Lu's study. This paper proposed a high-speed railway control system based on the fuzzy control method. The fuzzy control system of the high-speed railway is designed in the Matlab software according to the expert experience and knowledge. At first the input and output variables have been fuzzified in the fuzzification process. Then the membership function is designed and the control rules are discussed in detail bring into correspondence with expert knowledge. The parameters discussion about the maximum speed and traction effort are studied in detail. Finally, the defuzzify process can output the results directly to control the high speed railway train. The results indicated that the fuzzy control system is effective and accurate in the high speed railway control process [32].

J. Chen, C. Roberts, P. Weston's probe is Fault detection and diagnosis for railway track circuits using neuro-fuzzy systems. Railways are expected to operate with ever increasing levels of availability, reliability, safety and security. One way of ensuring high levels of dependability is through the use of condition monitoring systems. This paper presents the results of research on fault detection and diagnosis methods for railway track circuits. The proposed method uses a hybrid quantitative/qualitative technique known as a neuro-fuzzy system. Such a hybrid fault detection and diagnosis system combines the benefits of both fuzzy logic and neural networks, i.e. the ability to deal with system imprecision and to learn by neural network training processes. It is shown that the proposed method correctly detects and diagnoses the most commonly occurring track circuit failures in a laboratory test rig of one type of audio frequency jointless track circuit [33].

Decision support model for automated railway level crossing system using fuzzy logic control, is L. N. Pattanaika, Gaurav Yadav's study. This paper aims to discuss a decision support model for automated railway level crossing (LC) using fuzzy logic control (FLC) for providing robust decision making at unmanned railway level crossings, to save the overall operation time, to avoid any accidental fatalities, and to eliminate human errors. The decision support model proposed here provides intelligent decisive action signals as similar to a human brain (e.g. during arrival and departure of trains at railway level crossing). FLC model is designed which recognizes the events (i.e. arrival and departure of trains) and accordingly output action signals are generated (i.e. to warning siren, control actions for opening and closing of gates). This type of model can be implemented in unmanned railway level where the chances of accidents are higher and reliable control operation is required. Three primary inputs to the specified model are considered based on visual, acoustic, and vibration. This novel system makes use of all these three parameters as input for its decision taking parameters, which increases the robustness of this model as compared with previously proposed models where the input is dependent on a single event. The FLC structure implemented to generate this model is multiple input multiple output (MIMO) system [34].

D. STRUCTURAL ENGINEERING

Structural engineering is concerned with the structural design and structural analysis of buildings, bridges, towers, flyovers (overpasses), tunnels, off shore structures like oil and gas fields in the sea, aerostructure and other structures. This involves identifying the loads which act upon a structure and the forces and stresses which arise within that structure due to those loads, and then designing the structure to successfully support and resist those loads. The loads can be self weight of the structures, other dead load, live loads, moving (wheel) load, wind load, earthquake load, load from temperature change etc. The structural engineer must design structures to be safe for their users and to successfully fulfill the function they are designed for (to be serviceable). Due to the nature of some loading

conditions, sub-disciplines within structural engineering have emerged, including wind engineering and earthquake engineering.[35]

Design considerations will include strength, stiffness, and stability of the structure when subjected to loads which may be static, such as furniture or self-weight, or dynamic, such as wind, seismic, crowd or vehicle loads, or transitory, such as temporary construction loads or impact. Other considerations include cost, constructability, safety, aesthetics and sustainability.

Application of fuzzy logic approach in predicting the lateral confinement coefficient for RC columns wrapped with CFRP, is Bilge Doran, Kaan Yetilmezsoy, Selim Murtazaoglu's exploration. Worldwide ageing infrastructures which are vulnerable to seismic lateral loads and located in high seismicity regions have arrested the interest of many researchers to find alternative materials and techniques to strengthen in bending and shear, for example reinforced concrete (RC) beams, slabs, columns, etc. There are several strengthening/repair techniques and materials in literature. Although the method of strengthening concrete structures with fiber reinforced polymers (FRP) is a relatively new technique, it has existed for more than two decades. In this context, several confinement models have been developed for FRP-confined concrete for the prediction of stress–strain response and several researchers have developed various constitutive models to measure the increase in the axial strength of concrete due to the confinement effect of FRP laminates. In this study, RC columns wrapped with carbon FRP (CFRP) considering some existing confinement models in the literature have been investigated. Moreover, based on the experimental data set in the literature, a new artificial intelligence-based algorithm (a Mamdani-type fuzzy inference system) was implemented to model the strength enhancement of CFRP confined RC columns using fuzzy logic methodology. Fuzzy logic predicted results were compared with the outputs of a non-linear regression analysis-based exponential model derived in the scope of the present work. The best predictive performances of the models were assessed by means of various descriptive statistical indicators. The comparison of the proposed prognostic approach with existing empirical and experimental data exhibits a very good precision of the developed artificial intelligence-based model in predicting the lateral confinement coefficient in CFRP wrapped RC columns [36]

Felipe Núñez, Luis Tapia, Aldo Cipriano's inquiries is Hierarchical hybrid fuzzy strategy for column flotation control. Column flotation is widely used in the concentration of low grade ores. Often column flotation concentrate is the final product of a very complex circuit, and therefore control of the metallurgical performance has direct impact in the plant performance. Several control schemes has been implemented for the stabilization of column flotation process, including decentralized control, model predictive control and fuzzy approaches, which attempt to control froth depth, water bias and air holdup. At the same time many efforts have been oriented to improve process instrumentation, with the aim of providing better measurements for control purposes. Instrumentation improvements have made feasible the design of strategies focused on recovery and concentrate grade control. In this work we present the design and implementation of a new advanced controller for column flotation process. The controller was implemented in a 10 columns cleaning stage following a hierarchical scheme with two control levels: an improving level with the aim of metallurgical performance control of the whole process, and a stabilizing level in charge of the distribution of control actions in each column. The controller design was made based on a hybrid scheme with three different operation scenarios, defined by a recovery–concentrate grade domain partition. Results show that the controller is able to keep the process in the normal operation scenario 80% of the analyzed time; on the other hand, when the process was operated only with local control it achieved the normal operation scenario 43% of the analyzed time. Results also show that the controller is capable of increasing concentrate grade and

recovery mean values, despite variations on feed grade; while reducing recovery and concentrate grade standard deviations [37].

Neuro Fuzzy Model Forpredictingthe Dynamic Characteristicsof Beams, is Imad O. Bachi, Nabeel Abdulrazzaq, Zeng He's work. An adaptive neuro-fuzzy inference system (ANFIS) is introduced to predict the dynamic behavior of beams. The effects of axial forces and large displacements are considered in the analysis. A database of tests for the dynamic characteristics of beams is developed from the experimental tests. The responses of nonlinear vibration force for the single and multiple-stepped beams are calculated from the finite element method (FEM), experimental tests and neuro-fuzzy model for comparison. The neuro-fuzzy model provides a general framework for the combination of neural networks and fuzzy logic. It is more flexible with more options of incorporating the fuzzy nature of the real-world system and is an useful estimation tool for the dynamic characteristics of beams. Therefore, ANFIS can be a useful tool for dynamic behaviour analysis of multiple-stepped beams subjected to axial loads and large displacement [38].

Neuro-fuzzy modeling of rotation capacity of wide flange beams, is Abdulkadir Cevik's study. This study is a pioneer work that investigates the feasibility of neuro-fuzzy (NF) approach for the modeling of rotation capacity of wide flange beams. The database for the NF modeling is based on experimental studies from literature. The results of the NF model are compared with numerical results obtained by a specialized computer programme and existing analytical and genetic programming based equations. The results indicate that the proposed NF model performs better. By using the proposed NF model, a wide range of parametric studies are also performed to evaluate the main effects of each variable on rotation capacity [39].

Prediction of shear strength of FRP reinforced concrete beams using fuzzy inference system is Kourosh Nasrollahzadeh, Mohammad M. Basiri's investigation. The objective of this paper is to develop a more accurate and reliable alternative method using fuzzy inference system (FIS) to predict the shear strength of FRP-reinforced concrete beams. Such an accurate model, which can lead to an economical use of FRP reinforcement, is in high demand since existing design provisions for shear capacity of FRP-RC beams are either very conservative or even inadequate mainly due to two factors. Firstly, the current design codes follow the conventional assumption of superposition of concrete plus stirrup contribution to the shear strength, hence ignoring any interaction between shear resisting mechanisms. Secondly, the current design guidelines simply assume that some modified versions of the shear design equations which are empirically derived for steel-reinforced concrete beams can be easily extended to cover FRP-RC beams although the guidelines vary greatly in the manner they modify the equations. Given very different properties of FRP as compared to those of steel, such an assumption, however, needs to be examined and validated. To relax both of these assumptions, the FIS approach offers an attractive solution because it does not require a priori information. As a result, the proposed FIS model compares favorably with a large data base containing the test results of 197 FRP-RC beams assembled from literature. Moreover, the proposed FIS model outperforms the latest design provisions for shear strength of FRP-RC beams, namely ACI 440-06 and CSA S806-02. Also, a special attention is paid to differentiate between shear-compression mode and shear-tension mode of failure, which are the two common types of shear failure for FRP-RC beams with FRP stirrups. In light of the proposed FIS model, modifications to the shear-compression resistance provided by the considered design guidelines are recommended [40].

Kemel Sarp Arsava, Yeesock Kim, Kyu Han Kim, Bum-Shick Shin's study has the name Smart fuzzy control of reinforced concrete structures excited by collision-type forces. The purpose of this study is

to develop a smart controller for energy dissipation and damage mitigation of collision-excited reinforced concrete structures. This study is the first attempt to apply fuzzy logic theory to smart reinforced concrete structures equipped with MR dampers under collision forces for structural impact hazard mitigation. The parameters of the fuzzy controller are optimized using a backpropagation neural network. To train the fuzzy controller, a number of experiments were conducted using a smart reinforced concrete beam under a variety of impact loads. The smart reinforced concrete beam is equipped with a magnetorheological (MR) damper, accelerometers, linear variable differential transformer (LVDT), strain gages, and a voltage–current converter. It is implemented using National Instruments hardware with the LabView software. A proportional integral derivative controller (PID) is used as a baseline. It was shown from the comparisons of the fuzzy with the PID controllers that the smart fuzzy controller is an effective way to mitigate the complex impact response of reinforced concrete structures employing an MR damper [41].

Prediction of shear strength of reinforced concrete beams using adaptive neuro-fuzzy inference system and artificial neural network is J. Amani, R. Moeini's search. In this paper, the Artificial Neural Network (ANN) and the Adaptive Neuro-Fuzzy Inference System (ANFIS) are used to predict the shear strength of Reinforced Concrete (RC) beams, and the models are compared with American Concrete Institute (ACI) and Iranian Concrete Institute (ICI) empirical codes. The ANN model, with Multi-Layer Perceptron (MLP), using a Back-Propagation (BP) algorithm, is used to predict the shear strength of RC beams. Six important parameters are selected as input parameters including: concrete compressive strength, longitudinal reinforcement volume, shear span-to-depth ratio, transverse reinforcement, effective depth of the beam and beam width. The ANFIS model is also applied to a database and results are compared with the ANN model and empirical codes. The first-order Sugeno fuzzy is used because the consequent part of the Fuzzy Inference System (FIS) is linear and the parameters can be estimated by a simple least squares error method. Comparison between the models and the empirical formulas shows that the ANN model with the MLP/BP algorithm provides better prediction for shear strength. In adition, ANN and ANFIS models are more accurate than ICI and ACI empirical codes in prediction of RC beams shear strength [42].

Sunjai Nakshatharan, K. Dhanalakshmi, D. Josephine Selvarani Ruth's study is Fuzzy based sliding surface for shape memory alloy wire actuated classical super-articulated control systems. This paper presents the experimental study on a system which is an interesting crossover between astandard benchmark control problem and a smart material. The study represents the effect of stress, strainand temperature over bandwidth of antagonistic shape memory alloy (SMA) and its relative performancein influencing the stability of the system. The experiment is implicated on an underactuated open loopunstable ball and beam system, designed and developed to be driven by SMA. A proportional derivativecontroller cascaded with sliding mode controller (SMC) based on simplified fuzzy adaptive sliding surfaceis considered to study the dynamics of the system. The designed simplified fuzzy based sliding surfacecontroller is able to balance the ball and beam system around its equilibrium state, which as a controlperspective shows that performance of this controller is better than the conventional SMC. Furthermorefrom smart material perspective decisive results are arrived to handle the issues like stability, speed ofoperation and performance of antagonistic SMA [43].

E. HYDROLIC AND HYDROLOGY ENGINEERING

Hydraulic engineering is concerned with the flow and conveyance of fluids, principally water. This area of civil engineering is intimately related to the design of pipelines, water supply network, drainage facilities (including bridges, dams, channels, culverts, levees, storm sewers), and canals.

Hydraulic engineers design these facilities using the concepts of fluid pressure, fluid statics, fluid dynamics, and hydraulics, among others.

A comparative study of fuzzy logic systems approach for river discharge prediction, is the name of A.W. Jayawardena, E.D.P. Perera, Bing Zhu, J.D. Amarasekara, V. Vereivalu's studty. In recent years, flood disasters resulting from extreme rainfall have been on the increase in many regions of the world. In developed countries, the usual practice of mitigating flood disasters is by structural means which can reduce infrastructural damages as well as casualties but are unaffordable in most developing countries. The alternative then is to look for non-structural means that involve, among other things, early warning systems which can reduce casualties. The basic technical components of an early warning system involves a measurable input data set that trigger floods, a measurable output data set that quantify the extent of flood and an appropriate mathematical model that transforms the input data set into a corresponding output data set. There are many types of mathematical models that can be used to transform the input data into corresponding output data. The crux of this paper is on one type of data driven mathematical models, namely the use of fuzzy logic approach. The reliability and robustness of the approach are demonstrated with daily and 6-hourly discharge predictions in 4 rivers in 3 countries having contrasting climatological, geographical and land use characteristics. The first application is for two tropical rivers in Sri Lanka using daily upstream rainfall and discharge data to predict downstream discharge with the minimum implication function type Mamdani fuzzy inference system. The second application is for another tropical river in Fiji using similar type of data with daily and 6-h time scales. Both Mamdani type fuzzy inference system with minimum and product implication functions as well as Larsen type inference systems were used. In the third application, daily upstream and tributary discharges were used to predict downstream discharges in a temperate-climate river in China using the TSK type fuzzy inference system with clustering. The methods are robust and the results obtained are within reasonable agreement with observations [44].

Risk assessment for transboundary rivers using fuzzy synthetic evaluation technique, is the name of Subash P. Rai, Nayan Sharma, A.K. Lohani's essey. Large scale urbanization has resulted in greater withdrawals of shared waters and this withdrawal has been largely dependent on the hegemony of the riparian's. The last few decades has seen the upward surge of many countries in terms of development as well as hegemony. Existing structures of established water sharing framework typically evaluate only parameters related to historic water use such as historic water demand and supply, contribution to flow, and hydrology. Water conflicts and cooperation is affected by various issues related with development and hegemony. Characterization and quantification of development and hegemony parameters is a very complex process. This paper establishes a novel approach to predict river basins at risk; the approach addresses the issue of water conflict and cooperation within a methodologically more rigorous predictive framework. Fuzzy synthetic evaluation technique is used in this paper to undertake the risk assessment of international transboundary rivers. In this paper the fuzzy domain of risk consists of two fuzzy sets – hegemony and development, indices of which are developed with the help of fuzzy synthetic evaluation techniques. Then the compositional rule-base is framed to ascertain the fuzzy risk. This fuzzy risk can be further used to prioritize all the international river basins which can help in the identification of potentially high risk basins. Risk identification of international river basins is not only scientifically valuable, but also practically highly useful. Identifying those basins that are likely to be particularly prone to conflict or cooperation is of high interest to policy makers [45].

Xiaolong Song, Yuchuan Bai'es paper is A new empirical river pattern discriminant method based on flow resistance characteristics. A new empirical river pattern classification system is established based

on the generalization of the famous Darcy–Weisbach equation. A parameter representing river shape is derived and defined as the river pattern discriminant criteria. After transformation, a couple of discriminant thresholds are determined and expressed as dimensionless forms relating the resistance factor to the relative roughness factor of the channel, which reflect the integrative effects of channel slope, sediment size, bank strength and channel geometry. A threshold function is used to separate single-thread channels (including straight and meandering) from multi-thread channels, and another one is employed to distinguish stable and unstable multi-thread channels (i.e., anabranching and braided) in this paper. A novel bank strength impact factor (μ) is proposed and turns out to be rather representative. Some channel patterns are reasonably redefined using this method. Analysis of various data sets reveals that riparian vegetation condition is a sensitive part of this classification system, in particular for single-thread channels, but not braided channels, because an overlarge width–depth ratio (W/d) could strongly weaken this impact. The definition of anabranching and braided channels herein is actually consistent with the traditional braided channels to some extent. It is also trustworthy that transient anabranching or braiding pattern could occur in a single-thread typical zone following external disturbance, but would eventually return to dynamic equilibrium state. Despite some potential limitations in the construction mechanism, the proposed discriminant method is supported by the selected existing datasets and could effectively distinguish three distinct types of channels by just a few river hydraulic parameters [46].

Edangodage Duminda Pradeep Perera, Livia Lahat's exploration is Fuzzy logic based flood forecasting model for the Kelantan River basin, Malaysia. Among other flood forecasting tools, fuzzy logic is one of a simple and flexible approach which can be implemented in river basins where adequate hydrologic data is available and not good enough to use in a more sophisticated model. This paper assesses the potential of fuzzy logic approach for real time flood forecasting using the minimum implication function type Mamdani fuzzy inference system by applying the model to the Kelantan River basin in Malaysia. The developed models were tested for forecasting the downstream water levels of Guilemard and Kuala Krai stations using upstream hourly telemetric water levels of Dabong and Tualang stations. The membership functions (MFs) of triangular shapes with several fuzzy rule sets were utilized to check the efficiency of the fuzzy logic approach for the Kelantan River flood forecasting. For the Guilemard station, models of 8, 10 and 15 rules' sets were tested. In the calibration and validation events, the Guilemard station models' achieved MAE, ranges 0.35e0.45 m, NeS coefficient, ranges 0.87 e 0.89 and Coefficient of Determination ranges, R2 ranges 0.91e0.95. The water level prediction model developed for the Kuala Krai station consisted of 19 rules with triangular shape MFs. It shows the ranges for MAE: 0.26e0.76 m, NeS coefficient: 0.78e0.93 and R2: 0.91e0.96 in calibration and validation periods. The efficiencies of the developed models show acceptable levels according to the tested performance indicators implying the potential of establishing a flood forecasting system by using the fuzzy logic approach in the Kelantan River basin, Malaysia [47].

M. Pourtousi a, J.N. Sahu, P. Ganesana, Shahaboddin Shamshirband, Ghufran Redzwan's study has the name of A combination of computational fluid dynamics (CFD) and adaptive neuro-fuzzy system (ANFIS) for prediction of the bubble column hydrodynamics. This paper shows a combination of computational fluid dynamics (CFD) and adaptive neuro-fuzzy inference system (ANFIS) to propose a newviewpoint formultiphase flowmodeling, including the accuracy of soft computing techniques in the prediction of a three dimensional (3D) bubble column reactor. Since there are some difficulties (i.e., high computational time in numerical methods and expensive equipment in experimental techniques) in predicting bubble column reactors, particularly at different column locations and various operation conditions, soft computingmethods can be developed as a favorable replacement for conventional measurement and prediction techniques. This study employs CFD beside the

ANFISmethod to simulate the bubble column hydrodynamics for homogeneous regime. Existing experimental, numerical and correlation results in the previous studies have been used to validate the implementation of the current CFD investigation. The liquid velocity, turbulent kinetic energy and gas hold-up (air volume fraction) have been used as input training data in the ANFIS model. The ANFIS results have been also compared with the CFD results, using root-mean-square error (RMSE), coefficient of determination (R2) and Pearson's coefficient (r). Both CFD and ANFIS prediction methods illustrate that, towards the bubble column center, the gas hold-up is higher than wall regions. The results show that ANFIS is a robust method to predict bubble column hydrodynamics properties [48].

F. HIGHWAY ENGINEERING

Highway engineering is an engineering discipline branching from civil engineering that involves the planning, design, construction, operation, and maintenance of roads, bridges, and tunnels to ensure safe and effective transportation of people and goods.[49-51] Highway engineering became prominent towards the latter half of the 20th Century after World War 2. Standards of highway engineering are continuously being improved. Highway engineers must take into account future traffic flows, design of highway intersections/interchanges, geometric alignment and design, highway pavement materials and design, structural design of pavement thickness, and pavement maintenance.[50]

Decentralized adaptive fuzzy control for a class of large-scale MIMO nonlinear systems with strong interconnection and its application to automated highway systems, is the name of Yi-Shao Huang, Zhen-Yu Wang's study. In the previous work of Huang et al., a decentralized adaptive fuzzy controller of large-scale multiple-input multiple-output nonlinear systems is obtained predicated upon the assumption that the interconnections between subsystems can be bounded by first-order polynomials. In this note, we focus in the absence of the conservative assumption upon developing a novel decentralized adaptive fuzzy control scheme. In virtue of fuzzy systems and a regularized inverse matrix, the developed control scheme not only addresses controller singularity under an overall design framework but also copes with interconnections with arbitrary nonlinear bounds. The resulting closed-loop large-scale system is proved to be asymptotically stable. The controller design is applicable to an automated highway system, and simulation results confirm its practical usefulness [52].

Using fuzzy logic analysis for siting decisions of infiltration trenches for highway runoff control, is Seo Jin Ki, Chittaranjan Ray's work. Determining optimal locations for best management practices (BMPs), including their field considerations and limitations, plays an important role for effective stormwater management. However, these issues have been often overlooked in modeling studies that focused on downstream water quality benefits. This study illustrates the methodology of locating infiltration trenches at suitable locations from spatial overlay analyses which combine multiple layers that address different aspects of field application into a composite map. Using seven thematic layers for each analysis, fuzzy logic was employed to develop a site suitability map for infiltration trenches, whereas the DRASTIC method was used to produce a groundwater vulnerability map on the island of Oahu, Hawaii, USA. In addition, the analytic hierarchy process (AHP), one of the most popular overlay analyses, was used for comparison to fuzzy logic. The results showed that the AHP and fuzzy logic methods developed significantly different index maps in terms of best locations and suitability scores. Specifically, the AHP method provided a maximumlevel of site suitability due to its inherent aggregation approach of all input layers in a linear equation. The most eligible areas in locating infiltration trencheswere determined from the superposition of the site suitability and groundwater vulnerability maps using the fuzzy AND operator. The resulting map successfully balanced

qualification criteria for a low risk of groundwater contamination and the best BMP site selection. The results of the sensitivity analysis showed that the suitability scores were strongly affected by the algorithms embedded in fuzzy logic; therefore, caution is recommended with their use in overlay analysis. Accordingly, this study demonstrates that the fuzzy logic analysis can not only be used to improve spatial decision quality along with other overlay approaches, but also is combined with general water quality models for initial and refined searches for the best locations of BMPs at the sub-basin level [52].

Prioritizing highway safety improvement projects: A multi-criteria model and case study with Safety Analyst, is Jie Yu, Yue Liu's probe. This paper presents a multi-criteria model for prioritizing highway safety improvement projects, in which a set of criteria related to the project's technical, economic, and social impacts are properly weighted in consideration. The proposed model features an Analytical Hierarchy Process (AHP) framework to tackle the multi-criteria decision making problem. Different from the conventional AHP, this paper adds a fuzzy scale level between the criteria level and the alternative level, which offers the advantage of preventing the vagueness and uncertainty on judgments of the decision-maker(s). Such a unique modeling feature is further embedded with a non-linear optimization formulation to maximize the consistency in pair-wise comparison and weight estimation for each criterion. Case study results reveal that the proposed model is efficient not only for selecting the most suitable project for a specific site, but also for determining the priorities for implementing those suitable projects among multiple sites given the budget constraint. Comparative study between the proposed model and the existing ranking methods has also indicated its capability to capture the comprehensive impacts of all contributory factors which have been neglected by most existing single multi-criteria approaches during the safety project selection process. The clarity of model inputs, ease of synthesizing the final score of each candidate project, and the interpretation of results with respect to different selection criteria offer its best potential to be used as an effective tool for highway safety managers to assess and refine the safety improvement investments [53].

Sandro Filippo, Paulo Cezar Martins Ribeiro, Suzana Kahn Ribeiro's study is A Fuzzy Multi-Criteria Model applied to the management of the environmental restoration of paved highways. This paper presents a procedure for ranking environmentally valid highway restoration by priority, using a Fuzzy Multi-Criteria Model that supports decisions on which road segments require these works and services. This is a matter of much concern for the Brazilian Government, due to rising awareness of soil degradation and the depletion of plant cover, as accident rates and transport costs rise steadily. The criteria used are: risk of accidents, economic and strategic importance, environmental degradation and the risk of erosion and landslides along the highway. In order to apply the proposed model, an example compares two highway segments, conducting sensitivity analyses through weighting the sub-criteria and criteria [54].

Wu Zhongguang, Shen Ruijun's work is Safety evaluation model of highway construction based on fuzzy grey theory. In the light of factors influencing highway construction safety that have characteristics of fuzziness and uncertainty, combined with the principle of close degree in fuzzy mathematics, a fuzzy grey connection degree is put forward. The evaluation model based on the fuzzy grey relational analysis theory is established and the construction safety evaluation index system is constructed, the weight of each index is determined by Analytic Hierarchy Process (AHP) and the connection degree is also calculated, and then the rank of evaluated highway construction sites is obtained. It is shown that under the condition of mastering the inspection data of actual construction sites, good results can be achieved through application of the model [55].

G. GEOTECHNICAL ENGINEERING

Geotechnical engineering studies rock and soil supporting civil engineering systems. Knowledge from the field of soil science, materials science, mechanics, and hydraulics is applied to safely and economically design foundations, retaining walls, and other structures. Environmental efforts to protect groundwater and safely maintain landfills have spawned a new area of research called geoenvironmental engineering [56, 57]. Identification of soil properties presents challenges to geotechnical engineers. Boundary conditions are often well defined in other branches of civil engineering, but unlike steel or concrete, the material properties and behavior of soil are difficult to predict due to its variability and limitation on investigation. Furthermore, soil exhibits nonlinear (stress-dependent) strength, stiffness, and dilatancy (volume change associated with application of shear stress), making studying soil mechanics all the more difficult [56].

Ground movement analysis in deep iron mine using fuzzy probability theory, is the name of Wen-Xiu Li, Sheng-Jie Liu, Ji-Fei Li, Zhan-Hua Ji, Qi Wang, Xia Yin's study. The analysis of the ground movements due to underground mining operation is one of the many important problems of rock mass mechanics. It is difficult to calculate the ground movement due to deep underground mining of iron ore accurately because of the complexity of the problems. In this paper, the application is described of the fuzzy probability measures to the analysis of ground movements. Based on the definition of the fuzzy probability measure, the theories for the two- and three-dimensional problems are developed and are applied to the analysis of ground movements duo to underground deep underground mining of iron ore [58].

Y.M. Ali, L.C. Zhang's search is Surface roughness prediction of ground components using a fuzzy logic approach. In this paper a total of 16 variables, which are most influential on surface roughness in grinding, are considered. The variables are classified into three groups depending on their significance and effect on surface roughness. A three-layer fuzzy model is used to correlate these variables to surface roughness using the fuzzy rules generated based on experimental observations and recommendations from wheel manufacturers. Membership functions, fuzzy rule bases, and a worked example are presented in detail to demonstrate the strength of fuzzy logic in modeling such a complex system in an efficient manner [59].

H. EARTHQUAKE ENGINEERING

Earthquake engineering involves designing structures to withstand hazardous earthquake exposures. Earthquake engineering is a sub-discipline of structural engineering. The main objectives of earthquake engineering are [60] to understand interaction of structures on the shaky ground; foresee the consequences of possible earthquakes; and design, construct and maintain structures to perform at earthquake in compliance with building codes.

Wenchuan earthquake, China Gao Hongmei, Wang Zhihua, Jin Dandan, Chen Guoxinga, Jing Liping's study is Fuzzy evaluation on seismic behavior of reservoir dams during the 2008. The post-earthquake rapid risk evaluation on the reservoir dams plays an important role in the emergency danger disposal and reinforcement. The fuzzy Data Envelopment Analysis/Assurance Region (DEA/AR) approach was introduced evaluating the seismic behavior of reservoir dams, in which the seismic risk of dam site, the structure characteristics of reservoir dam, and pre-earthquake state of dams were taken as input variables; in the meantime the seismic crack, leakage and deformation of dams induced by the earthquake were taken as output variables. The proposed DEA/AR approach was

adopted to evaluate the seismic behavior of 19 reservoir dams suffered from Wenchuan earthquake in Luojiang County, Sichuan Province. The input and output variable values all originated from the post-earthquake field investigation data. And the weight values of DEA/AR model were determined by the entropy weight method which was able to avoid the interference from subjective consciousness. The evaluation results on the seismic behavior obtained from DEA/AR approach were mainly consistent with those from the experts in the field, which verified that the approach was valid and rational. The proposed DEA/AR approach was based on the objective data and the cognitive ability of the model self to give the evaluation results, which was adaptive for the situation that the seismic behaviors of the reservoir dams were not easy to distinguish. A rankingmethod was recommended to judge the order of quality of seismic behavior of the evaluated reservoir dams. The ranking results could serve for the post-earthquake emergency disposal and reinforcement [61].

P.F. Alvanitopoulos, I. Andreadis, A. Elenas' research is Neuro-fuzzy techniques for the classification of earthquake damages in buildings. The identification of damages produced by severe earthquakes on constructions is important for several reasons such as public safety, economical recourses management, infrastructure and urban planning. After the manifestation of an earthquake, engineers have to evaluate the safety of existing structures and decide the actions to be taken. In this study two techniques are proposed for automatic damage classification in buildings. The inherent information contained in accelerograms is described by 20 seismic parameters. Two classification models of earthquake damages based on artificial neural networks and neuro-fuzzy systems were designed. Furthermore, they were tested for their effectiveness to classify structural, architectural, mechanical–electrical-plumbing and contents damages. The proposed systems were trained and tested with three reinforced concrete frame structures. Results show correct classification rates up to 98%. According to these classification rates these techniques are proven a suitable tool for classification of earthquake damages in structures [62].

Neuro-fuzzy control strategy for earthquake-excited nonlinear magnetorheological structures, is the name of Zhao-Dong Xua, Ying-Qing Guo's study. Magnetorheological (MR) damper is a prominent semi-active control device for earthquake responses mitigation of structures. The most important topic for the intelligent MR structures is choosing the control current of MR dampers quickly and accurately. The typical control strategy is on–off control strategy, i.e. bi-state control strategy, while inherent time-delay and coarse control precision lie in this strategy. This paper proposes neuro-fuzzy control strategy, in which the neural-network technique is adopted to solve time-delay problem and the fuzzy controller is used to determine the control current of MR dampers quickly and accurately. Through comparison between the bi-state control and the neuro-fuzzy control strategies and a numerical example about a three-story reinforced concrete structure, it can be concluded that the control strategy is very important for semi-active control, the neuro-fuzzy control strategy can determine currents of MR dampers quickly and accurately, and the control effect of the neuro-fuzzy control strategy is better than that of the bi-state control strategy [63].

M. Akhoondzadeh's work has the name, An Adaptive Network-based Fuzzy Inference System for the detection of thermal and TEC anomalies around the time of the Varzeghan, Iran, (Mw = 6.4) earthquake of 11 August 2012. Anomaly detection is extremely important for forecasting the date, location and magnitude of an impending earthquake. In this paper, an Adaptive Network-based Fuzzy Inference System (ANFIS) has been proposed to detect the thermal and Total Electron Content (TEC) anomalies around the time of the Varzeghan, Iran, (Mw = 6.4) earthquake jolted in 11 August 2012 NW Iran. ANFIS is the famous hybrid neuro-fuzzy network for modeling the non-linear complex systems. In this study, also the detected thermal and TEC anomalies using the proposed method are

compared to the results dealing with the observed anomalies by applying the classical and intelligent methods including Interquartile, Auto-Regressive Integrated Moving Average (ARIMA), Artificial Neural Network (ANN) and Support Vector Machine (SVM) methods. The duration of the dataset which is comprised from Aqua-MODIS Land Surface Temperature (LST) night-time snapshot images and also Global Ionospheric Maps (GIM), is 62 days. It can be shown that, if the difference between the predicted value using the ANFIS method and the observed value, exceeds the pre-defined threshold value, then the observed precursor value in the absence of non seismic effective parameters could be regarded as precursory anomaly. For two precursors of LST and TEC, the ANFIS method shows very good agreement with the other implemented classical and intelligent methods and this indicates that ANFIS is capable of detecting earthquake anomalies. The applied methods detected anomalous occurrences 1 and 2 days before the earthquake. This paper indicates that the detection of the thermal and TEC anomalies derive their credibility from the overall efficiencies and potentialities of the five integrated methods [64].

Rapid visual earthquake hazard evaluation of existing buildings by fuzzy logic modeling, is Zekai Şen's study. Earthquake hazard assessment of existing buildings is among the most important issues for pre- and post-earthquake warning, preparation, vulnerability, and mitigation works. In any potential earthquake prone area, it is necessary to classify the existing building stoke into different categories according to rapid, simple, reliable, logical and expert view based models and software. This paper presents a soft computation methodology based on the fuzzy logic model (FLM) and system principles for the classification of buildings into five distinctive but mutually inclusive classes in terms of fuzzy sets as ''without", ''slight", ''moderate", ''heavy", and ''complete" hazard categories. The preliminary modeling stages in reinforced concrete building evaluation against possible earthquakes of magnitude seven or over in Istanbul City municipality area are presented with specific emphasis on existing building grading. The essence of this model is the fuzzy logic with its logical rule bases and inference system methodology. Visually assessable variables, namely, storey number, cantilever extension, soft storey, weak storey, building quality, pounding effect, hill-slope effect, and peak ground velocity are considered as inputs with a single output variable as earthquake hazard category. The model inputs and outputs are fuzzified with expert views and logical implications (fuzzy-rules, associations) are proposed between the input variables and output. The application of the proposed model is presented for 1249 existing reinforced concrete buildings on the European side of Istanbul, Turkey. It is found that about 49% of the buildings fall within the ''complete" and ''heavy" hazard categories. Majority of the buildings falls in the ''moderate" hazard category [65].

Supervised fuzzy logic modeling for building earthquake hazard assessment is olso Zekai Şen's study. Building hazard assessment prior to earthquake occurrence exposes interesting problems especially in earthquake prone areas. Such an assessment provides an early warning system for building owners as well as the local and central administrators about the possible hazards that may occur in the next scenario earthquake event, and hence pre- and post-earthquake preparedness can be arranged according to a systematic program. For such an achievement, it is necessary to have efficient models for the prediction of hazard scale of each building within the study area. Although there are subjective intensity index methods for such evaluations, the objective of this paper is to propose a useful tool through fuzzy logic (FL) to classify the buildings that would be vulnerable to earthquake hazard. The FL is a soft computing intelligent reasoning methodology, which is rapid, simple and easily applicable with logical and rational association between the building-hazard categories and the most effective factors. In this paper, among the most important factors are the story number (building height), story height ratio, cantilever extension ratio, moment of inertia (stiffness), number of frames, column and

shear wall area percentages. Their relationships with the five hazard categories are presented through a supervised hazard center classification method. These five categories are ‘‘none’’, ‘‘slight’’, ‘‘moderate’’, ‘‘extensive’’, and ‘‘complete’’ hazard classes. A new supervised FL classification methodology is proposed similar to the classical fuzzy c-means procedure for the allocation of hazard categories to individual buildings. The application of the methodology is presented for Zeytinburnu quarter of Istanbul City, Turkey. It is observed that out of 747 inventoried buildings 7.6%, 50.0%, 14.6%, 20.1%, and 7.7% are subject to expected earthquake with ‘‘none’’, ‘‘slight’’, ‘‘moderate’’, ‘‘extensive’’, and ‘‘complete’’ hazard classes, respectively [66].

Abraham Ahumada, Abdusselam Altunkaynak, Ashraf Ayoub’s quest is Fuzzy logic-based attenuation relationships of strong motion earthquake records. Fuzzy logic techniques have been widely used in civil and earthquake engineering applications in the past four decades. However, no thorough research studies were conducted to use them for deriving attenuation relationships for peak ground accelerations (PGA). This paper is an attempt to fill this gap by employing a fuzzy approach with fuzzy sets for earthquake magnitude and distance from source with the objective of proposing new ground motion attenuation models. Recent earthquake records from USA and Taiwan with magnitudes 5 or greater were used; and consisted of horizontal peak ground acceleration recorded on three different site conditions: rock, soil and soft soil. The use of Fuzzy models to quantify ground motion records, which are typically characterized by a high level of uncertainty, leads to a rational analytical tool capable of predicting accurate results. Testing of the fuzzy model with an independent data set confirmed its accuracy in predicting PGA values [67].

Active control of earthquake excited structures using fuzzy supervisory technique, is Kwan-Soon Park, Hyun-Moo Koh, Seung-Yong Ok’s probe. A fuzzy supervisory technique for the active control of earthquake-excited building structures is studied in this paper. The method has a hierarchical structure, which consists of a supervisor at the higher level and several sub-controllers at the lower level. Each sub-controller is designed to reduce the story-drift of each floor by using an optimal control theory and a fuzzy logic is adopted to obtain a desirable supervisor. A fuzzy supervisor appropriately tunes the predesigned control gains at every moment by estimating the state of a structure through the fuzzy inference mechanism. The improved seismic control performance can be achieved by converting a simply designed static gain into a real-time variable dynamic gain through a fuzzy tuning process. Example designs and numerical simulations of an earthquake excited three-story building are performed to prove the validity of the proposed control strategy [68].

I. TUNNEL ENGINEERING

A tunnel is an underground or underwater passageway, dug through the surrounding soil/earth/rock and enclosed except for entrance and exit, commonly at each end. A pipeline is not a tunnel, though some recent tunnels have used immersed tube construction techniques rather than traditional tunnel boring methods. A tunnel may be for foot or vehicular road traffic, for rail traffic, or for a canal. The central portions of a rapid transit network are usually in tunnel. Some tunnels are aqueducts to supply water for consumption or for hydroelectric stations or are sewers. Utility tunnels are used for routing steam, chilled water, electrical power or telecommunication cables, as well as connecting buildings for convenient passage of people and equipment.Secret tunnels are built for military purposes, or by civilians for smuggling of weapons, contraband, or people. Special tunnels, such as wildlife crossings, are built to allow wildlife to cross human-made barriers safely [69]. Designing and constructing tunnels present some of the most formidable challenges in the field of geoengineering [70].

Ranking of geological risks in mechanized tunneling by using Fuzzy Analytical Hierarchy Process (FAHP), is Hamidreza Nezarat, Farhang Sereshki, Mohammad Ataei's study. Many variables make foundation conditions unpredicted and uncertain in tunnel and underground constructions which could endanger the safety and adversely impact economy of a project. Evaluating and risk assessment of projects such as mechanized tunneling is necessary to manage and respond to the associated risks, hence, identification of risk factors would be required. In this study by contribution of experienced technicians and use of geological study eight (category) levels of risks are considered. Probability and impact factors are used in the ideal risk analysis. Additionally, in this study ideal and some supplementary factors such as uncertainty of estimates and risk manageability are also addressed. Ranking of risks are determined by Multi-Criteria Decision Making (MCDM) techniques like Fuzzy Analytical Hierarchy Process (FAHP). The present research in Golab tunnel is located in the northwest of Esfahan (Iran), shows that squeezing and face tunnel instability have highest level and gas emissions and clogging of clay have the lowest level of risks [71].

Shao-shuai Shi, Shu-cai Li, Li-ping Li, Zong-qing Zhou, JingWang's paper is Advance optimized classification and application of surrounding rock based on fuzzy analytic hierarchy process and Tunnel Seismic Prediction. An advance optimized classification method is proposed to accurate predict the surrounding rock classification based on Fuzzy Analytic Hierarchy Process (FAHP) and Tunnel Seismic Prediction (TSP). Several factors that greatly affect rock mass classification are selected as evaluation indices of FAHP based on analysis of numerous TSP data. Evaluation indices are divided into five grades according to its response characteristics of seismic wave field, and their membership functions are proposed by using frequency statistical method. Comprehensive assigning method is adopted to determine theweights of evaluation indices, and a FAHP model is established for optimized classification of surround rock. Engineering application of Shimenya Tunnel of Yi-Ba Highway is taken as a case study, and proved that the evaluation indices are easy to obtain and the evaluation results are accurate and reliable. The FAHP-TSP method can be further used for other tunnel engineering [72].

Estimation of convergence of a high-speed railway tunnel in weak rocks using an adaptive neuro-fuzzy inference system (ANFIS) approach is the name of A. C. Adoko, Li Wu's essay. Estimation of tunnel diameter convergence is a very important issue for tunneling construction, especially when the new Austrian tunneling method (NATM) is adopted. For this purpose, a systematic convergence measurement is usually implemented to adjust the design during the whole construction, and consequently deadly hazards can be prevented. In this study, a new fuzzy model capable of predicting the diameter convergences of a high-speed railway tunnel was developed on the basis of adaptive neuro-fuzzy inference system (ANFIS) approach. The proposed model used more than 1 000 datasets collected from two different tunnels, i.e. Daguan tunnel No. 2 and Yaojia tunnel No. 1, which are part of a tunnel located in Hunan Province, China. Six Takagi-Sugeno fuzzy inference systems were constructed by using subtractive clustering method. The data obtained from Daguan tunnel No. 2 were used for model training, while the data from Yaojia tunnel No. 1 were employed to evaluate the performance of the model. The input parameters include surrounding rock masses (SRM) rating index, ground engineering conditions (GEC) rating index, tunnel overburden (H), rock density (□), distance between monitoring station and working face (D), and elapsed time (T). The model's performance was assessed by the variance account for (VAF), root mean square error (RMSE), mean absolute percentage error (MAPE) as well as the coefficient of determination (R2) between measured and predicted data as recommended by many researchers. The results showed excellent prediction accuracy and it was suggested that the proposed model can be used to estimate the tunnel convergence and convergence velocity [73].

Mohammadi Mohammada, Hossaini Mohammad Farouq, Mirzapour Bahman, Hajiantilaki Nabiollah's work is Use of fuzzy set theory for minimizing overbreak in underground blasting operations – A case study of Alborz Tunnel, Iran. In order to increase the safety of working environment and decrease the unwanted costs related to overbreak in tunnel excavation projects, it is necessary to minimize overbreak percentage. Thus, based on regression analysis and fuzzy inference system, this paper tries to develop predictive models to estimate overbreak caused by blasting at the Alborz Tunnel. To develop the models, 202 datasets were utilized, out of which 182 were used for constructing the models. To validate and compare the obtained results, determination coefficient (R2) and root mean square error (RMSE) indexes were chosen. For the fuzzy model, R2 and RMSE are equal to 0.96 and 0.55 respectively, whereas for regression model, they are 0.41 and 1.75 respectively, proving that the fuzzy predictor performs, significantly, better than the statistical method. Using the developed fuzzy model, the percentage of overbreak was minimized in the Alborz Tunnel [74].

J. CONSTRUCTION MATERIAL SCIENCE

Materials science is closely related to civil engineering. It studies fundamental characteristics of materials, and deals with ceramics such as concrete and mix asphalt concrete, strong metals such as aluminum and steel, and polymers including polymethylmethacrylate (PMMA) and carbon fibers. Materials engineering involves protection and prevention (paints and finishes). Alloying combines two types of metals to produce another metal with desired properties. It incorporates elements of applied physics and chemistry. With recent media attention on nanoscience and nanotechnology, materials engineering has been at the forefront of academic research. It is also an important part of forensic engineering and failure analysis.

Estimation of the compressive strength of 28-day-old concrete by use of an adaptive cuckoo–fuzzy logic model, is Bahador Abolpour, Ali Mohebbi'es study. In this study, the cuckoo optimization algorithm was used to design a fuzzy logic model for determination of the compressive strength of 28-day-old concrete. Experimental results from 50 concrete mixtures were loaded into the fuzzy logic model for training, and the model was then optimized by use of the cuckoo optimization algorithm. Input variables of the fuzzy logic model are water-tocement weight ratio and coarse aggregate-to-fine aggregate weight ratio; the output variable is concrete compressive strength. The results obtained from the optimized model were compared with those from an adaptive neuro fuzzy inference system model; they were also validated experimentally [75].

Bahador Abolpour, Benafsheh Abolpour, Roozbeh Abolpour, Hossein Bakhshi'es exploration is Estimation of concrete compressive strength by a fuzzy logic model. Concrete mix design is a process of proportioning the ingredients in right proportions. The aim of this study is to design a fuzzy logic model for determination of the compressive strength of a concrete. The datasets which have been loaded into a fuzzy logic model contain 1,030 concrete mixtures. Input fields of the fuzzy expert system are weight percent of cement, water, blast furnace slag, fly ash, super plasticizer, fine aggregate, coarse aggregate, and age of the concrete. Output field is concrete compressive strength. Finally, 897 rules used for this fuzzy logic modeling [76].

Fuzzy Logic Model for Prediction of Properties of Fiber Reinforced Self-compacting Concrete, is the name of Osman Gencel, Cengiz Ozel, Fuat Koksal, Gonzalo Martínezbarrera, Witold Brostow, Hasan Polat's investigation. A fuzzy logic prediction model for fresh and hardened properties of self-compacting concrete (SCC) containingfly ash and polypropylene fibers has been developed. Materials studied experimentally contained 0 %, 10 %, 20 % and 30 wt. % fly ash replacing cement, with four

fiber contents at 3, 6, 9 and 12 kg/m3 in each concrete. Water/cement ratio and superplasticizer content were kept constant at 0.40 % and 1.0 % of cement content, respectively. In our models, properties of fresh and hardened concrete containing fibers, fly ash and cement content were predicted for fresh as well as a function of time for hardened concrete. The results obtained from the fuzzy logic prediction model were compared with the average results of the experiments and were found to be remarkably close to one another. Polypropylene fibers provide a reinforcement, the use of fly ash lowers environmental contamination, while satisfactory properties are obtained [77].

Kadir Güler, Fuat Demir, Ferhat Pakdamar's quest is Stress–strain modelling of high strength concrete by fuzzy logic approach. In this study, a fuzzy approach is presented for modelling of high strength concrete under uni-axial loading. Usually, experimental data cannot be defined by mathematical expressions easily, but the fuzzy approximation enables to describe the data more accurately. The fuzzy logic approach applied to test data of concrete cylinder test is available in the literature. In the present paper the stress–strain behaviour of high strength concrete subjected to axial load is obtained by using the fuzzy logic model. It is shown that the present model can predict the stress–strain behaviour of concrete accurately by taking into account the parameters of the problem. The results are compared with the analytical models given in various studies concerning cylinder tests. The new approach shows that there is no need to obtain different expressions for ascending and descending branches of the stress–strain behaviour [78].

Emadaldin Mohammadi Golafshani, Alireza Rahai, Mohammad Hassan Sebt, Hamed Akbarpour's inquiry is Prediction of bond strength of spliced steel bars in concrete using artificial neural network and fuzzy logic. Artificial neural networks (ANNs) and fuzzy logic (FL) models have been used in many areas of civil engineering applications in recent years. The main purpose of this study is to develop an ANN and FL models to predict the bond strength of steel bars in concrete. For this purpose, the experimental data of 179 different splice beam tests were used for training, validating and testing of the models. The models have six inputs including the splice length, the relative rib area, the minimum concrete cover, ratio of the area of longitudinal tension bars to the effective cross section in the splice region, ratio of the cross-sectional area of stirrups to their spacing in the splice region and concrete compressive strength. The bond strength of steel bars in concrete was the output data for both models. The mean absolute percentage error was found to be less than 6.60% for ANN and 6.65% for FL and R2 values to be about 99.50% and 99.45% for ANN and FL for the test sets respectively. The results revealed that the proposed models have good prediction and generalization capacity with acceptable errors. Meanwhile, in this study the proposed ANN is a slightly more accurate than FL [79].

Fatih Özcan, Cengiz D. Atis, Okan Karahan, Erdal Uncuoğlu, Harun Tanyıldızı have a study, which name is Comparison of artificial neural network and fuzzy logic models for prediction of long-term compressive strength of silica fume concrete. In this study, an artificial neural network (ANN) and fuzzy logic (FL) study were developed to predict the compressive strength of silica fume concrete. A data set of a laboratory work, in which a total of 48 concretes were produced, was utilized in the ANNs and FL study. The concrete mixture parameters were four different water–cement ratios, three different cement dosages and three partial silica fume replacement ratios. Compressive strength of moist cured specimens was measured at five different ages. The obtained results with the experimental methods were compared with ANN and FL results. The results showed that ANN and FL can be alternative approaches for the predicting of compressive strength of silica füme concrete [80].

Fuzzy logic model for prediction of mechanical properties of lightweight concrete exposed to high temperature, is Harun Tanyıldızı's study. In this study, a fuzzy logic prediction model for compressive and splitting tensile strength of lightweight concrete made with scoria aggregate and fly ash after exposed to high temperature was devised. Cement dosages (400 and 500 kg/m3) were used in this study. The mixes incorporating 0%, 10%, 20% and 30% of fly ash were prepared. After being heated to temperatures of 200, 400 and 800 ^{o}C, respectively, the compressive and splitting tensile strength of lightweight concrete was tested. The obtained results with fuzzy logic were compared with the experimental methods and found remarkably close to each other. The results show that the fuzzy logic can be used to predict the compressive and splitting tensile strength of lightweight concrete after exposed to high temperature [81].

İlker Bekir Topçu, Mustafa Sarıdemir's quest is Prediction of mechanical properties of recycled aggregate concretes containing silica fume using artificial neural networks and fuzzy logic. Artificial neural networks and fuzzy logic have been widely used in many areas in civil engineering applications. In this study, the models in artificial neural networks and fuzzy logic systems for predicting compressive and splitting tensile strengths of recycled aggregate concretes containing silica fume have been developed at the age of 3, 7, 14, 28, 56 and 90 days. For purpose of constructing these

models, experimental results for 210 specimens produced with 35 different mixture proportions were gathered from the literature. The data used in the artificial neural networks and fuzzy logic models are arranged in a format of eight input parameters that cover the age of specimen, cement, water, sand, aggregate, recycled aggregate, superplasticizer and silica fume. According to these input, in the artificial neural networks and fuzzy logic models are predicted the compressive and splitting tensile strengths values from mechanical properties of recycled aggregate concretes containing silica fume. In the models of the training and testing results have shown that artificial neural networks and fuzzy logic systems have strong potential for predicting 3, 7, 14, 28, 56 and 90 days compressive and splitting tensile strengths values of recycled aggregate concretes containing silica füme [82].

K. CONSTRUCTION MANAGEMENT

The entire environment of homes, buildings, roads, freeways, bridges, and much more result from the delivery of construction projects. It is the responsibility of the construction engineer and construction manager to deliver these projects in a manner that maximizes value – a quality product at a fair price, safely constructed in a timely fashion. This final step in the development of our infrastructure – construction – is one of the most visible products in all of engineering [83].

Jiuping Xu, Huan Zheng, Ziqiang Zeng, Shiyong Wu, Manbin Shen's investigation is Discrete time–cost–environment trade-off problem for large-scale construction systems with multiple modes under fuzzy uncertainty and its application to Jinping-II Hydroelectric Project. This paper presents a discrete time–cost–environment trade-off problem for large-scale construction systems with multiple modes under fuzzy uncertainty. A multi-objective decision making model is established in which the total project duration is regarded as a fuzzy variable. To deal with the uncertainty, the fuzzy numbers in the model are defuzzified by using an expected value operator with an optimistic–pessimistic index. The objective functions are to minimize the total project cost, project duration, crashing cost, and environmental impact. Furthermore, a fuzzy-based adaptive-hybrid genetic algorithm is developed to find feasible solutions. The one-point crossover and repairing strategy for mutations are designed to avoid infeasible solutions. Finally, the Jinping-II Hydroelectric Project is used as a practical example to demonstrate the practicality and efficiency of the model. Results and a sensitivity analysis are

presented to highlight the performance of the optimization method, which proves to be very effective and efficient compared to other algorithms [84].

Conceptual cost estimates using evolutionary fuzzy hybrid neural network for projects in construction industry, is the name of Min-Yuan Cheng, Hsing-Chih Tsai, Erick Sudjono's study. Conceptual cost estimates are important to project feasibility studies and impact upon final project success. Such estimates provide significant information that can be used in project evaluations, engineering designs, cost budgeting and cost management. This study proposes an artificial intelligence approach, the evolutionary fuzzy hybrid neural network (EFHNN), to improve conceptual cost estimate precision. This approach first integrates neural networks (NN) and high order neural networks (HONN) into a hybrid neural network (HNN), which operates with alternating linear and non-linear neuron layer connectors. Fuzzy logic (FL) is then used in the HNN to handle uncertainties, an approach that evolves the HNN into a fuzzy hybrid neural network (FHNN). As a genetic algorithm is employed on the FL and HNN to optimize the FHNN, the final version used for this study may be most aptly termed an 'EFHNN'. For this study, estimates of overall and category costs for actual projects were calculated and compared. Results showed that the proposed EFHNN may be deployed effectively as an accurate cost estimator during the early stages of construction projects. Moreover, the performance of linear and non-linear neuron layer connectors in EFHNN surpasses models that deploy a singular linear NN [85].

Abel Pinto's work is QRAM a Qualitative Occupational Safety Risk Assessment Modelfor the construction industry that incorporate uncertainties by the use of fuzzy sets. Occupational safety risk assessment is the core of safety practices. Is a complex process that requires the consideration of sundry parameters, which are often difficult to quantify. This paper presents the new developed fuzzy QRAM model, which intends to support construction companies in carrying out their responsibilities to reduce occupational safety risks. The innovative aspects of QRAM model is to embody assess of the safety climate and the safety barriers effectiveness as assessment dimensions and the use of fuzzy sets theory to enhance the use of imprecise and incomplete information, elicited by linguistic variables. The QRAM model was designed based on the best academic and empirical knowledge about safety risks on construction industry, biomechanical data and laws of physics, chemistry and engineering. The lack of credible and accurate data, resulting from the in-depth investigation of work accidents in construction industry was the greatest difficulty in carry-out this work. QRAM was, firstly evaluated by ''peer'' review, with 12 safety experts from Brazil (2), Bulgaria (1), Greece (3), Turkey (3) and Portugal (3) and, then, appraised by comparing QRAM with 2 other occupational safety risk assessment techniques. The safety experts evaluators concluded that: (a) QRAM is a versatile tool to assess occupational safety risk assessment on construction sites; (b) the specific checklists for knowledge elicitation are a good aid and enhance the process objectivity, and (c) the use of linguistic variables is a better way to rate the risk factors thus to render the risk assessment process more objective and reliable [86].

Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies, is Osman Taylana, Abdallah O. Bafailb, Reda M.S. Abdulaala, Mohammed R. Kabli'es study. Construction projects are initiated in dynamic environment which result in circumstances of high uncer-tainty and risks due to accumulation of many interrelated parameters. The purpose of this study is to usenovel analytic tools to evaluate the construction projects and their overall risks under incomplete anduncertain situations. It was also aimed to place the risk in a proper category and predict the level of it inadvance to develop strategies and counteract the high-risk factors. The study covers identifying the keyrisk criteria of construction projects at King Abdulaziz University (KAU), and

assessing the criteria by theintegrated hybrid methodologies.The proposed hybrid methodologies were initiated with a survey for data collection. The relative impor-tance index (RII) method was applied to prioritize the project risks based on the data obtained. Theconstruction projects were then categorized by fuzzy AHP and fuzzy TOPSIS methodologies. Fuzzy AHP(FAHP) was used to create favorable weights for fuzzy linguistic variable of construction projects overallrisk. The fuzzy TOPSIS method is very suitable for solving group decision making problems under thefuzzy environment. It attempted to incorporate vital qualitative attributes in performance analysis ofconstruction projects and transformed the qualitative data into equivalent quantitative measures. Thirtyconstruction projects were studied with respect to five main criteria that are the time, cost, quality, safetyand environment sustainability. The results showed that these novel methodologies are able to assessthe overall risks of construction projects, select the project that has the lowest risk with the contributionof relative importance index. This approach will have potential applications in the future [87].

Contractor selection for construction project, with the use of fuzzy preference relation, is the name of Nabi Ibadova's study. During the phase of investment planning, choice of contractor is one of the most important decisions. One of the methods for assessing competences of contractors applying for the contract is their pre-selection. In the article, author describes algorithm for choice (selection) of contractor. The algorithm is based on fuzzy preference relation. In mathematical point of view, it is based on ordering theory and fuzzy sets theory. The article provides an example of the algorithm used for selection of contractor for construction works. The choice was made basing on criteria such as: reputation, technical capabilities, financial situation and organizational skills [88].

IV. Conclusion

According to the studies which investigated in this perusal, it can be understand that fuzzy logic applications used in different areas of civil engeering discipline with success, like; quantification in the damage assessments of a cable-stayed bridges, bridge risk assessments, selecting suitable bridge construction methods, evaluating conceptual bridge designs, combined effects of winter road maintenances and cyclic loading on concrete slab bridges, bridge information modellings, seismic behaviors of reservoir dams during earthquakes, shape optimal designing of arch dams, modelling of dam behaviours, evaporation from the reservoirs of dams, risk assessments of hydropower stations, reservoir operations, risk analysis for gravity dam instabilities, forecasting sea levels in harbors, crossing railway level system using fuzzy logic control, controlling to full railway vehicle models, railway track circuits, high speed railway controlling, railway traffic controlling, risk information in the railway risk decision making process, rescheduling modelling in a double-track railway network, designing railway risk management systems, making railroad blocking models, new methods for beam-damage-diagnosis, column flotation controls, for predicting the dynamic characteristics of beams, rotation capacities of wide flange beams, shear strength of FRP reinforced concrete beams, reinforced concrete structures excited by collision-type forces, prediction of shear strength of reinforced concrete beams, river discharge predictions, risk assessments for transboundary rivers, flood forecasting models for river basins, coordinating contracts and price dependent demand, supply chain models for long-term contracts, ranking of geological risks in mechanized tunneling, tunnel seismic predictions, estimations of convergence of a high-speed railway tunnels, minimizing overbreak in underground blasting operations in tunnels, analysis for siting decisions of infiltration trenches for highway runoff control, highway safety improvements, time–cost–quality trade-off problems in highway construction projects, management of the environmental restorations of paved

highways, safety evaluation models of highway constructions, ground movement analysis, surface roughness predictions of ground components etc. Once developed, the fuzzy logic models can be used for further monitoring activities, as a predictive management tool.

Fuzzy membership functions and linguistic variables can be particularly employed to suit applications to tackling construction problems facing the aforesaid nature of construction. In addition, hybrid fuzzy techniques, such as neurofuzzy and fuzzy neural network, can be more broadly adopted because they can better solve some construction problems that fuzzy set/fuzzy logic alone may not best suit [89].

Findings and recommendations which given below can be mentioned;

- FL applications, gives very positive results in civil engeering applications.
- A construction project is achieving success with many unknowns at the end of a process. FL offers an appropriate risk management tool in such cases.
- For determining the magnitude of impact of the construction project risks, Analytic Hierarchy Processes' theory of FL's risk analysis and management model has been observed in recent years has become more available.
- Optimization and control of civil engeering problems can be made with FL approach.
- It is often encountered that in construction projects, with the obligation to choose among alternatives. It's understood that it can be used as decision support systems for quantitative decision making methods in choosing from the available alternatives that require cases in acquisition and investment decisions. It has been shown in the examined studies that; in solving the problem of multi-purpose, Fuzzy AHP (Analytical Hierarchy) method with taking into account the uncertainties, to be useful as a tool to provide a solution.
- One of the methods commonly used in multi-criteria decision-making methods of fuzzy TOPSIS method, on multiple criteria-based assessment and decision-makers is a successful method. In addition to use of linguistic variables, it is able to offer a qualitative method.
- Optimization techniques with FL approach would develop decision-making skills in the construction industry.
- An important point for the success of fuzzy model results is; it is essential to have sufficient experience and foresight of the persons concerned (experts) who would realize the application.
- The number of membership functions of the inputs and the number of training epochs should be selected optimally and carefully.

The potential role of fuzzy sets in analysing system and human uncertainty is investigated in the paper. Fuzzy concepts thrown its wide variety of application for the field of civil engineering. Hence, engineers should explore it for its potential application for the problems we face in this engineering world.

V. REFERENCES

[1] Anonymous, https://www.ahdictionary.com/, The American Heritage Dictionary of the English Language, Fourth Edition, Houghton Mifflin Company, 2004 *(accessed: 8th of August, 2007).*

[2] Anonymous, http://www.asce.org/templates/award-detail.aspx?id=616, History and Heritage of Civil Engineering, ASCE, *(Retrieved: 8th of August, 2007).*

[3] Anonymous, https://www.ice.org.uk/, Institution of Civil Engineers What is Civil Engineering (PDF), ICE, *(Retrieved: 22th of September, 2007).*

[4] Anonymous, https://csce.ca/, What is Civil Engineering?, The Canadian Society for Civil Engineering, *(Retrieved: 8th of August, 2007).*

[5] W.C. Oakes, L.L. Leone, C.J. Gunn, *Engineering Your Future*, Great Lakes Press, (2001).

[6] Anonim, https://en.wikipedia.org/wiki/Artificial_intelligence.

[7] L.A. Zadeh, Foreword, *Fuzzy Logic Toolbox for use with MATLAB, User's Guide Version 2*, The Math Works Inc., Natick, MA, (1995).

[8] A. Awad, A.R. Fayek *Automation in Construction* **21** (2012) 89–98.

[9] L.-C. Chao, M.J. Skibniewski *Journal of Construction Engineering and Management* **124 (4)** (1998) 297–304.

[10] L.-C. Chao *Computer- Aided Civil and Infrastructure Engineering* **22(6)** (2007) 449–460.

[11] M. Marzouk, O. Moselhi *Journal of Construction Engineering and Management* **130(6)** (2004) 878–886.

[12] J.H.M. Tah, V. Carr *Construction Management and Economics* **18(4)** (2000) 491–500.

[13] Anonim,http://civil-resources.blogspot.com.tr/2010/06/application-of-fuzzy-concepts-in-civil.html.

[14] D.I. Blockley *Fuzzy Sets and Systems* **2(4)** (1979) 267-278.

[15] Anonim, http://www.wisegeek.org/what-does-a-bridge-engineer-do.htm.

[16] D. Degrauwe, G. De Roeck, G. Lombaert *Computers and Structures* **87(17-18)** (2009) 1077–1084.

[17] Y.-M. Wang, T.M.S. Elhag *Computers & Industrial Engineering* **53(1)** (2007) 137–148.

[18] N.-F. Pan *Automation in Construction* **17(8)** (2008) 958–965.

[19] H. Malekly, S. Meysam Mousavi, H. Hashemi *Expert Systems with Applications* **37(7)** (2010) 4910–4920.

[20] P. Štemberk, W.R.L. da Silva, J. Sy´ korová, J. Bartová *Advances in Engineering Software* **62-63** (2013) 97-108.

[21] N. Markiz, A. Jrade *International Journal of Sustainable Built Environment* **3(1)** (2014) 135–152.

[22] G. Hongmei, W. Zhihua, J. Dandan, C. Guoxinga, J. Liping *Engineering Geology* **197** (2015) 1–10.

[23] D. Hamidian, S.M. Seyedpoor *Applied Mathematical Modelling* **34(6)** (2010) 1574–1585.

[24] V. Rankovic´, N. Grujovic´, D. Divac, N. Milivojevic´, A. Novakovic *Engineering Structures* **35** (2012) 107–113.

[25] F. Salazar, M.A. Toledo, E. Oñate, R. Morán *Structural Safety* **56** (2015) 9–17.

[26] Y. Ji, G.H. Huang, W. Sun *Expert Systems with Applications* **42(12)** (2015) 5380–5389.

[27] H. Su, Z. Wen *Engineering Failure Analysis* **33** (2013) 83–96.

[28] M. Yaghini, M. Momeni, M. Sarmadi, M. Seyedabadi, M.M. Khoshraftar *Applied Mathematical Modelling* **39(20)** (2015) 6114–6125.
[29] M. An, Y. Chen, C.J. Baker *Information Sciences* **181(18)** (2011) 3946–3966.
[30] M. An, Y. Qin, L.M. Jia, Y. Chen *Safety Science* **82** (2016) 18–28.
[31] A. Fay *Engineering Applications of Artificial Intelligence* **13(6)** (2000) 719-729.
[32] W.Y. Liu, J.G. Han, X.N. Lu *Expert Systems with Applications* **40(15)** (2013) 6115–6124.
[33] J. Chen, C. Roberts, P. Weston *Control Engineering Practice* **16(5)** (2008) 585–596.
[34] L. N. Pattanaika, G.Yadav *Procedia Computer Science* **48** (2015) 73–76.
[35] R. Narayanan, A. Beeby, *Introduction to Design for Civil Engineers*, London: Spon, (2003).
[36] B. Doran, K. Yetilmezsoy, S. Murtazaoglu *Engineering Structures* **88** (2015) 74–91.
[37] F. Núñez, L. Tapia, A. Cipriano *Minerals Engineering* **23** (2010) 117–124.
[38] I.O. Bachi, N. Abdulrazzaq, Z. He *Acta Mechanica Solida Sinica* **27(1)** (2014).
[39] A. Cevik *Expert Systems with Applications* **38** (2011) 5650–5661.
[40] K. Nasrollahzadeh, M.M. Basiri *Expert Systems with Applications* **41** (2014) 1006–1020.
[41] K.S. Arsava, Y. Kim, K.H. Kim, B.-S. Shin *Expert Systems with Applications* **42** (2015) 7929–7941.
[42] J. Amani, R. Moeini *Scientia Iranica, Transactions A: Civil Engineering* **19** (2012) 242–248.
[43] S. Nakshatharan, K. Dhanalakshmi, D.J.S. Ruth *Applied Soft Computing* 32 (2015) 580–589.
[44] A.W. Jayawardena, E.D.P. Perera, B. Zhu, J.D. Amarasekara, V. Vereivalu *Journal of Hydrology* **514** (2014) 85–101.
[45] S.P. Rai, N. Sharma, A.K. Lohani *Journal of Hydrology* **519 Part B** (2014) 1551–1559.
[46] X. Song, Y. Bai *Catena* **135** (2015) 163–172.
[47] E.D.P. Perera, L. Lahat *Journal of Hydro-environment Research* 9(4) (2015) 542-553.
[48] M. Pourtousi , J.N. Sahu, P. Ganesana, S. Shamshirband, G. Redzwan *Powder Technology* **274** (2015) 466–481.
[49] M. Rogers, *Highway engineering*, Oxford, UK: Blackwell Science (2002).
[50] C.A. O'Flaherty, *Highways the location, design, construction and maintenance of road pavements (4th ed.)*, Oxford: Butterworth-Heinemann, (2002).
[51] Highway engineering, *McGraw-Hill Concise Encyclopedia of Science and Technology*, New York: McGraw-Hill, 2006, Credo Reference. Web. 13 February 2013.
[52] Y.-S. Huang, Z.-Y. Wang *Information Sciences* **274** (2014) 210–224.
[53] J. Yu, Y. Liu *Safety Science* **50** (2012) 1085–1092.
[54] S. Filippo, P.C.M. Ribeiro, S.K. Ribeiro *Transportation Research Part D* **12** (2007) 423–436.
[55] W. Zhongguang, S. Ruijun *Procedia Engineering* **45** (2012) 64–69.
[56] J.K. Mitchell, *Fundamentals of Soil Behavior (2nd ed*.), John Wiley and Sons, (1993).
[57] A.V. Shroff, D.L. Shah, *Soil Mechanics and Geotechnical Engineering*, Taylor & Francis, (2003).
[58] W.-X. Li, S.-J. Liu, J.-F. Li, Z.-H. Ji, Q. Wang, X. Yin *Applied Mathematical Modelling* **37** (2013) 345–356.
[59] Y.M. Ali, L.C. Zhang *Journal of Materials Processing Technology* **89–90** (1999) 561–568.
[60] W.-F. Chen, C. Scawthorn, *Earthquake Engineering Handbook*, CRC Press, (2003).
[61] W. earthquake, C.G. Hongmei, W. Zhihua, J. Dandan, C. Guoxinga, J. Liping *Engineering Geology* **197** (2015) 1–10.
[62] P.F. Alvanitopoulos, I. Andreadis, A. Elenas *Measurement* **43** (2010) 797–809.
[63] Z.-D. Xua, Y.-Q. Guo *Soil Dynamics and Earthquake Engineering* **28** (2008) 717–727.

[64] M. Akhoondzadeh *Advances in Space Research* **52** (2013) 837–852.

[65] Z. Şen *Expert Systems with Applications* **37** (2010) 5653–5660.

[66] Z. Şen *Expert Systems with Applications* **38** (2011) 14564–14573.

[67] A. Ahumada, A. Altunkaynak, A. Ayoub *Expert Systems with Applications* **42** (2015) 1287–1297.

[68] K.-S. Park, H.-M. Koh, S.-Y. Ok *Advances in Engineering Software* **33** (2002) 761–768.

[69] Anonim, https://en.wikipedia.org/wiki/Tunnel.

[70] Anonim, http://www.schnabel-eng.com/services/tunnel-engineering/.

[71] H. Nezarat, F. Sereshki, M. Ataei *Tunnelling and Underground Space Technology* **50** (2015) 358–364.

[72] Shao-shuai Shi, Shu-cai Li, Li-ping Li, Zong-qing Zhou, J. Wang *Automation in Construction* **37** (2014) 217–222.

[73] A.C. Adoko, L. Wu *Journal of Rock Mech. Geotech. Eng.* **4 (1)** (2012)11–18.

[74] M. Mohammada, H.M. Farouq, M. Bahman, H. Nabiollah *International Journal of Mining Science and Technology* **25** (2015) 439–445.

[75] B. Abolpour, A. Mohebbi *Res. Chem. Intermed* **39** (2013) 4001–4009.

[76] B. Abolpour, B. Abolpour, R. Abolpour, H. Bakhshi *Res. Chem. Intermed* **39** (2013) 707–719.

[77] O. Gencel, C. Ozel, F. Koksal, G. Martínezbarrera, W. Brostow, H. Polat *Materials Science (Medžiagotyra)* **19(2)** (2013).

[78] K. Güler, F. Demir, F.Pakdamar *Construction and Building Materials* **37** (2012) 680–684.

[79] E.M. Golafshani, A. Rahai, M.H. Sebt, H. Akbarpour *Construction and Building Materials* **36** (2012) 411–418.

[80] F. Özcan, C.D. Atis, O. Karahan, E. Uncuoğlu, H. Tanyıldızı *Advances in Engineering Software* **40** (2009) 856–863.

[81] H.Tanyıldızı *Materials and Design* **30** (2009) 2205–2210.

[82] İ.B. Topçu, M. Sarıdemir *Computational Materials Science* **42** (2008) 74–82.

[83] Anonim, http://cce.oregonstate.edu/content/construction-engineering-management.

[84] J. Xu, H. Zheng, Z. Zeng, S. Wu, M. Shen *International Journal of Project Management* **30** (2012) 950–966.

[85] M.-Y. Cheng, H.-C. Tsai, E. Sudjono *Expert Systems with Applications* **37** (2010) 4224–4231.

[86] A. Pinto *Safety Science* **63** (2014) 57–76.

[87] O. Taylana, A.O. Bafailb, R.M.S. Abdulaala, M.R. Kabli *Applied Soft Computing* **17** (2014) 105–116.

[88] N. Ibadova *Procedia Engineering* **111** (2015) 317 – 323.

[89] A.P.C. Chan, D.W.M. Chan, J.F.Y. Yeung *Journal of Construction Engineering and Management* **135(11)** (2009) 1241-1252.