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Prioritization of the barriers of vaccine supply chain in India

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A B S T R A C T

The COVID-19 outbreak has illustrated the wide range of issues that supply networks confront when they are subjected to major interruptions. The supply networks for vaccines are no exception. To get out of this pandemic, it's critical to identify and address problems with the COVID-19 vaccine supply chain (VSC). This work identifies 13 challenges and prioritizes those. The findings provide stakeholders and government policymakers with realistic advice for developing a better VSC. This paper proposes a methodology based on fuzzy analytical hierarchy process (Fuzzy-AHP) with the use of triangular fuzzy numbers for prioritizing VSC barriers. It has been found that the impact of poor health worker training facilities becomes maximum with the highest weightage. Moreover, the managerial implication of the results is also provided, which will be useful for VSC sectors to take suitable decisions to overcome these obstacles.

1. Introduction

At present time, the world has faced the corona virus disease known as Covid-19. The first case of the corona virus was reported in December 2019 in Wuhan city of China which is known as the major transportation hub of China. The virus has affected the lives of many people. The pandemic has resulted in major changes in the way government organizations work. The main strategies to control this pandemic are maintaining social distance, lockdown, wearing personal protective equipment and getting vaccinated (Mulberry et al., 2021). Coronavirus is a large family of viruses that has spread devastatingly among people in India and all over the world. Common human coronavirus typically causes an upper respiratory tract infection like common cold and fever (Jangre et al., 2022). The Covid 19 outbreaks give a significant effect to the lives and wellbeing of billions of citizens in India (Ivanov & Dolgui, 2021). Many countries have shut down their sea docks and airports after the spread of the virus. This pandemic has implied huge changes in administration associations work (Narayanamurthy & Tortorella, 2021). To combat this situation, India has also closed the international borders and by imposing nationwide lockdown for which manufacturing, and logistics sectors are seriously affected due to demand and supply fluctuations (Raju et al., 2022). Various kinds of tests for detection of the virus have been reported by researchers (Chakraborty & Mali, 2021). Nowadays the Health care industry are more focused on COVID 19 more than any other health issue and the vaccination program is the ultimate solution to overcome this pandemic (Alizadeh et al., 2021). The Covid 19 vaccine supply chain (VSC) is different from traditional VSC (Golan et al., 2021; Sadjadi et al., 2019; de Carvalho et al., 2019) because the government is procuring this vaccine directly from manufacturer and protects this supply chain from traditional wholesalers and distributors (Abbasi et al., 2020). Healthcare experts and VSC analysts are looking for proper policies and adequate strategies for appropriate vaccine manufacturing and distribution to fight against the Covid 19 pandemic. It is critical to investigate pandemic VSCs and understand the challenges they provide to put a stop to the pandemic's devastation. Because of the overall volume required by each nation to reduce rates of infection and avoid lockdowns, the COVID-19 VSC is particularly troublesome. India, like other countries, is no exception. The first case of COVID-19 was reported in Kerala, India, on January 27, 2020. (Andrews et

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al. 2020), and as of 29 August 2021, with a record of 3.25 cores of positive samples of COVID-19 worst-hit nations, the country was ranked second in the world. (WHO 2020). From the beginning, the Indian government and state governments took precautions to minimize the virus from spreading. The Indian government to enforce a one-day curfew, known as Janta Curfew, on March 22, 2020, continued by a phased lockdown starting March 25, 2020.The lockdown stopped the spread of the initial communities, but it is already making a huge impact on India's economy. Despite the lockdown and limitations, the number of confirmed cases continues to increase at an exponential rate, putting pressure on India's health system and socioeconomic infrastructure (Chang et al., 2020).The lack of oxygen, beds, doctors, and nurses, as well as ill-equipped hospital infrastructure, medicine limitations, and the demand for adequate vaccines, can increase the risk of vulnerability (Yeasmin et al. 2020). Migrant workers, who are mostly dependent on daily wages, are one of the most vulnerable populations, wanting to return to their hometowns. Most of them began walking or cycling miles and miles to their allocated locations and many of them died on the edge of returning home due to poor health caused by hunger and dehydration (Singh & Chauhan, 2020). People began crowding train stations and bus terminals, carrying the virus home, resulting in community transmission and the spread of the infection to vulnerable people, creating a serious global threat.

The covid 19 vaccine distribution is the most challenging task the VSC sector has ever seen since World War II. The various factors should be identified and prioritized based on their importance for better planning and implementation of VSC (Raju et al., 2022). The vaccine's availability will be primarily determined by the elimination of bottlenecks in the supply chain's development and fulfillment phases. The vaccine distribution system, being a bio-pharmaceutical chain, is a very complicated and sensitive system that must be effectively managed and maintained due to its direct impact on public health (Yadav & Kumar, 2022). While creating novel vaccines and evaluating their efficacy in people is the primary emphasis, it is equally critical to understand and solve VSC concerns to improve vaccine efficacy (Lee & Haidari, 2017). Improved vaccine supply chain performance (VSCP) will help counter the COVID-19 pandemic while also addressing the sustainable development goals (SDG) by ensuring vaccinations evenly across India.

For making judgments in complex situations, multiple criteria decision-making methods (MCDM) are commonly used. India, with a population of 130 million people, plans to provide vaccination to all its residents. Due to India's enormous population, importing vaccines may not be the best solution. According to the International Air Transport Association (IATA), transporting the vaccine from production facilities abroad to distribution regions will need thousands of flights. COVID-19 immunization will be completely regulated by the government, at least in the beginning. For efficient cooperation and collaboration among the main departments participating in COVID-19 immunizations, high-level coordination has been created at the national, state, and district levels. The launch of the COVID-19 vaccine is being planned by 23 ministries/departments and several developmental partners. Their responsibilities are outlined in operating guidelines released by India's Ministry of Health and Family Welfare. Countries that devised step-by-step tactics in the early stages of the pandemic performed better in terms of limiting disease transmission. Lockdown, broad testing, digital surveillance of people (i.e., identifying and monitoring persons who have been in close contact with someone sick), and isolation of infected patients are among the strategies utilized so far. During this time, some important hurdles that hampered supply chains (SC) in India have been studied. This work is expected to aid the industrial sector in finding the best solution. The sensitivity of regional and global SCs to catastrophic events raises a slew of challenges in terms of analysis, transport, and logistics. Despite the numerous advantages, supply chain management (SCM) implementation is challenging, and businesses continue to confront difficulties that prevent them from implementing efficient SCM (Meehan & Muir, 2008).

2. Barriers of vaccine supply chain (VSC) management

In the present study, an effort has been exerted to identify the barriers to the Indian vaccine supply chain for Covid-19 vaccine. The barriers relevant to Indian context, such as poor health worker training facilities, inaccuracies in the vaccination registration, inaccurate vaccine demand forecasting, limited vaccine supply and logistics, consumers' unwillingness to undergo vaccination, distance between vaccine storage and immunization camps, inadequate vaccination promotion, difficulties in maintaining and monitoring vaccine temperature, difficulty of tracking vaccinated population, lack of coordination among members of the vaccine supply chain have been determined through exhaustive literature review and conducting brainstorming sessions with experts in the domain. Detailed description of the barriers has been presented in Table 1.

Table 1
Description of barriers

Barriers	Definition	Description of the barriers
C1	Poor health worker training facilities	Existing health workers were included in this vaccination program without any prior training and not attending any awareness program about this serious issue resulting failure to bring the rural people to vaccination center.
C2	Inaccuracies in the vaccination registration	The rural people could not do online registration properly due to the digital divide, as a result less registration was reported.
C3	Limited vaccine supply and logistics	The key challenge in the covid-19 scenario to provide vaccines a large no of population in India but a limited no of companies who can successfully produce effective vaccine, which can restrict vaccination.

Table 1
Description of barriers (Continued)

C4	Inaccurate Vaccine demand forecasting.	The Vaccine demand in India can be affected by the per capita income of that region, vaccine-related knowledge, knowledge of medical care staff, urbanization, and vaccination missions. The inability to predict the variables mentioned above can reduce the efficacy of COVID-19 VSC.
C5	Consumers' unwillingness to undergo vaccination	The fear of potential side effects of vaccines, misconception and misinformation and the negative beliefs, consumers can reject the vaccine.
C6	Inadequate Vaccination promotion	COVID-19 vaccine acceptance by the people largely depends on positive vaccine marketing. Only positive vaccine marketing can change the perception of negatively influencing public of COVID-19 vaccines.
C7	Distance between vaccine storage and immunization camps.	The significant distance between vaccine stores and vaccination camps can also impact negatively on vaccine distribution programs.
C8	Poor planning and controlling	Proper planning and scheduling is also important to influence immunization enrollment, vaccine purchase, storage, and distributions.
C9	Insufficient storage systems	In remote locations, the lack of a proper storage system of vaccines can delay the delivery of vaccines, which in turn may reduce the effectiveness of the COVID-19 Vaccine supply chain.
C10	Difficulties in maintaining and monitoring vaccine temperature	Inability to maintain the recommended temperature while transferring vaccines from manufacturers to consumers may reduce the efficacy of VSC, especially in the tropical regions
C11	Ineffective collaboration with local organizations	Inappropriate coordination with local healthcare organizations may impede the rapid vaccine supply and distributions by creating communication gaps. Coordination with local organizations is customary for opening multiple channels depending on size of service area and population for proper distribution of the COVID-19 vaccine to the people.
C12	Difficulty of tracking vaccinated population	Tracking of vaccinated population can reduce the transparency and equal distribution of the COVID-19 vaccine which is becomes a difficult work. In India, without a central health registry of their population will face challenges to monitor and track the total number of vaccinated populations.
C13	Lack of coordination among members of the vaccine supply chain.	Health workers are also affected by these diseases, as a result, the communication between one health worker to others health care breaks down.

3. Methodology

Due to covid 19 pandemic, financial issues became a major factor in the day to day living of people. People have faced job risk and pay cuts during this pandemic. Earlier, a multicriteria approach was used to optimize vaccination planning (Ng et al., 2018). To combat this pandemic with incorporation of appropriate VSC, many challenges of VSC have been identified and many methods have been introduced to examine these challenges. Alam et al. (2021) used the intuitionistic Fuzzy DEMATEL (IF-DEMATEL) method to assess fifteen such VSC challenges. Chandra and Kumar (2021) developed a framework in VSC using structural equation modeling. During the pandemic, Taghipour et al. (2023) proposed a three-objective optimization model to allocate mobile and fixed vaccine injection centers. Mishra et al. (2023) proposed blockchain based secure VSC that provides guarantees the complete integrity and immutability of vaccine supply records. Liu et al., (2023) constructed a VSC game model consisting of a vaccine manufacturer and a vaccination unit and analyzed the conditions for applying blockchain technology in the VSC. Cano-Marin et al., (2023) used social media analytics for exploring the impact of COVID-19 vaccine supply chain challenges from a global perspective. Abbasi et al., (2023) used multi-objective mixed-integer programming (MOMIP) and multi-objective gray wolf optimizer (MOGWO) algorithm to optimize cost and environmental concerns in VSC. The AHP approach, which is a traditional MCDM approach, was first put forward by Saaty (1980). To capture the fuzziness and uncertainty in decision making process, many fuzzy multicriteria decision making models have come up (Chen & Eyoun, 2021; Chen & Hwang, 1992; Chen and Lee, 2010; Chiao 2020), to estimate the rank of the criterion, the fuzzy-AHP approach could be used. The fuzzy-AHP is a modified AHP that allows for systematic alternative selection and justification (Zadeh 1965). In the fuzzy-AHP approach, the fixed value of pay off has been replaced with interval judgment, offering the user more confidence. This approach has a variety of advantages such as, it is simple to learn and comprehend, it can capture imprecision in assessments, and it returns to a clear value in the conclusion. For pair-wise comparison of one criterion over another, a fuzzy scale (Table 2) developed by Chang (1996) has been used for the present study.

Table 2
Fuzzy Scale

Preference of pairwise comparisons	Fuzzy numbers
Equal	(1,1,1)
Moderate	(0.67,1,1.5)
Strong	(1.5,2,2.5)
Very strong	(2.5,3,3.5)
Extremely Strong	(3.5,4,4.5)

In this work, the extent fuzzy AHP (Chang,1996) is utilized for de fuzzification.

4. Data and Computation

For determining relative weight of one criterion over another, a pairwise comparison matrix (PWCM) has been developed by aggregating the opinion of experts from diverse domains. To express the relative importance of criteria, a fuzzy scale as mentioned in Table 2 has been used. Thus, PWCM developed has been presented in Table 3.

Table 3
Pair wise comparison matrix of 13 criteria

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**
C1	(1,1,1)	(1.5,2,2.5)	(0.7,1,1.5)	(1.5,1,0.7)	(1.5,2,2.5)	(2.5,3,3.5)	(0.7,1,1.5)	(2.5,3,3.5)	(1.5,2,2.5)	(0.7,1,1.5)	(3.5,4,4.5)	(0.7,1,1.5)	(1.5,2,2.5)
C2	(0.4,0.5,0.7)	(1,1,1)	(1.5,2,2.5)	(0.4,0.5,0.7)	(0.7,1,1.5)	(0.4,0.5,0.7)	(1.5,2,2.5)	(2.5,3,3.5)	(0.67,1,1.5)	(0.7,1,1.5)	(1.5,2,2.5)	(0.67,1,1.5)	(0.7,0.5,0.4)
C3	(0.7,1,1.5)	(0.4,0.5,0.7)	(1,1,1)	(0.67,1,1.5)	(0.67,1,1.5)	(1.5,2,2.5)	(2.5,3,3.5)	(0.7,0.5,0.4)	(0.67,1,1.5)	(0.7,1,1.5)	(2.5,3,3.5)	(0.7,0.5,0.4)	(2.5,3,3.5)
C4	(0.7,1,1.5)	(1.5,2,2.5)	(0.7,1,1.5)	(1,1,1)	(0.67,1,1.5)	(0.7,1,1.5)	(1.5,2,2.5)	(0.7,1,1.5)	(0.67,1,1.5)	(0.7,1,1.5)	(1.5,2,2.5)	(2.5,3,3.5)	(1.5,2,2.5)
C5	(0.4,0.5,0.7)	(0.7,1,1.5)	(0.7,1,1.5)	(0.7,1,1.5)	(1,1,1)	(1.5,2,2.5)	(2.5,3,3.5)	(0.7,1,1.5)	(0.4,0.5,0.7)	(0.7,1,1.5)	(1.5,2,2.5)	(1.5,2,2.5)	(2.5,3,3.5)
C6	(0.3,0.3,0.4)	(1.5,2,2.5)	(0.7,0.4,0.5)	(0.67,1,1.5)	(0.7,1,1.5)	(1,1,1)	(1.5,2,2.5)	(1.5,2,2.5)	0.7,1,1.5)	(0.67,1,1.5)	(0.7,0.5,0.4)	(1.5,2,2.5)	(0.7,0.5,0.4)
C7	(0.7,1,1.5)	(0.4,0.5,0.7)	(0.3,0.3,0.4)	(0.4,0.5,0.7)	(0.3,0.3,0.4)	(0.4,0.5,0.7)	(1,1,1)	(0.67,1,1.5)	(0.67,1,1.5)	(0.7,1,1.5)	(1.5,2,2.5)	(0.67,1,1.5)	(1.5,2,2.5)
C8	(0.3,0.3,0.4)	(0.3,0.3,0.4)	(1.5,2,2.5)	(0.67,1,1.5)	(0.67,1,1.5)	(0.4,0.5,0.7)	(0.7,1,1.5)	(1,1,1,)	(0.67,1,1.5)	(0.7,1,1.5)	(0.67,1,1.5)	(1.5,2,2.5)	(1.5,2,2.5)
C9	(0.4,0.5,0.7)	(0.7,1,1.5)	(0.7,1,1.5)	(0.7,1,1.5)	(1.5,2,2.5)	(0.67,1,1.5)	(0.7,1,1.5)	(0.7,1,1.5)	(1,1,1)	(0.67,1,1.5)	(0.7,1,1.5)	(1.5,2,2.5)	(0.67,1,1.5)
C10	(0.7,1,1.5)	(0.67,1,1.5)	(0.67,1,1.5)	(0.67,1,1.5)	(0.67,1,1.5)	(0.7,1,1.5)	(0.67,1,1.5)	(0.67,1,1.5)	(0.7,1,1.5)	(1,1,1)	(0.67,1,1.5)	(0.7,1,1.5)	(0.67,1,1.5)
C11	(0.2,0.3,0.3)	(0.4,0.5,0.7)	(0.3,0.3,0.4)	(0.4,0.5,0.7)	(0.4,0.5,0.7)	(1.5,2,2.5)	(0.4,0.5,0.7)	(0.7,1,1.5)	(0.67,1,1.5)	(0.7,1,1.5)	(1,1,1)	(1.5,2,2.5)	(1.5,2,2.5)
C12	(0.7,1,1.5)	(0.7,1,1.5)	(1.5,2,2.5)	(0.3,0.3,0.4)	(0.4,0.5,0.7)	(0.4,0.5,0.7)	(0.7,1,1.5)	(0.4,0.5,1.5)	(0.4,0.5,0.7)	(0.7,1,1.5)	(0.4,0.5,0.7)	(1,1,1)	(0.67,1,1.5)
C13	(0.4,0.5,0.7)	(1.5,2,2.5)	(0.3,0.3,0.4)	(0.4,0.5,0.7)	(0.3,0.3,0.4)	(1.5,2,2.5)	(0.4,0.5,0.7)	(0.4,0.5,0.7)	(0.7,1,1.5)	(0.7,1,1.5)	(0.4,0.5,0.7)	(0.7,1,1.5)	(1,1,1)

From PWCM (Table 3), fuzzy synthetic extent for 13 barriers has been computed following the steps mentioned in the literature (Chang, 1996) and the values are shown in Table 4.

Table 4
Fuzzy synthetic extent for 13 barriers

Criteria	Fuzzy synthetic extent (S_i)	Value of S_i
Poor health worker training facilities	S_1	(0.075,0.120,0.19)
Inaccuracies in the vaccination registration	S_2	(0.048,0.080,0.133)
Limited vaccine supply and logistics	S_3	(0.057,0.093,0.149)
Inaccurate Vaccine demand forecasting.	S_4	(0.054,0.095,0.163)
Consumers' unwillingness to undergo vaccination	S_5	(0.056,0.095,0.158)
Inadequate Vaccination promotion	S_6	(0.046,0.074,0.121)
Distance between vaccine storage and immunization camps.	S_7	(0.035,0.061,0.106)
Poor planning and controlling	S_8	(0.040,0.070,0.123)
Insufficient storage systems	S_9	(0.039,0.073,0.131)
Difficulties in maintaining and monitoring vaccine temperature	S_{10}	(0.035,0.065,0.124)
Ineffective collaboration with local organizations	S_{11}	(0.037,0.063,0.106)
Difficulty of tracking vaccinated population	S_{12}	(0.031,0.054,0.101)
Lack of coordination among members of the vaccine supply chain.	S_{13}	(0.033,0.056,0.095)

Following the steps mentioned in Chang (1996), degree of possibility V(Sj≥Si) and minimum degree of possibility corresponding to each criterion, have been calculated and shown in Table 5.

Table 5
Values of V (Sj≥Si)

Degree of possibility	V(Sj≥Si)	Value of V(Sj≥Si)	Min V(Sj≥Si)
D′(1)=	minV(S1≥S2,S3,S4,S5,S6,S7,S8,S9,S10,S11,S12,S13)	min(1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1,00,1.00,1.00)	1.00
D′(2)=	minV(S2≥S1,S3,S4,S5,S6,S7,S8,S9,S10,S11,S12,S13)	min(0.59,1.00,0.86,0.84,0.84,1.07,1.24,1.11,1.09,1.18,1.22,1.34,1.32)	0.59
D′(3)=	minV(S3≥S1,S2,S4,S5,S6,S7,S8,S9,S10,S11,S12,S13)	min(0.73,1.14,1.00,0.97,0.97,1.21,1.38,1.25,1.22,1.31,1.36,1.48,1.46)	0.73
D′(4)=	minV(S4≥S1,S2,S3,S5,S6,S7,S8,S9,S10,S11,S12,S13)	min(0.78,1.15,1.02,1.00,1.00,1.22,1.37,1.25,1.22,1.31,1.34,1.45,1.43)	0.78
D′(5)=	minV(S5≥S1,S2,S3,S4,S6,S7,S8,S9,S10,S11,S12,S13)	min(0.77,1.16,1.03,1.00,1.00,1.23,1.38,1.26,1.23,1.32,1.36,1.47,1.45)	0.77
D′(6)=	minV(S6≥S1,S2,S3,S4, S5,S7,S8,S9,S10,S11,S12,S13)	min(0.50,0.93,0.78,0.76,0.76,1.00,1.18,1.04,1.02,1.12,1.15,1.29,1.26)	0.50
D′(7)=	minV(S7≥S1,S2,S3,S4, S5,S6,S8,S9,S10,S11,S12,S13)	min(0.34,0.75,0.60,0.60,0.59,0.82,1.00,0.87,0.85,0.94,0.97,1.10,1.07)	0.34
D′(8)=	minV(S8≥S1,S2,S3,S4, S5,S6,S7,S9,S10,S11,S12,S13)	min(0.49,0.89,0.75,0.74,0.74,0.96,1.13,1.00,0.98,1.07,1.10,1.22,1.20)	0.49
D′(9)=	minV(S9≥S1,S2,S3,S4, S5,S6,S7,S8,S10,S11,S12,S13)	min(0.54,0.92,0.79,0.77,0.77,0.98,1.14,1.02,1.00,1.08,1.11,1.22,1.20)	0.54
D′(10)=	minV(S10≥S1,S2,S3,S4, S5,S6,S7,S8,S9,S11,S12,S13)	min(0.47,0.83,0.71,0.70,0.69,0.89,1.05,0.93,0.92,1.00,1.02,1.13,1.11)	0.47
D′(11)=	minV(S11≥S1,S2,S3,S4, S5,S6,S7,S8,S9,S10,S12,S13)	min(0.35,0.77,0.62,0.62,0.61,0.84,1.03,0.89,0.87,0.97,1.00,1.13,1.11)	0.35
D′(12)=	minV(S12≥S1,S2,S3,S4, S5,S6,S7,S8,S9,S10,S11,S13)	min(0.28,0.67,0.53,0.54,0.53,0.73,0.91,0.79,0.77,0.86,0.88,1.00,0.98)	0.28
D′(13)=	minV(S13≥S1,S2,S3,S4, S5,S6,S7,S8,S9,S10,S11,S12)	min(0.24,0.66,0.51,0.51,0.50,0.73,0.92,0.79,0.77,0.87,0.89,1.03,1.00)	0.24

Therefore, the weight vector becomes as $W' = (1.00,0.59,0.73,0.78,0.77,0.50,0.34,0.49,0.54,0.47,0.35,0.28,0.24)^T$.

Normalizing the weight vector, we get $W = (0.14,0.11,0.11,0.10,0.08,0.08,0.07,0.07,0.07,0.05,0.05,0.04,0.03)^T$.

It is observed from the final weights that poor health worker training facilities (C1) becomes the most potential barrier of the covid 19 vaccine supply chain whereas lack of coordination among members of the vaccine supply chain (C13) has minimum impact on VSC. The graphical view of the weightages of barriers has been presented in Fig. 1.

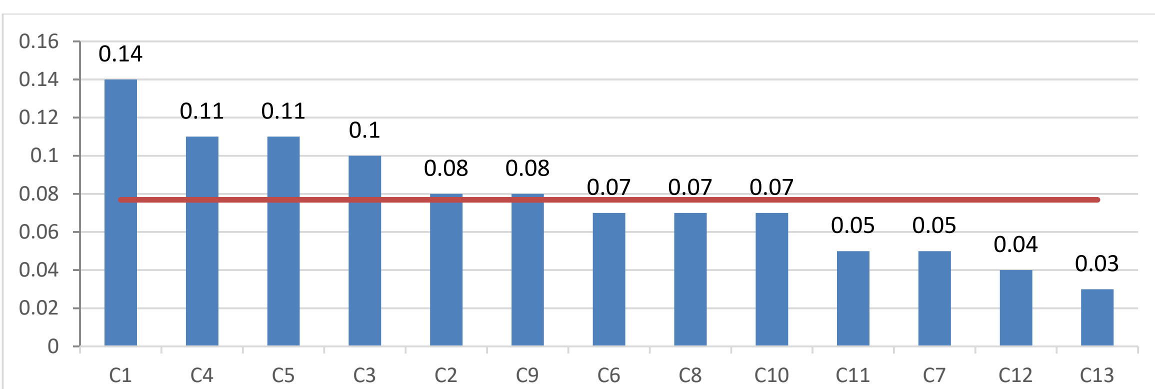

Fig. 1. Relative weights of barriers

5. Conclusion

Due to COVID-19 pandemic, the whole of India has faced a lockdown, quarantine, job losses, a lot of deaths and economic woes. Only the vaccination program helps to prevent the spreading of this disease and protect the lives of people. The main purpose of the vaccine supply chain is to supply the vaccine to the proper place at the right time and in the right quantity, but a lot of restrictions disrupted the vaccine supply chain process that in turn caused a huge gap in the vaccination program. In this paper, we have focused on thirteen main barriers of the vaccine supply chain and used the Fuzzy-AHP model to evaluate the weightage of different barriers due to COVID-19. It has been seen from Fig. 1, that poor health worker training, limited vaccine supply and logistics, inaccuracies in the vaccination registration, inaccurate vaccine demand forecasting, consumers' unwillingness to undergo vaccination, insufficient storage systems are lying above the mean weightage line which gives a negative impact on the vaccine supply chain. Therefore, suitable policies and actions should be undertaken to remove these six barriers first. Once these barriers are overcome, the covid-19 vaccine supply chain in particular, and any vaccine supply chain in general, go smoothly and efficiently.

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