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Research Article

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Planning of airport pavement with artificial intelligence methods

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Highlights

- Artificial intelligence can be used for pavement design
- High regression of 97% has been achieved
- ANFIS generate the pavement design faster

Abstract

Rigid pavements slab thicknesses are determined using readings from design curves where human, reading, and curve mistakes could commonly occur. In addition, readings from these design curves take precious time and need high attention and diligence. In this study, the ANFIS model is developed instead of the traditional curve reading method, which is more practical and timesaving. So, it could decrease the mistakes which are occurring from curve readings. For this purpose, it has produced a random data set. A slab thickness for each data in the set has been determined using design curve readings. Obtained slab thicknesses are used for training the ANFIS model and an alternative method has been obtained. The created model has predicted the slab thicknesses with a regression of 97.05% compared to the slab thicknesses obtained from curve readings.

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1. Introduction

The developments in the aviation sector first gained momentum in and after the 1st World War. It provided war superiority, ensured the smooth and safe transportation of people, soldiers, and equipment in a short time, and continued to progress rapidly on the road opened. This mobility; Along with the emerging problems, research, development, and scientific activities, have increased rapidly. Research and development activities have not focused only on the development of the aircraft to be used. Improvements; flight runways, parking areas (hangars), maintenance and repair units, security systems, and units require the existence of a large facility, and the sustainability of these interconnected systems has also revealed the necessity of ensuring smooth, dynamic, and low-cost sustainability [1-3]. Today, air travel and the necessity of using these facilities are because of military needs, and the intensity of civil aviation is increasing [4]. There are publications in the literature about fuzzy logic applications in airports [5-12].

Gopalakrishnan et al. [13] used an adaptive neural fuzzy inference system (ANFIS) to recalculate the airport's flexible pavement layer modulus. They aimed to explore the feasibility of using ANFIS for the inverse analysis of multilayer aerodrome flexible pavements based on falling weight deflectometer (FWD) data. This approach is hybridized using a finite element structural model to calculate pavement responses with known properties of pavement materials subjected to FWD loading. The finite element model deals with the nonlinear and stress-dependent behaviour of the geomaterials used underlying the free pavement layers, resulting in modelling the responses and characterizing the suitable materials.

Kaur and Kaur [14] provided a design for weather conditions using the fuzzy logic method and the neuro-fuzzy method. Simulation results of both neuro-fuzzy management and fuzzy logic are compared to indicate the better one between the two. As a result of the study, neuro-fuzzy is superior to fuzzy logic because it provides adaptability and learning.

Charts are used to determine the layer thicknesses of airport rigid pavements. Unless the chart readings are done carefully, reading errors are made. For this reason,

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it is aimed to investigate the usability of the ANFIS method, which is faster and minimizes errors, instead of the chart method.

2. Material and Method

2.1. Material

The readings from the layer thickness determination chart were used to make the airport runway pavement thickness design with the fuzzy logic method. The chart of layer thickness is given in Figure 1.

"K" ground module; represents the soil strength category and makes it easy to predict the possible pavement behaviour of the soil. Categorized as high strength, medium strength, low strength, deficient strength [15]. When the chart was analyzed, it was determined that the third-order parabola curves of the K coefficient curves and the aircraft weight curves were linear. The equations for the values of 50, 100, 200, 300, and 500 for the K coefficient are shown in Equations 1, 2, 3, 4, and 5, respectively. For these values, the x-axis is considered the unit axis.

$$y_{50}=-4.1667x^3+77.5x^2-568.33x+2020 \quad (1)$$

$$y_{100}=-6.6667x^3+100x^2-598.33x+1875 \quad (2)$$

$$y_{200}=-5x^3+70x^2-420x+1475 \quad (3)$$

$$y_{300}=-9.4167x^3+110.5x^2-529.38x+1502.5 \quad (4)$$

$$y_{500}=-7.8544x^3+85.69x^2-405.21x+1252.5 \quad (5)$$

The variable y in the above equations expresses the concrete strength of psi.

3. Method

3.1. Takagi-Sugeno Method

Takagi-Sugeno (T-S) method, which is a qualitative modelling method based on fuzzy logic [16], is a convenient method for engineering applications [17]. T-S method, which is a fuzzy logic modelling used in the analysis of nonlinear systems; used to deal with complex analysis and synthesis problems; It is standard modelling that can give average weighted values with the results of nonlinear systems and can also be studied with different linear system theories [18].

The most important advantages of this method are; have simple output functions that are functions of the inputs; It can be listed as reducing the processing load, high computational speed, and practicality of its use for systems that do not require sensitive results but are dynamically changing rapidly [19]. Figure 2 shows the association of membership levels from the blurring unit with the polynomial output membership functions in the Takagi-Sugeno inference method. In the Takagi-Sugeno inference method, polynomial functions are used for the output, as seen in Figure 2.

In Sugeno type fuzzy modelling; Output membership functions are grouped with different subheadings according to whether they are linear or fixed [22]

- Zero-order Sugeno fuzzy model (Output membership functions fixed)
- 1st order Sugeno fuzzy model (1st order line equation.

The mathematical calculation logic of the T-S fuzzy model is as follows [23];

For a nonlinear dynamic system (Equation 6)

$$\dot{x}=f(x,u), \qquad x\in X\subset R^n \text{ ve } u\in U\in R^r \quad (6)$$

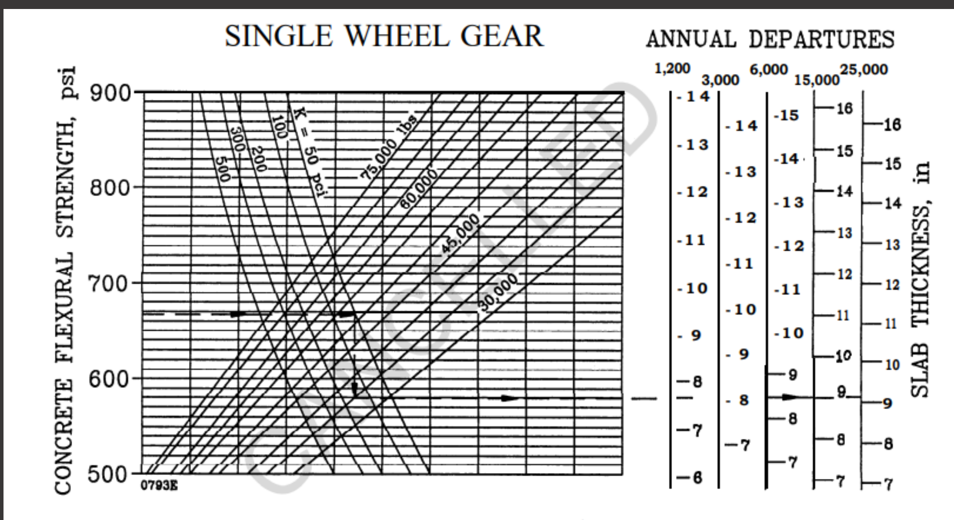

Figure 1. Rigid Pavement Design Curve [21]

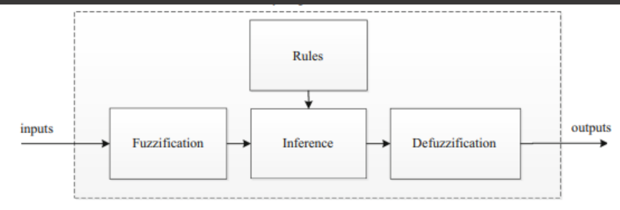

Figure 2. Basic elements of fuzzy logic [20]

A Takagi–Sugeno fuzzy model will approximate this system by properly interpolating it to local systems. Each local model contributes to the global model in a fuzzy subset of X x U. This fuzzy set; is defined by a membership function, leading to the Takagi-Sugeno fuzzy model (Equation 7).

$$\dot{x}= \sum_{i=1}^{N}(A_i x+ B_i u+d_i)w_i(x,u) \quad (7)$$

w_i:X x U→[0,1] (Equation 8), where the weighting functions are given by fuzzy inference;

$$w_i(x,u)=\frac{\mu_i(x,u)}{\sum_{j=1}^{N}\mu_j(x,u)} \quad (8)$$

Results and Discussion

This study, it is aimed to prevent undesirable situations that will occur as a result of situations such as loss of time, attention errors, and calculus errors that people will naturally experience while reading with a fuzzy logic model. In this context, readings were taken with high meticulousness and accuracy on the provided charts and ensured that they were correct. Random values were derived from doing readings, and readings were taken with these values. Then, using the reading values obtained with the same input data, a fuzzy logic model was developed. The main structure of the generated fuzzy logic model is shown in Figure 3. The model was established with five inputs and one output.

In creating the data set, 500 and 900 psi values, which are the chart limits for concrete strength, were taken as limit values, and 5793 random values were generated in EXCEL with the RAND command in this range. In addition, for the "K" coefficient, data production was carried out with the “RAND” commend and between 50 and 500 values. Then, ten different aircraft weights that will use the runway were selected as 13620, 15890, 18160, 20430, 22700, 24970, 27240, 29510, 31780, and 34050 kg. For this selection, each aircraft's weight took a value between 1 and 10, and 5793 integers between 1 and 10 were produced with the RAND command. The weight corresponding to the produced integer was used in the relevant combination. Finally, the method used in the estimation of aircraft weight was used for 1200, 3000, 6000, 15000 and 25000 years/number of aircraft take-offs, which can be read on the chart, each weight was given an integer from 1 to 5, respectively, and these five numbers were given with the RAND command. The integer is generated. The take-off value corresponding to the integer produced is the annual number of take-offs in the combination. In this way, 1449 values created differently were read over the chart, and layer thickness values were obtained. Random 80% of the values obtained in this way (1157) were used to train the Fuzzy Logic model, and the remaining 20% (292) was used for testing the created model. The main structure of the created model is shown in Figure 3.

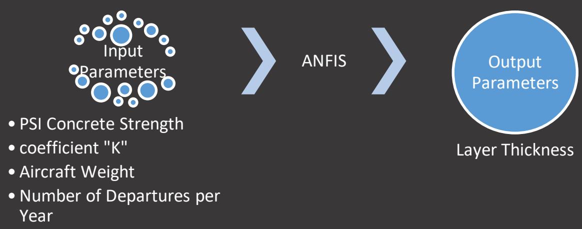

Figure 3. The main structure of the Fuzzy Logic model

The model shown in Figure 3 has four inputs and one output. As ANFIS parameters, each input is of trimf type. The output membership function is determined as constant. In the fis formation, the effect range value was 0.5, the compression factor was 1.25, the acceptance rate was 0.5, and the rejection rate was 0.15. The hybrid method was used as the optimization method in the Train Fis type. Because of 1000 iterations, the error value was 0.55.

To establish a smooth relationship between all input data and output data on the created model, 243 rules were written. The relationship between the input and output parameters after the written rules is shown in Figure 4. To test the model after writing the rules, the test data set was entered on the query screen, and the results were compared with the actual values. Because of the comparison, an R^2 value of 97% was reached (Figure 5).

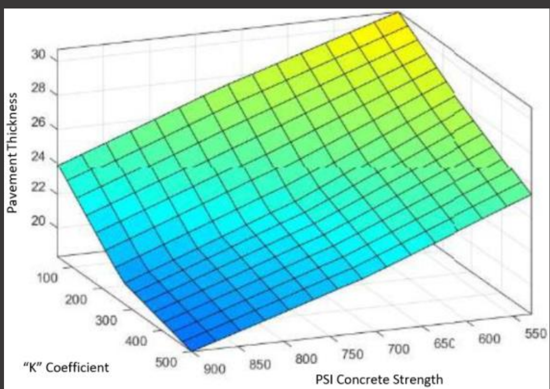

Figure 4. The change in the output value depending on the input data of the created model.

Because of the training, Figure 5 was obtained when the values obtained from the model were compared with the output parameter of the data set used for training the model. When Figure 5 is examined, it has been obtained that the data set used because of the model's training can represent the output values by 97.40%. Because of the examination, it can be said that the training was concluded successfully. After the values obtained because of the training were obtained with an accuracy of 97.77%, the model created was tested. The layer thicknesses obtained by the model because of the test data and the layer thicknesses obtained from the test inputs and the abacus were compared. Because of the comparison, Figure 6 was obtained. When Figure 6 is examined, it is seen that the layer thicknesses obtained from the test data of the model match the layer thicknesses read from the abacus with an accuracy of 97.05%. The model was developed because the test process can estimate layer thicknesses.

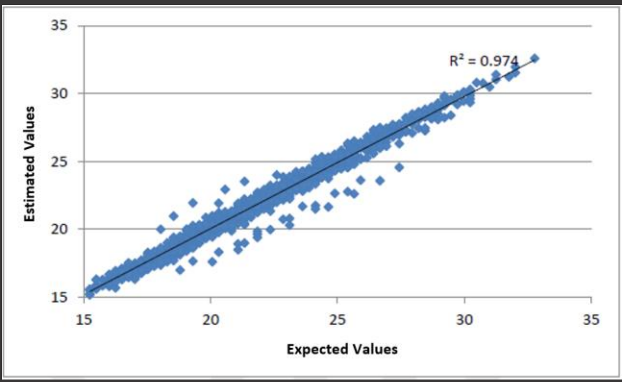

Figure 5. The relationship between the predicted and the education values read from the chart.

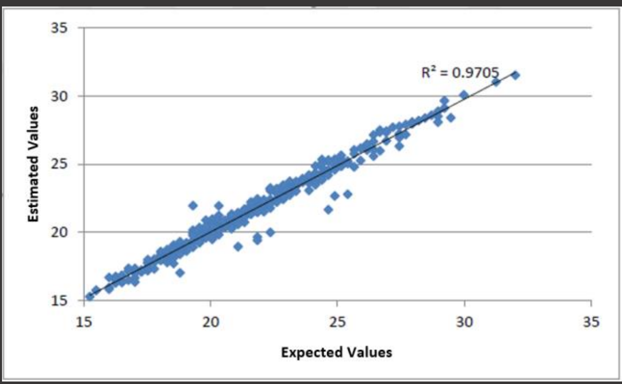

Figure 6. The relationship between the predicted and the test values read from the chart.

4. Conclusion

This study aimed to determine a more practical and fast rigid pavement layer thickness with the ANFIS model instead of determining the airport rigid pavement layer thickness with the traditional abacus method. In this way, the errors caused by the chart, reading errors, and human errors can be prevented. In addition, results can be achieved in a much faster and more practical way.

For this purpose, a random data set was created, and abacus readings were performed with high precision for each set. The obtained results were used to train the ANFIS model, producing an alternative solution instead of the abacus reading. The model obtained in this context could predict the layer thicknesses obtained because of the chart readings at a rate of 97.05%. This result shows the usability of the created model in determining the rigid pavement layer thicknesses of airports. Besides the high accuracy rate, losing time during abacus readings is significantly reduced.

The data analysis of the study was carried out only on the single wheel landing gear and considering the relevant results; In future studies, repeating the same study with double-wheel landing gear readings and results and extracting accuracy relationships with chart tables will be beneficial in minimizing time losses and human error factor in this area. Besides the method used in the experimental study process, the comparison of the results obtained by processing the same data with the Mamdani inference method and the results of the Sugeno inference method will both enrich the literature, and the difference between the accuracy factor between the two methods will be evaluated in terms of applicability.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution Statement

B. Kucukcapraz: Formal analysis, Investigation, Software, Visualization, Writing – Original Draft – **S. Terzi**: Conceptualization, Funding acquisition, Software, Supervision, Writing – Review&Editing

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