Scientometrics (2024) 129:4695–4719
https://doi.org/10.1007/s11192-024-05108-x

Exploring the influence of factors causing stress among doctoral students by combining fuzzy DEMATEL-ANP with a triangular approach

Shanky Garg[1] · **Rashmi Bhardwaj**[1]

Received: 15 June 2023 / Accepted: 10 July 2024 / Published online: 21 July 2024

Abstract
Besides the highest academic degree with lots of merits post that, getting a Ph.D. and the journey throughout the Ph.D. is not so easy due to which stress and trauma become common among Ph.D. research students. Stress among them can't be overlooked and is also of major concern as it not only impacts their academic performances but also their mental health, and increases emotional exhaustion. There are many factors that are involved in causing stress among students. Doctoral students are more prone to it as it demands time, selfless effort, and much sacrifice. Moreover, they are in the stage where there are a lot of things going on that distract their minds or sometimes contradict their decisions be it related to their future or to their family, or be it from the institute side. This article mainly deals with analyzing the factors which cause stress, their effects on Ph.D. students, how these factors interrelate with each other, and their percentage share in causing this. Seven dimensions/factors are explored i.e., Institutional Issues, Personal Issues, Supervisor relations, Academic Issues, Fears, Mental Health, and Time Management, which overall depict the entire Doctoral journey. For the analysis of all these dimensions and for finding out the percentage share, a new hybrid method of MCDA (Multi-Criteria Decision Analysis) i.e., fuzzy DEMATEL-ANP with the triangular approach of responses i.e., Optimistic, Pessimistic & Most-Likely is proposed. Performance Analysis and Sensitivity Analysis are done to do the validity check and robustness of the proposed model and by doing this analysis, we identified that the most likely approach in the proposed model is most reliable than the Optimistic and Pessimistic approach due to its non-biased behavior and Supervisor feedback and Uncertain future are the most influential factors and change of city is the least influential one. Moreover, Academic Issues (Poor Writing Skills as well as Publication issues) together with Satisfaction with topic selection during course work period as well as the supervisor's feedback contributes more with weights of 8.1%, 7.7% & 7.5% respectively in causing stress to the doctoral students.

Keywords Doctoral students · Stress · Fuzzy DEMATEL-ANP · Triangular approach · Performance analysis

Mathematics Subject Classification 90B50

Extended author information available on the last page of the article

Introduction

When the demand for something exceeds the person's ability or the person's strength, it will create a situation of stress. Stress not only hinders the full utilization of resources/strength but also affects our mental and physical health which includes being prone to many psychological diseases, suppressing our immune system, and affecting our relationships too. We can find stress in every field such as in family, in job, and in business and the students also can't escape from this (Prasad & Vaidya, 2017). Stress is responsible for the changes in life but it may be harmful when it becomes a habit and the individual is not able to address it.

The tension during the higher studies is normal but taking tension in excess will become a stress in the long run. According to the reports on college students in the US, a lot of stress and pressure are experienced by students pursuing higher studies and around 53% of students face problems in their personal and social lives because of the high demands, peer pressures, challenges, and rejections during their academic career. Not only taking admission and cracking the entrance tests is sufficient, but cracking interviews for these high academic degrees is also a tedious task, and getting these degrees is not so easy as it demands concentration, time, and lots of effort and sacrifices. It is not necessary that everyone have the same experience and face the same intensity of stress. Some might definitely have many positive experiences in their research journey (Manathunga, 2005). It is not necessary that stress and tension only happen because of the problems as there is a possibility of both negative and positive stress but negative stress harms the most as it leads to a decrease in our efficiency to generate positive outcomes (Anthony-McMann et al., 2017; El-Ghoroury et al., 2012; Kinman et al., 2006).

As researchers are the future generations of knowledge workers in society and stress among them reduces their productivity which is again a social and economic loss (Guthrie et al., 2017). Therefore, it is necessary to understand the stress as well as the stressors which are causing this as it will indirectly increase the tenure of their study as well as degrade the quality of their research (Manathunga, 2005). According to European studies, upto 30% of doctoral students were diagnosed with the same mental disorder (Levecque et al., 2017). Mental health support is also needed at a higher education level for the student's well-being (Mackie & Bates, 2018). According to Goplerud (1980), there is an inverse relationship between stressful incidents and the number of times an interaction between peers takes place. Some further studies reveal that throughout the Ph.D., there are many factors or phases which directly or indirectly put pressure on the researchers which in turn causes stress (Goplerud, 1980; Hockey, 1994; Lazarus & Folkman, 1984). It is very difficult to conclude that only early or late-stage researchers have experienced maximum stress because of entering into a new environment or because of their completion stage. The research environment in which students are working plays an important role to their mental wellbeing (Mackie & Bates, 2018). Lack of transparency, unclear expectations by the higher authorities, and unable to make decisions by the students had an adverse impact on their health and also acted as stressors (Appel & Dahlgren, 2003; Levecque et al., 2017). Hunter and Devine (2016) discovered that students with less experienced supervisors, supervisors' lack of attention towards their students, and other leadership shortcomings are more likely to indicate emotional weariness among students due to which the chances are high that they decide to drop their academic career.

Academic stress among researchers can seriously impact their memory, thinking ability, and analytical skills which are necessary for them to excel academically

(Abdullah et al., 2020). It has an impact on their physical health too such as a weakened immune system, and causes cardiovascular diseases (Schneiderman et al., 2005). According to Rich (2016), long-term high stress usually hinders productivity and creative thoughts. Reducing stress can also help students become healthier, more resilient, and more adaptive, which will benefit their long-term professional performance and also improve their overall quality of life which makes their research career easier and more innovative (Feizi et al., 2024). Due to the negative impact of ongoing stress on PhD students' academic performance, mental health, and general well-being, it is necessary that proper steps should be taken to reduce their stress.

In this paper, we are talking about stress in Ph.D. students and mainly focusing on achieving a broad overview of the stress factors and their contribution and briefly explaining all the factors that affect the researchers/ doctoral students during their Ph.D. journey and their interrelationship among them and how they affect the researchers. So, there is a need to explore these research questions which we will try to answer in this study:

(1) Sources of stress among the Doctoral Students
(2) How do these factors affect the researchers?
(3) The connection between the factors.
(4) Are all the factors negatively affect the researchers?
(5) Percentage share of all of these factors.
(6) How to cope up with these stresses?

We try to answer the above questions using different blended and novel approaches. Firstly, we will identify the stress dimensions which will be covered in this paper with the help of expert opinions. The questionnaire was filled out by around 10 experts and researchers working in different domains and different fields. The important dimension, percentage share of each dimension as well as relationship analysis is done by fuzzy DEMATEL-ANP with a Triangular approach of responses and then compare the analysis with the simple DEMATEL and DEMATEL (Decision-Making Trial and Evaluation Laboratory) -ANP (Analytic Network Process) Techniques.

The further part of the study is described as follows: In "Literature review" section, a brief overview of the past research is given, how this problem arises, what are the sources of stress, and what techniques are used to solve this problem. In "Factors causing stress among Ph.D. students" section, we discuss the stress-causing factors in researchers, "Proposed approach–fuzzy DEMATEL-ANP with the triangular approach of Responses" section comprises the proposed model i.e., fuzzy DEMATEL-ANP with the triangular approach of responses, how it works, and the gist of the DEMATEL and DEMATEL-ANP technique. In "Application of the proposed approach in finding the contribution of stress factors in the Ph.D. journey" section we discuss the application part of the model. In "Analysis of ranking of key factors by the proposed methodology" section, the rank analysis is discussed. "Performance of the proposed model" section and "Sensitivity analysis" section discuss the performance and sensitivity analysis of the model. In "Conclusion" section, we discuss the conclusion along with the scope of future work. In Online Appendix A, the results of the optimistic and pessimistic are discussed.

Literature review

One of the highest academic degrees a person could have and the greatest achievement in the industry of research is tagged as "Doctor" which is honorable and prestigious, and admirable by the society. With too many motivating and glorifying stories, there are many factors that are mostly ignored by society. One of the surprising things during their journey is that they have to face a lot of challenges and go through many harsh stages and many rejections which led to tears, fears, and feelings of demotivation most of the time.

According to the studies of British Universities, stress-related issues, anxiety, fear, and exhaustion were more prevalent in academia as compared to the other professions (Kinman, 1998). Many researchers quantify this stress by taking all the aspects (Appel & Dahlgren, 2003; Bazraftan et al., 2016; Bi, 2007; Castle, 2013; Haksever & Manisali, 2000). A USA study of 2014 on Ph.D. students revealed that 47% of students who were doing research were under stress as compared to 37% of masters students (Panger, 2015). There are many factors that increase the level of stress in doctoral students. Many researchers try to find out these factors and from the literature of past research, we find some of the factors like relationship with the supervisor, academic issues, work-life balance, and uncertain future (Mackie & Bates, 2018; Wisker & Robinson, 2013) are the common ones. Even after the pandemic, the situation became worse as the education sector also suffer a lot, and stress levels among students increases when it returns to the normality (Teresa, 2021). A study in Mexico is done that analyzes the stress, depression level, and health status of the students due to the pandemic (Leon Montoya et al., 2021). The next section will cover the literature on various factors causing stress in the researchers and how to overcome this using different methodologies suggested by different researchers and adopted by different universities and institutions.

Review of factors causing stress in researchers

Researchers identify different factors and the intensity of each factor varies. Even many students while continuing on their journey of getting this degree fight with their own negative thoughts including suicidal ideation (Woolston, 2019). Overload of work, factors related to the roles, psychological, emotional, and behavioral factors also contributed to the stress which was explained in the literature. Relationship with the guide also has a major impact on the physical, and mental well-being of the researcher and also has an impact on the academic success of the students (Mostafaei, 2012). There are many other sources of stress according to different researchers which include the support of a family (Mallinckrodt et al., 1989), financial problems (Hopwood & Paulson, 2012; Nelson et al., 2001), problems during their coursework as well as during thesis writing (Myers et al., 2012), time limitations, and sleeping issues (El-Ghoroury et al., 2012). Even the change in the environment is a major problem mainly for international students (Robinson-Pant, 2009). These factors not only hinder the performance of the students but also in many cases students drop out from their academic careers which is a major setback. To define stress and to measure its effect, the stress, and its factors must be accurately studied. A program by IRSCP (Institute Research Scholar Companion Programme) was initiated by IIT Bombay to help research scholars with their academic and non-academic issues to manage and cope with stress issues (Samrat, 2016).

Coping with stress will have an important role in academic success. There are different coping strategies which are suggested by different researchers i.e., positive strategies which include proper sleep, meditation, and yoga, sharing thoughts with family and friends. According to a survey, students who can easily cope with stress have a low chance of psychological problems (Pariat et al., 2014). Some students also adopted negative strategies like surfing irrelevant websites, drinking alcohol, and smoking which harms their health and does not help in reducing their stress (Stewart et al., 1997). One way to cope up with this situation is to provide necessary support by the universities which includes counselling, creating awareness among the students, and management of various mental health-related activities (Hargreaves et al., 2017; Panger, 2015). Wright (2006) concluded that Time-conscious psychological therapy is effective which results in less psychological discomfort and chances of completion of their career are pretty high. Meditation should be practiced so that the researchers can feel better and experience less stress and anxiety. Some factors which are taken for the study in this paper will be explained in further sections.

Review of MCDM and its techniques

MCDM is a tool that was introduced in the early eighteenth century to support the decision-makers in making complex decisions (Abdulaal & Bafail, 2021). It helps in selecting the criteria's as well as alternatives and ensures that decisions will be made through reliable solutions. Simulations also help in making decisions by decision makers. Elastic predicates and many value labelling functions are proposed by Gore et al. (2015) which makes the debuggers more effective by using random variable and continuous number which minimizes the number of program statements that require examination. MCDA is based on criteria that have a contradicting nature (Hwang & Yoon, 1981). A huge amount of literature related to MCDM is present which includes its descriptions as well as applications. The main advantage of the MCDM is that it integrates both computational and mathematical methods which helps the decision makers in analyzing the performance of criteria and rank their choices in a more effective way (Triantaphyllou, 2000).

Different MCDM methods are used by the decision makers in different fields. When there is an uncertainty in the problem, fuzzy logic is used which has already been applied by some of the researchers in evaluating the performance of suppliers (Ordoobadi, 2009), in making correct investment decisions (Gunasekaran et al., 2006; Tanaka et al., 1976) and has applications in other areas too. However, the main disadvantage of this technique is lacking of consistency measures. AHP (Analytical Hierarchy Process) is also one of the oldest techniques that was developed by Saaty in the 1980s. AHP computes weights from the pairwise comparison matrices (Pakkar, 2016). Using the results of the criteria weights and priorities of alternatives, a decision maker can take optimal decisions (Issa et al., 2022). However, consistency is again an issue in this case because whenever the consistency ratio is above the threshold value, we need to modify our inputs (Calabrese et al., 2019). As there is always some uncertainty present in human perceptions so it is very much difficult to convert it into exact numerical data. Therefore, Zadeh introduced the theory of fuzzy set (Zadeh, 1965) which handles the real-word problems with uncertainty/vagueness (Tsai et al., 2015).

To improve this, several modified versions are also developed like fuzzy-AHP, and AHP-ELECTRE but there is a risk of errors due to heavy calculations. BWM (Best Worst Method) uses fewer pair-wise comparisons as compared to other methods (Khan et al.,

2023; Rezaei, 2015). TOPSIS is also one of the MCDM techniques proposed by Hwang and Yoon (Aires & Ferreira, 2019). The concept works on the minimum/maximum distance from the positive/negative ideal solutions. However, it fails to incorporate the correlation of attributes (Urošević et al., 2021). There are many other techniques that are used like TOPSIS in knowledge sharing (Maheshwarkar & Sohani, 2013), and PROMTHEE in the transportation industry (Turcksin et al., 2011). The CRITIC method is used along with the fuzzy concept to assess the traffic congestion situation scheme in 5G-IOV through which researchers determine the weight as well as each traffic congestion indicator's degree of affiliation (Liu et al., 2021).

As there are many techniques which are already developed but the main problem is selecting the appropriate one. Some researchers suggested that we can select techniques based on their applicability to a particular problem (Urošević et al., 2021; Wang et al., 2016). In this paper, we are using fuzzy DEMATEL-ANP with the triangular approach which will be discussed in "Proposed approach–fuzzy DEMATEL-ANP with the triangular approach of responses" section.

Factors causing stress among Ph.D. students

From the literature and with the help of opinions taken by the decision-makers, we identify factors and subfactors that directly or indirectly cause stress among the researchers, mentioned in Table 1 with the description of the factors and their references:

Proposed approach-fuzzy DEMATEL-ANP with the triangular approach of responses

As the doctoral journey is not so easy, finding the appropriate factors which become hindrance in this journey is also a challenging task. Few studies have been done in the past which discussed about the stresses among scholars. A survey is done to find out the effect of different factors that cause stress among scholars (some of which are discussed above) based on their performances and uses different statistical techniques like Descriptive Analysis, Correlation Analysis, and Multiple Regression Analysis and it was found out that Physiological factors have a significant contribution in stress (Prasad & Vaidya, 2017). Moreover, some studies reported that responsibilities regarding academics, financial problems, work-life balance, and discrimination among minority students act as stressors for the students (El-Ghoroury et al., 2012). A preventive approach is also suggested by some researchers to improve the course completion time as well as explored the reasons why students did not discuss the difficulties with their supervisors (Manathunga, 2005). Even, a Regression analysis is also done to find the factors that increase the student success rate and results show that there should be a good match between the student and the supervisor (Rooij et al., 2021). Even past studies identify different sources of stress but these studies ignore the fuzziness which is important for real-life situations, the relationship among the factors, and the mathematics behind it. Moreover, the percentage share of different factors causing stress has not been explored properly.

Therefore in this study, we are using the fuzzy DEMATEL-ANP with a Triangular approach to investigate how different factors affect performance and cause stress among students by evaluating their weights and analyzing the relationship among the factors, and

Table 1 Dimensions with cofactors

S. no	Factors with cofactors	Description	References (authors with years)
1	Institutional issues 1.1 Paper work & financial crunches (EF^{1})	These are the issues that are related to the universities/colleges during the admission time as well as during the tenure of study which includes fellowship issues, and proper course allocation issues	Prasad and Vaidya (2017)
2	Personal issues 2.1 City/Country change (EF^{2})	These issues mainly deal with the pressure of the family regarding jobs, fellowships, and living far away from the family is also a difficult task in the case of outstation/international students	El-Ghoroury et al. (2012)
3	Supervisor relation 3.1 Journal selection (EF^{3}) 3.2 Feedback (EF^{4})	It depicts the relationship that a student has with their supervisor as their suggestions, support, as well as behavior, will create a major impact on a student's journey and productivity	Prasad and Vaidya (2017)
4	Academic issues 4.1 How to start the work (EF^{5}) 4.2 Writing skills & paper publication (EF^{6}) 4.3 Plagiarism removal (EF^{7})	These issues are related to the student's work during the doctoral study which is mainly found in early-stage Ph.D. students	Manathunga (2005)
5	Fears 5.1 Fear of rejection (EF^{8}) 5.2 Peer pressure (EF^{9})	These issues started within the minds of the students because of the rejections from the journals and pressure from their peers	Hopwood and Paulson (2012)
6	Mental health 6.1 Uncertain future (EF^{10}) 6.2 Satisfaction with topic selection (EF^{11}) 6.3 Emotional strain (EF^{12}) 6.4 Harassment & discrimination (EF^{13})	These issues mainly dealt with the insecure future, getting jobs, inner satisfaction, and emotional pressure from their family and friends	Manathunga (2005)
7	Time management 7.1 Missed deadlines (EF^{14}) 7.2 Work-life balance (EF^{15})	These issues mainly arise due to low confidence, poor management of time, and engaging in unnecessary work/activities	Hopwood and Paulson (2012)

comparing it with the DEMATEL and DEMATEL-ANP and their overall ranking using the Borda score (Hu et al., 2015; Truchon, 2008; Saari, 2000).

DEMATEL

The DEMATEL method was developed by the Battelle Memorial Institute of Geneva to solve bigger complex problems (Fontela & Gabus, 1976). The DEMATEL method is a comprehensive approach that is adopted by many researchers to cover different aspects of analysis in multiple fields and to find feasible solutions of a complex problem. It helps us to construct and analyze a structural and hierarchical model, analyze the direct–indirect relationships, and also the cause-effect relationships among the criteria (Li & Tzeng, 2009). In DEMATEL, cause refers to the factors that have an impact on the other factors and effect refers to the factors that are influenced by other factors within the system. This relationship is important for making predictions and informed decision-making by the decision maker.

The steps to be followed in DEMATEL are as follows:

(1) The first step in DEMATEL comprises understanding the problem, extracting the factors/dimensions that define our research problem based on past studies and from the views of the experts, and the dimension's influence degree is based on the 5-point scale i.e., 0—No Influence (NI), 1—Very Low Influence (VLI), 2—Low Influence (LI), 3—High Influence (HI), 4—Very High Influence (VHI).

(2) Construct a direct relationship matrix M by using a Questionnaire that was filled by the experts using the above-mentioned scale and then the net direct relationship matrix $M^{'}$ is evaluated using Eq. (1).

$$M = \begin{matrix} 0 & M_{11} & \dots & M_{1n} \\ M_{21} & 0 & \dots & M_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ M_{n1} & M_{n2} & \dots & 0 \end{matrix} \; and \; M' = \frac{1}{m} \sum_{l=1}^{m} M_{ij}^{l}, \tag{1}$$

where M_{ij} represents the values that were given by the experts by keeping in mind how i^{th} factor influences the j^{th} factor, m represents the number of experts and $0 \leq M_{ij}, M^{'} \leq 4$.

(3) A normalized relation matrix (X) is calculated using the net direct relationship matrix and given by Eq. (2):

$$X = k.M' \text{ where } k = \frac{1}{\max\limits_{1 \leq i \leq n} \sum_{j=1}^{n} M_{ij}} \tag{2}$$

(4) The total relationship matrix (T) was evaluated by the normalized matrix X by Eq. (3).

$$T = X(I - X)^{-1} \tag{3}$$

(5) Calculate the sum of each row which is represented by R_i and the sum of each column represented by C_j $R_i + C_j$ is calculated to analyze the relationship among the factors. Higher the value of $R_i + C_j$, the higher the relationship among the factors and vice-

versa. $R_i - C_j$ is calculated to analyze the kind of relation between the factors. If the value comes out positive then the factor belongs to the causal group and if the value comes out negative then it belongs to the effect group.

(6) Calculate the threshold value (λ) which is given by Eq. (4) to check which factor has a negligible effect on other factors.

$$\Lambda = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left[M_{ij}\right]}{N} \tag{4}$$

(7) Analyze the direct–indirect relationship using the cause-and-effect diagram. It tells us about the importance of criteria as well as their level of influence in a complex problem.

DEMATEL-ANP

DEMATEL-ANP is a coupled MCDM (Multi-criteria Decision Making) method that combines DEMATEL and ANP. Although we can easily analyze the relationships among the factors as well as the weights using these methods individually but there are some shortcomings in DEMATEL as well as in ANP, relationship maps do not have any relationship loops and the factors interact linearly in DEMATEL. Similarly, while calculating the weighted supermatrix in ANP, the influence of various degrees among the factors is ignored (Ou Yang et al., 2008).

The steps to be followed in DEMATEL-ANP are as follows:

(1) Steps 1–4 are same and followed in the same manner as explained in the above DEMATEL method.
(2) In Step-5, take the total influence matrix T that we get in Step-4 as an unweighted supermatrix (U) of ANP.
(3) In Step-6, normalize the matrix U to get the weighted supermatrix (U*).
(4) In Step-7, from weighted supermatrix (U*) generate a limiting supermatrix (L) to calculate the DEMATEL-ANP weights and rank the factors according to the weights.

Fuzzy DEMATEL-ANP with the triangular approach of responses

In analyzing different real-life situations, the satisfaction level is based on properties which are usually defined using some predefined scale with a precise value. But sometimes it does not reflect the reality if these precise value scales are used. As there are hidden difficulties in implementing the methodology on a real-world dataset, it is necessary that it should be automated. To ease this problem (Hao et al., 2013) proposed probability distribution criteria to localize predicate-based statistical fault. Moreover, in situations where the simulations predicted behaviour is uncertain or involves random fluctuations, it is difficult to categorize sets. Kamensky et al. (2011) categorize their outputs into passing and failing sets by the use of the membership function concept in fuzzy theory during non-deterministic simulations. Therefore, fuzzy numbers are used in place of precise values to properly evaluate the satisfaction degree and analyze the results (Gharakhani, 2012).

In this study, we combine the fuzzy theory with DEMATEL-ANP to get ideal solutions from group decision-making with a variation in the CFCS (Converting fuzzy data into crisp scores) during the defuzzification process which proved to be effective by researchers rather than the centroid method (Yu, 2008). A triangular approach of responses (Rajput & Singh, 2019) is applied during the integration of the crisp values rather than the average method which means the Integration of crisp values is done by assuming optimistic, pessimistic, and most-likely situations. A detailed procedure of applying the Fuzzy DEMATEL-ANP with the triangular approach of responses is described below:

(1) The first step comprises understanding the problem and forming the key factors that define our research problem based on past studies and the views of the chosen experts.
(2) The fuzzy scale is defined to handle the vagueness involved in human perceptions (Gharakhani, 2012; Li, 1999). The linguistic terms along with their influence score and fuzzy numbers are shown in Table 2.

(3) Construct a fuzzy initial direct relation matrix X^k by using the expert opinions as well as the fuzzy numbers where k represents the number of experts and $X^k = [x_{ij}^k]$, x_{ij} is the influence of factor i on factor j, and $x_{ij} = 0$ where $i = j$.

$$X^k = \begin{matrix} [0,0] & \otimes x_{12}^k & \dots & \otimes x_{1n}^k \\ \otimes x_{21}^k & [0,0] & \dots & \otimes x_{2n}^k \\ \vdots & \vdots & \vdots & \vdots \\ \otimes x_{n1}^k & \otimes x_{n2}^k & \dots & [0,0] \end{matrix} \text{ where } x_{ij}^k = \left(l_{ij}, m_{ij}, u_{ij}\right),$$

where l_{ij},m_{ij},u_{ij} represents the lower, median and upper value of the perception.

4. Normalize the fuzzy initial direct relation matrix X^k by using Eqs. (5–11). The process of normalization is as follows:

   1. Normalise these fuzzy numbers by using Eqs. (5–7).

$$xu_{ij}^n = \left(u_{ij}^n - \min l_{ij}^n\right) \Big/ \Delta_{\min^{\max}}, \tag{5}$$

$$xm_{ij}^n = \left(m_{ij}^n - \min l_{ij}^n\right) \Big/ \Delta_{\min^{\max}}, \tag{6}$$

Table 2 Scores & fuzzy number of linguistic term

Linguistic term	Score	Fuzzy number
No influence	0	(0, 0, 0.25)
Very low influence	1	(0, 0.25, 0.5)
Low influence	2	(0.25, 0.5, 0.75)
High influence	3	(0.5, 0.75, 1)
Very high influence	4	(0.75, 1, 1)

$$xl_{ij}^{n} = \left(l_{ij}^{n} - \min l_{ij}^{n}\right) \Big/ \Delta_{\min^{\max}}, \tag{7}$$

where $\Delta_{\min}^{\max} = \max u_{ij}^{n} - \min l_{ij}^{n}$ & $xu_{ij}^{n}, xm_{ij}^{n}, xl_{ij}^{n}$ represents the initial normalized values.

5. Calculate left(lv) and right(uv) normalised value by using Eqs. (8, 9).

$$xuv_{ij}^{n} = xu_{ij}^{n} \Big/ \left(1 + xu_{ij}^{n} - xm_{ij}^{n}\right), \tag{8}$$

$$xlv_{ij}^{n} = xm_{ij}^{n} \Big/ \left(1 + xm_{ij}^{n} - xl_{ij}^{n}\right) \tag{9}$$

6. Calculate total normalized crisp values by Eq. (10).

$$x_{ij}^{n} = \frac{\left[xlv_{ij}^{n}\left(1 - xlv_{ij}^{n}\right) + xuv_{ij}^{n} * xuv_{ij}^{n}\right]}{\left[1 - xlv_{ij}^{n} + xuv_{ij}^{n}\right]} \tag{10}$$

7. Compute the crisp values for each decision maker and make a matrix by Eq. (11).

$$Z_{ij}^{n} = \min l_{ij}^{n} + x_{ij}^{n} * \Delta_{\min}^{\max} \tag{11}$$

8. Integrate all the crisp values using the triangular approach of responses i.e., here we take three cases to get the final integrated matrix i.e., optimistic, pessimistic, and most-likely responses.

Case 1 For the Optimistic case, we integrate the opinion of the experts by taking the maximum value which is given by Eq. (12).

$$Z_{ij} = \max\left(Z_{ij}^{n}\right) \text{ where } 1 \leq n \leq k \tag{12}$$

Case 2 For the Pessimistic case, we integrate the opinion of the experts by taking the minimum value which is given by Eq. (13).

$$Z_{ij} = \min\left(Z_{ij}^{n}\right) \text{ where } 1 \leq n \leq k \tag{13}$$

Case 3 For the Most-Likely case, we integrate the opinion of the experts by taking the average value which is given by Eq. (14).

$$Z_{ij} = \frac{1}{k}\sum_{n=1}^{k} x_{ij}^{k} \tag{14}$$

9. Create a generalized normalized matrix X by using Eq. (15).

$$X = k.Z_{ij} \text{ and } k = \frac{1}{\max\limits_{1 \leq i \leq n} \sum_{j=1}^{n} Z_{ij}} \tag{15}$$

10. The total relationship matrix (T) is evaluated by using Eq. (16).

$$T = X(1 - X)^{-1} \tag{16}$$

11. Calculate the sum of each row which is represented by R_i and the sum of each column represented by C_j. The higher the value of $R_i + C_j$, the higher the relationship among the factors and vice-versa. Further, it represents the extent to which the factor i contributes to the system (total sum of effect received and given). $R_i - C_j$ is calculated which shows the kind of relation between the factors. Further, it indicates the overall impact that factor i has on the system (Falatoonitoosi et al., 2013). If its value comes out positive then the factor belongs to the causal group or that factor is a net causer and if the value comes out negative then it belongs to the effect group or to the net receiver group.
12. In Step-9, take the total influence matrix T that we get in Step-7 as an unweighted supermatrix (U) of ANP.
13. In Step-10, normalize the matrix U to get the weighted supermatrix (U*).
14. In Step-11, from weighted supermatrix (U*), generate a limiting supermatrix (L) to calculate the DEMATEL-ANP weights and rank the factors according to the weights. Calculate the overall ranking of the model using the Borda score.

Application of the proposed approach in finding the contribution of stress factors in the Ph.D. journey

In this study, we mainly focus on finding the contribution of critical stress factors that affect doctorate students during their academic careers and become a hindrance to their success. Based on the severity and complexity of the problem and to overcome the issues of relationship loops and the linearity among factors, fuzziness in the data and to avoid the ignorance of influencing characteristics among the factors, we proposed a novel methodology of MCDM. In this study, we are using fuzzy DEMATEL-ANP based on the triangular approach of responses and evaluate the direct as well as the indirect relationships among the factors. The prototype of the proposed approach is shown in Fig. 1 and the steps to be followed are as follows:

Step 1 After going through the rigorous literature survey and keeping in mind the experts' views, a prototype is designed for the factors causing stress that includes 7 factors and 15 cofactors which are mentioned in Table 1. A Questionnaire is designed to collect data from experts to evaluate the influences of one factor over another. Scores of 0, 1, 2, 3, 4 represent NI, VLI, LI, HI, and VHI respectively which are given by the decision makers based on their experiences.

Step 2 Before the implementation of the proposed model, 10 decision-makers who have experience in this domain and have gone through these stages evaluated the factors taken for this study. Evaluators are of different ages and have different work experiences working with different organizations and in different fields. Based on their knowledge and expertise, they have different opinions. The evaluator's characteristics are given in Table 3.

Step 3 A five-point scale is used by the evaluators and the comparison is made by the linguistic variables given in Table 2 with their influence score. Total comparisons made by the decision maker based on the scale is 15×15.

Step 4 Generate direct fuzzy relation matrix M by using Step-3 described in "Fuzzy DEMATEL-ANP with the triangular approach of responses" section.

In this study, each decision maker is given a 15*15 decision matrix for the comparison of stress factors during the filling of the questionnaire. Here CF stands for cofactors.

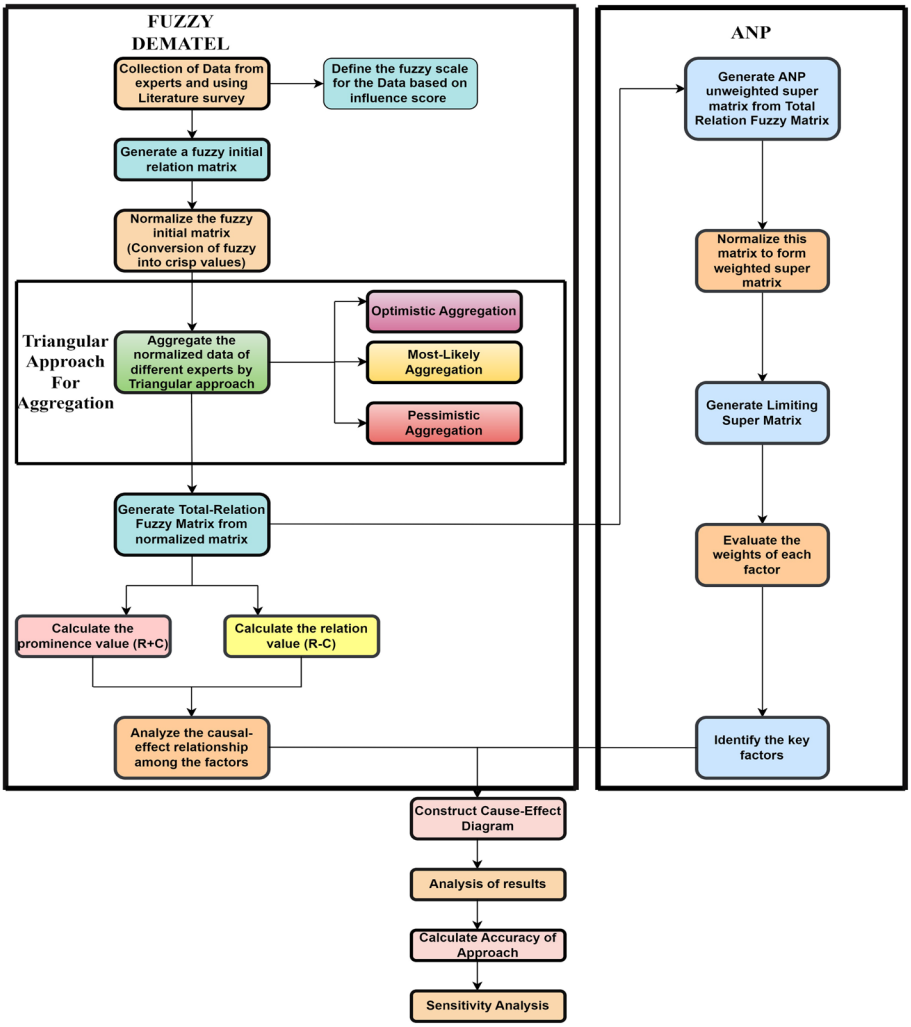

Fig. 1 Prototype of the approach

$\mathbf{EF^i}$ represents the factors taken for this study. Data in the form of a complete direct fuzzy matrix of ten experts is given in Online Appendix A.

Step 5 Convert the direct fuzzy relation matrix M into the initial direct relation matrix.

In this step, we convert the fuzzy numbers into crisp values for each evaluator's direct fuzzy relation matrix by using Eqs. (5–11) and then compute the aggregated values of the initial direct matrix by using the optimistic, pessimistic and, most-likely approach by using Eqs. (12–14) and the most-likely result is shown in Table 4. Refer to Online Appendix A for the optimistic and pessimistic Results.

Step 6 Construct normalized matrices (N) for each approach by using Eq. (15). Refer to Online Appendix A for the normalized optimistic, pessimistic, and most-likely results.

Step 7 Construct a total relation fuzzy matrix (T) for each approach using Eq. (16). The most-likely approach is shown in Table 5.

Table 3 Evaluators table

Decision maker (DM)	Age	Exp	Job description
DM 1	50–55	> 22	Professor in a reputed university and wrote many research papers
DM 2	50–55	> 25	Head at Bhabha Atomic Research Centre
DM 3	50–55	> 20	Professor in a reputed university and wrote many research papers
DM 4	40–50	> 15	Professor in a reputed university
DM 5	30–35	> 10	Professor in a reputed university
DM 6	30–35	> 10	Professor in a reputed university
DM 7	30–35	> 10	Working as a senior manager in corporate and doing research in the field of finance
DM 8	25–30	> 5	A part-time Ph.D. student and is doing research in the field of AI and data science
DM 9	25–30	> 4	Ph.D. Late-Stage Student
DM 10	25–30	> 3	Ph.D. Early-Stage Student

Table 4 Initial direct relation matrix with most-likely approach

	EF^1	EF^2	EF^3	EF^4	EF^5	EF^6	EF^7	EF^8	EF^9	EF^{10}	EF^{11}	EF^{12}	EF^{13}	EF^{14}	EF^{15}
EF^1	0	0.58	0.42	0.33	0.21	0.61	0.26	0.39	0.29	0.29	0.61	0.61	0.45	0.5	0.57
EF^2	0.51	0	0.26	0.37	0.26	0.45	0.3	0.5	0.42	0.18	0.46	0.26	0.62	0.26	0.5
EF^3	0.66	0.26	0	0.78	0.58	0.74	0.46	0.47	0.43	0.26	0.58	0.66	0.5	0.66	0.57
EF^4	0.62	0.3	0.74	0	0.69	0.81	0.85	0.62	0.62	0.66	0.54	0.66	0.66	0.58	0.58
EF^5	0.3	0.14	0.66	0.7	0	0.73	0.35	0.34	0.18	0.46	0.38	0.58	0.42	0.42	0.42
EF^6	0.58	0.22	0.62	0.69	0.58	0	0.46	0.42	0.37	0.69	0.69	0.58	0.62	0.58	0.69
EF^7	0.41	0.3	0.39	0.74	0.5	0.62	0	0.58	0.5	0.58	0.54	0.38	0.35	0.69	0.7
EF^8	0.43	0.46	0.34	0.35	0.21	0.42	0.77	0	0.34	0.38	0.66	0.54	0.65	0.62	0.54
EF^9	0.38	0.49	0.3	0.54	0.26	0.33	0.34	0.73	0	0.5	0.65	0.77	0.54	0.55	0.7
EF^{10}	0.3	0.14	0.57	0.7	0.5	0.85	0.73	0.46	0.3	0	0.77	0.58	0.54	0.66	0.57
EF^{11}	0.37	0.5	0.42	0.62	0.53	0.62	0.58	0.69	0.34	0.7	0	0.62	0.65	0.66	0.66
EF^{12}	0.42	0.3	0.34	0.62	0.46	0.7	0.42	0.74	0.37	0.46	0.78	0	0.66	0.69	0.41
EF^{13}	0.58	0.54	0.42	0.47	0.42	0.58	0.34	0.58	0.66	0.42	0.5	0.66	0	0.43	0.62
EF^{14}	0.37	0.3	0.69	0.77	0.57	0.85	0.77	0.78	0.54	0.42	0.74	0.62	0.7	0	0.5
EF^{15}	0.42	0.38	0.43	0.54	0.34	0.62	0.58	0.62	0.7	0.33	0.57	0.38	0.62	0.54	0

Step 8 Calculate the $R_i + C_j$ and $R_i - C_j$ and analyze the values.

As the value of $R_i + C_j$ in all three approaches is maximum for factor EF^4 (Supervisor Feedback) and minimum for factor EF^2 (City/Country Change). Therefore, EF^4 (Supervisor Feedback) is the most influential factor and EF^2 (city change) is the least influential factor. The negative value of $R_i - C_j$ means the factor belongs to the effect group and the positive value depicts that it belongs to the cause group. Moreover, EF^{10} (Uncertain future) has the highest value of $R_i - C_j$ which means this is also the most influential factor besides EF^4 which need more attention. Moreover, through the analysis of this study, we can conclude that the factors which belong to the causal group are more powerful than other factors. To

Table 5 Total relation matrix in terms of the most-likely approach

	EF^1	EF^2	EF^3	EF^4	EF^5	EF^6	EF^7	EF^8	EF^9	EF^{10}	EF^{11}	EF^{12}	EF^{13}	EF^{14}	EF^{15}
EF^1	0.19	0.21	0.24	0.28	0.21	0.33	0.25	0.28	0.22	0.23	0.32	0.30	0.29	0.29	0.30
EF^2	0.22	0.13	0.20	0.25	0.19	0.27	0.22	0.26	0.21	0.19	0.27	0.23	0.27	0.23	0.26
EF^3	0.31	0.21	0.25	0.38	0.29	0.40	0.32	0.34	0.27	0.27	0.37	0.36	0.35	0.36	0.35
EF^4	0.34	0.24	0.36	0.35	0.34	0.46	0.40	0.40	0.33	0.35	0.42	0.40	0.41	0.40	0.40
EF^5	0.23	0.16	0.27	0.32	0.19	0.35	0.26	0.28	0.21	0.25	0.30	0.30	0.29	0.28	0.29
EF^6	0.30	0.21	0.32	0.38	0.30	0.34	0.33	0.35	0.27	0.32	0.39	0.36	0.37	0.36	0.37
EF^7	0.27	0.21	0.28	0.37	0.28	0.38	0.26	0.34	0.27	0.29	0.36	0.32	0.32	0.35	0.36
EF^8	0.25	0.21	0.25	0.30	0.23	0.33	0.32	0.26	0.24	0.25	0.34	0.31	0.33	0.32	0.32
EF^9	0.26	0.22	0.26	0.34	0.24	0.34	0.29	0.35	0.21	0.28	0.36	0.35	0.33	0.33	0.35
EF^{10}	0.28	0.20	0.32	0.38	0.29	0.42	0.36	0.35	0.27	0.25	0.40	0.36	0.36	0.37	0.36
EF^{11}	0.29	0.24	0.30	0.38	0.30	0.40	0.34	0.38	0.27	0.32	0.32	0.37	0.37	0.37	0.37
EF^{12}	0.28	0.21	0.28	0.36	0.27	0.39	0.31	0.36	0.26	0.29	0.38	0.28	0.36	0.35	0.33
EF^{13}	0.28	0.23	0.27	0.33	0.26	0.36	0.29	0.34	0.28	0.27	0.34	0.34	0.28	0.32	0.34
EF^{14}	0.31	0.24	0.35	0.42	0.32	0.46	0.39	0.41	0.31	0.32	0.43	0.39	0.40	0.33	0.39
EF^{15}	0.27	0.21	0.27	0.34	0.25	0.37	0.31	0.34	0.29	0.26	0.35	0.31	0.34	0.33	0.28

remove this problem, universities as well as concerned authorities should focus on these factors following which other factors in the effect group are also improved as they are directly affected by the factors presenting in the causal group (see Table 6).

Step 9 Draw the digraph of the causal-effect relationship as shown in Fig. 2. Refer to Online Appendix A. for the optimistic and pessimistic results.

Step 10 Take the total matrix that we get from fuzzy DEMATEL as the unweighted matrix (U) of ANP.

Step 11 Construct the weighted matrix (U*) by dividing each entry of the unweighted matrix by its row sum which is shown in Online Appendix A.

Step 12 Construct a limiting supermatrix (L) by multiplying U* by itself until it becomes convergent and reaches a particular number. From this matrix, we can see the contribution of each factor in causing stress. From Table 7, we can conclude that Academic Issues (Poor Writing Skills as well as Publication issues) together with Satisfaction with topic selection during course work period as well as the supervisor's feedback contribute more causing stress to the doctoral students.

Analysis of ranking of key factors by the proposed methodology

In this study, we are using the concept of fuzzy DEMATEL to overcome the issue of precise values as well as combine it with the ANP which overcomes the dependency as well as looping issues among the criteria (Yu, 2008). Here ranking is done based on the Borda score (Zadeh, 1965) to avoid the problems of each method in evaluating the rank. As we are using three approaches to integrate the data received from different decision makers, for the evaluation of the rank, the rank of prominence i.e., $R_i + C_j$ of fuzzy DEMATEL with each approach, and the rank of the Fuzzy DEMATEL-ANP are summed up to get a single score and combined rank is shown in Table 8 for most-likely approach.

Table 6 Cause and effect group of each approach

		R_i+C_i	R_i-C_i	Cause/effect		R_i+C_i	R_i-C_i	Cause/effect		R_i+C_i	R_i-C_i	Cause/effect
EF^1	Optimistic	17.34	−0.51	Effect	Pessimistic	1.55	−0.59	Effect	Most-likely	7.97	−0.15	Effect
EF^2		14.89	−0.03	Effect		1.22	0.12	Cause		6.57	0.24	Cause
EF^3		17.24	0.34	Cause		3.23	0.95	Cause		9.07	0.60	Cause
EF^4		19.02	0.45	Cause		5.10	0.35	Cause		10.79	0.41	Cause
EF^5		16.12	−0.73	Effect		2.19	0.00	Cause		7.94	0.00	Cause
EF^6		18.57	−0.28	Effect		4.93	−1.00	Effect		10.58	−0.63	Effect
EF^7		17.06	0.48	Cause		3.89	−0.12	Effect		9.32	0.02	Cause
EF^8		17.03	−0.25	Effect		3.88	−0.57	Effect		9.31	−0.74	Effect
EF^9		17.71	0.18	Cause		2.53	0.45	Cause		8.42	0.59	Cause
EF^{10}		17.52	0.55	Cause		3.50	1.29	Cause		9.09	0.84	Cause
EF^{11}		18.73	−0.16	Effect		3.85	−0.14	Effect		10.38	−0.31	Effect
EF^{12}		18.23	0.31	Cause		3.72	−0.75	Effect		9.71	−0.27	Effect
EF^{13}		17.99	−0.18	Effect		3.83	−0.02	Effect		9.59	−0.52	Effect
EF^{14}		18.37	0.16	Cause		4.68	0.07	Cause		10.46	0.49	Cause
EF^{15}		18.50	−0.33	Effect		3.05	−0.05	Effect		9.58	−0.56	Effect

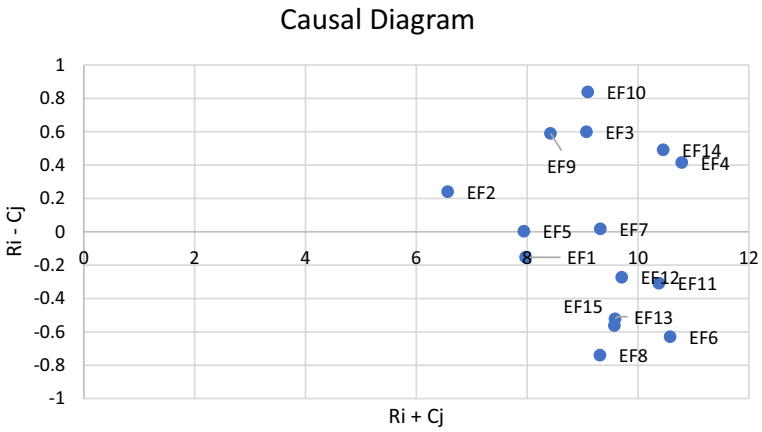

Fig. 2 For most-likely approach

Performance of the proposed model

Based on the different results obtained by fuzzy DEMATEL-ANP by all the three approaches i.e., Optimistic, Pessimistic, and most likely, the performance of this approach is evaluated by the symmetric mean absolute percentage error square error test (sMAPE). This test is used to check the accuracy of the models and it imposes less penalty for negative errors (Krishnan et al., 2021). In this study, for calculating the sMAPE equation is used

$$W_j^* = \sum_{j=1}^{n} \frac{W_j}{n} \tag{17}$$

$$sMAPE = \frac{100\%}{n} \sum_{j=1}^{n} \frac{\left|W_j^* - W_J\right|}{\frac{\left(W_j^* + W_J\right)}{2}}. \tag{18}$$

Here W_j^* represents the aggregated weight and W_j represents the weight of each criterion and n represent the number of the methods used to calculate the weights. Table 9 shows the sMAPE for each proposed model and from the results we find out that that Most-likely approach of the fuzzy DEMATEL model has more accuracy than the Optimistic and Pessimistic approaches.

Sensitivity analysis

Sensitivity analysis is a popular method in MCDM to test the robustness of various models and to check the reliability of decisions made by the decision maker. It tells us how a small change in the input will affect the output. In this study, we are looking at the effect of different combinations of inputs that we obtained. As from the performance metrics (sMAPE), we already identified that fuzzy DEMATEL-ANP based on the most-likely approach is the most accurate model. Now, we are taking different scenarios (See

Table 7 Most-likely limiting matrix

	EF^{1}	EF^{2}	EF^{3}	EF^{4}	EF^{5}	EF^{6}	EF^{7}	EF^{8}	EF^{9}	EF^{10}	EF^{11}	EF^{12}	EF^{13}	EF^{14}	EF^{15}
EF^{1}	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
EF^{2}	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
EF^{3}	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
EF^{4}	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
EF^{5}	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
EF^{6}	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
EF^{7}	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
EF^{8}	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
EF^{9}	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
EF^{10}	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
EF^{11}	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
EF^{12}	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
EF^{13}	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
EF^{14}	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
EF^{15}	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073

Table 8 Ranking based on most-likely approach

Most-likely	Fuzzy DEMATEL (prominence value)	Rank	Fuzzy D-ANP (weights)	Rank	Borda score	Overall rank
EF^1	7.97	13	0.059	12	25	12
EF^2	6.57	15	0.046	15	30	15
EF^3	9.07	11	0.061	10	21	10
EF^4	10.79	1	0.075	3	4	2
EF^5	7.94	14	0.057	13	27	14
EF^6	10.58	2	0.081	1	3	1
EF^7	9.32	8	0.067	9	17	9
EF^8	9.31	9	0.072	6	15	8
EF^9	8.42	12	0.057	14	26	13
EF^{10}	9.09	10	0.060	11	21	10
EF^{11}	10.38	4	0.077	2	6	3
EF^{12}	9.71	5	0.072	8	13	7
EF^{13}	9.59	6	0.073	5	11	5
EF^{14}	10.46	3	0.072	7	10	4
EF^{15}	9.58	7	0.073	4	11	5

Table 9 Model performance

	f-DANP (optimistic)	f-DANP (pessimistic)	f-DANP (most-likely)
sMAPE	13.6%	20.3%	5.2%

Table 10 Different scenarios

Decision makers	Scenario 1	Scenario 2	Scenario 3
DM 1	0.1	0.2	0.2
DM 2	0.1	0.18	0.25
DM 3	0.1	0.15	0.2
DM 4	0.1	0.12	0.025
DM 5	0.1	0.1	0.025
DM 6	0.1	0.1	0.025
DM 7	0.1	0.05	0.025
DM 8	0.1	0.05	0.05
DM 9	0.1	0.025	0.1
DM 10	0.1	0.025	0.1

Table 10). Initially in Scenario 1, decision-makers are assigned equal weights, and then weights are changed according to their professional experience, job domain, and age in the rest of the scenarios i.e., professors and Ph.D. scholars can relate more to this rather than the industrial expert so more weights assigned to them.The result of the cause-and-effect analysis is shown in Table 11.

Table 11 Prominence and relation value in different scenarios

Scenario 1		Scenario 2		Scenario 3	
Ri + Cj	Ri − Cj	Ri + Cj	Ri − Cj	Ri + Cj	Ri − Cj
7.973	− 0.153	6.607	− 0.164	6.762	− 0.222
6.567	0.240	5.884	0.208	5.867	0.240
9.071	0.599	8.647	0.572	7.071	0.607
10.791	0.414	9.425	0.471	9.777	0.328
7.942	0.003	6.226	0.004	6.873	− 0.003
10.582	− 0.630	9.970	− 0.646	10.233	− 0.537
9.323	0.017	8.804	0.017	8.398	0.018
9.315	− 0.740	9.983	− 0.864	9.255	− 0.693
8.423	0.590	8.406	0.408	8.131	0.438
9.094	0.837	9.503	0.830	9.178	0.779
10.379	− 0.310	9.379	− 0.319	10.454	− 0.367
9.708	− 0.273	9.025	− 0.248	9.598	− 0.218
9.588	− 0.522	9.190	− 0.516	7.036	− 0.684
10.457	0.491	10.107	0.404	10.425	0.473
9.576	− 0.563	9.806	− 0.530	8.298	− 0.610

From Table 11 we can see that the ranking remains almost unchanged in all the scenarios irrespective of taking different weights and we get valid results that are close to the choices of the decision makers.

Conclusion

This study proposed a novel research framework i.e., fuzzy DEMATEL-ANP with a triangular approach of responses to analyze and identify the factors of stress among doctoral students and their individual contribution in terms of weights which help the concerned authorities which may be universities here or the family of the students or student themselves to analyze the severity of the situation and take actions accordingly. Recently, we have heard so many cases of suicide of students because of stress so working on these factors can act as a pre alarming sign in such cases. In this study, we try to improvise the existing DEMATEL-ANP technique by coupling it with the triangular approach so that we get the result from each angle of perception. The superiority of the proposed method is that here we are using the fuzzy approach which handles the linguistic as well as probabilistic approach. Moreover, ANP is coupled with the DEMATEL to overcome the looping disadvantage in DEMATEL. The triangular approach of responses covers all types of possibilities of perceptions that we can have i.e., ranges from the optimistic to the most likely and to the pessimistic approach. All three approaches for the integration of crisp values are different in nature. Optimistic and Pessimistic approaches are dependent on the maximum and minimum values i.e., different values given by decision makers are integrated by taking their maximum in the optimistic case and minimum in the pessimistic case which somewhere loses the important data and also causes biasedness. We have also verified this in the performance analysis process where sMAPE is higher in the case of the optimistic and pessimistic approaches. The validation of the model is also done by doing the sensitivity

analysis by taking different cases and we obtained the results that are very close to the original results.

The analytical result of the study and the suggestions are described below. The result of the optimal approach is described here. The factors belonging to the cause group directly or indirectly affect the effect group factors so our focus should be more on the cause group. The value of $R_i + C_j$ in all three approaches is maximum for factor EF^4 and minimum for factor EF^2. Therefore, EF^4 (Supervisor Feedback) is the most influential factor which means it has a maximum relationship with other factors and EF^2 (city change) is the least influential factor. Moreover, EF^8 (Uncertain future) has the highest value of $R_i - C_j$ which means this is also the most influential factor besides EF^4. Moreover, Academic Issues (Poor Writing Skills as well as Publication issues) together with the Satisfaction with topic selection during course work period as well as the supervisor feedback contribute more in causing stress to the doctoral students. Therefore, authorities need to focus on these factors so that other factors are also improved.

Universities should give proper training to the students on writing a research article as well as how to search journals in the first year itself. In addition, universities can organize mental health wellness programs, frequently interact with the students, and address their issues. Supervisors should help their students in the selection of topics in their desired interest area. They should monitor their students' performance regularly and universities can also provide training to the supervisor for this. Research Students can do yoga for their mental health, they should give regular updates to their supervisor and discuss their ideas with them, and upgrade their skills by taking different courses that will enhance their research career.

Although the proposed framework is analyzed by the experts but still there are some suggestions or scope for future research. Due to the limitation on resources and time, the questionnaire was filled by a few decision makers which can be increased in further studies also more factors can be explored besides those mentioned in this study as it will increase the strength of the analysis. Moreover, in future studies, researchers may link this analysis to check the mental health condition of the students.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11192-024-05108-x.

Acknowledgements We are thankful to Guru Gobind Singh Indraprastha University for undertaking this research.

Author contributions Shanky Garg: methodology, software, writing—original draft Rashmi Bhardwaj: conceptualization, supervision, investigation, writing—review & editing.

Data availability Data analyzed during the study are given in Online Appendix section.

Declarations

Conflict of interest The authors have not disclosed any competing interests.

References

Abdulassal, R. M. S., & Bafail, O. A. (2021). A comparative study between GLP and GBWM. *Mathematical Problems in Engineering*. https://doi.org/10.1155/2021/5555933

Abdullah, S., Ahmad Shah, N., & Mohamad Idaris, R. (2020). Stress and its relationship with the academic performance of higher institution students. *International Journal of Advanced Research in Education and Society, 2*(1), 61–73.

Aires, R. F. D. F., & Ferreira, L. (2019). A new approach to avoid rank reversal cases in the TOPSIS method. *Computers & Industrial Engineering, 132*, 84–97. https://doi.org/10.1016/j.cie.2019.04.023

Anthony-McMann, P. E., Ellinger, A. D., Astakhova, M., & Halbesleben, J. R. B. (2017). Exploring different operationalizations of employee engagement and their relationships with workplace stress and burnout. *Human Resource Development Quarterly, 28*(2), 163–195. https://doi.org/10.1002/hrdq.21276

Appel, M. L., & Dahlgren, L. G. (2003). Swedish doctoral students' experiences on their journey towards a PhD: Obstacles and opportunities inside and outside the academic building. *Scandinavian Journal of Educational Research, 47*(1), 89–110. https://doi.org/10.1080/00313830308608

Bazrafkan, L., Shokrpour, N., Yousefi, A., & Yamani, N. (2016). Management of stress and anxiety among PhD students during thesis writing: A qualitative study. *Health Care Manager, 35*(3), 231–240. https://doi.org/10.1097/hcm.0000000000000120

Bi, H. (2007). *Why did not the professor tell me?* Lawpress Corporation.

Calabrese, A., Costa, R., Levialdi, N., & Menichini, T. (2019). Integrating sustainability into strategic decision-making: A fuzzy AHP method for the selection of relevant sustainability issues. *Technological Forecasting and Social Change, 139*, 155–168. https://doi.org/10.1016/j.techfore.2018.11.005

Castle, J. (2013). I had no time to bleed: Heroic journeys of PhD students in a South African school of education. *Journal of Education, 57*, 103–127.

El-Ghoroury, N. H., Galper, D. I., Sawaqdeh, A., & Bufka, L. F. (2012). Stress, coping, and barriers to wellness among psychology graduate students. *Training and Education in Professional Psychology, 6*(2), 122–134.

Falatoonitoosi, E., Ahmed, S., & Sorooshian, S. (2013). Expanded DEMATEL for determining cause and effect group in bidirectional relations. *The Scientific World Journal, 2014*(1), 103846. https://doi.org/10.1155/2014/103846

Feizi, S., Knäuper, B., & Elgar, F. (2024). Perceived stress and well-being in doctoral students: Effects on program satisfaction and intention to quit. *Higher Education Research & Development*. https://doi.org/10.1080/07294360.2024.2317276

Fontela, E., & Gabus, A. (1976). *The DEMATEL observer battelle institute Geneva research center.*

Gharakhani, D. (2012). The evaluation of supplier selection criteria by fuzzy DEMATEL method. *Journal of Basic and Applied Scientific Research, 2*(4), 3215–3224.

Goplerud, E. N. (1980). Social support and stress during the 1st year of graduate-school. *Professional Psychology, 11*(2), 283–290. https://doi.org/10.1037/0735-7028.11.2.283

Gore, R., Reynolds, P. F., Jr., Kamensky, D., Diallo, S., & Padilla, J. (2015). Statistical debugging for simulations. *ACM Transactions on Modeling and Computer Simulation*. https://doi.org/10.1145/2699722

Gunasekaran, N., Rathesh, S., Arunachalam, S., & Koh, S. C. L. (2006). Optimizing supply chain management using fuzzy approach. *Journal of Manufacturing Technology Management, 17*(6), 737–749. https://doi.org/10.1108/17410380610678774

Guthrie, S., Lichten, C. A., Belle, J. V., Ball, S., Knack, A. & Hofman, J. (2017). *Understanding mental health in the research environment: A rapid evidence assessment.* RAND Corporation. https://www.rand.org/pubs/research_reports/RR2022.html.

Haksever, A. M., & Manisali, E. (2000). Assessing supervision requirements of PhD students: The case of construction management and engineering in the UK. *European Journal of Engineering Education, 25*(1), 19–32. https://doi.org/10.1080/030437900308616

Hao, P., Zheng, Z., Gao, Y., & Zhang, Z. (2013). Statistical fault localization in decision support system based on probability distribution criterion. *Joint IFSA World Congress and NAFIPS Annual Meeting (IFSA/NAFIPS),* 878–883. https://doi.org/10.1109/IFSA-NAFIPS.2013.6608516

Hargreaves, C. E., De Wilde, J. P., Juniper, B., & Walsh, E. (2017). *Re-evaluating doctoral researchers' well-being: What has changed in five years.*

Hockey, J. (1994). New territory-problems of adjusting to the 1st year of a social-science PhD. *Studies in Higher Education, 19*(2), 177–190. https://doi.org/10.1080/03075079412331382027

Hopwood, N., & Paulson, J. (2012). Bodies in narratives of doctoral students' learning and experience. *Studies in Higher Education, 37*(6), 667–681. https://doi.org/10.1080/03075079.2010.537320

Hu, Y.-C., Chiu, Y.-J., Hsu, C.-S., & Chang, Y.-Y. (2015). Identifying key factors for introducing GPS-based fleet management systems to the logistics industry. *Mathematical Problems in Engineering*. https://doi.org/10.1155/2015/413203

Hunter, K. H., & Devine, K. (2016). Doctoral students' emotional exhaustion and intentions to leave academia. *International Journal of Doctoral Studies, 11*(2), 35–61.

Hwang, C. L., & Yoon, K. (1981). Methods for multiple attribute decision making. In C. L. Hwang & K. Yoon (Eds.), *Multiple attribute decision making. Lecture notes in economics and mathematical systems.* Springer. https://doi.org/10.1007/978-3-642-48318-9_3

Issa, U., Saeed, F., Miky, Y., Alqurashi, M., & Osman, E. (2022). Hybrid AHP-fuzzy TOPSIS approach for selecting deep excavation support system. *Buildings, 12*(3), 295. https://doi.org/10.3390/buildings12030295

Kamensky, D., Gore, R., & Reynolds, P. F. (2011). Applying enhanced fault localization technology to Monte Carlo simulations, *In Proceedings of the 2011 Winter Simulation Conference (WSC)*, 2798–2809. https://doi.org/10.1109/WSC.2011.6147984

Khan, S. A., Ojiako, U., Marshall, A., Dalalah, D., Ceylan, S., Shabani, N. N. A., & Al Sharqawi, S. I. (2023). The critical risk factors that influence production-oriented projects in the United Arab Emirates: A 'best-worst Method' (BWM) analysis. *Engineering Management Journal, 35*(2), 144–160. https://doi.org/10.1080/10429247.2022.2041963

Kinman, G. (1998). *Pressure points: A survey into the causes and consequences of occupational stress in UK academic staff. Association of University Teachers*. http://www.ucu.org.uk/media/pdf/pressurepoints.pdf

Kinman, G., Jones, F., & Kinman, R. (2006). The well-being of the UK academy, 1998–2004. *Quality in Higher Education, 12*(1), 15–27. https://doi.org/10.1080/13538320600685081

Krishnan, A. R., Kasim, M. M., Hamid, R., & Ghazali, M. F. (2021). A modified CRITIC method to estimate the objective weights of decision criteria. *Symmetry, 13*(6), 973. https://doi.org/10.3390/sym13060973

Lazarus, R., & Folkman, S. (1984). *Stress, appraisal, and coping*. Springer. https://doi.org/10.1007/978-1-4419-1005-9_215(BOOK)

León Montoya, G. B., Tejada Muñoz, S., del Chotón Calvo, M. R., & Saavedra Chinchayán, M. E. (2021). Expectations and attitudes towards COVID-19 among nursing students from a Peruvian public university. *Magazine of the University of Zulia, 12*(33), 183–195.

Levecque, K., Anseel, F., De Beuckelaer, A., Van der Heyden, J., & Gisle, L. (2017). Work organization and mental health problems in PhD students. *Research Policy, 46*(4), 868–879. https://doi.org/10.1016/j.respol.2017.02.008

Li, C., & Tzeng, G. (2009). Identification of a threshold value for the DEMATEL method using the maximum mean de-entropy algorithm to find critical services provided by a semiconductor intellectual property mall. *Expert Systems with Applications, 36*(6), 9891–9898. https://doi.org/10.1016/j.eswa.2009.01.073

Li, R. (1999). Fuzzy method in group decision making. *Computers & Mathematics with Applications, 38*(1), 91–101. https://doi.org/10.1016/S0898-1221(99)00172-8

Liu, L., Lian, M., Lu, C., Zhang, S., Liu, R., & Xiong, N. N. (2021). TCSA: A traffic congestion situation assessment scheme based on multi-index fuzzy comprehensive evaluation in 5G-IoV. *Electronics, 11*(7), 1032. https://doi.org/10.3390/electronics11071032

Mackie, S. A., & Bates, G. W. (2018). Contribution of the doctoral education environment to PhD candidates' mental health problems: A scoping review. *Higher Education Research & Development, 38*(3), 565–578. https://doi.org/10.1080/07294360.2018.1556620

Maheshwarkar, M., & Sohani, N. (2013). Combined AHP-TOPSIS based approach for the evaluation of knowledge sharing capabilities of supply chain partners. *Management Science Engineering, 7*, 27–32. https://doi.org/10.3968/j.mse.1913035X20130703.2573

Mallinckrodt, B., Leong, F. T. L., & Kralj, M. M. (1989). Sex-differences in graduate student life-change stress and stress symptoms. *Journal of College Student Development, 30*(4), 332–388.

Manathunga, C. (2005). Early warning signs in postgraduate research education: A different approach to ensuring timely completions. *Teaching in Higher Education, 10*(2), 219–233. https://doi.org/10.1080/1356251042000337963

Mostafaei, A. (2012). The relationship between stress and mental health in university students. *Annals of Biological Research, 3*(7), 3468–3473.

Myers, S. B., Sweeney, A. C., Popick, V., Wesley, K., Bordfeld, A., & Fingerhut, R. (2012). Self-care practices and perceived stress levels among psychology graduate students. *Training and Education in Professional Psychology, 6*(1), 55–66. https://doi.org/10.1037/a0026534

Nelson, N. G., Dell'Oliver, C., Koch, C., & Buckler, R. (2001). Stress, coping, and success among graduate students in clinical psychology. *Psychological Reports, 88*(3), 759–767. https://doi.org/10.2466/pr0.2001.88.3.759

Ordoobadi, S. M. (2009). Development of a supplier selection model using fuzzy logic. *Supply Chain Management, 14*(4), 314–327. https://doi.org/10.1108/13598540910970144

Ou Yang, Y. P., Leu, J. D., & Tzeng, G.-H. (2008). A novel hybrid MCDM model combined with DEMATEL and ANP with applications. *International Journal of Operations Research, 5*, 160–168.
Pakkar, M. S. (2016). A hierarchical aggregation approach for indicators based on data envelopment analysis and analytic hierarchy process. *Systems, 4*(1), 6. https://doi.org/10.3390/systems4010006
Panger, G. (2015). *Graduate student happiness & well-being report.*
Pariat, L., Rynjah, A., Joplin, M., & Kharjana, M. G. (2014). Stress levels of college students: interrelationship between stressors and coping strategies. *IOSR Journal of Humanities and Social Science, 19*(8), 40–46.
Prasad, K. D. V., & Vaidya, R. (2017). Causes of stress among PhD research scholars with reference to Rashtrasant Tukadoji Maharaj Nagpur University: An empirical analysis. *International Review of Management and Business Research, 6*(2), 472–480.
Rajput, S., & Singh, S. P. (2019). Connecting circular economy and industry 4.0. *International Journal of Information Management, 19*, 98–113. https://doi.org/10.1016/j.ijinfomgt.2019.03.002
Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega, 53*, 49–57. https://doi.org/10.1016/j.omega.2014.11.009
Rich, S. (2016). A brief examination of the effects of occupational stress on creativity and innovation. *The Psychologist-Manager Journal, 19*(2), 107–121. https://doi.org/10.1037/mgr0000042
Robinson-Pant, A. (2009). Changing academics: exploring international PhD students' perspectives on 'host' and 'home' universities. *Higher Education Research and Development, 28*(4), 417–429. https://doi.org/10.1080/07294360903046876
Rooij, E. V., Bruinsma, M. F., & Jansen, E. (2021). Factors that influence PhD candidates' success: The importance of PhD project characteristics. *Studies in Continuing Education, 43*(1), 48–67. https://doi.org/10.1080/0158037X.2019.1652158
Saari, D. G. (2000). Mathematic structure of voting paradoxes. *Economic Theory, 15*, 1–53.
Samrat, P. (2016). Stress management for research scholars at IIT Bombay, 2 March 2016, http://www.mid-day.com/articles/stress-management-for-research-scholars-at-iit-bombay/17005170
Schneiderman, N., Ironson, G., & Siegel, S. D. (2005). Stress and health: Psychological, behavioral, and biological determinants. *Annual Review of Clinical Psychology, 1*, 607. https://doi.org/10.1146/annurev.clinpsy.1.102803.144141
Stewart, S. M., Betson, C., Lam, T. H., Marshall, I. B., Lee, P. W. H., & Wong, C. M. (1997). Predicting stress in first year medical students: A longitudinal study. *Medical Education, 31*(3), 163–168. https://doi.org/10.1111/j.1365-2923.1997.tb02560.x
Tanaka, H., Okuda, T., & Asai, K. (1976). A formulation of fuzzy decision problems and its application to an investment problem. *Kybernetes, 5*(1), 25–30. https://doi.org/10.1108/eb005404
Teresa, M. (2021). Relationship among perceived stress, life satisfaction and academic performance of education sciences students of the University of Jaén after the COVID-19 pandemic. *Education Sciences, 11*(12), 802. https://doi.org/10.3390/educsci11120802
Triantaphyllou, E. (2000). Multi-criteria decision making methods. In *Multi-criteria decision making methods: A comparative study* (pp. 5–21). Springer.
Truchon, M. (2008). Borda and the maximum likelihood approach to vote aggregation. *Mathematical Social Sciences, 55*(1), 96–102. https://doi.org/10.1016/j.mathsocsci.2007.08.001
Tsai, S., Chien, M., Xue, Y., Li, L., Jiang, X., Chen, Q., Zhou, J., & Wang, L. (2015). Using the fuzzy DEMATEL to determine environmental performance: A case of printed circuit board industry in Taiwan. *PLoS ONE, 10*, e0129153. https://doi.org/10.1371/journal.pone.0129153
Turcksin, L., Bernardini, A., & Macharis, C. (2011). A combined AHP-PROMETHEE approach for selecting the most appropriate policy scenario to stimulate a clean vehicle fleet. *Procedia—Social and Behavioral Sciences, 20*, 954–965. https://doi.org/10.1016/j.sbspro.2011.08.104
Urošević, K., Gligorić, Z., Miljanović, I., Beljić, Č, & Gligorić, M. (2021). Novel methods in multiple criteria decision-making process (MCRAT and RAPS)—application in the mining industry. *Mathematics, 9*(16), 1980. https://doi.org/10.3390/math9161980
Wang, P., Zhu, Z., & Wang, Y. (2016). A novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods based on experimental design. *Information Sciences, 345*, 27–45. https://doi.org/10.1016/j.ins.2016.01.076
Wisker, G., & Robinson, G. (2013). Doctoral 'orphans': Nurturing and supporting the success of postgraduates who have lost their supervisors. *Higher Education Research & Development, 32*(2), 300–313. https://doi.org/10.1080/07294360.2012.657160
Woolston, C. (2019). PhDs: The torturous truth. *Nature*. https://doi.org/10.1038/d41586-019-03459-7
Wright, T. (2006). Issues in brief counselling with postgraduate research students. *Counselling Psychology Quarterly, 19*(4), 357–372. https://doi.org/10.1080/09515070601043203

Yu, R. (2008). *MCDM combined with fuzzy decision maps for the structural modeling problem*. National Taiwan University.
Zadeh, L. (1965). Fuzzy set. *Information and Control, 8*(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

Authors and Affiliations

Shanky Garg[1] · **Rashmi Bhardwaj**[1]

✉ Rashmi Bhardwaj
rashmib@ipu.ac.in

Shanky Garg
shanky.5240890020@ipu.ac.in

[1] University School of Basic and Applied Sciences (USBAS), Guru Gobind Singh Indraprastha University (GGSIPU), Dwarka, Delhi, India