

An intuitionistic fuzzy decision support system for COVID-19 lockdown relaxation protocols in India [☆]

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ABSTRACT

In January 2020, the World Health Organization (WHO) identified a world-threatening virus, SARS-CoV-2. To diminish the virus spread rate, India implemented a six-month-long lockdown. During this period, the Indian government lifted certain restrictions. Therefore, this study investigates the efficacy of India's lockdown relaxation protocols using fuzzy decision-making. The decision-making trial and evaluation laboratory (DEMATEL) is one of the fuzzy MCDM methods. When it is associated with intuitionistic fuzzy circumstances, it is known as the intuitionistic fuzzy DEMATEL (IF-DEMATEL) method. Moreover, converting intuitionistic fuzzy into a crisp score (CIFCS) algorithm is an aggregation technique utilized for the intuitionistic fuzzy set. By using IF-DEMATEL and CIFCS, the most efficient lockdown relaxation protocols for COVID-19 are determined. It also provides the cause and effect relationship of the lockdown relaxation protocols. Additionally, the comparative study is carried out through various DEMATEL methods to see the effectiveness of the result. The findings would be helpful to the government's decision-making process in the fight against the pandemic.

1. Introduction

In the past 20 years, two epidemics of a beta coronavirus were discovered: (1) From February 2003 to July 2003, Guangdong city of China was affected by the severe acute respiratory syndrome coronavirus (SARS-CoV). There were over 8000 reported cases with 9.6% fatality rate. (2) In 2012, Saudi Arabia was afflicted by the middle-east respiratory syndrome coronavirus (MERS-CoV). Over 2400 reported cases with 34.4% fatality rate [1]. Followed by this, a new virus emerged in December 2019. The China government

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Table 1
COVID-19 outbreak program of the Indian government [6].

The year 2020 outbreak programs	Date
1. Avert travel to China	January 17
2. Thermal screening for passengers from China and Hong Kong	January 18
3. Highly urged to avoid traveling to China	January 30
4. Electronic visa facility deferred for Chinese	February 3
5. Passengers from other countries are quarantined based on their health condition	February 26
6. Suspension of visa for Iran, Italy, China, South Korea and Japan	March 3
7. Universal screening for all International flights	March 4
8. People from Italy must carry the medical history report	March 5
9. International travelers should undergo home quarantine for 14 days	March 10
10. All international flights are suspended	March 19
11. Extension of suspension of all international flights	March 25

found more lung infection cases in Wuhan city. Initially, the cases were recorded with people who had visited and worked at the seafood market. The analysis found that the disease was caused by a new virus named ‘SARS-CoV-2’ or 2019 novel coronavirus (2019-nCoV). The most dangerous aspect of the virus is highly contagious and difficult to detect in its early stages [2,3]. Coronavirus is a massive virus family. They are cysts made up of a genomic core enveloped by a protein-spiked. It resembles 70% of the SARS-CoV virus. The virus transmitted from animals to humans is called spillover, caused by factors such as a virus mutation (or) increased human–animal interaction. The world health organization (WHO) declared that COVID-19 affects all age-group people and most people with chronic diseases. COVID cases were increased rapidly among elderly people around the world. On January 31, 2020, the WHO risk communication squad launched the EPI-WIN network to destroy this dangerous virus [4]. The WHO planned the lockdown as the number of COVID-19 positive cases grew by the day, which led to a global lockdown in March 2020 to control the spread of the virus. From January 2020, the COVID-19 was steadily increasing in India. And therefore, India had acknowledged the lockdown order. Even though lockdown was an effective method for limiting the virus’s spread, it was a huge task for country like India with a large population. This unexpected global community lockdown disrupts each group of public lifestyles. The Indian government imposed a complete lockdown for nearly three months, which led to stress, frustration, fury, depression, anxiety and panic attacks. Initially, the lockdown affected the lives of immigrant laborers, day-to-day workers, and ordinary people who were battling for survival. They were also affected by unemployment and addiction to unwanted social behavior, which contributed to mental illness. Also, the Indian government struggled to cope with the country’s economic decline. The Indian government has revealed several lockdown relaxation protocols to balance the economic flaws, each with its own set of constraints. Therefore, this work presents the effectiveness of the released lockdown relaxation protocols under the intuitionistic fuzzy environment.

1.1. COVID-19 outbreak in India

The foremost confirmed case of SARS-CoV-2 was reported in Kerala on January 30, 2020, who was a student returning to India from Wuhan, China. On February 3, 2020, the ministry of health and family welfare (MoHFW) confirmed three positive cases of COVID-19 in Kerala. These patients were isolated and closely monitored in the hospitals. Due to the rise in COVID positive cases, the MoHFW quickly established 11 regional laboratories to test public samples. From February 13, 2020, initiated screening for travelers in 21 airports, 12 international seaports, and border crossing regions [5]. Additionally, the Indian medical research council organized 52 laboratories to test the sample for passengers. On March 09, 2020, the Indian government found the confirmed cases in various states like Delhi, Jammu, Ladakh, Haryana, Tamil Nadu, Kerala, Punjab, Telangana, Uttar Pradesh and Rajasthan. Due to its global spread, the WHO announced the coronavirus as a pandemic. To control the virus, the Indian government enacted the epidemic diseases act. In all States and Union Territories, quarantine, community surveillance, isolation wards, trained manpower, adequate PPEs, and strengthened the rapid response teams for COVID-19. On Sunday, March 22, 2020, the Prime Minister of India declared a ‘Janata curfew’ from 7 am–9 pm, which was followed every Sunday for three months. All incoming international flights and Indian railways and inter-state travels were restricted. Table 1 demonstrates the list of COVID-19 outbreaks implemented in India.

The COVID-19 pandemic impacted the Indian government economically. Therefore, the government has implemented a few protocols to improve India’s financial situation. Table 2 portrays India’s acknowledged lockdown relaxation protocols.

1.2. Motivation of the research

The research on COVID-19 problems is considered as social-related problem because this pandemic has created unimaginable consequences like distressing public health, drop on economy, and affected people’s normal way of living. India controlled these consequences by releasing a few lockdown relaxation protocols. Hence, this study aims to portray a picture on how to determine the efficiency of lockdown relaxation protocols. While doing this piece of work, the following questions were arised.

- Why did the government bring lockdown relaxation protocols?
- Are the people’s safety benefited by the lockdown relaxation protocols?
- Are the released lockdown relaxation protocols effective?
- Whether the lockdown relaxation protocols really decelerated the virus’s spread?

Table 2
Unlock Programs [7].

1. Worship regions, entertainment spots are permitted with certain standard operating procedure 2. Night curfew from 9 pm – 5 am 3. Limitations applied in domestic flights and trains 4. Reduced the timing for night curfew from 10 pm - 5 am	June
5. According to the Ministry of Home Affairs (MHA), the district administrators reaffirm Inter and Intra-state movements of people and goods	July
6. Except containment zone, the other regions are allowed for regular activities with time restrictions	August
7. Higher education institutions are opened with MHA concern	September
8. Personal events are permitted to conduct with the small gathering along with few protocols	October

- Which is the most effective lockdown relaxation protocol?

The algorithm converting fuzzy into crisp score (CFCS) was used as a defuzzification process for the triangular fuzzy environment by Opricovic [8]. This work of Opricovic motivates to extend the CFCS algorithm under the triangular intuitionistic fuzzy environment, which is known as converting intuitionistic fuzzy into crisp score (CIFCS) algorithm. This serves as the novelty of this study. This article is designed to answer the above questions through the intuitionistic fuzzy decision-making trial and evaluation laboratory (IF-DEMATEL) method. The DEMATEL method is highly efficient in producing the interrelationships between criteria and transforms the structured model into a graphical format.

1.3. Purpose of utilizing the DEMATEL method

The DEMATEL is one of the fuzzy multi-criteria decision making (MCDM) methods. In 1973, the Battelle memorial institute first implemented the DEMATEL method in the Geneva research center, which was proposed by Fonetla and Gabus in 1971. The DEMATEL method employs matrix operations and structural models to determine the causal relationship between multiple complex criteria. Specifically, it is based on digraphs or directed graphs, which are more valuable than undirected graphs because they show the directed relationships between criteria. The relations between criteria are presented in values that exhibit the extent of influence. The involved criteria can be divided into cause and effect groups through this relationship. Therefore, DEMATEL can identify the interrelationship among the criteria. Because of these advantages, the lockdown relaxation protocols are scrutinized, the relationships are assigned, and their efficiency can be determined under the intuitionistic fuzzy DEMATEL method.

1.4. Contribution of the research

- Fuzzy decision-making models aid in answering the motivated questions.
- Lockdown relaxation protocols are incorporated into the fuzzy MCDM methods through the intuitionistic fuzzy set. It indicates the disparity in an uncertain environment and identifies the importance of the possible criteria.
- The fuzzy DEMATEL is framed in the intuitionistic fuzzy environment.
- Opricovic CFCS algorithm is extended into an intuitionistic environment and are denoted as the CIFCS algorithm, which acts as a defuzzification process for triangular intuitionistic fuzzy sets incorporated in the intuitionistic fuzzy DEMATEL (IF-DEMATEL) method.
- The problem of the efficiency of lockdown relaxation protocols is illustrated to show the reliability of the proposed method.
- The strength of the IF-DEMATEL method is demonstrated by comparing its outcomes with the different situations of the DEMATEL method.

Therefore, the work proceeds with the DEMATEL method and the proposed CIFCS algorithm to used analyze India's lockdown relaxation protocols under an intuitionistic fuzzy set.

1.5. Research objectives

This study aims to analyze the effectiveness of the protocols through the intuitionistic fuzzy DEMATEL process. DEMATEL method is flexible in solving decision-making problems in complex situations. This method mainly focuses on differentiating the criteria into cause and effect groups. It determines the excellent performer among the criteria. In addition to this, a threshold value is determined to find the causal relationships between criteria, which aid in finding the connection between cause and effect criteria and identify the most preferred and least preferred lockdown relaxation protocols. The triangular intuitionistic fuzzy set (TIFS) is applied to indicate the vagueness of the problem. The TIFS is converted into crisp values using the CIFCS algorithm. The analysis

of IF-DEMATEL with CIFCS will pave the way for policymakers to determine the effectiveness of COVID-19 lockdown relaxation protocols.

This study is structured as follows: Section 2 presents a literature review on intuitionistic fuzzy DEMATEL and COVID-19. Section 3 describes the proposed CIFCS algorithm and the proposed IF-DEMATEL method. Section 4 provides the adaption of the proposed method for finding the efficiency of the lockdown relaxation protocols and the comparative study determined in the same section. Section 5 carries a discussion of the obtained results. Finally, Section 6 includes the conclusion and scope of future direction.

2. Related work

2.1. Intuitionistic Fuzzy DEMATEL method

The DEMATEL can perform in different environments. In the crisp DEMATEL, the interrelationship between criteria is indicated in the binary form [9]. Sometimes, the perceptions of the criteria relationships are unclear due to insufficient information. Therefore, the fuzzy concept is expressed in linguistic terms, which aid in eliciting the experts' opinions about the problem. The fuzzy DEMATEL solved various decision-making problems [10]. The intuitionistic fuzzy number is defined by belongingness and non-belongingness elements, where $0 \leq \mu_S(x) + \nu_S(x) \leq 1$, and they are better in dealing with uncertain information than fuzzy in decision-making. Therefore, the fuzzy DEMATEL is extended to intuitionistic fuzzy DEMATEL, replacing the fuzzy number with the intuitionistic fuzzy number. This study defines the linguistic variables using the triangular intuitionistic fuzzy number (TIFN). A few works on DEMATEL and intuitionistic fuzzy methods are listed. Yu W et al. [11] used for the site selection problem in Shijiazhuang. Büyüközkan G et al. [12] applied to determine the weights for the criteria in selecting business partner problems. Velmathi and Felix [13] assessed the interdependency between the fabrication process based on consumer demand criteria. Akyuz Z and Celik E [14] examined the risk procedure of the gas freeing process through the cause–effect relation. The COVID pandemic created a massive impact on people's lifestyles. Even though the government took viable steps to recover from COVID impacts, the academic researchers also contributed their work in analyzing various COVID-19 problems. The following are some papers that used DEMATEL to solve COVID problems. Altuntas F et al. [15] proposed a universal guideline for making the quarantine decision, which could benefit the hospital industry. Selerio E et al. [16] studied the emergency preparedness criteria. Maqbool A et al. [17] analyzed the COVID-19 prevention criteria. Hosseini S et al. [18] probed the appropriate recovery criteria for ecotourism centers, which suffered significant losses in the COVID pandemic. During the pandemic outbreak, the education system was one of the most severely impacted industries. Song P et al. [19] evolved the emergency management criteria to get around this issue. Gulketin B et al. [20] demonstrated the risk faced by logistic services. Due to the enormous spread rate of COVID-19, many people are unable to receive necessary medical treatment. The government introduced the mHealth (mobile Health) system to avoid this issue. Alzahrani A I et al. [21] evaluated the criteria involved in the service quality of mHealth using secondary data.

3. Proposed method

3.1. Preliminaries

Definition 3.1 (Intuitionistic Fuzzy Set). IFS is the extension of the fuzzy set theory proposed by Atanassov's which comprises both belonging and non-belonging elements of the set [22]. Let U be a nonempty set. An intuitionistic fuzzy set S in U having set of ordered triples of the form

$$S = \{x, \mu_S(x), \nu_S(x) : x \in U\} \tag{1}$$

where $\mu_S(x) \rightarrow [0, 1]$ symbolize the grade of element belongs to the set S and $\nu_S \rightarrow [0, 1]$ symbolize the grade of element not belongs to the set S , which is the subset of U and for every element $x \in U, 0 \leq \mu_S(x) + \nu_S(x) \leq 1$.

Additionally, $\pi_S(x) = 1 - \mu_S(x) - \nu_S(x)$ called the hesitation margin of x in S . $\pi_S \in [0, 1]$ and $0 \leq \pi_S \leq 1$ for every $x \in U$.

Definition 3.2 (Triangular Intuitionistic Fuzzy Number). The TIFN $\tilde{A}^I = (a, b, c, a', b, c')$ is the intuitionistic fuzzy set in R with the following membership function $\mu_{\tilde{A}^I}(x)$ and non-membership function $\nu_{\tilde{A}^I}(x)$ [23]

$$\mu_{\tilde{A}^I}(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & x = b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & x > c \end{cases} \quad \nu_{\tilde{A}^I}(x) = \begin{cases} 1, & x < a' \\ \frac{b-x}{b-a}, & a' \leq x \leq b \\ 0, & x = b \\ \frac{x-b}{c-b}, & b \leq x \leq c' \\ 1, & x > c' \end{cases} \tag{2}$$

where $a' < a < b < c < c'$ and $\mu_{\tilde{A}^I}(x) + \nu_{\tilde{A}^I}(x) \leq 1$ or $\mu_{\tilde{A}^I}(x) = \nu_{\tilde{A}^I}(x)$.

Definition 3.3. In a universe U , the IFS A can be interpreted as a mapping $U \rightarrow [0, 1] \times [0, 1]$ and represented by a 2-tuple $\mu_{\tilde{A}}(x)$ indicates the membership and $\nu_{\tilde{A}}(x)$ indicates the non-membership for every $x \in A$ and satisfies the condition $\mu_{\tilde{A}}(x) + \nu_{\tilde{A}}(x) \leq 1$. The set B is a standard fuzzy subset when $\mu_{\tilde{A}}(x) + \nu_{\tilde{A}}(x) = 1$. The crispification operator as a map $[0, 1] \times [0, 1] \rightarrow R$ is introduced. Here, $U = R$ for IFS.

Definition 3.4. The set G is an IFS. By Definition 3.3, Let $D_\lambda : [0, 1] \times [0, 1] \rightarrow R$ is the crispification operator of D . The two steps of this technique are interpreted [24].

- (a) Transform G into the (standard) fuzzy set.
- (b) Calculate the standard fuzzy set by using a defuzzification method.

For (a), the operator D_λ is defined as

$$D_\lambda(G) = \{x, \mu_G(x) + \lambda\pi_G(x), v_G(x) + (1 - \lambda)\pi_G(x) : x \in X\}; \lambda \in [0, 1].$$

The $D_\lambda(G)$ is a standard fuzzy subset with a membership function $\mu_G(x) = \mu_G(x) + \lambda\pi_G(x)$.

In particular, $\lambda = 0.5$ is a solution of the minimization problem $d(D_\lambda(G), G)$, where d represents the Euclidean distance.

The fuzzy set $D_{0.5}(G)$ is characterized the membership function with $\lambda=0.5$.

$$\mu(x) = \frac{1}{2}(1 + \mu_G(x) - v_G(x)) \tag{3}$$

For (b): any defuzzification process can be adapted.

3.2. CIFCS algorithm

Defuzzification is the process of achieving a crisp term from a fuzzy term. In short, it converts imprecise data into precise data and is also known as the reverse of the fuzzification process. Commonly used defuzzification methods are center of area (COA), center of gravity (COG), center of sums method (COS), weighted average method and maxima methods. In 2003, Obricovic [8] introduced the CFCS algorithm as a defuzzification method for the triangular membership functions. In the CFCS algorithm, the standardized left and right scores were calculated from the lower and upper limits, respectively. A weighted average represents the total score. This study extends the CFCS into the CIFCS algorithm. This extension can be applied to the triangular intuitionistic fuzzy set as a defuzzification method. Using the CIFCS algorithm, the triangular intuitionistic fuzzy numbers (TIFN) can be easily defuzzified. Let $(a_{ij}^n, b_{ij}^n, c_{ij}^n, a_{ij}^{n'}, b_{ij}^{n'}, c_{ij}^{n'})$ be the parameters of triangular intuitionistic fuzzy number, where $a_{ij}^n, b_{ij}^n, c_{ij}^n$ and $a_{ij}^{n'}, b_{ij}^{n'}, c_{ij}^{n'}$ are the membership and non-membership functions of the set, respectively. These parameters are defuzzified using the proposed CIFCS algorithm. The following stages represents the procedure of the CIFCS algorithm.

Stage (a): Calculate the normalized matrix for the triangular intuitionistic fuzzy matrix.

Normalizing each term of the triangular intuitionistic fuzzy (TIF) set.

$$(xa_{ij}^n = \frac{a_{ij}^n - \min a_{ij}^n}{\Delta_{\min}^{\max}}, xb_{ij}^n = \frac{b_{ij}^n - \min a_{ij}^n}{\Delta_{\min}^{\max}}, xc_{ij}^n = \frac{c_{ij}^n - \min a_{ij}^n}{\Delta_{\min}^{\max}}, xa_{ij}^{n'} = \frac{\max c_{ij}^{n'} - a_{ij}^{n'}}{\nabla_{\min}^{\max}}, xb_{ij}^{n'} = \frac{\max c_{ij}^{n'} - b_{ij}^{n'}}{\nabla_{\min}^{\max}}, xc_{ij}^{n'} = \frac{\max c_{ij}^{n'} - c_{ij}^{n'}}{\nabla_{\min}^{\max}}) \text{ where } \Delta_{\min}^{\max} = \max c_{ij}^n - \min a_{ij}^n, \nabla_{\min}^{\max} = \max c_{ij}^{n'} - \min a_{ij}^{n'}$$

Stage (b): Evaluate the left and right scores

Compute the left and right spread scores using each normalized member of the TIF set.

$$(xas_{ij}^n = \frac{xb_{ij}^n}{1+xb_{ij}^n-xa_{ij}^n}, xcs_{ij}^n = \frac{xc_{ij}^n}{1+xc_{ij}^n-xb_{ij}^n}), (xas_{ij}^{n'} = \frac{xa_{ij}^{n'}}{1+xa_{ij}^{n'}-xb_{ij}^{n'}}, xcs_{ij}^{n'} = \frac{xb_{ij}^{n'}}{1+xb_{ij}^{n'}-xc_{ij}^{n'}})$$

Stage (c): Determine the total normalized matrix

$$(x_{ij}^n = \frac{xas_{ij}^n(1-xas_{ij}^n)+(xcs_{ij}^n)^2}{1-xas_{ij}^n+xcs_{ij}^n}, x_{ij}^{n'} = \frac{xcs_{ij}^{n'}(1-xcs_{ij}^{n'})+(xas_{ij}^{n'})^2}{1-xcs_{ij}^{n'}+xas_{ij}^{n'}})$$

Stage (d): Calculate the separated values

$$(Z_{ij}^n = \min a_{ij}^n + x_{ij}^n \times \Delta_{\min}^{\max}, Z_{ij}^{n'} = x_{ij}^{n'} \times \Delta_{\min}^{\max} - \min a_{ij}^{n'})$$

3.3. Proposed IF-DEMATEL algorithm

The proposed method paves the way to categorize the criteria by combining the CIFCS algorithm and the IF-DEMATEL method. In short, this algorithm splits into three stages. In the first stage, criteria are determined for the problem. In the second stage, experts' opinions are converted into intuitionistic fuzzy numbers, and in the third stage, they are implemented into the DEMATEL method.

Step 1: Choose the possible criteria.

Let $C = \{C_1, C_2, \dots, C_n\}$ be the available criteria related to the problem.

Step 2: Construct the linguistic decision matrix.

Setup the linguistic decision matrix based on k decision-makers. Let E_1, E_2, \dots, E_k be the k linguistic decision matrices.

Step 3: Convert the linguistic decision matrices into the triangular intuitionistic fuzzy matrices.

Transform the linguistic decision matrices $E_h, h = 1, 2, \dots, k$ into the triangular intuitionistic fuzzy matrices $A_h, h = 1, 2, \dots, k$.

$$A_k = [\tilde{a}_{kij}]_{n \times n} = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ C_1 & - & \tilde{a}_{k12} & \dots & \tilde{a}_{k1n} \\ C_2 & \tilde{a}_{k21} & - & \dots & \tilde{a}_{k2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & \tilde{a}_{kn1} & \tilde{a}_{kn2} & \dots & - \end{matrix}$$

where $\tilde{a}_{kij} = (a_{kij}, b_{kij}, c_{kij}, a'_{kij}, b'_{kij}, c'_{kij})$. Let \tilde{a}_{kij} be the judgements on the relationship between C_i and C_j given by the experts $E_h, h = 1, 2, \dots, k; i, j = 1, 2, \dots, n$. If there is no relationship between C_i and C_j , \tilde{a}_{kij} is denoted as '-'.

Step 4: Compute the defuzzified matrix.

Apply the procedure of the CIFCS algorithm in the triangular intuitionistic fuzzy matrices $A_h, h = 1, 2, \dots, k$ to obtain the defuzzified matrices $B_h, h = 1, 2, \dots, k$.

Step 5: Aggregate the defuzzified matrices.

All the defuzzified matrices $B_h, h = 1, 2, \dots, k$ are grouped using averaging operator.

$$B = \frac{1}{h}(B_1 + B_2 + \dots + B_h) \tag{4}$$

Step 6: Evaluate the overall defuzzified matrix.

Again defuzzify the belongingness and non-belongingness using a scoring function.

$$D = \frac{1}{2}(1 + \mu(x) - \nu(x)) \tag{5}$$

Step 7: Calculate the normalized matrix.

Normalization is calculated by dividing each element of matrix B by the sum of the maximum element of the column and its value between $[0,1]$.

$$N = \frac{a_{ij}}{\max(\sum a_{ij})}; i, j = 1, 2, \dots, n \tag{6}$$

Step 8: Determine the total relation matrix.

This step indicates the influence level between each criterion.

$$\begin{aligned} T &= (N + N^2 + \dots + N^l) \\ &= N(I + N + N^2 + \dots + N^{l-1})(I - N)(I - N)^{-1} \\ &= N(I - N^l)(I - N)^{-1} \\ T &= N(I - N)^{-1} \end{aligned} \tag{7}$$

where I is an identity matrix

Step 9: Construct the cause and effect group.

Here, d - the addition of rows and e - the addition of columns of T .

$$d = [d_i]_{(n \times 1)} = \sum_{i=1}^n [t_{ij}]_{(n \times 1)} \tag{8}$$

$$e = [e_i]_{(1 \times n)} = \sum_{j=1}^n [t_{ij}]_{(1 \times n)} \tag{9}$$

where d_i is the sum of i th row and e_j is the sum of j th column. These values determine the interrelationship between criteria, represented in matrix T as a combination of $(d + e)$ and $(d - e)$. The sum of rows and columns indicates the causal effects given and received by matrix T respectively.

$$(d + e) = \sum_{i=1}^n t_{ij} + \sum_{j=1}^n t_{ij} \tag{10}$$

The $(d - e)$ splits the factors into cause and effect groups. If $(d - e)$ is positive, grouped under the cause and if $(d - e)$ is negative, grouped under the effect.

$$(d - e) = \sum_{i=1}^n t_{ij} - \sum_{j=1}^n t_{ij} \tag{11}$$

Step 10: Determine the relation level between criteria.

The interrelation between criteria is based on threshold value. Using Eq. (12) the threshold value is found.

$$\alpha = \frac{\sum_{i=1}^n \sum_{j=1}^n t_{ij}}{N^*} \tag{12}$$

where α is the average of total relation matrix, N^* is the total number of elements in matrix T .

The threshold value will reduce the complexity of the problem by neglecting a few effect category criteria and determining the impact relationship between criteria. Only a few criteria in matrix T hit the threshold value, making it easy to frame the interrelation mapping between criteria. If the mapping is complex, then the threshold value is very low. The chosen criteria are independent if the threshold value is too high [25]. The digraph is depicted using the coordinates $(d + e)$ and $(d - e)$.

Step 11: Comparative analysis

The outcomes are compared with two different situations of DEMATEL. One is crisp DEMATEL deals with binary data, i.e. 0 and 1. Another is fuzzy DEMATEL, where the uncertainty between criteria deals only by assigning the membership values. Fig. 2 denotes the flow of the proposed IF-DEMATEL method.

Table 3
Criteria and its notation.

P_{r1}	Controlled public movement.
P_{r2}	Curfew for red, green, and white industries.
P_{r3}	Complete functioning of orange industries.
P_{r4}	Restrictions of a non-essential crowd gathering.
P_{r5}	Providing protective measures to government essential workforces.
P_{r6}	Entertainment spots are allowed with controlled movements.
P_{r7}	Public transportation operated on schedule
P_{r8}	Monitoring public well-being.
P_{r9}	Global operations are restricted.
P_{r10}	Priority-based functioning of education institutions.
P_{r11}	Opened the religious places with safety protocols.
P_{r12}	E-pass is issued to enter inter-districts.

Table 4
Linguistic decision matrix E_1 .

	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
P_{r1}	—	s_2	s_6	s_3	s_3	s_4	s_4	s_6	s_3	s_6	s_6	s_6
P_{r2}	s_2	—	s_3	s_1	s_3	s_6	s_5	s_5	s_4	s_2	s_0	s_0
P_{r3}	s_3	s_2	—	s_2	s_3	s_2	s_3	s_3	s_0	s_0	s_0	s_3
P_{r4}	s_6	s_2	s_3	—	s_3	s_4	s_5	s_4	s_6	s_6	s_3	s_5
P_{r5}	s_3	s_2	s_3	s_2	—	s_4	s_1	s_5	s_6	s_2	s_1	s_2
P_{r6}	s_6	s_3	s_2	s_5	s_5	—	s_4	s_3	s_2	s_1	s_5	s_0
P_{r7}	s_5	s_2	s_2	s_4	s_4	s_3	—	s_2	s_5	s_2	s_4	s_5
P_{r8}	s_4	s_4	s_4	s_5	s_4	s_5	s_5	—	s_4	s_3	s_5	s_6
P_{r9}	s_5	s_5	s_4	s_2	s_3	s_4	s_2	s_2	—	s_1	s_2	s_0
P_{r10}	s_3	s_0	s_1	s_3	s_2	s_1	s_0	s_5	s_2	—	s_1	s_0
P_{r11}	s_3	s_0	s_3	s_5	s_3	s_4	s_1	s_6	s_1	s_1	—	s_0
P_{r12}	s_0	s_1	s_1	s_3	s_0	s_1	s_4	s_4	s_2	s_3	s_2	—

Table 5
Linguistic decision matrix E_2 .

	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
P_{r1}	—	s_1	s_4	s_3	s_5	s_6	s_4	s_4	s_2	s_4	s_5	s_0
P_{r2}	s_0	—	s_3	s_1	s_3	s_5	s_6	s_5	s_4	s_3	s_2	s_2
P_{r3}	s_4	s_6	—	s_1	s_3	s_4	s_5	s_2	s_0	s_4	s_1	s_2
P_{r4}	s_0	s_1	s_3	—	s_2	s_1	s_5	s_2	s_1	s_4	s_6	s_2
P_{r5}	s_3	s_4	s_5	s_1	—	s_6	s_5	s_4	s_2	s_4	s_1	s_0
P_{r6}	s_0	s_1	s_5	s_3	s_2	—	s_3	s_3	s_1	s_2	s_6	s_1
P_{r7}	s_1	s_0	s_3	s_2	s_1	s_4	—	s_3	s_1	s_4	s_6	s_4
P_{r8}	s_3	s_2	s_4	s_1	s_5	s_6	s_4	—	s_0	s_3	s_6	s_2
P_{r9}	s_0	s_1	s_3	s_1	s_3	s_4	s_1	s_2	—	s_5	s_2	s_6
P_{r10}	s_3	s_0	s_1	s_4	s_2	s_3	s_5	s_6	s_2	—	s_1	s_2
P_{r11}	s_6	s_0	s_1	s_5	s_3	s_4	s_5	s_2	s_1	s_2	—	s_3
P_{r12}	s_0	s_1	s_1	s_4	s_2	s_6	s_3	s_2	s_2	s_5	s_4	—

4. Adaption of the proposed method for finding the efficiency of the lockdown relaxation protocols

The intent is to determine the efficacy of lockdown relaxation protocols of the Indian government using the proposed method. The lockdown relaxation protocols were framed to boom back the economic loss of individuals and public sectors with the safety measures and aid in preventing the spread of the coronavirus. The DEMATEL procedure enacts the cause and effect protocols and evolves the structured method.

Step 1: The declared lockdown relaxation protocols are chosen as criteria. The protocols are framed using the unlock 1.0 to unlock 5.0 programs of the Indian government. According to the considered problem, the criteria are denoted as P_r (Protocols) where $P_r = (P_{r1}, P_{r2}, \dots, P_{r12})$ and the respective protocols are portrayed in Table 3.

Step 2: The linguistic decision matrices are constructed for chosen criteria based on the opinion of three decision-makers. The decision-makers belong to different professions. The first decision-maker is Dr. S. Rubina, who works as a volunteer in the COVID-19 healthcare centers. The second is the essential government worker, Mr. Raja works in the revenue department, and the third is Mr. Arulgnanam, an entrepreneur. Tables 4–6 express the experts’ opinions about the relation between criteria.

Step 3: The linguistic decision matrices are transformed into triangular intuitionistic fuzzy matrices. Linguistic variables whose values are signified using normal language or words instead of numbers are called linguistic variables. The linguistic decision matrices are constructed using seven linguistic variables: supreme low (SL), very low (VL), low (L), medium (M), high (H), very high (VH), supreme high (SH). These are then transformed into triangular intuitionistic fuzzy matrices using Table 7. The linguistic

Table 6
Linguistic decision matrix E_3 .

	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
P_{r1}	—	s_2	s_3	s_4	s_4	s_2	s_4	s_4	s_4	s_3	s_5	s_5
P_{r2}	s_5	—	s_3	s_5	s_5	s_0	s_0	s_1	s_0	s_0	s_0	s_0
P_{r3}	s_0	s_1	—	s_0	s_5	s_0	s_0	s_3	s_0	s_0	s_0	s_0
P_{r4}	s_6	s_1	s_2	—	s_3	s_4	s_4	s_6	s_6	s_3	s_3	s_5
P_{r5}	s_0	s_3	s_3	s_2	—	s_2	s_0	s_4	s_3	s_1	s_1	s_2
P_{r6}	s_6	s_3	s_3	s_4	s_4	—	s_4	s_5	s_4	s_3	s_4	s_3
P_{r7}	s_6	s_2	s_2	s_6	s_4	s_4	—	s_5	s_4	s_4	s_3	s_6
P_{r8}	s_6	s_4	s_4	s_5	s_5	s_6	s_5	—	s_5	s_3	s_4	s_5
P_{r9}	s_6	s_5	s_5	s_6	s_4	s_5	s_5	s_6	—	s_3	s_4	s_6
P_{r10}	s_5	s_4	s_4	s_6	s_2	s_3	s_4	s_5	s_5	—	s_3	s_4
P_{r11}	s_3	s_3	s_3	s_4	s_3	s_3	s_2	s_4	s_3	s_3	—	s_1
P_{r12}	s_0	s_1	s_1	s_5	s_0	s_1	s_3	s_3	s_2	s_3	s_3	—

Table 7
Linguistic terms for Triangular Intuitionistic Fuzzy Number.

Linguistic variables	Triangular Intuitionistic Fuzzy Number
Supreme low (s_0)	(0.00,0.00,0.15, 0.00,0.00,0.18)
Very low (s_1)	(0.00,0.15,0.30, 0.00,0.15,0.373)
Low (s_2)	(0.15,0.30,0.45, 0.10,0.30,0.46)
Moderate (s_3)	(0.30,0.45,0.60, 0.30,0.45,0.65)
High (s_4)	(0.45,0.60,0.75, 0.55,0.60,0.70)
Very high (s_5)	(0.60,0.75,0.90, 0.62,0.75,0.85)
Supreme high (s_6)	(0.75,0.90,1.00, 0.80,0.90,1.00)

Table 8
Defuzzified values of TIFS of B_1 .

	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}
P_{r1}	-	(0.3060,0.6993)	(0.8847,0.1061)	(0.4515,0.5379)	(0.4515,0.5379)	(0.5970,0.3898)
P_{r2}	(0.3060,0.6993)	-	(0.4515,0.5379)	(0.0151,0.9798)	(0.4515,0.5379)	(0.8847,0.1061)
P_{r3}	(0.4400,0.2008)	(0.3000,0.3553)	-	(0.3000,0.3553)	(0.4400,0.2008)	(0.3000,0.3553)
P_{r4}	(0.4515,0.5379)	(0.3060,0.6993)	(0.4515,0.5379)	(0.3060,0.6993)	-	(0.5970,0.3898)
P_{r5}	(0.4515,0.5379)	(0.3060,0.6993)	(0.4515,0.5379)	(0.3060,0.6993)	-	(0.5970,0.3898)
P_{r6}	(0.8847,0.1061)	(0.4515,0.5379)	(0.3060,0.6993)	(0.7425,0.2603)	(0.7425,0.2603)	-
P_{r7}	(0.7393,0.1123)	(0.3054,0.5510)	(0.3054,0.5510)	(0.5946,0.2423)	(0.5946,0.2423)	(0.4500,0.3914)
P_{r8}	(0.5970,0.3898)	(0.5970,0.3898)	(0.5970,0.3898)	(0.7425,0.2531)	(0.7425,0.3898)	(0.7425,0.2531)
P_{r9}	(0.7393,0.1565)	(0.7393,0.1565)	(0.5946,0.2912)	(0.3054,0.6003)	(0.4500,0.4400)	(0.5946,0.2912)
P_{r10}	(0.4500,0.4400)	(0.0161,0.8786)	(0.1607,0.8786)	(0.4500,0.4400)	(0.3054,0.6003)	(0.1607,0.7239)
P_{r11}	(0.4515,0.5379)	(0.0151,0.9798)	(0.4515,0.5379)	(0.7425,0.2603)	(0.4515,0.5379)	(0.5970,0.3898)
P_{r12}	(0.0179,0.6757)	(0.1762,0.5240)	(0.1762,0.5240)	(0.4464,0.2477)	(0.0179,0.6757)	(0.1762,0.5240)

	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
P_{r1}	(0.5970,0.3898)	(0.8847,0.1061)	(0.4515,0.5379)	(0.8847,0.1061)	(0.8847,0.1061)	(0.8847,0.1061)
P_{r2}	(0.7425,0.2603)	(0.7425,0.2603)	(0.5970,0.3898)	(0.3060,0.6993)	(0.0151,0.9798)	(0.0151,0.9798)
P_{r3}	(0.4400,0.2008)	(0.4400,0.2008)	(0.0200,0.6249)	(0.0200,0.6249)	(0.0200,0.6249)	(0.4400,0.2008)
P_{r4}	(0.7425,0.2603)	(0.5970,0.3898)	(0.8847,0.1061)	(0.8847,0.1061)	(0.4515,0.5379)	(0.7425,0.2603)
P_{r5}	(0.1605,0.8242)	(0.7425,0.8242)	(0.8847,0.1061)	(0.3060,0.6993)	(0.1605,0.8242)	(0.3060,0.6993)
P_{r6}	(0.5970,0.3898)	(0.4515,0.5379)	(0.3060,0.6993)	(0.1605,0.8242)	(0.7425,0.2603)	(0.0151,0.9798)
P_{r7}	-	(0.3054,0.5510)	(0.7393,0.1123)	(0.3054,0.5510)	(0.5946,0.2423)	(0.7393,0.1123)
P_{r8}	(0.7425,0.2531)	-	(0.5970,0.3898)	(0.4515,0.5379)	(0.7425,0.2531)	(0.8847,0.1061)
P_{r9}	(0.3054,0.6003)	(0.3054,0.6003)	-	(0.1607,0.7239)	(0.3054,0.6003)	(0.0161,0.8786)
P_{r10}	(0.0161,0.8786)	(0.7393,0.1565)	(0.3054,0.6003)	-	(0.1607,0.7239)	(0.0161,0.8786)
P_{r11}	(0.1758,0.8242)	(0.8847,0.1061)	(0.1758,0.8242)	(0.1758,0.8242)	-	(0.0151,0.9798)
P_{r12}	(0.5893,0.0973)	(0.5893,0.0973)	(0.3036,0.4039)	(0.4464,0.2477)	(0.3036,0.4039)	-

terms are necessary to convert the usual language into a fuzzy value called the fuzzification process. These terms further aid in explicit the individual’s opinion about the problem.

Step 4: The defuzzified matrices are constructed by applying the proposed CIFCS algorithm represented in Fig. 1. Table 8 contains the defuzzified values of E_1 .

In matrix E_1 , the interrelation of $P_{r14}=(0.30,0.45,0.60,0.30,0.45,0.65)$, where $a_{14}=0.30, b_{14}=0.45, c_{14}=0.60, a'_{14}=0.30, b'_{14}=0.45, c'_{14}=0.65$. The numerical steps of the CIFCS algorithm

Stage (a): The normalized value are constructed for elements P_{r14} in matrix E_1 .

$$(xa_{14}^1 = \frac{(0.30-0)}{1} = 0.30, xb_{14}^1 = \frac{(0.45-0)}{1} = 0.45, xc_{14}^1 = \frac{(0.60-0)}{1} = 0.60, xa_{14}^{1'} = \frac{(1-0.30)}{1} = 0.7, xb_{14}^{1'} = \frac{(1-0.45)}{1} = 0.55, xc_{14}^{1'} = \frac{(1-0.65)}{1} = 0.35)$$

Table 9
Aggregated matrix *B*.

	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}
P_{r1}	-	(0.2573,0.6895)	(0.6439,0.2958)	(0.4992,0.4394)	(0.5962,0.3468)	(0.5957,0.3470)
P_{r2}	(0.3535,0.6041)	-	(0.4510,0.4891)	(0.3050,0.6457)	(0.5474,0.4030)	(0.5478,0.3981)
P_{r3}	(0.3510,0.4728)	(0.4536,0.3784)	-	(0.1589,0.6691)	(0.5436,0.2906)	(0.3044,0.5243)
P_{r4}	(0.5948,0.3973)	(0.2141,0.7826)	(0.4030,0.5917)	-	(0.4030,0.5917)	(0.4515,0.5346)
P_{r5}	(0.3070,0.5838)	(0.4498,0.4456)	(0.5468,0.3486)	(0.2567,0.6425)	-	(0.5951,0.2999)
P_{r6}	(0.5948,0.3973)	(0.3545,0.6333)	(0.5000,0.4992)	(0.5970,0.3960)	(0.5485,0.4498)	-
P_{r7}	(0.5948,0.34750)	(0.2088,0.7416)	(0.3543,0.5943)	(0.5951,0.3492)	(0.4507,0.4898)	(0.5480,0.3947)
P_{r8}	(0.6444,0.3446)	(0.5000,0.4930)	(0.5970,0.3898)	(0.5485,0.4459)	(0.6940,0.3035)	(0.8373,0.1551)
P_{r9}	(0.5464,0.4141)	(0.5474,0.4137)	(0.5962,0.3631)	(0.4502,0.5102)	(0.4995,0.4559)	(0.6447,0.3138)
P_{r10}	(0.5480,0.4127)	(0.2094,0.7494)	(0.3061,0.6460)	(0.6439,0.3120)	(0.3058,0.6663)	(0.3546,0.5999)
P_{r11}	(0.5942,0.2972)	(0.1589,0.7358)	(0.3528,0.5366)	(0.6914,0.2060)	(0.4498,0.4412)	(0.5468,0.3424)
P_{r12}	(0.0160,0.8784)	(0.1657,0.7241)	(0.1657,0.7241)	(0.5953,0.2993)	(0.1130,0.7849)	(0.4071,0.4848)

	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
P_{r1}	(0.5962,0.3406)	(0.6921,0.2461)	(0.4507,4932)	(0.6439,0.2958)	(0.7888,1665)	(0.5465,0.4063)
P_{r2}	(0.5478,0.3981)	(0.5537,0.3981)	(0.4034,0.5358)	(0.2579,0.6884)	(0.0154,0.9292)	(0.1124,0.8357)
P_{r3}	(0.3995,0.4297)	(0.3987,0.4305)	(0.0171,0.8109)	(0.2110,0.6142)	(0.0655,0.7590)	(0.2540,0.5760)
P_{r4}	(0.6940,0.3035)	(0.5959,0.3984)	(0.6433,0.3455)	(0.6444,0.3446)	(0.5959,0.3940)	(0.5970,0.4066)
P_{r5}	(0.3070,0.5867)	(0.6429,0.2491)	(0.5457,0.3510)	(0.3597,0.5377)	(0.1657,0.7241)	(0.2082,0.6943)
P_{r6}	(0.5970,0.3898)	(0.5485,0.4454)	(0.3545,0.6378)	(0.3060,0.6871)	(0.7414,0.2521)	(0.2090,0.7806)
P_{r7}	-	(0.4998,0.4430)	(0.4989,0.4465)	(0.4998,0.4479)	(0.6436,0.2990)	(0.6918,0.2521)
P_{r8}	(0.6940,0.3011)	-	(0.4515,0.5433)	(0.4515,0.5379)	(0.7414,0.2497)	(0.6444,0.3552)
P_{r9}	(0.4028,0.5616)	(0.4987,0.4686)	-	(0.4516,0.5074)	(0.4028,0.5631)	(0.5952,0.3636)
P_{r10}	(0.4519,0.5096)	(0.7888,0.1743)	(0.4513,0.5200)	-	(0.2576,0.6953)	(0.3064,0.6559)
P_{r11}	(0.4073,0.4961)	(0.5933,0.3009)	(0.2609,0.6320)	(0.3094,0.5904)	-	(0.2091,0.6806)
P_{r12}	(0.4974,0.3910)	(0.4489,0.4448)	(0.4981,0.4031)	(0.5468,0.3486)	(0.4507,0.4439)	-

Table 10
Defuzzified matrix *D*.

	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
P_{r1}	-	0.2839	0.6745	0.5299	0.6247	0.6245	0.6278	0.7230	0.4787	0.6740	0.8115	0.5701
P_{r2}	0.3747	-	0.4809	0.3296	0.5722	0.5748	0.5749	0.5778	0.4338	0.2847	0.0431	0.1383
P_{r3}	0.4391	0.5376	-	0.2449	0.6265	0.3901	0.4849	0.4841	0.1031	0.2984	0.1533	0.3390
P_{r4}	0.5987	0.2157	0.4056	-	0.4056	0.4584	0.6952	0.5987	0.6489	0.6499	0.6009	0.5952
P_{r5}	0.3616	0.5021	0.5991	0.3071	-	0.6476	0.3602	0.6969	0.5974	0.4110	0.2208	0.2570
P_{r6}	0.5988	0.3606	0.5004	0.6005	0.5494	-	0.6036	0.5516	0.3584	0.3095	0.7447	0.2142
P_{r7}	0.6237	0.2336	0.3800	0.6229	0.4805	0.5767	-	0.5284	0.5262	0.5260	0.6723	0.7199
P_{r8}	0.6499	0.5035	0.6036	0.5513	0.6953	0.8411	0.6965	-	0.4541	0.4568	0.7459	0.6446
P_{r9}	0.5662	0.5669	0.6166	0.4700	0.5218	0.6655	0.4206	0.5151	-	0.4721	0.4199	0.6158
P_{r10}	0.5677	0.2300	0.3301	0.6659	0.3198	0.3774	0.4712	0.8073	0.4657	-	0.2812	0.3253
P_{r11}	0.6485	0.2116	0.4081	0.7427	0.5043	0.6022	0.4556	0.6462	0.3145	0.3595	-	0.2643
P_{r12}	0.0688	0.2208	0.2208	0.6480	0.1641	0.4612	0.5532	0.5021	0.5475	0.5991	0.5034	-

Stage (b): The left and right spread values are evaluated. $(x_{as}^1_{14} = \frac{(0.45)}{1+0.45-0.30} = 0.3913, x_{cs}^1_{14} = \frac{(0.60)}{1+0.60-0.45} = 0.5217, x_{as}^1_{14}' = \frac{(0.75)}{1+0.7-0.55} = 0.6087, x_{cs}^1_{14}' = \frac{(0.55)}{1+0.55-0.35} = 0.4583)$

Stage (c): The total normalized values are determined.

$$(x_{14}^1 = \frac{0.3913(1-0.3913)+(0.5217)^2}{1-0.3913+0.5217} = 0.4515, x_{14}' = \frac{0.4583(1-0.4583)+(0.6087)^2}{1-0.4583+0.6087} = 0.5379)$$

Stage (d): The separated values for membership and non-membership are determined.

$$Z_{14}^1 = 0 + 0.4515 \times 1 = 0.4515, Z_{14}' = 0.5379 \times 1 - 0 = 0.5379$$

Step 5: All the triangular intuitionistic fuzzy matrices are aggregated using the proposed CIFCS algorithm. Then the distinct defuzzified matrices are grouped into a single matrix and demonstrated in [Table 9](#).

Step 6: The aggregated matrix is defuzzified using the scoring function Eq. (5) and the defuzzified values are described in [Table 10](#).

Step 7: The normalized values are indicated in [Table 11](#) using Eq. (8). The normalized matrix is evaluated by dividing each element of matrix by the sum of the maximum element of columns, where the values of all the criteria lie between [0,1].

Step 8: The total relation matrix *T* is represented in [Table 12](#) using Eq. (9). The matrix *T* indicates the influence level of each criterion.

Step 9: The criteria are split into cause and effect groups. Here, *d* denotes the addition of rows, and *e* represents the addition of columns of the matrix *T*. (*d + e*) indicates the strongest criteria and (*d - e*) differentiates the criteria into the cause and effect group. The criteria categorization is demonstrated in [Table 13](#). The cause and effect group criteria and interrelation map are depicted in [Figs. 3 and 4](#).

Based on the coordinate position, the criteria are split into four cases:

(1) When (*d + e*) is small and (*d - e*) is positive, the criteria are independent and can influence only a few other criteria.

Table 11
Normalization of defuzzified matrix N .

	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
P_{r1}	-	0.0428	0.1017	0.0799	0.0942	0.0942	0.0947	0.1090	0.0722	0.1016	0.1224	0.0860
P_{r2}	0.0565	-	0.0725	0.0497	0.0863	0.0867	0.0867	0.0871	0.0654	0.0429	0.0065	0.0209
P_{r3}	0.0662	0.0811	-	0.0369	0.0945	0.0588	0.0731	0.0730	0.0155	0.0450	0.0231	0.0511
P_{r4}	0.0903	0.0325	0.0612	-	0.0612	0.0691	0.1048	0.0903	0.0979	0.0980	0.0906	0.0898
P_{r5}	0.0545	0.0757	0.0903	0.0463	-	0.0977	0.0543	0.1051	0.0901	0.0620	0.0333	0.0388
P_{r6}	0.0903	0.0544	0.0755	0.0906	0.0829	-	0.0910	0.0832	0.0540	0.0467	0.1123	0.0323
P_{r7}	0.0941	0.0352	0.0573	0.0939	0.0725	0.0870	-	0.0797	0.0794	0.0793	0.1014	0.1086
P_{r8}	0.0980	0.0759	0.0910	0.0831	0.1049	0.1268	0.1050	-	0.0685	0.0689	0.1125	0.0972
P_{r9}	0.0854	0.0855	0.0930	0.0709	0.0787	0.1004	0.0634	0.0777	-	0.0712	0.0633	0.0929
P_{r10}	0.0856	0.0347	0.0498	0.1004	0.0482	0.0569	0.0711	0.1217	0.0702	-	0.0424	0.0491
P_{r11}	0.0978	0.0319	0.0615	0.1120	0.0760	0.0908	0.0687	0.0974	0.0474	0.0542	-	0.0399
P_{r12}	0.0104	0.0333	0.0333	0.0977	0.0247	0.0696	0.0834	0.0757	0.0826	0.0903	0.0759	-

Table 12
Total relation matrix T .

	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
P_{r1}	0.3890	0.3147	0.4571	0.4734	0.4680	0.5163	0.4979	0.5517	0.4102	0.4452	0.4879	0.4139
P_{r2}	0.3206	0.1911	0.3207	0.3172	0.3447	0.3766	0.3626	0.3898	0.2973	0.2822	0.2674	0.2523
P_{r3}	0.3063	0.2502	0.2326	0.2860	0.3305	0.3293	0.3294	0.3551	0.2361	0.2662	0.2608	0.2594
P_{r4}	0.4350	0.2785	0.3871	0.3631	0.4018	0.4541	0.4679	0.4926	0.4019	0.4112	0.4271	0.3889
P_{r5}	0.3488	0.2834	0.3643	0.3456	0.2946	0.4192	0.3663	0.4402	0.3438	0.3253	0.3189	0.2925
P_{r6}	0.4099	0.2799	0.3766	0.4158	0.3980	0.3607	0.4279	0.4554	0.3385	0.3399	0.4186	0.3127
P_{r7}	0.4362	0.2797	0.3827	0.4483	0.4102	0.4682	0.3721	0.4826	0.3854	0.3943	0.4360	0.4027
P_{r8}	0.4875	0.3508	0.4582	0.4859	0.4877	0.5558	0.5181	0.4644	0.4169	0.4261	0.4897	0.4310
P_{r9}	0.4191	0.3213	0.4075	0.4159	0.4099	0.4706	0.4232	0.4707	0.3027	0.3769	0.3900	0.3788
P_{r10}	0.3802	0.2451	0.3302	0.3995	0.3416	0.3872	0.3859	0.4590	0.3325	0.2745	0.3362	0.3097
P_{r11}	0.4068	0.2531	0.3555	0.4250	0.3819	0.4332	0.3999	0.4566	0.3256	0.3393	0.3102	0.3124
P_{r12}	0.2881	0.2227	0.2866	0.3725	0.2911	0.3661	0.3666	0.3873	0.3194	0.3319	0.3368	0.2375

Table 13
Grouping the criteria into cause and effect class.

d	e	$(d + e)$	$(d - e)$	Category
5.4253	4.6275	10.0528	0.7978	Cause
3.7225	3.2705	6.9930	0.4520	Cause
3.4419	4.3591	7.8010	-0.9172	Effect
4.9092	4.7482	9.6574	0.1610	Cause
4.1429	4.5600	8.7029	-0.4171	Effect
4.5339	5.1373	9.6712	-0.6034	Effect
4.8984	4.9178	9.8162	-0.0194	Effect
5.5721	5.4054	10.9775	0.1667	Cause
4.7866	4.1103	8.8969	0.6763	Cause
4.1816	4.2130	8.3946	-0.0314	Effect
4.3995	4.4796	8.8791	-0.0801	Effect
3.8066	3.9918	7.7984	-0.1852	Effect

- (2) When $(d + e)$ is large and $(d - e)$ is positive, the criteria are under cause class can solve the problem.
- (3) When $(d + e)$ is small and $(d - e)$ is negative, the criteria are independent and can influence only a few criteria.
- (4) When $(d + e)$ is large and $(d - e)$ is negative, the criteria are under the effect class.

Step 10: The threshold value is determined to detect the influencing level between criteria. The α value is the threshold value determined by Eq. (12) is the mean of the total relation matrix T .

$$\alpha = \frac{53.8205}{144} = 0.3738$$

From the result, P_{r8} is monitoring the public well-being is the most vital criterion, and has a maximum number of receiver class compared with other criteria because it has the highest connectivity with neighborhood criteria. The criteria P_{r12} perform as a transmitter class because they are unaffected by other criteria and the least preferred criteria. The only criterion that acts as a receiver class is P_{r3} .

Step 11: The obtained results are compared with two DEMATEL situations. The categorization and ranking of criteria for the three DEMATEL situation are demonstrated in Table 14, and grading are determined in Table 15. The graphical representation of categorization and interrelation between criteria are in Figs. 5 and 6.

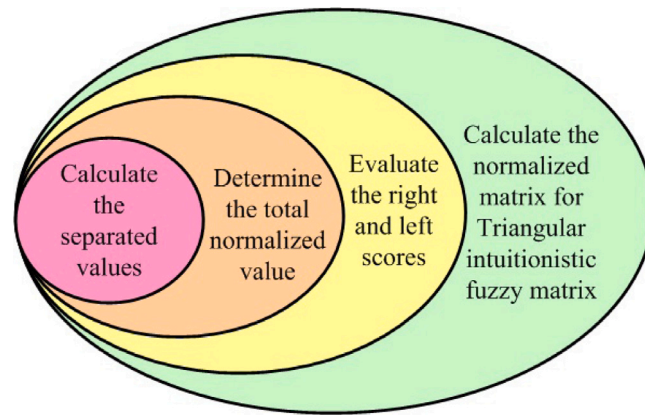


Fig. 1. Flow of the CIFCS algorithm.

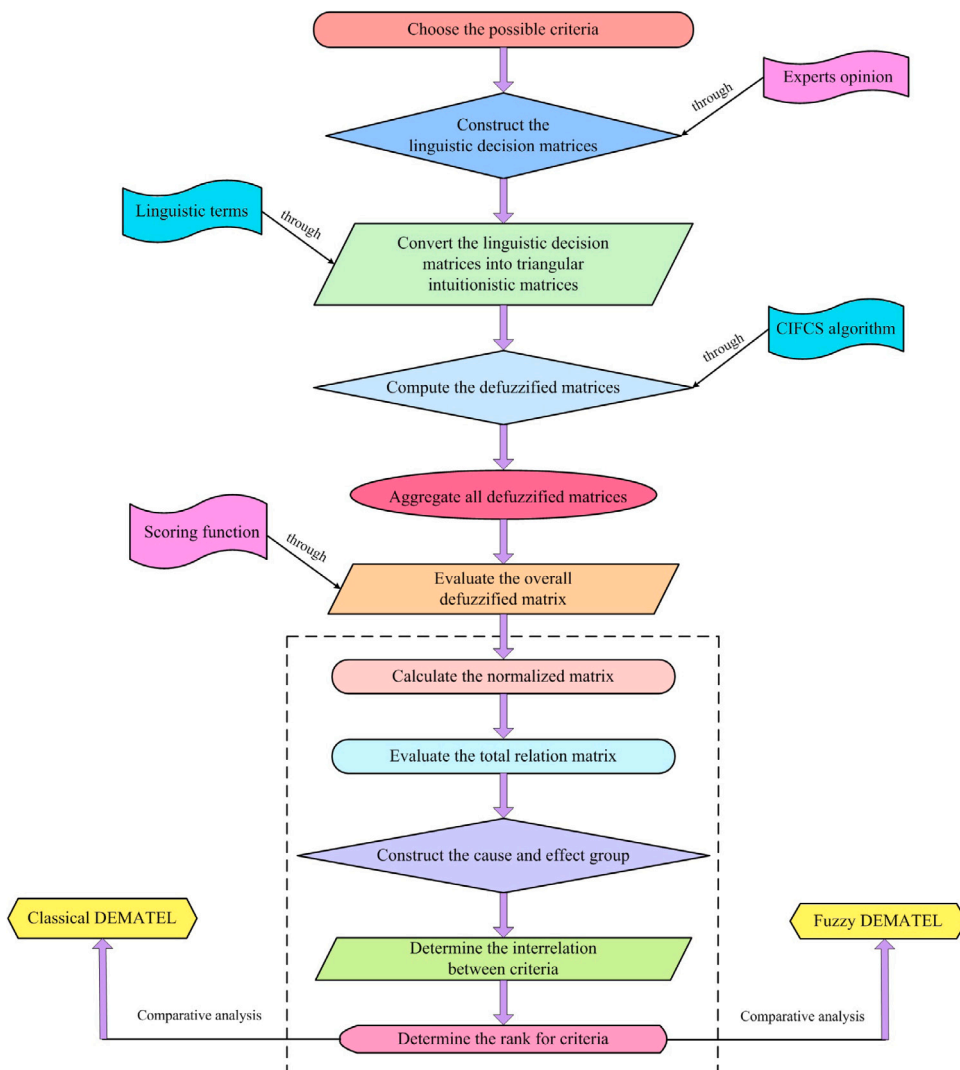


Fig. 2. Flow of the IF-DEMATEL algorithm.

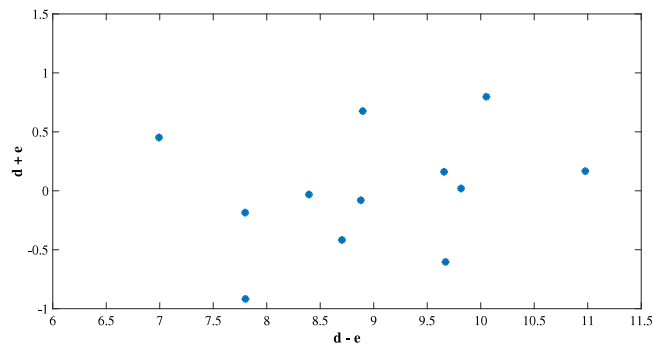


Fig. 3. Cause and effect group of IF-DEMATEL.

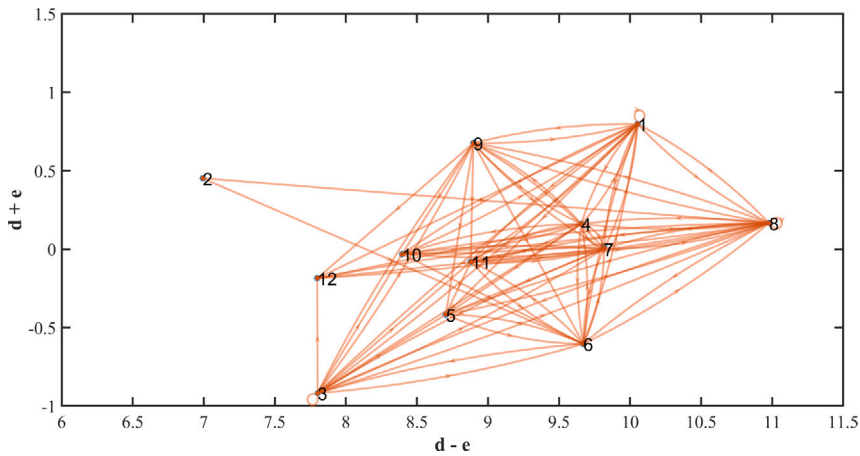


Fig. 4. Interrelation map of IF-DEMATEL.

Table 14
Different situations of DEMATEL.

Methods	Ranking	Cause and Effect group
Crisp DEMATEL	$P_{r11} > P_{r7} > P_{r6} > P_{r8} > P_{r4} > P_{r2} > P_{r5} > P_{r1} > P_{r10} > P_{r3} > P_{r12} > P_{r9}$	Cause: $P_{r1}, P_{r2}, P_{r3}, P_{r4}, P_{r5}, P_{r8}, P_{r9}, P_{r10}, P_{r12}$, Effect: P_{r6}, P_{r7}, P_{r11}
Fuzzy DEMATEL	$P_{r8} > P_{r1} > P_{r4} > P_{r6} > P_{r7} > P_{r9} > P_{r11} > P_{r5} > P_{r10} > P_{r12} > P_{r3} > P_{r2}$	Cause: $P_{r1}, P_{r2}, P_{r3}, P_{r7}, P_{r8}, P_{r9}, P_{r10}$, Effect: $P_{r3}, P_{r5}, P_{r6}, P_{r11}, P_{r12}$
IF-DEMATEL	$P_{r8} > P_{r1} > P_{r7} > P_{r6} > P_{r4} > P_{r9} > P_{r11} > P_{r5} > P_{r10} > P_{r3} > P_{r12} > P_{r12}$	Cause: $P_{r1}, P_{r2}, P_{r4}, P_{r8}, P_{r9}$, Effect: $P_{r3}, P_{r5}, P_{r6}, P_{r7}, P_{r10}, P_{r11}, P_{r12}$

Table 15
Ranking of lockdown relaxation protocols in different DEMATEL context.

(d + e)	P_{r1}	P_{r2}	P_{r3}	P_{r4}	P_{r5}	P_{r6}	P_{r7}	P_{r8}	P_{r9}	P_{r10}	P_{r11}	P_{r12}
Crisp-DEMATEL	8	6	10	5	7	3	2	4	12	9	1	11
Fuzzy-DEMATEL	2	12	11	3	8	4	5	1	6	9	7	10
IF-DEMATEL	2	12	10	5	8	4	3	1	6	9	7	11

5. Results and discussion

This study analyzes the efficiency of lockdown relaxation protocols of the Indian government using the IF-DEMATEL method. Initially, three different professionals gave their opinions on the considered protocols. Based on their views, the linguistic decision matrices are framed and fuzzified using linguistic terms through the TIFN. The TIF matrices are defuzzified using the CIFCS

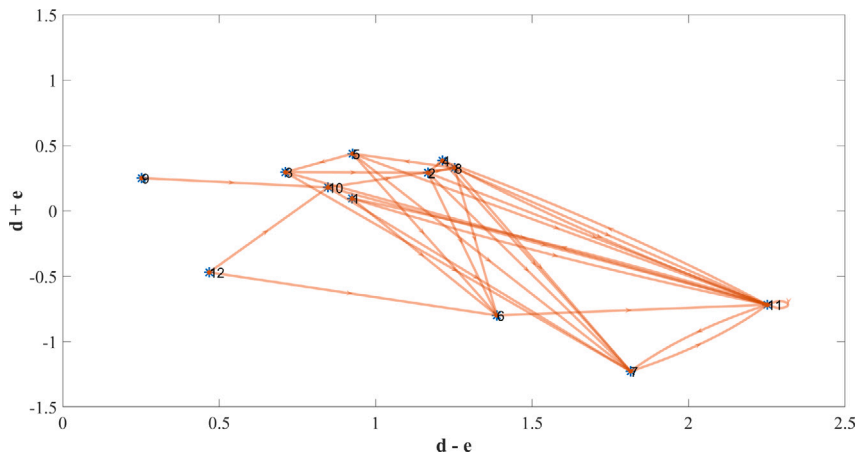


Fig. 5. Interrelation map of Classical-DEMATEL.

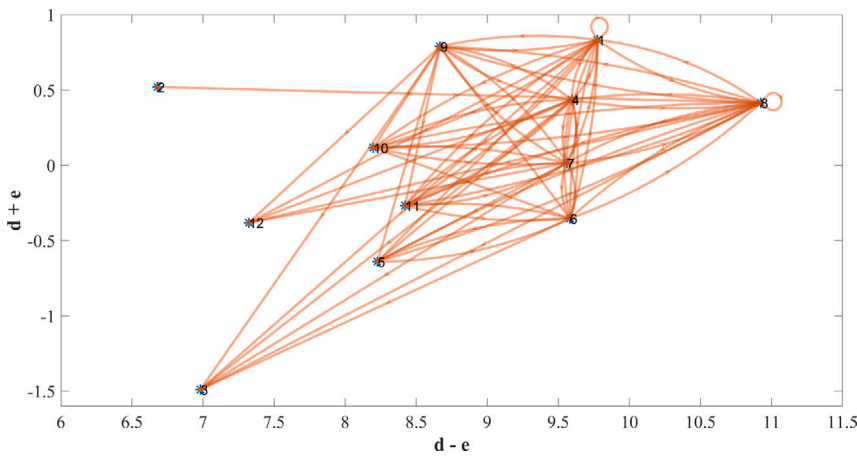


Fig. 6. Interrelation map of Fuzzy-DEMATEL.

algorithm. After this, the averaging operator is used to aggregate the defuzzified triangular intuitionistic fuzzy matrices, and the aggregated matrix is defuzzified using the scoring function. Then, the defuzzified matrix is applied to the DEMATEL method to split the factors into cause and effect groups categorized by positive and negative terms from $(d - e)$. The efficiency of the criteria depends on the highest rank of $(d + e)$ in Table 13. The criteria belonging to the cause group are treated as the most decisive criteria. The threshold value aid in eliminating the non-significance criteria. The problem is analyzed using the IF-DEMATEL method, which provided the ranking for all the considered lockdown relaxation protocols. Consequently, P_{r8} represents monitoring the public well-being, which serves as the first preferable criteria, P_{r1} is controlled public movement, and P_{r7} implies public transportation operated on schedule is ranked second and third.

The Indian government has also taken measures like creating the Aarogya Setu app to track each individual, dividing the country into different zones based on the affected percentage, and instilling regular public awareness. Personal gatherings, festival gatherings, and traditional gatherings were all outlawed. Nearly 80% of people used social transportation, which has the potential to spread the virus quickly. So, all modes of transportation, including airways and highways, operate on a strict schedule. Therefore, the obtained results are similar to the Indian government’s decision. The least preferred criteria are P_{r2} represents curfew for red, green, and white industries, including chemical manufacturers, pesticides, power plants, non-motor vehicles, bio-fertilizers, cement manufacturers, and rubber manufacturers. The red, green, and white industries were closed depending on the period.

The second least preferred criterion is P_{r12} signifies E-pass is issued to enter inter-districts. The electronic passes scheme was introduced with proper guidance and provided only for substantial reasons. The P_{r3} represents the complete functioning of orange industries and is the third-least preferred criterion. Orange industries like milk production and dairy products production are allowed for the public’s welfare. The DEMATEL process produces fuzzy decision mapping (FDM) when the threshold value is linear. The comparison was made under the various situations of the DEMATEL method, which include crisp and fuzzy. The outcomes of all three DEMATEL methods are depicted through MATLAB. The number of indegrees and outdegrees between criteria differs according to the DEMATEL situations. Based on the comparative study, the result under an intuitionistic situation divulges better results as it

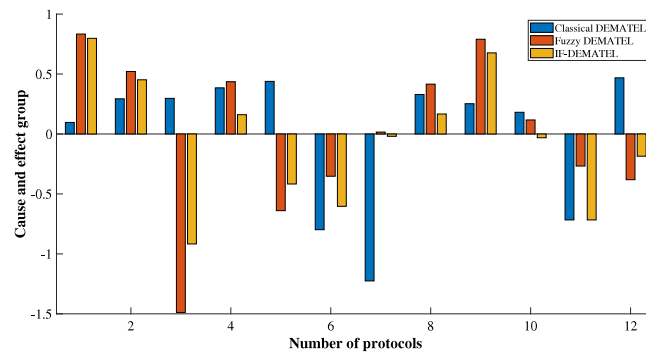


Fig. 7. Comparison of all DEMATEL cases.

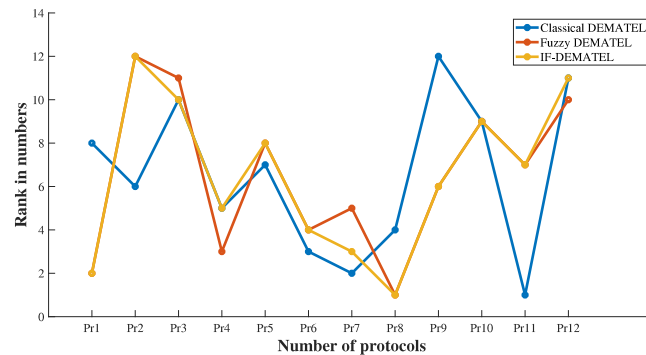


Fig. 8. Ranking of all DEMATEL cases.

incorporates the belongingness and non-belongingness information of the chosen protocols. Figs. 7 and 8 demonstrate the difference in the grouping and ranking of criteria, respectively. The variation in outcomes is because every DEMATEL situation follows a unique structure for indicating the relationship between criteria.

This study contains some limitations because the work depends only on India's lockdown situation, and samples are constructed from India's COVID lockdown relaxation protocols. Other countries can utilize this work where sample sizes and protocols vary according to the location and have divergent decision-makers opinions.

6. Conclusion

The COVID-19 lockdown entirely changed the regular life-cycle of people and affected both people and the government financially. Later, the lockdown was released with a few protocols. The Indian government brought these protocols to improve the economic status and people's well-being. Therefore, the twelve selected lockdown relaxation protocols are probed to find their efficacy. This work improved the DEMATEL method by incorporating intuitionistic fuzzy sets, which effectively neglect ambiguous and imprecise information. The IF-DEMATEL is the extension of DEMATEL and fuzzy DEMATEL, which can handle a wider range of uncertain information. The defuzzification and aggregation process are the two main features of group MCDM methods. The TIFN is defuzzified into a crisp value through the proposed CIFCS algorithm. In the proposed method, an averaging operator aggregates the decision-makers' opinions. The developed IF-DEMATEL method was applied to find the efficacy of Indian government lockdown relaxation protocols. It revealed the protocols needed for reducing the spread of coronavirus and suggested the most preferred and the least preferred protocols. The obtained results are compared with crisp DEMATEL and fuzzy DEMATEL. The fuzzy and the intuitionistic fuzzy DEMATEL provided the ranking order with minimum differences, whereas the crisp DEMATEL showed maximum differences. This variation occurs due to the nature of the DEMATEL situations. It shows that the wider range of fuzzy, eliminates the ambiguity of the problem. As a result, (P_{r8}) monitoring public well-being and (P_{r1}) public movement control are preferred protocols over others, and the Indian government took them as the foremost preventive measure to avoid the spread of COVID-19. Thus, the lockdown relaxation protocols proclaimed by the Indian government are very effective. Through these protocols, India recorded 95% of the National recovery percentage, which is one of the highest in the world. Further, the proposed method can be enhanced by incorporating the Pythagorean and q -rung orthopair fuzzy environments to investigate the various COVID-19 related problems. It can also be applied to determine the efficiency of the COVID-19 vaccines.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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