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Ensuring flight safety by optimizing test points in fighter aircraft

Savaş uçaklarında test noktalarının optimizasyonu ile uçuş güvenliğinin sağlanması

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Ensuring Flight Safety by Optimizing Test Points in Fighter Aircraft

Highlights

- *Parameters of the flight test*
- *Flight test in safe conditions*
- *A critical aspect of flight testing is the analysis of risk*
- *The ANFIS method is a technique employed in the field of fuzzy logic*

Graphical Abstract

In the study, the user inputs the eight flight test parameters into the system at specified intervals, generating a flight test point risk level output.

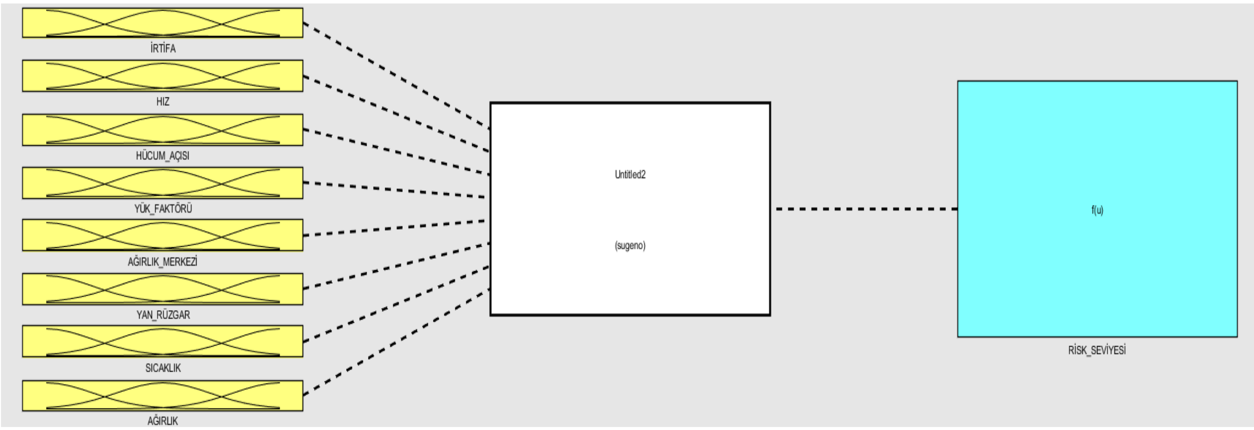

Figure. Flight Test Risk Modelling

Aim

The numerical representation of flight parameters and the development of risk output.

Design & Methodology

The Adaptive Neuro Fuzzy Inference System (ANFIS) is implemented using the MATLAB Fuzzy Logic Toolbox.

Originality

The study significantly contributes to the current literature by completing a thorough examination of the potential risks associated with flight testing involving eight inputs.

Findings

A risk analysis of flight test outcomes for unstable parameters utilizing various membership functions is provided.

Conclusion

The risk level of the flight test parameters is categorized into five distinct classifications: Very Safe, Safe, Moderate, Risky, and Very Risky.

Declaration of Ethical Standards

The authors of this work affirm that the materials and procedures employed in this study do not necessitate ethics committee or legal-special authorization.

Ensuring Flight Safety by Optimizing Test Points in Fighter Aircraft

Araştırma Makalesi / Research Article

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ABSTRACT

Fighter aircraft have undergone numerous testing procedures throughout their historical evolution to improve their efficiency during modernization. This study provides an analysis of the parameters, outcomes, and safety standards related to flight testing. The aim of this study is to assess the ability of fighter aircraft to execute the specified test points safely and under controlled conditions. A risk analysis is performed to ensure the test's dependability and safe execution. The testing process is executed systematically and under controlled conditions, with negligible departure from the ideal values. The data provided relates to flying tests of fourth and fifth-generation conceptual fighters with specified attributes. The conceptual aircraft is designed simultaneously with the F-16 and the strategically important Hürjet. Upon completion of the study, due to the intrinsic challenges in articulating complex systems characterized by uncertainty through straightforward mathematical formulas, the ANFIS method—an adaptive learning model derived from literature research utilizing the MATLAB Fuzzy Logic Sugeno Module—is utilized to analyze intricate data sets and effectively forecast risk factors. The established approach facilitates the assessment of numerical risk levels for flight test points using eight input variables, thereby averting hazardous flights and reducing the potential for loss of life and property.

Keywords: Flight test, flight safety, risk analysis, ANFIS.

Savaş Uçaklarında Test Noktalarının Optimizasyonu ile Uçuş Güvenliğinin Sağlanması

ÖZ

Savaş uçakları, modernizasyon sırasında verimliliklerini artırmak için tarihsel evrimleri boyunca çok sayıda test prosedüründen geçmiştir. Bu çalışma, uçuş testleriyle ilgili parametrelerin, sonuçların ve güvenlik standartlarının bir analizini sunmaktadır. Bu çalışmanın amacı, savaş uçaklarının belirtilen test noktalarını güvenli bir şekilde ve kontrollü koşullar altında yürütme yeteneğini değerlendirmektir. Testin güvenilirliğini ve güvenli yürütülmesini sağlamak için bir risk analizi yapılmaktadır. Test süreci sistematik olarak ve kontrollü koşullar altında, ideal değerlerden ihmal edilebilir bir sapma ile yürütülmektedir. Sağlanan veriler, belirtilen niteliklere sahip dördüncü ve beşinci nesil kavramsal savaş uçaklarının uçuş testleriyle ilgilidir. Kavramsal uçak, F-16 ve stratejik açıdan önemli Hürjet ile aynı anda tasarlanmaktadır. Çalışmanın tamamlanmasının ardından, belirsizlikle karakterize edilen karmaşık sistemleri basit matematiksel formüllerle ifade etmedeki içsel zorluklar nedeniyle, MATLAB Bulanık Mantık Sugeno Modülünü kullanan literatür araştırmasından türetilen uyarlanabilir bir öğrenme modeli olan ANFIS yöntemi, karmaşık veri kümelerini analiz etmek ve risk faktörlerini etkili bir şekilde tahmin etmek için kullanılmaktadır. Kurulan yaklaşım, sekiz girdi değişkeni kullanılarak uçuş test noktaları için sayısal risk seviyelerinin değerlendirilmesini kolaylaştırmaktadır, böylece tehlikeli uçuşları önlemektedir ve can ile mal kaybı potansiyelini azaltmaktadır.

Anahtar Kelimeler: Uçuş testi, uçuş güvenliği, risk analizi, ANFIS.

1. INTRODUCTION

Since the introduction of technology systems in warfare, combat aircraft have been the principal factor in determining operational capability across nations. Initiatives to upgrade and prolong the operational lifespan of aircraft models are in progress. Intermediate-generation fighter jets are classified as 4th and 5th generation and have the capability to avoid radar detection [1]. The fifth generation, presently operational and under ongoing development, plays a crucial part in the military superiority of nations. The development of an airplane is a multifaceted and elaborate process, commencing with a conceptual idea. The aircraft must be engineered to effectively execute its mission in flight and land safely without incurring damage. This mission must be executed under diverse situations and must satisfy both design performance and flight safety requirements. Fighter jets incorporate several mission systems, posing a challenge to flight safety assurance [2].To alleviate this risk, many regulations have been instituted to avert loss of life after a system failure. The aviation sector has a history of incidents, resulting in the cliché that "Aviation history is inscribed in blood." This occurs because regulations and standards are frequently instituted post-accident [3]. Consequently, flying safety holds utmost significance in this scenario.

This study offers a quantitative risk evaluation of test sites in flight tests performed by TAI (Turkish Aerospace Industries), a Turkish defense and aerospace firm. The study aims to diminish the frequency of hazardous flights

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by performing a risk analysis of the accident fractures that have transpired in aviation. Flight tests rely on a sequence of measurements conducted throughout the flight. Therefore, numerous values must be measured and assessed concurrently during any flight test. The process is highly complex and time-intensive, leading to considerable financial strain [4]. The research, titled "Ensuring Flight Safety by Optimizing Test Points in Fighter Aircraft," focuses on the fundamental aspect of this procedure: flight safety. Safety is of utmost importance throughout the entire process, encompassing the pilot's safety throughout tests, attaining success under optimal conditions, and executing process enhancements. The ability to conduct the test "regarding safety" under optimal settings positively influences the overall testing process [5].

The literary studies are categorized into two segments. The preliminary step of the project involves an analysis of risk assessment approaches related to aviation safety [6]. After identifying the ideal risk assessment approach for fighter aircraft, the subsequent phase of the study concentrated on a comprehensive analysis of its application in the literature. The majority of literature research on fourth generation fighter jets, which were designed and deployed in the 1970s, were undertaken in the 1980s [7]. A thorough search was performed utilizing several search engines and keywords related to flight safety and flying danger. To locate relevant material on flight safety, the following keywords were employed: "flight test, flight safety, flight risk, flight integration, dynamic flight, aerodynamics, aviation hazards, and risk analysis." The keywords were subsequently searched across the Web of Science, Yök Thesis, Google Scholar, and Scopus platforms. The dates were chosen to guarantee the incorporation of more current and relevant information than that offered by risk analysis techniques. A thorough examination of the literature was performed for the employed approaches. The literature review utilizes the fuzzy-based Sugeno approach and expert opinion for flight risk analysis, making it particularly appropriate for the issue at hand [8]. Fuzzy-based approaches are utilised for the modelling of uncertainties and the enhancement of decision-making processes[9]. Analysis of existing literature reveals that the "Adaptive Neuro Fuzzy Inference System" (ANFIS) method is primarily utilized in the risk assessment of flight test operations through the Matlab Fuzzy Logic module [10]. All studies, including Ervural, have been reviewed, and with the endorsement of experts from the TAI Integrated Flight Test Team, the risk analysis of flight test points has been incorporated into the literature utilizing the ANFIS method, an adaptive learning model capable of processing complex data sets and accurately forecasting risk factors [11]. Complex systems characterized by uncertainties are challenging to articulate using straightforward and exact mathematical methods and equations [12].

The literature research has thoroughly analyzed risk assessment methodologies. Risk analysis methodologies are primarily utilized in relation to civil aviation difficulties, as evidenced by Kurnaz and Sunar's academic work [13]. Military aviation systems' intricate, non-linear, and stochastic nature renders precise and accurate mathematical modeling of most physical systems difficult [14]. Due to the challenges in characterizing complex systems with uncertainty through straightforward mathematical formulas, the literature review concluded that the fuzzy logic method, a flight safety risk analysis technique, presents the most promising solution to the identified issue [15]. After meetings with academic and industrial experts, the findings from the literature review and the fuzzy logic approach were considered suitable for implementation. In the subsequent section of the literature review, the following search terms were employed: "Flight test risk assessment," "flight test risk analysis," "risk assessment in aviation flight tests," "ANFIS in risk assessments," "fuzzy logic in risk assessments," "flight test risk management methodologies," and "flight test safety analysis." The terms were queried on the Web of Science, Yök Thesis, Google Scholar, Scopus, and SpringerLink platforms.

The research involved a comprehensive analysis of risk assessments utilizing ANFIS and fuzzy logic. The fuzzy-based cockpit warning system was developed to minimize the incidence of critical situations leading to aviation accidents. The suggested system utilizes a fuzzy-based sensor to detect flying parameter values instantly. This strategy is crucial for implementing preventative interventions in the presence of unidentified risk factors. The proposed system aids the pilot in executing measures that maximize risk mitigation for potential scenarios. The study utilized the fuzzy-based Sugeno approach alongside expert opinions [16].

This study utilized a test point risk assessment approach to examine the relative significance of two fighter jets: the "Hürjet," crucial for national strategic defense, and the "F16," presently undergoing modernization efforts. Due to the similarities between the Hürjet and F16 models, assessing them concurrently was considered more effective. A 4.5-generation conceptual airplane was delineated based on these aircraft models. This research significantly enhances the current literature and the aviation sector. the aircraft features and capabilities were precisely defined, and a design was developed to enable the requisite tests [17]. This risk assessment program, designed for the conceptual aircraft, can be utilized by inputting alternative aircraft's parameters and value ranges and functioning as an 8-input ANFIS research. The following portions of the study elucidate the fuzzy logic method, introduce the inputs, and establish their ranges. Furthermore, figures from the Matlab implementation are provided, and the findings are analyzed.

2. MATERIAL and METHOD

2.1. Fuzzy Logic

Fuzzy sets and fuzzy logic theory constitute a significant application in control systems. These systems are generally built on knowledge or rules. Effective system control necessitates the selection of a suitable mathematical model. Fuzzy sets address scenarios characterized by uncertainty, as opposed to conventional set theory, which relies on definitive options such as "1" (exist) or "0" (do not exist). In conventional set theory, no value exists between "0" and "1." Nonetheless, fuzzy sets are appropriate for addressing uncertainty-related issues. This facilitates the incorporation of a controller that demonstrates human-like behavior within the system. Figure 1 illustrates the configuration of the fuzzy inference procedure [18].

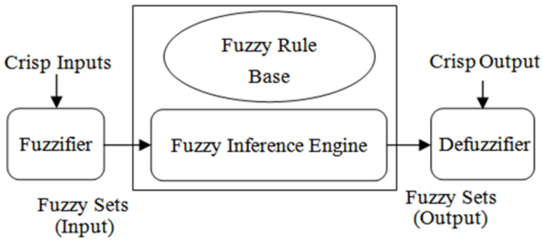


Figure 1. Fuzzy logic process

A fuzzy control system converts precise input values into fuzzy values based on the membership functions. Figure 2 illustrates that distinct input values on the x-axis correlate with membership degrees on the y-axis, determined by established membership functions such as low, mid, and high [19]. During this process, each input value is allocated to a fuzzy set defined by its corresponding membership function. This assignment process quantifies the extent to which the input values align with the designated membership function. The imprecise values signify the extent of membership within a specific membership function, therefore facilitating the processing of input values through fuzzy logic.

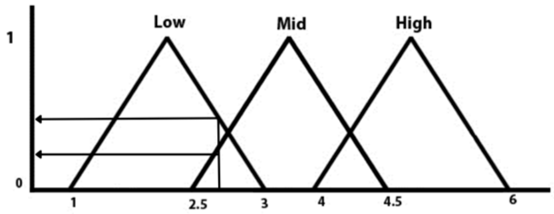


Figure 2. Fuzzification process

The preliminary phase in the formulation of a fuzzy inference system generally involves the establishment of a table of if-then rules. Specialists generally formulate these regulations. A fuzzy rule base is a system that encapsulates the correlations between input and output fuzzy sets. This mechanism is responsible for aggregating the operations that dictate how a fuzzy control system generates an output in response to inputs. The system's behavior is dictated by the inferences derived from each rule, which are amalgamated to yield this result. This crucial element is known as the "inference engine" or "fuzzy engine" and constitutes the basis for fuzzy logic control. Fuzzy rule-based systems may utilize many analytical methodologies. The most prominent among these are the Mamdani and Sugeno models.

The outcome of the inference process is a fuzzy set. Fuzzy expressions or fuzzy sets generally lack direct significance in the real world. Therefore, it is imperative to convert the ambiguous information obtained from the inference process into actionable data for practical application. The transformation process occurs during the clarifying phase [20].

2.2. Artificial Neural Networks

Artificial Neural Networks (ANNs) are algorithms modeled after the human brain, designed to acquire new knowledge and extract insights from the information obtained. As ANNs mimic the human brain, they possess the ability to learn from provided data, generalize, and operate with an infinite number of variables. Figure 3 illustrates that ANNs consist of separate layers like artificial neurons. In this context, it is comparable to biological neurons. The basic operational units in an ANN are known as artificial neurons or processing elements.

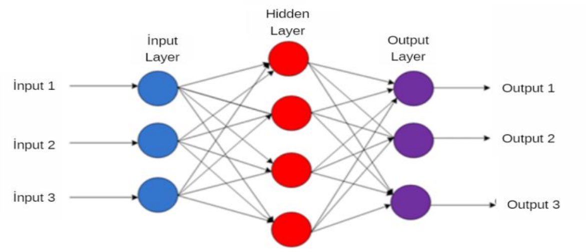


Figure 3. Multilayer Artificial Neural Networks

In ANNs, processing units are organized into interconnected networks. Upon receiving weight values, the network commences training. Initially, these values may be allocated arbitrarily. As ANN assimilates data over time, it adjusts the connection values and formulates the learning rules. For the ANN to execute this function, it must be capable of processing numerical data. The aforementioned properties aid in resolving intricate situations where formulating a mathematical model is difficult [21].

2.3. ANFIS

ANFIS is fundamentally a fuzzy inference system designed for adaptive networks. A hybrid learning method allows ANFIS to develop an input-output framework that embodies fuzzy-based rules and human expertise. ANFIS produces all possible rules relevant to the topic being examined or, alternatively, permits assignment by an expert. ANFIS generates all potential rules relevant to the topic at hand or permits their assignment by an expert. Consequently, in numerous predictive tasks, artificial neural networks (ANN) leverage expert insights and yield superior outcomes compared to the mean square error criteria. In order to model uncertainties and improve safety in flight test processes, risk assessment was performed in this study with an ANFIS-based fuzzy modeling approach, similar to the fuzzy fault tree analysis applied on robotic lines.[22]

ANFIS comprises six levels. The initial layer is referred to as the input layer. Data flow is supplied by external cells. The secondary layer is referred to as the blurring layer. Jang's ANFIS model is employed to categorize input values into fuzzy sets. The nodes' output fluctuates based on the input values and the employed membership function. The rule is established at the third tier. The result of each rule is the multiplication of the membership degrees from the second layer. The fourth layer is the normalizing layer. The defuzzification process is executed in the fifth layer. In this layer, the weighted values of the specified rule are computed at each node. The sixth and final layer is the entire layer. The definitive output value of the ANFIS system is derived by aggregating the output values of each node in the fifth layer [23].

3. FINDINGS

The aim of the study, titled "Ensuring Flight Safety by Optimizing Test Points in Fighter Aircraft," is to execute a risk analysis for flight reliability and to conduct the test safely. The aim is to ascertain the parameters that constitute the test points and evaluate the corresponding risk of flight testing at different levels of these characteristics. Upon determining the risk level based on the test parameter values, the ideal test spots can be selected, facilitating the safe execution of the flight test. The procedural phases of the investigation are presented in the sequence illustrated in Figure 4.

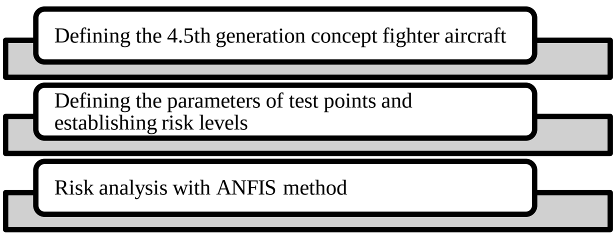


Figure 4. Implementation phase

Based on expert opinion, this study utilized ANFIS to identify eight risk criteria and their ranges for fighter aircraft. As highlighted in Table 1, each parameter was chosen to align with the specifications of the 4.5th generation concept aircraft, whose mission capabilities were previously established. The ANFIS model was subsequently executed, and the feasibility and dependability of the flight were analyzed. Figure 5 illustrates the overall architecture of the neural fuzzy inference system developed for risk analysis.

A test point is delineated as a collection of test parameters along with their corresponding values. A modification in the value of any parameter inherently leads to the establishment of a distinct test point. This section

Table 1. Concept aircraft specification

- 2 Flight Hours Endurance
- Ability to perform day and night operations
- Dual cockpit with tandem seats
- Jet turbofan engine with afterburner
- Fully authorized digital flight control system
- Full stops/turns/authorized departure features
- Autopilot with direction, attitude, and altitude modes
- Escape system with ejection seats
- 8000 ft minimum runway length
- 7 tons of weight without ammunition
- Maximum loaded weight of 10 tons
- 35,000 ft maximum altitude
- Adjustable cabin pressure control according to the altitude at which the aircraft is flying
- Minimum speed 0.2 mach
- Maximum speed 1.2 mach
- AoA (angle of attack) capability between -5/25 degrees
- Throttle lever value capability between 20/100
- 30 knot crosswind landing capability
- 3G/+8G Normal Load Limits
- Mission capability in -30/50 degree outdoor environment
- Advanced jet trainer to test all capabilities

identifies eight test parameters—altitude, speed, angle of attack, load factor, center of gravity, crosswind, temperature, and weight—deemed appropriate for the test points in agreement with the TAI Flight Test Specialist. The choice of test parameters was predicated on the belief that continuous functions and unstable parameters would yield more precise evaluations of the flying test's risk level. Moreover, the chosen parameters are the most appropriate and widely employed for the test points used in flight test campaigns.

Regarding the importance of parameter selection, if we clarify this part further, the procedure used is as follows.

The procedure applied in the selection of eight parameters was selected by considering the most important parameters in flight test campaigns in military aviation with the opinion of experts at the defense industry company TAI, with whom the research was jointly conducted. For example, in aviation tests, pilots gave subjective feedback, especially when testing angles of attack. In light of pilot experiences, the angle of attack parameter will be selected and an objective evaluation opportunity will be provided with a mathematical equivalent. There are also uncontrollable realities while performing the test. These are environmental factors. For this reason, the most obvious environmental effect, temperature, was also selected as one of the main parameter elements. The study allows the update of parameters and their membership functions in both qualitative and quantitative terms. In this respect, it is an

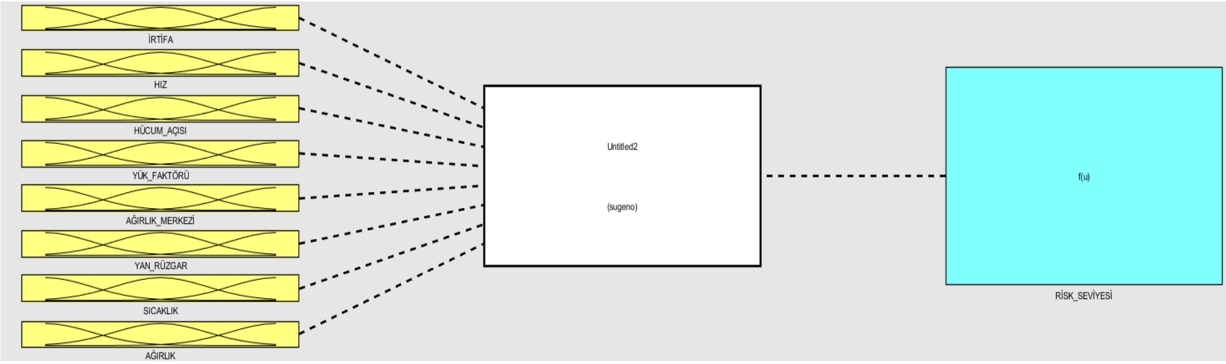


Figure 5. Fuzzy inference system

Table 2. Input parameter values

Input	Input Name	Fuzzy Label	Explanation
Input 1	Altitude (0-35000)	Low-High	Reduced air density at high altitudes reduces the performance of airplanes.
Input 2	Speed (0.2-1.2)	Slow-Medium-High	Too high speeds can negatively affect the situation—the risk level increase from slow to fast.
Input 3	Angle of Attack ((-5)-25)	Risky AoA - Safe AoA	The greater the angle of attack, the greater the danger.
Input 4	Load Factor ((-3)-8)	Risky LF -Safe LF	To achieve the desired flight path, the pilot needs to move correctly. This means they need to fly faster or increase the angle of attack.
Input 5	Center of Gravity (25-33)	Front Side- Rear Side	The center of gravity allows the pilot to control the stability of the aircraft.
Input 6	Sideslip (0-30)	Stable-Windy	During normal flight operations, the risk increases as the sideslip increases.
Input 7	Temperature (-30 +50)	Cold-Warm-Hot	Temperature changes affect the aerodynamic characteristics of the aircraft, engine performance, fuel consumption, and the operation of other systems.
Input 8	Weight (7-10)	Light-Medium-Heavy	In general, the risk of danger increases as the weight increases and the maneuver angle decreases.

open template. It will shed light on future risk analysis measurements using the same methodology (ANFIS). In this respect, it is also a dynamic study.

The evaluation of risk analysis techniques provides a methodological framework analogous to the ANFIS-based approaches employed in our study, thus leading to the development of a comparable strategy for prioritizing risk factors.[24]. Each test point parameter consists of subcomponents, namely membership functions in the ANFIS methodology. The parameter ranges were established based on the attributes of our 4.5th generation fighter aircraft, which was conceptualized. The membership functions for each parameter and the sequence of risk generation for these values are presented below. Table 2 presents the names, characteristics, and value ranges of the eight inputs utilized in the study.

The outputs indicating the system's mathematical results, specifically the risk levels, are delineated and instructed from Risk Level 1 to Risk Level 10 for the purpose of sensitization. The final results are shown in Table 3, categorized into five distinct levels: Very Safe, Safe, Medium, Risky, and Very Risky, according to standard practices in fuzzy logic risk analysis found in the literature.

Table 3. Risk level rating

Risk Level 1	Very Safe
Risk Level 2	
Risk Level 3	Safe
Risk Level 4	
Risk Level 5	Medium
Risk Level 6	
Risk Level 7	Risky
Risk Level 8	
Risk Level 9	Very Risky
Risk Level 10	

Table 3 highlights that risk, the sole outcome utilized in the study, is categorized into 10 levels and articulated through 5 distinct fuzzy linguistic variables.

The risk analysis study utilized grid partitioning to develop ANFIS. The model was constructed utilizing the ANFIS interface, which operates as a fuzzy logic function integrated within the MATLAB environment. Figure 6 illustrates that from a total of 150 data sets identified as appropriate for training the network, 120 were allocated to the training set, while 30 were designated for the test set.

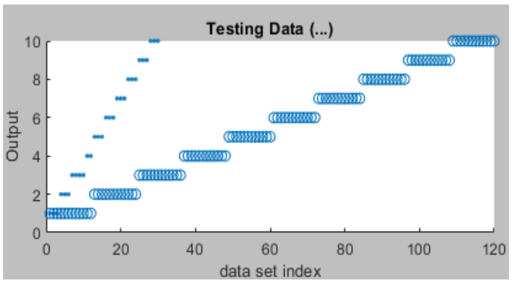


Figure 6. Training set and test set

During the development of the risk analysis model, the data was partitioned into three distinct datasets. Additionally, a total of 100 data sets were employed for the control set, excluding the outputs used for the risk level. Upon entering the data into the model for training, the network acquires the correlation between inputs and outputs. The parameters of the membership functions are further modified until the target error level is attained. The justification for integrating the control data into the model with the training set is that, at a certain point, the error rate of the control set abruptly increases while the error rate of the training set decreases. This event is termed the "overfitting point." The testing phase begins thereafter. The test dataset is utilized to evaluate the network's learning and generalization capabilities using data that the trained and parameterized model has not before encountered.

Figure 7 illustrates that subsequent to selecting the kind and quantity of the membership function from the interface, the preferred number of iterations is inputted in the "epochs" field on the screen. The network training commences upon selecting the "train now" option.

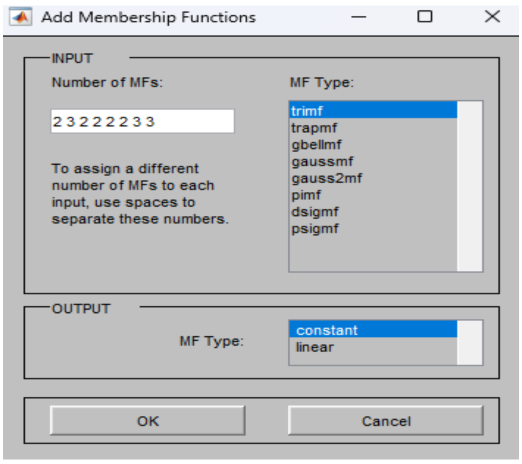
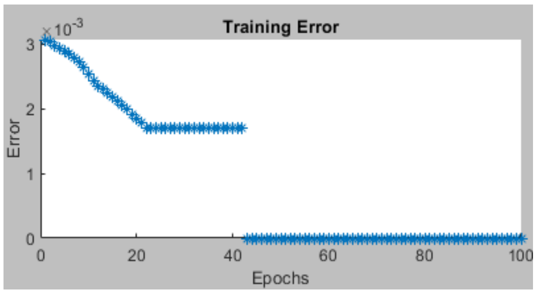
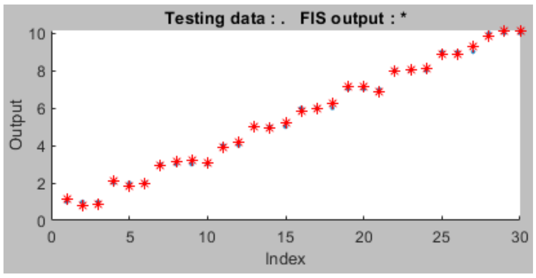


Figure 7. Membership function type

Figure 8a illustrates the training procedure of the fuzzy neural network. The graph illustrates the progression of training error over time, as shown by the curve. The training error exhibited a declining trend until it attained the value of 20. A persistent inaccuracy is noted from the 20th data point onward. Consequently, it is unnecessary to await the 100th iteration. The resultant data is presented in Figure 8b. Upon completion of the network training, the testing phase commences. The inaccuracy rate of the network's data predictions is shown in the bottom left corner of the figure. Should the error rate be considered excessive, the parameters are adjusted. Nevertheless, as the error rate was maintained at an acceptable threshold of 13%, the intended network architecture was successfully realized.



(a)



(b)

Figure 8. (a) Training process, (b) testing process

Figure 9 illustrates the architecture of the ANFIS model, comprising eight inputs, one output, and 864 rules. Each input value corresponds to a specific quantity of membership functions. The input data have been modified to enable comparison between the model developed by expert opinion and other models.

Figure 10 illustrates the membership functions of the altitude data, which constitute the model's first input. Membership functions categorized as low and high denote the proportion of any value to which the respective function pertains.

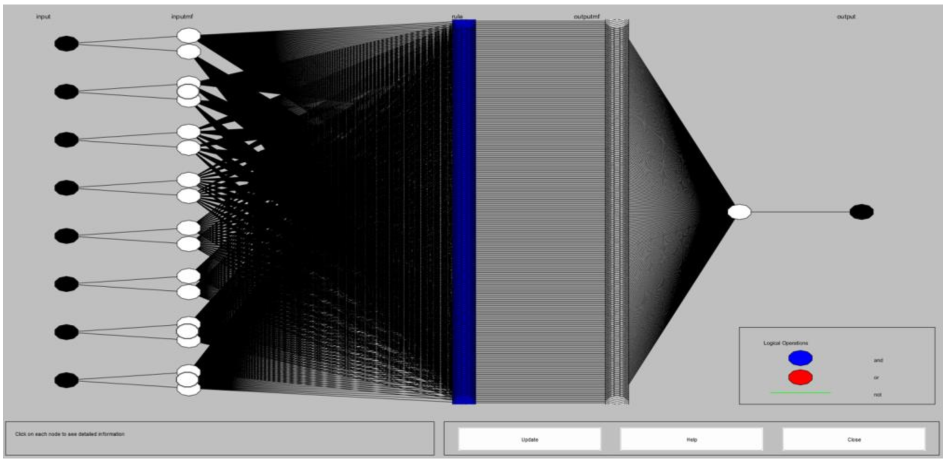


Figure 9. ANFIS rule structure

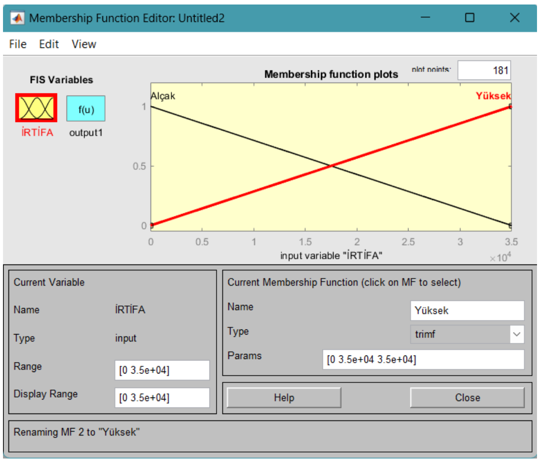


Figure 10. Altitude membership function

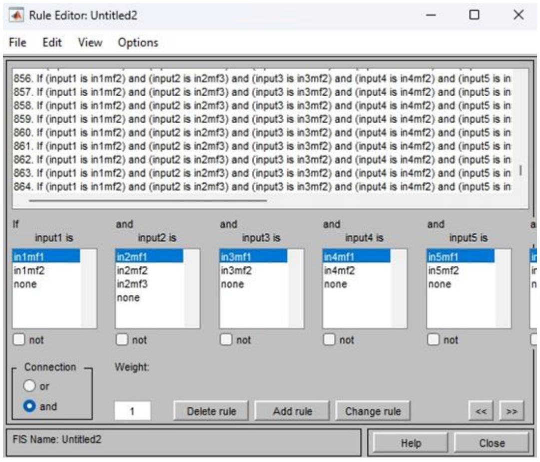


Figure 11. Fuzzy rules

For example, when the altitude is designated as 0, it is categorized inside the low membership function with a membership degree of around 1. If the altitude is set at 17,500 m, it is categorized as belonging to both the low and high membership functions with a membership degree of 0.5.

Figure 11 illustrates the rules generated by the fuzzy neural network. The 864 established rules facilitate the observation of output variations as a function of input values.

Figure 12 illustrates the risk level corresponding to the input values obtained from the network structure's learned rule.

Table 4 contains values for eight entries corresponding to their respective ranges. Consequently, the output level achieved and the associated fuzzy linguistic variable are documented. To reduce the error of the mathematical model, a plot of the squared errors was generated. Upon generating the R^2 chart for 120 data points in the training dataset, the model exhibits an accuracy rate of 99%, as illustrated in Figure 13. The equation for the risk level line was established.

Upon applying the R^2 test to the 30 data points comprising the test dataset, the model has a 98% success rate, as illustrated in Figure 14.

Table 4. Fuzzy test parameters example

TEST PARAMETERS		FUZZY LINGUISTIC VARIABLES
Altitude	2766	Low
Speed	1	High
Angle of Attack	-4	Risky AoA
Load Factor	8	Safe LF
Center of Gravity	29	Rear Side
Sideslipe	29	Windy
Temperature	45	Hot
Weight	9	Heavy

Risk Level	7,58	Risky Flight

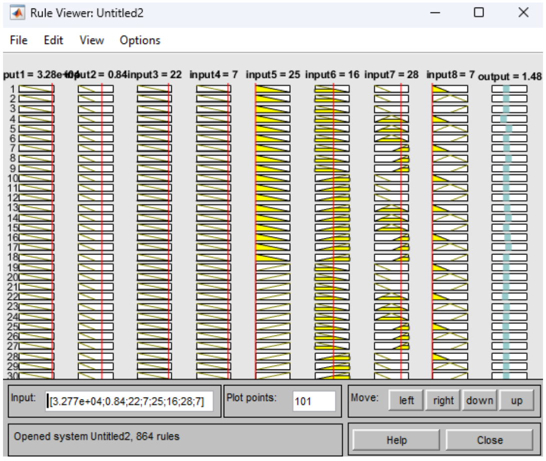


Figure 12. Rule viewer

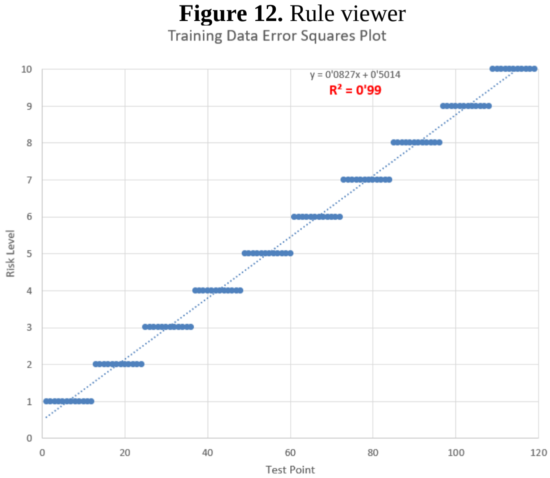


Figure 13. Training error squares plot

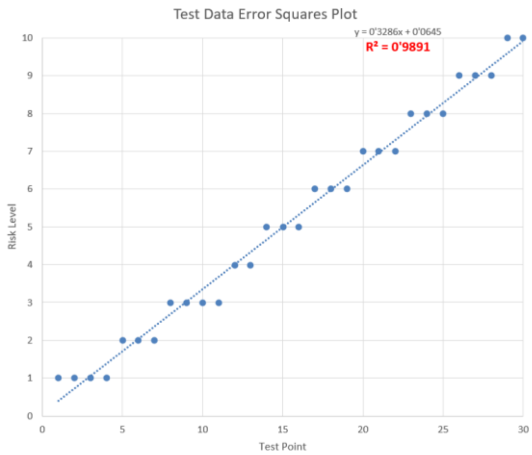


Figure 14. Test error square plot

The equation for the risk level was also eliminated. The R^2 test evaluates the model's ability to elucidate or forecast the dependent variable. The R^2 value is a coefficient that varies from 0 to 1. A rating of 0.99 signifies the model's excellent fit to the data. Simultaneously, the R^2 score signifies the model's capacity for precise forecasting of forthcoming data.

Figure 15 illustrates the correlation between Input1, altitude, and Input3, angle of attack. As altitude diminishes and the angle of attack escalates, the risk level output on the surface correspondingly intensifies.

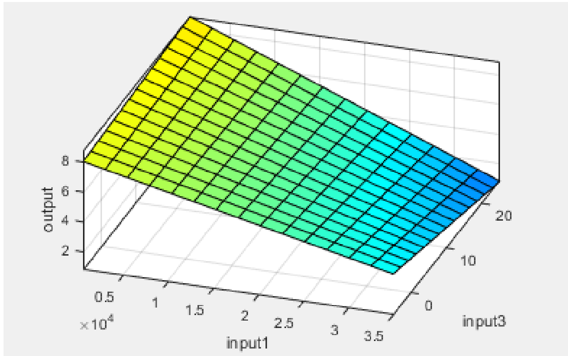


Figure 15. Relationship between altitude and angle of attack

4. DISCUSSION

4.1. Model Benchmarking

Alongside the 2 3 2 2 2 2 3 3 membership functions established by expert consensus, the model was additionally evaluated against three distinct types of membership functions for comparative analysis.

Figure 16 illustrates the impact of altering the membership functions of the inputs utilized in the study on the error rate.

RMSE	m23222223	m22222222	m33222333	m33322333
	0.14	0.24	0.66	0.88

Figure 16. RMSE benchmarks

A decrease in the number of membership functions to two caused a decline in the model's sensitivity, resulting in an elevated error rate. As the number of membership functions in the model's inputs is elevated to three, the error rate escalates once again due to the disruption in the integration of the features associated with the idea of "fighter aircraft" within the fuzzy system. The model study results suggested that the membership functions ought to be established as 2, 3, 2, 2, 2, 2, 3, 3 based on expert opinion. The literature review revealed that the error rate has been diminished to an acceptable threshold.

5. GAINS

This work significantly contributes to the aviation and defense sectors by creating risk analysis methodologies for evaluating next-generation concept warplanes under secure flight conditions. The risk analysis conducted using the ANFIS method in the study facilitates the identification and mitigation of hazards associated with flight test processes. This approach enhances flight safety and mitigates potential accidents and security breaches. Optimal test processes, devoid of randomness, minimize test length and reduce expenses. Consequently, testing procedures are executed with more efficiency and cost-effectiveness.

In contrast to existing literature, the comprehensive rule structure employed in this work, along with the ANFIS model of 864 rules, achieved elevated accuracy rates in risk analysis. The methodology and technology employed in the study have been rendered adaptable for various aircraft and systems. A versatile framework is introduced for assessing risks, particularly for unmanned aerial vehicles and other aerial systems.

This study can enhance risk analysis and testing processes in national projects, given Turkey's advancements in the defense sector. Thus, it can significantly contribute to the creation and evaluation of domestic and national defense systems. Alongside flying safety, enhancing operational efficiency is a significant accomplishment of this endeavor. Identifying the optimal test points enhances the efficiency and management of warplane development processes.

The findings of the study and the employed methodologies illuminate potential avenues for further research. A foundation has been established for conducting risk analyses and optimizing tests for various aircraft models and types. This study significantly enhances tactics for improving operational efficiency and safety by optimizing risk analysis and testing processes in the aviation and defense industries.

6. CONCLUSION

This study delineates all physical and technical characteristics pertaining to the F16 and Hürjet aircraft 4.5. It encompasses studies to conduct testing of the next-generation conceptual combat aircraft under secure conditions. Conceptualize aircraft resembling fighter jets; it is characterized as analogous to the Hürjet and F-16. This can subsequently illuminate the flight test procedures of existing programs. The objective of the study "Ensuring Flight Safety By Optimizing Test Points In Fighter Aircraft" is to conduct a risk analysis for flight reliability and to execute tests safely. This approach will expedite the testing process and diminish associated expenditures. The testing process can be conducted at an optimal level, free from randomness.

Literature studies have concentrated on the various categories of threats that warplanes may face. The risk analysis methodologies employed in military aviation were scrutinized. The paper provides a comprehensive discussion of risk analysis approaches. The literature review revealed that the fuzzy-based Sugeno method employed in Wagner and Westphal's research, along with the flight risk analysis incorporating expert opinions, is appropriate for the investigation. Upon reviewing other research in the literature, the intricacy of the overall architecture of flight test operations, together with non-linearity and unpredictability, becomes evident. It is recognized that perfect modeling is challenging for numerous reasons. Consequently, research has demonstrated the application of the "Adaptive Neuro Fuzzy Inference System," abbreviated as ANFIS, in conjunction with the "Matlab Fuzzy Logic" module for risk analysis. All studies relevant to the literature were reviewed, and with the endorsement of TAI Integrated Flight Test Team specialists, a risk analysis was conducted using the ANFIS approach in the research titled "Test Point Optimization under Safe Flight Conditions for Warplanes". 4.5 The utilization of next-generation conceptual fighter aircraft and the selection and quantity of test parameters distinguish this study from others. It has enhanced the literature with a far more intricate rule structure.

The application phase involved determining the test point settings and establishing risk levels based on expert opinion. Parameters serve as inputs for risk assessment. The study identified eight critical inputs, namely test parameter values, for assessing flight risk. Each parameter assumes changeable values and amalgamates them to provide a distinct quantity of test points for execution in various test campaigns. The output "Risk Level," which assesses flying safety, establishes five distinct risk categories based on the value of each parameter. Two distinct data sets were utilized in the development of the risk analysis model in the study. Out of the total 150 data sets designated for network training, 120 were allocated to the training set and 30 to the test set. The membership function established by expert consensus generates 864 rules within the ampis methodology. The error rate of the data trained with ANFIS was a satisfactory 0.13, and the intended network architecture was realized. This study presents alternate models developed with various membership functions for comparison with the primary model. The study employed the square error method to evaluate the model's accuracy. It was noted that 99% accuracy was achieved on the training set and 98% accuracy was attained on the test data.

The findings from the study illuminate possible solutions to enhance flight safety and operational efficiency. Mathematical outputs derived from risk analysis can facilitate the efficient optimization of flight test procedures, expedite the construction of military aircraft, and enable the execution of testing processes at reduced costs. The application is available for development for potential future research. The quantity of parameters and the criteria for their selection are subject to modification. This modification enables the system to be adaptive for various aircraft types. In light of our nation's advancements in unmanned aerial vehicles and other aerial systems, as well as in defense, a system has been developed to enhance risk assessment in national projects. Future studies should prioritize the practical implementations of these optimization methodologies and their impacts on various aircraft models.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods they used in their work do not require ethics committee approval and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

H. Ediz ATMACA: Guided the writing process, supported the conceptual framing, and contributed to manuscript structuring and clarity.

Sena AYDOĞAN: Provided methodological guidance, supervised the experimental design, contributed significantly to the methodological rigor and accuracy, and collaborated in manuscript revision.

H. Yusuf NARLI: Conducted the primary research and analysis, collected data, implemented experiments, and drafted initial sections of the manuscript.

Rıdvan BAKIR: Conducted the primary research and analysis, collected data, implemented experiments, and drafted initial sections of the manuscript.

M. Can SARIKINACI: Conducted the primary research and analysis, collected data, implemented experiments, and drafted initial sections of the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Mevlütoğlu, A., "The Future of Turkey's Airpower", ***Insight Turkey***, 22(3), 131-160, (2020).

[2] Čestić, M. M., Sokolović, V. S., and Dodić, M. D., "Technical aspects of flight safety of military aircraft", ***Vojnotehnički glasnik/Military Technical Courier***, 70(4), 1017-1038, (2020).

[3] Kaya, M., and Ateş, S. S. "The Share of Communication Errors in Aircraft Accidents and Artificial Intelligences That Can Be Developed Based on Communication in Aviation", ***International Journal of Entrepreneurship and Management Inquiries***, 7(12), 82-95, (2023).

[4] Stoliker, F. N. (Ed.)., "Introduction to flight test engineering (AGARDograph No. 300, Vol. 14)", NATO Advisory Group for Aerospace Research and Development (AGARD), (1995).

[5] Bliss, D. T., "ICAO's Strength: Reinventing itself to address the challenges facing international aviation", ***Air & Space Law***, 32:3, 2019.

[6] Marhavilas, P. K., Koulouriotis, D., and Gemeni, V., "Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000–2009", ***Journal of Loss Prevention in the Process Industries***, 24(5), 477-523, 2011.

[7] Stensrud, R., Valaker, S., Mikkelsen, B., & Betten, S., "5th generation fighter aircraft and future command and control: A note on some possible changes", 25th ICCRTS, 1-29, (2020).

[8] Božić, V., "Fuzzy Approach to Risk Management: Enhancing Decision-Making Under Uncertainty" [Preprint], (2023).

[9] Kara, M., and Eren, T., "Hasar tespit çalışmalarında görevlendirilebilecek dronların bulanık karar verme yöntemleri ile değerlendirilmesi", ***Politeknik Dergisi***, 27(5), 2029-2041, 2024.

[10] Durmaz, O., "Uyarlanabilir sinirsel bulanık çıkarım sistemi (ANFIS) ile bir insansız hava aracı için uçuş kontrolü", Master's thesis, Anadolu University (Turkey), (2015).

[11] Ervural, B. Ç., "İki Aşamalı Risk Değerlendirme Yöntemi ile Havacılık Sektöründe Uygulama", ***International Journal of Advances in Engineering and Pure Sciences***, 35(4), 460-484, (2023).

[12] Voloşencu, C. (Ed.), ***Adaptive Neuro-Fuzzy Inference System as a Universal Estimator***, BoD–Books on Demand, (2024).

[13] Kurnaz, S., and Sunar, O. N. "Havacılıkta Risk Yönetimi: Türk Sivil Havacılık Sistemi Açısından Bir Değerlendirme", III. Ulusal Havacılık Teknolojileri ve Uygulamaları Kongresi, Konak, İzmir, (2015).

[14] Bucharles, A., Cumer, C., Hardier, G., Jacquier, B., Janot, A., Le Moing, T., ... and Vacher, P., "An Overview of Relevant Issues for Aircraft Model Identification", ***Aerospace Lab***, (4), p-1, (2012).

[15] Goncharenko, Y., Blyskun, O., Martyniuk, O., Radko, O., Kolomiiets, Y., and Bilokur, M. "Flight safety fuzzy risk assessment for combat aviation system", In Proceedings of the 2nd. IEEE International Conference on Advanced Trent in Information Theory, Kyiv (pp. 132-137), (2020).

[16] Veshneva, I., Bolshakov, A., and Kulik, A. "Increasing the safety of flights with the use of mathematical model based on status functions", In International Conference on Information Technologies (pp. 608-621). Cham: Springer International Publishing, (2019).

[17] İris, M. "Zeytin Dalı Harekâtı'nda Kullanılan Yerli Silahların Medyada Yer Alış Biçimi", ***Uluslararası Kültürel ve Sosyal Araştırmalar Dergisi***, 5(2), 530-546, (2019).

[18] Hellmann, M. "Fuzzy logic introduction", Université de Rennes, 1(1), (2001).

[19] Sharma, D. "Designing and modeling fuzzy control Systems", ***International Journal of Computer Applications***, 16(1), 46-53, (2011).

[20] Guillaume, S., and Charnomordic, B. "Fuzzy inference systems: An integrated modeling environment for collaboration between expert knowledge and data using FisPro", ***Expert Systems with Applications***, 39(10), 8744-8755, (2012).

[21] Ataseven, B., "Yapay sinir ağlari ile öngörü modellemesi", ***Öneri Dergisi***, 10(39), 101-115, (2013).

[22] Kaymakçı, Ö. T., "Robotik Kaynak Hatlarının Bulanık Hata Ağacı Analizi", ***Politeknik Dergisi***, 27(4), 1243-1256, (2023).

[23] Jang, J. S., "ANFIS: adaptive-network-based fuzzy inference system", ***IEEE transactions on systems, man, and cybernetics***, 23(3), 665-685, (1993).

[24] Adem, A., "İş sağlığı ve güvenliğinde kullanılan risk analizi tekniklerinin değerlendirilmesi için bir rehber önerisi", ***Politeknik Dergisi***, 25(3): 1319-1328, (2022).