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Fuzzy-Based Early Academic Risk Prediction System in Educational Institutions

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Abstract: ***Improving possession, performance, and overall academic results requires early identification of students at education instability. The ambiguity and complexity included in student performance data may not be well captured by the traditional prediction algorithms, which frequently depend on strict thresholds and binary classifications. In order to represent an imprecise, ambiguous, and multi-dimensional academic indicator, this study proposed a fuzzy-based, early prediction of educational instability among students.This method incorporates significant input variables, including participation level, quiz results, attendance rate, assignment completion, and socio-academic aspects.***
Using fuzzy theorizing rules, and team effort of the academic experts, these inputs are transformed into linguistic variables and processed through a fuzzy rule based system. The model applies fuzzification, rule evaluation, aggregation, and de - fuzzification to generate a continuous risk score, Classifying students into risk levels such as low risk, medium risk, and high risk. With the help of the suggested system, tutors and administrators can spot students who are at risk early in the semester and provide prompt action like academic support program, counselling, or mentoring. According to experimental evaluation, the fuzzy-based approach improves early detection accuracy while preserving decision rule transparency by offering dependable and flexible predictions. The system provides educational institutions looking to improve student success through proactive academic monitoring with a scalable and adaptable solution.
Keywords: Fuzzy logic, Academic risk prediction, Improvement in Teaching, Defuzzification.

I. INTRODUCTION

Academic achievement and student acquisition continue to be the major goals of educational establishments around the globe. Early detection of pupils who are at risk of academic underperformance is crucial for timely implementation and targeted intervention. In addition to improving student learning, early identification increases institutional effectiveness, optimizes resource use, and promotes long-term student success. However, due to the complexity and dynamic nature of the factors influencing student performance, it is difficult to anticipate academic risk with any degree of accuracy.

Grade point averages (CGPAs), test scores, and attendance records are examples of quantitative indicators that are the mainstay of traditional early warning systems. Although these metrics offer helpful benchmarks, they frequently fall short of capturing the nuanced and context-dependent realities of student development. Furthermore, a lot of current prediction models - including some machine learning methods - need a lot of fully labelled data and are frequently "black-box" systems. Even while these models could be capable of producing precise forecasts, their inability to be interpreted could restrict their use in the educational setting, where decision-making requires transparency and intelligibility. Teachers and administrators want tools that can both accurately identify danger and offer justifications for corrective actions.

In this context, fuzzy logic presents a compelling alternative framework for early academic risk prediction. Unlike binary logic systems that classify inputs into rigid categories, fuzzy logic allows variables to possess degrees of membership, thereby accommodating uncertainty and vagueness. By utilizing linguistic variables and rule - based inference mechanisms, fuzzy systems emulate human reasoning processes and integrate expert knowledge into predictive models. This makes them particularly suitable for modeling the complex and imprecise nature of educational data.

By combining a variety of academic and socio-academic characteristics into an adaptable and comprehensible framework, the suggested Fuzzy-Based Early Academic Risk Prediction System seeks to overcome the shortcomings of traditional models. The method provides a comprehensive assessment of possible academic difficulties by converting qualitative and quantitative student indicators into a continuous risk score through the use of fuzzy inference. This research aims to aid in the creation of more flexible, transparent, and context-sensitive early warning systems by utilizing fuzzy logic's advantages in managing uncertainty and

promoting human-like thinking. In increasingly complex learning contexts, the suggested system seeks to enhance student assistance, academic achievement, and overall educational results.

II. LITERATURE REVIEW

Early identification of students at academic risk has become a significant research area in higher education due to increasing concerns about dropout rates, poor academic performance, and ineffective intervention timing. Traditional evaluation approaches rely heavily on crisp thresholds such as fixed GPA cut-offs, which fail to capture the uncertainty and gradual nature of academic performance decline. To address these limitations, fuzzy logic-based approaches have gained considerable attention.

One of the early applications of fuzzy logic in academic risk prediction was proposed by Ajiboye (2013)[1]. Their study developed a fuzzy logic model to predict students' risk status based on predictive academic indicators. The model analyzed students' past academic records and associated variables to determine the degree of risk rather than assigning binary classifications. The findings demonstrated that fuzzy modeling could effectively classify students into varying risk levels, enabling timely intervention. Importantly, the study emphasized the practical implications of the system for institutional decision-making, including scholarship allocation and academic counselling. However, the study primarily focused on past academic achievement without integrating broader behavioural or engagement-related indicators.

More recently, Hegazi, M.O (2023)[3] proposed a fuzzy reasoning model for predicting academic performance, published in Applied Sciences. Their work introduced the Fuzzy Propositional Model (FPM), which integrates propositional logic with fuzzy set theory to better represent uncertainty and imprecision in educational data. Unlike traditional fuzzy inference systems, FPM transforms if–then rules into weighted fuzzy production rules, improving reasoning capability. The model was validated in two scenarios: predicting final exam performance from lab exam results and assessing the effect of absenteeism on academic outcomes. Comparative analysis showed that the fuzzy model outperformed linear regression methods. This study contributes significantly by enhancing interpretability and reasoning structure; however, it focuses primarily on performance prediction rather than early academic risk identification during initial semesters.

Beyond academic grades, fuzzy logic has also been applied to broader student risk management systems. For example, Ma, M. (2025)[4] developed a fuzzy-based early warning mechanism for mental health management among higher education students. Their model incorporated multi-level risk indicators such as developmental status, social environment, and emotional factors. By integrating this system with fuzzy inference mechanisms, the system generated mental health risk scores and established safety thresholds. The study highlights the flexibility of fuzzy systems in handling multidimensional uncertainty. Although focused on psychological well-being rather than academic performance, it reinforces the applicability of fuzzy-based early warning systems in higher education contexts.

Hybrid intelligent systems combining fuzzy logic with artificial neural networks have also been explored. Nosseir A and Fathy (2020)[6] designed a mobile application integrating neural networks and fuzzy inference to predict student GPA before university enrolment. Their framework used historical institutional data and diagnostic testing via a mobile platform. The fuzzy component refined neural network outputs by estimating performance categories. This hybrid approach demonstrated improved adaptability and early-stage prediction capability. Nevertheless, it targeted pre-admission performance forecasting rather than continuous academic risk monitoring during study progression.

The theoretical foundation of fuzzy-based educational models can be traced back to Lotfi A. Zadeh, who introduced fuzzy set theory in 1965 to mathematically model partial truths and uncertainty. Subsequent advancements have extended fuzzy concepts to intuitionistic, vague, and neutrosophic sets, broadening uncertainty management capabilities. For instance, Mary Tency and Helen (2024)[5] discussed applications of vague sets in modeling uncertainty in optimization problems, emphasizing the importance of handling incomplete and imprecise information. Such developments support the suitability of fuzzy methodologies for complex decision-making scenarios in education, where data ambiguity is inherent.

Further advancements in fuzzy multi - criteria decision-making (MCDM) are evident in the work of Alghazzawi. D (2024)[2], published in IEEE Access. Their T - intuitionistic fuzzy TOPSIS model addressed ambiguity in decision-making by incorporating flexible distance measures. Although not directly applied to academic risk prediction, the study demonstrates the robustness of advanced fuzzy environments in handling imprecise datasets and ranking alternatives under uncertainty. Such approaches can inspire future extensions of academic risk prediction systems into multi - criteria evaluation frameworks.

The traditional monitoring systems rely on fixed cut-off marks (e.g., attendance below 75% or CGPA below 5.0), which fail to capture gradual risk levels and uncertainty in student performance. Hence, a flexible early warning system is detected and tried its best to find the early prediction of student's academic risk through Fuzzy logic.

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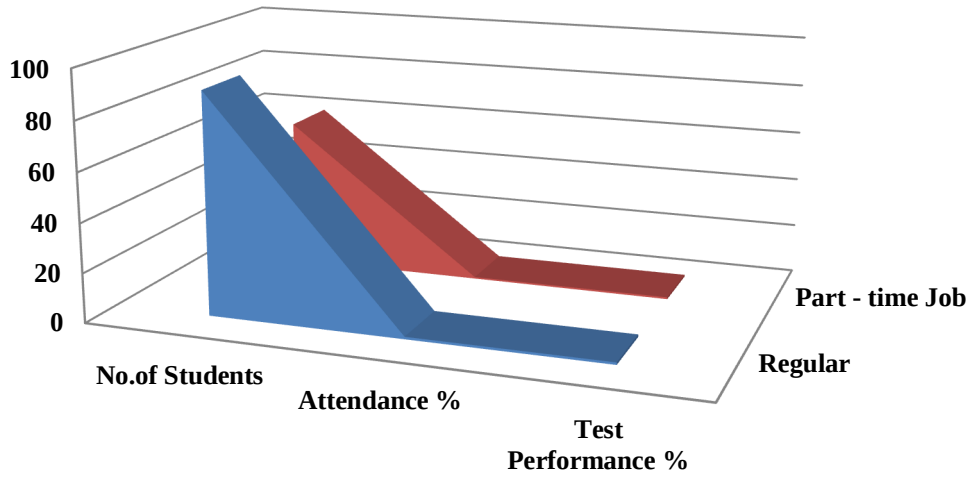
III. SECONDARY-LEVEL STUDY AND RESEARCH PROBLEM

Although advanced fuzzy - based methodologies have not been extensively applied to academic risk prediction, existing studies demonstrate their robustness in handling imprecise datasets and prioritizing alternatives under conditions of uncertainty. Such approaches provide valuable insights for enhancing academic monitoring systems, particularly by extending them into multi-criteria evaluation frameworks. Traditional student monitoring systems rely heavily on rigid cut-off thresholds - such as attendance below 75% or a CGPA under 5.0 - which fail to capture the gradual progression and inherent uncertainty in student performance. Consequently, these conventional methods often lack the sensitivity required for timely and nuanced identification of at - risk students.

To overcome these limitations, this study proposes a flexible early warning system based on fuzzy logic, designed to improve the accuracy and responsiveness of academic risk prediction. The research is grounded in a secondary data analysis of 150 undergraduate students from an Arts & Science College, representing multiple departments including B.Com.,B.Com CA., B.Com IB., and B.Com IT. A significant proportion of these students are engaged in part-time employment due to financial constraints and personal responsibilities.

PERFORMANCE CHART OF
PART- TIME JOB GOERS & REGULAR STUDENTS



	No.of Students	Attendance %	Test Performance %
Regular	90	100%	97%
Part - time Job	60	64%	76%

While part-time work provides essential financial support, it also introduces several challenges that may contribute to academic instability. These include workload imbalance, increased fatigue, reduced study time, and heightened stress levels. Academic risk among working students is therefore not the result of a single factor but emerges from a complex interaction of multiple academic and socioeconomic variables. This multidimensional and uncertain nature of the problem makes fuzzy logic an appropriate and effective analytical tool.

In this context, the study focuses on key risk indicators observed among part-time working students: attendance percentage (64%), internal assessment marks (58%), weekly working hours (approximately 30 hours), high stress levels, and limited study time (approximately 6 hours per week). These factors collectively contribute to academic instability. For instance, extended working hours often lead to irregular class attendance and reduced academic engagement. Simultaneously, elevated stress levels and insufficient study time negatively affect students' academic performance and learning outcomes.

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Tab 1: Input And Output Variables of The Fuzzy Inference System

Variable type	Variable name	Description
Input	Attendance (%)	Percentage of classes attended
Input	Internal Assessment Marks	Academic performance in Internal exams (%)
Input	Weekly working hours	Number of hours spent in part – time job
Input	Stress level	Psychological stress level
Input	Study hours per week	Time spent on Academic study

Tab 2: Linguistic Variables And Membership Ranges

Variable	Linguistic Terms	Range/Values
Attendance (%)	Low	0 – 60
	Medium	50 – 75
	High	70 – 100
Internal Marks (%)	Poor	0 – 50
	Average	45 – 70
	Good	65 – 100
Weekly Working Hours	Low	0 – 10
	Moderate	8 – 25
	High	20 – 40
Stress Level (1–10)	Low	1 – 3
	Medium	3 – 7
	High	7 – 10
Study Hours per Week	Low	0 – 8
	Moderate	6 – 15
	High	12 – 25
Academic Risk (Output)	Low Risk	0 – 3
	Moderate Risk	3 – 7
	High Risk	7 – 10

This interconnected set of challenges highlights the need for an intelligent predictive model capable of capturing the complexity of student behaviour. Accordingly, the research aims to develop a fuzzy inference system (FIS) that integrates both academic indicators (such as attendance and internal assessment scores) and socioeconomic factors (including working hours, stress levels, and study time). By incorporating these variables, the proposed system can generate a more realistic and individualized assessment of academic risk levels.

Tab 3: Sample Fuzzy Rule Base

Rule No.	Fuzzy Conditions	Output
1	Attendance is low and marks are poor and working hours are high	High Risk
2	Attendance is medium and marks are average and stress is high	Moderate Risk
3	Attendance is high and marks are good and study hours are high	Low Risk
4	Working hours are high and study hours are low	High Risk
5	Stress is high and attendance is low	High Risk
6	Working hours are moderate and study hours are moderate	Moderate Risk
7	Attendance is high and stress is low	Low Risk
8	Marks are average and study hours are low	Moderate Risk
9	Attendance is medium and working hours are high	High Risk
10	Stress is medium and study hours are moderate	Moderate Risk

Tab 4: Example Case Evaluation

Parameter	Value	Linguistic Interpretation
Attendance	64%	Medium
Internal Marks	58%	Average
Working Hours	30	High
Stress Level	High	High
Study Hours	6	Low
Predicted Output	—	High Academic Risk

The objective of this secondary-level investigation is to enable early identification of students at risk of academic instability, particularly those balancing academic responsibilities with part-time employment. By providing a more adaptive and comprehensive evaluation framework, the fuzzy-based model supports timely and targeted interventions by educators and institutions. Ultimately, this approach contributes to improving student performance, enhancing retention rates, and promoting overall academic success in higher education settings.

IV. RESEARCH GAPS & FUTURE RECOMMENDATIONS

The suggested fuzzy-based early prediction method gives educational institutions a proactive way to spot overworked and academically fragile pupils early on. The approach allows for the following by combining socioeconomic variables like part-time work with academic success indicators:

1) Early detection of pupils who have an imbalance between work and study
2) Prompt academic mentorship and counselling services
3) Restructuring flexible schedules for students who work
4) The creation of work-study balance rules within institutions
5) Enhanced academic perseverance and student retention

The continuous risk score generated by the fuzzy inference system allows faculty members and administrators to move beyond rigid pass - fail thresholds and adopt a more nuanced, student – centred monitoring strategy.

Rather than early academic risk identification in the first year, the majority of research concentrate on predicting academic success. There is little research that concurrently incorporates engagement metrics, behavioural aspects, internal appraisal, and attendance into a single fuzzy inference framework. In evolving educational environments, there are few models designed especially for Arts and Science colleges. Simpler interpretable fuzzy inference systems appropriate for institutional implementation are still understudied, despite the existence of hybrid and sophisticated fuzzy extensions.

Future studies may concentrate on verifying the suggested fuzzy-based early prediction model in a variety of educational contexts, such as varied student populations at arts and science schools.

Predictive robustness might be further improved by including other dynamic variables including psychological well-being, part-time work status, digital learning involvement, and family background characteristics. Additionally, hybrid systems that combine fuzzy logic with machine learning methods like decision trees or neural networks may increase the accuracy of predictions and the creation of adaptive rules. To investigate the long-term effects of early actions induced by the model, longitudinal studies are also advised. In order to enhance data-driven academic decision-making while upholding ethical norms and data privacy compliance, future work should investigate the creation of user-friendly dashboards for administrators and faculty members.

V. CONCLUSION

This study shows how well a fuzzy inference system (FIS) can detect early indicators of academic instability in undergraduate students, especially those who work part-time. The suggested fuzzy-based methodology takes into account uncertainty, imprecision, and gradual changes in student performance, in contrast to conventional evaluation techniques that depend on strict criteria like attendance percentages or CGPA cut-offs. The approach offers a more accurate and adaptable evaluation of student risk levels by including a variety of contributing elements, including working hours, attendance, tiredness levels, study time, and academic performance.

The results demonstrate that, despite its financial advantages, part-time work can have a substantial impact on academic stability if it is not well balanced. The fuzzy model successfully categorizes students into different risk levels (low, moderate, high), enabling early identification of vulnerable students. This early detection is crucial for timely intervention by educators and institutional administrators.

In summary, the use of fuzzy logic in academic risk prediction presents a viable substitute for traditional monitoring methods. It encourages a more sophisticated, data-driven approach to arranging interventions and evaluating students. Future studies might concentrate on creating real-time decision-support tools for educational institutions, validating the model with bigger and more varied datasets, and combining machine learning methods with fuzzy systems.

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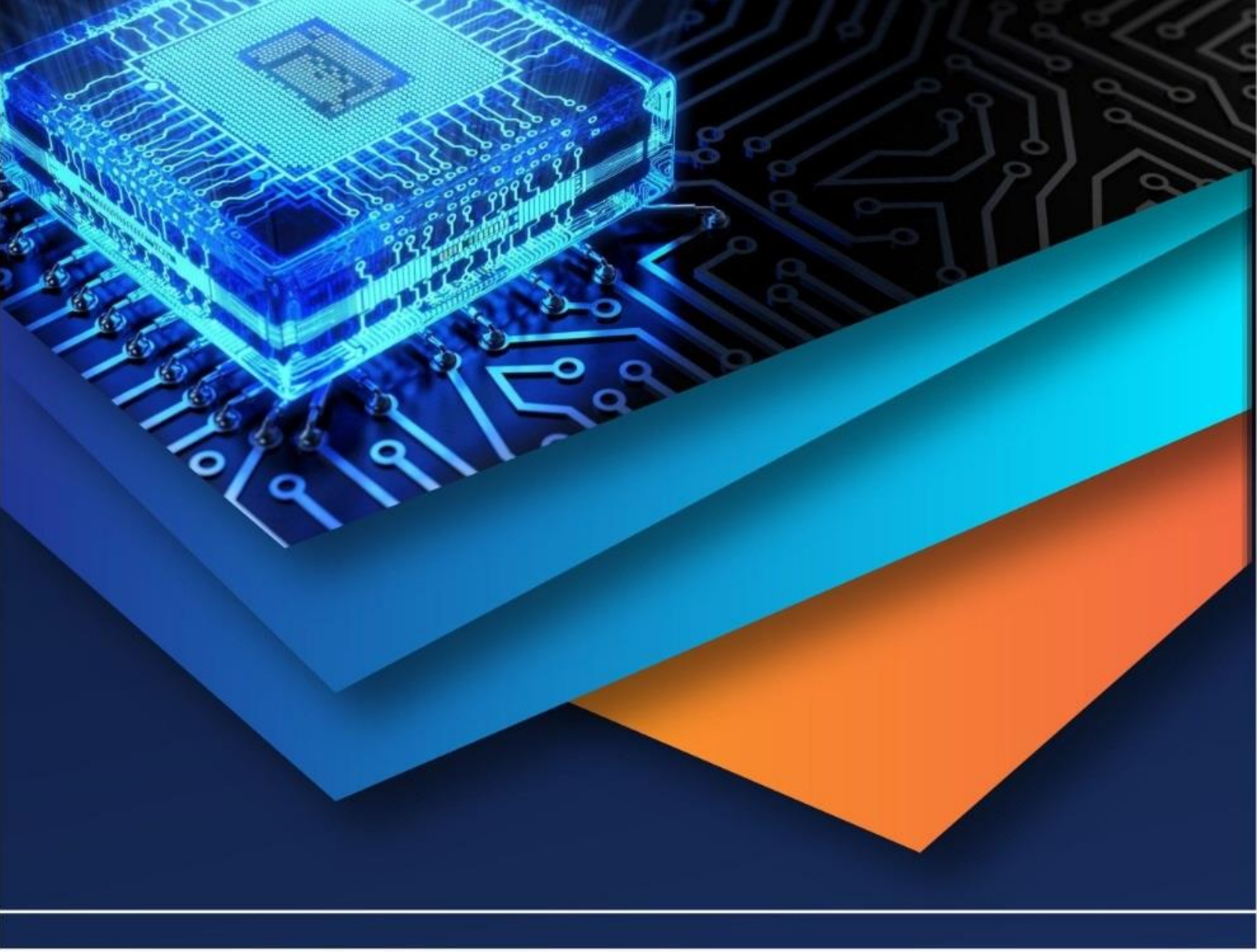

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