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Evaluation of Factors for Effective Distribution of Covid-19 Vaccines

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Abstract

Purpose: The government of India has initiated the Covid-19 Vaccination drive from early January 2021. Vaccination is identified to be best option to protect the people across the globe. However, owing to fast wide spread of the Covid-19, the Vaccine Distribution is a major challenge owing various issues like temperature control, infrastructure, hesitancy, geographical diversity, and other critical factors. Various research is carried out globally to understand and study the Vaccine Distribution issues based on the respective country issues and factors. **Research Design, Data, and Methodology:** This research paper attempts to explore prominent factors that could be taken up on priority for better and effective vaccination program. The study tries to rank various factors and sub-factors affecting vaccine distribution in India. AHP methodology based on feedback from 22 experts from the Vaccine industry has been deployed to get the desired results. **Result:** The results show that factors vaccine approval process, geographical prioritization, power supply, infrastructure maintenance costs for vaccine storage, and vaccine pricing are the prominent factors of effective vaccination in the country. **Conclusion**: The role and need for district-level health officers towards vaccine storage has been brought forward. A long-term effective vaccination policy is needed for optimum vaccine distribution.

Keywords : Vaccine, Distribution, AHP, Covid-19, Delivery

JEL Classification Code : I140, I180, R410

1. Introduction

India has faced the COVID-19 virus from early 2020 like the rest of the world, with a high death toll and challenging the present health infrastructure of the country. The unprecedented rise of cases across the country has caught the country unaware, even though the first wave was controlled to a larger extent with stringent lockdown measures. The country's GDP has been badly hit due to stringent lockdown and containment measures which saved many lives. India is one of the countries that has been rated for putting the most stringent response towards the pandemic by closing international borders and by imposing nationwide lockdown. As a result, the economy was badly affected, stopping people from working and students from going schools and other institutions. Manufacturing and logistics were one of the sectors that were affected mainly due to the demand and supply fluctuations. Vaccines are one of the most effective health strategies for reducing infectious

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diseases and their negative health effects while also improving the population's quality of life. Vaccines have cost-effectively improved human health over time by minimizing avoidable human pain, costs of care and treatment, and economic effects of work, such as reduced productivity and job loss. More and more illnesses, including major killers including pneumonia and diarrhea, are becoming vaccine-preventable, and the equipment used to do so is rapidly improving the present situation that has affected globally wherein healthcare professionals have tried and are still trying to bring in the most effective COVID-19 vaccine. The COVID-19 vaccine distribution is the most challenging task that the logistics and supply chain sector has ever seen since World War II. Therefore, the distribution should be planned even before the vaccine is authorized, as there will be complexities in the distribution of vaccines on a large scale. The various factors involved in the distribution should be identified and prioritized based on their importance for better planning and implementation. The vaccine production process has been accelerated in response to the pandemic. There are currently many vaccines that are authorized by most of the national regulatory authorities worldwide for public use. It includes vaccines from Pfizer and BioNTech vaccine and Moderna vaccine where both are RNA vaccines; Covaxin, BBIBP-CorV, CoronaVac, and CoviVac are conventional inactivated vaccines; viral vector vaccines including Sputnik V, Oxford and AstraZeneca vaccine, Covaxin from Bharat biotech India, Convidicea, the Johnson & Johnson vaccine and peptide vaccine which is EpiVacCorona.

There are many challenges faced over a for vaccine Distribution and last mile delivery is a paramount factor (Sun, Zhang, Gehl, Fricke, Nawaz, Gluesenkamp, Shen, Munk, Hagerman, & Lapsa, 2022). The study relates to Moderna and Pfizer vaccine distribution at -300C to -700C of storage and transportation. The inadequate infrastructure for freezing temperature has led to vaccine waste and cost for vaccination drive. Discrete choice methodology was deployed in USA to study the references for Covid-19 vaccine distribution (Eshun, Mody, Tram, Bradley, Sheye, Fox, Thompson, & Geng, 2021). From various results of the study, waiting time for vaccination at health facilities was found to be less compared to other centres. Vaccine hesitancy and community vaccination were factors which emerged as major ones. Various models related to selective issues of distribution have been brought forward by authors in (Davahli, Karwowski, & Fiok, 2021; De Paula, Costa, Drumond, Moreira, Gomes, Santos, & Maeda, 2021; Shukla, Fressin, Coetzer, & Chaguturu, 2022). An AHP model was used to collect public opinion towards various principles in global distribution of Covid-19 vaccine distribution in United States and Germany (Klumpp, Monfared, & Vollmer, 2022). However, the study was limited to principles such as medical emergency, free market, equal access and production. Keeping in view the Indian scenario, the main concern is how to distribute the vaccines equally among the citizens of any country worldwide, especially in a country like India with a huge population. The research paper tries to unearth the prominent factors and ranks that affect vaccine distribution and last-mile delivery in India using AHP model. Section 1 Introduction deals with the need for effective vaccination and logistics distribution research. Section 2 discusses a literature review of various factors and sub-factors studied for previous vaccines and by the World health organization. The section also establishes the research gap in vaccine distribution. The third and fourth sections address the research methodology of AHP and the analysis of various factors and sub-factors, respectively. Section 5 deliberates the conclusion which consists of various sub-factors which need to be resolved for effective vaccination.

2. Literature Review

There are various factors affecting the of distribution vaccines, the authors have identified them from existing literature related to other vaccine distributions. These have been divided into five major categories namely Economic factors (ECF), Operation factors (OPF), Administrative factors (AMF), and Geopolitical factors (GPF).

2.1. Economic Factors

Infrastructure maintenance cost (ECF1) is one of the first economic factors brought forward in the papers. Since Cold storage is essential, the costs for maintenance have been the major factors identified. Vaccine Price (ECF2) is the second subfactor as discussed in the papers (Jadhav, Gautam, & Gairola, 2014; Robbins & Lunday, 2016). The major infrastructural factor to support distribution keeping in view the cold stage and refrigeration is the uninterrupted power supply (ECF3) which has been discussed in (Bogale, Amhare, & Bogale, 2019). Vaccine wastage (ECF4) is a major factor that leads rise in demand and thereby increases in obtaining cost. The studies regarding this sub-factor have been discussed by authors in (Das, Sood, Tambe, Sharma, Parande, Surwade, Salunke, Patil, Pawar, Guleri, Kaushal, & Sindhu, 2020; Guichard, Hymbaugh, Burkholder, Diorditsa, Navarro, Ahmed, & Rahman, 2010). Interestingly, the said studies have been done in India and Bangladesh for vaccination programs. The fifth important sub-factor is the quality of equipment (ECF5) which has been discussed in (Lahariya, 2014).

2.2. Operational Factors

Operational factors include various physical distribution and supply chain management-related issues. The foremost sub-factors in the category are Storage infrastructure (OPF1), Cold chain temperature (OPF2), and temperature monitoring mechanism (OPF3) which have been examined in (Chojnacky, Santacruz, Miller, & Strouse, 2015; Falcón, Porras, Altamirano, & Kartoglu, 2020; Haidari, Connor, Wateska, Brown, Mueller, Norman, Schmitz, Paul, Rajgopal, Welling, Leonard, Chen, & Lee, 2013; Long & Hayney, 2013). The said sub-factors are perceived to be major challenges in the present scenario of emergency and widespread pandemics. The said sub-factors are also important keeping in view various vaccine candidates being developed, are to be stored and transported between -70C to 8C depending on the type of vaccine. A review of various studies related to freezing temperatures has been detailed by authors (Matthias, Robertson, Garrison, Newland, & Nelson 2007). The cold storage temperature has been identified to be critical for various vaccines for children. Transport network (OPF4) which is an important feature for logistics has been examined (Adida, Dey, & Mamani, 2013; Lin, Zhao, & Lev, 2020). Uncertainties in consumption and production are the major issues for the transport networks and decision-making. Vaccine Order quantity (OPF5) has, and economic order quantity and minimum order quantity affect the costs, manufacturing, and logistics in the distribution. The Vaccine inventory (OFC6) is the next sub-factor that is essential to be maintained at health/vaccination centers that have been examined (Iwu, Ngcobo, McCaul, Mangqalaza, Magwaca, Chikte, & Wiysonge, 2020). Packaging (OFC7) is an essential sub-factor keeping in view the cold chain distribution of vaccines (Norman, Rajgopal, Lim, Gorham, Haidari, Brown, & Lee 2015). The sub-factors OPF5, OPF6, and OPF7 are critical in most cold chain logistics and distribution, and they have been found to be prominent in vaccine distribution too.

2.3. Administrative Factors

The border process (AMF1) which involves cross-border cooperation and customs clearance has been identified by authors in (Wang, Zhang, Yu, Wen, Yan, Tang, Zhang, Fan, Reilly, Xu, Li, Ding, & Luo, 2015). The regulatory system (AMF2) is the foremost sub-factor where the administration of the respective country and WHO have expectations. Conflicts in many countries having religious, socio-economic diversities and civil unrest have been a major issue in vaccination. In such situations, sub-factor Security (AMF3) is an essential concern (Hussain, Boyle, Patel, & Sullivan, 2016). Effective Control of counterfeit mechanism (AMF4) is quite rampant in countries with weak administration mechanisms when there is a surge in demand. The last sub-factor is the vaccine approval process (AMF5) which is a quiet complex in nature and vital for starting the vaccine distribution (Pickering, Meissner, Orenstein, and Cohn, 2020).

2.4. Geopolitical Factors

Access (GPF1) is a vital sub-factor which are guided by political intervention and will. Access is dependent on income levels, political factors, and region (Mihigo, Okeibunor, Cernuschi, Petu, Satoulou, & Zawaira, 2019). Most of the countries have geographical diversifications based on topography, demographic conditions and need for effective geographical prioritization (GPF2) decision model is needed catering to various segments (Otieno, Nyawanda, Audi, Emukule, Lebo, Bigogo, Ochola, Muthoka, Widdowson, Shay, Burton, Breiman, Katz, & Mott, 2014; Yarmand, Ivy, Denton, & Lloyd, 2014). The authors (Berkley, 2019; Shakeel, Brown, Sethi, & Mackey, 2019) have bought forward Political will (GPF3) for effective vaccination. Vaccine Hesitancy and awareness (GPF4) is a major issue for early vaccination in many countries due to misbeliefs as in discussed many studies examined by authors in (Xiao, Cheung, Wu, Ni, Cowling, & Liao, 2022). Vaccine Policy (GPF5) of any country in developing, importing and effective distribution is a key driver. Vaccine Policy with well-defined objectives and the respective country's Vaccine program defines outcomes for effective vaccination (Epling, 2020; Yamin, & Gavious, 2013).

2.5. Research Gap

A pandemic of this nature is unprecedented. One of the ways to arrest the spread of the coronavirus is to have a rapid vaccination drive that may facilitate building herd immunity amongst the citizens. It may sound easy, but the challenges on ground zero are many, particularly in a diverse country like India. Vaccination drive of this colossal magnitude has never been carried out before and nations including India are grappling through a steep learning curve to speed up the process. Earlier research (Lemmens, Decouttere, Vandale, & Bernuzzi, 2016) around distribution and supply chain models have been developed for vaccines but were restricted to small populations and geographical spreads. Earlier literature as discussed above has identified several factors such as Economic factors (ECF), Operation factors (OPF), Administrative factors (AMF), and Geopolitical factors (GPF) for effective vaccine distribution in different contexts.

The supply chain models and factors for vaccine distribution are known to an extent from literature, but the current context is very different and difficult. There is a need to test and apply the known knowledge to this current COVID-19 context to support the vaccination drive and build academic understanding around effective vaccine distribution in pandemic situations like these. This study tries to evaluate and prioritize the vaccine distribution factors in a context of a developing nation like India.

Specifically, the research addresses the following questions:

1. Which of the vaccine distribution factors and their sub-factors from the existing literature need prioritization at the implementation stage to speed up vaccination for the citizens?

2. Which of the factors and their sub-factors as prioritized acts as enablers and barriers to the vaccination drive?

The outcome of this research would enable the government and other stakeholders to work on prominent factors and barriers, thereby designing an efficient supply chain system.

3. Research Methods

The objective of the research paper is to identify critical factors for the effective distribution of Covid-19 vaccines in India. The various main factors and sub-factors have been identified through the literature review. Since Covid-19 is a new virus and there is an absence of sufficient study about its distribution in other countries, factors were identified from studies related to other existing vaccines in the market. Analytical Hierarchy Process (AHP) which is a well know method of multi-criteria decision making (MCDM) has been used for the analysis. A questionnaire has been circulated to 22 various professionals in existing vaccine distribution in India to measure the relative weights for the identified factors. The AHP has been used in many research articles (Asgari, Hassani, Jones, & Nguye, 2015; Gaudenzi & Borghesi, 2006) which bring forth the prioritization for alternatives based on the criteria.

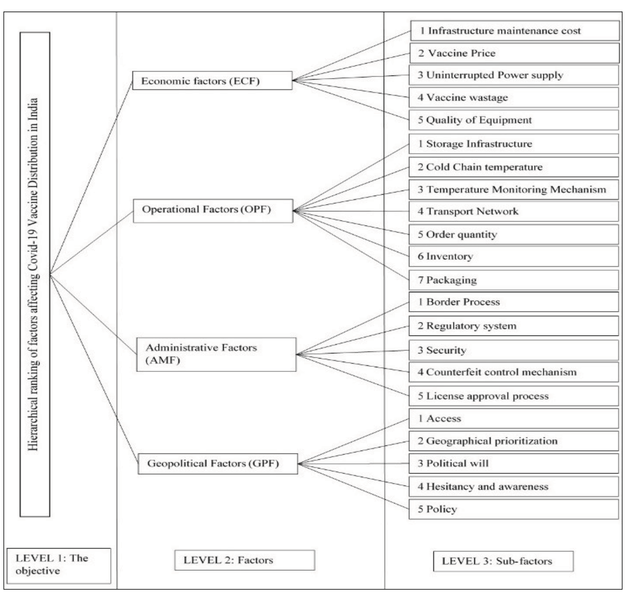

Figure 1: AHP Model

The various strides involved in the AHP process are (Sengar, Garg, & Raju, 2018)

1. Define and understand the research problem. The research problem in this paper is to distinguish various factors for vaccine distribution and to frame a hierarchy model.

2. Design a questionnaire and make pair-wise comparisons from Professionals working in various vaccine supply chains and distribution.

3. Analysing the normalized weighs for sub-factors factors affecting the vaccine distribution. Ranking and criteria are made based on weighs.

4. The consistency ratio (CR) which is used to evaluate the reliability and consistency of the group is determined for pair-wise comparisons consistency.

The CR is calculated by the formula CR= CI/RI.

RI is the random index and CI is the consistency index shown in Table 5.

The CI needs to be less than 0.10 as a thumb rule else values need to be recalculated until the desired results are obtained.

Table 1: Pairwise Comparison Scale

Strength of significance	Definition
1	Equally significant
3	Moderately significant
5	Strongly significant
7	Very strongly significant
9	Absolutely significant
2, 4, 6, 8	For intermediate values
Reciprocals	For inverse comparison

4. Results

Table 2: Random Index

N	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41

Table 3: Pairwise Comparison Matrix Source : (Saaty, 1987)

Criteria	ECF	OPF	AMF	GPF	Weights	Ranking
ECF	1	1.36	3.15	3.54	0.25147	2
OPF	0.735294	1	3.56	2.19	0.258665	1
AMF	0.31746	0.280899	1	2.81	0.248022	3
GPF	0.282486	0.456621	0.355872	1	0.241843	4

Table 4: Values Obtained from AHP

Highest Eigen Values (λmax)	Consistency CI	Random Index RI	Consistency Ratio CR
4.22	0.074	0.9	0.082

Table 5: Pairwise Matrixfor ECF

Criteria	ECF1	ECF2	ECF3	ECF4	ECF5	Weights	Ranking
ECF1	1	0.59	1.43125	2.92375	2.35125	0.20917	2
ECF2	1.694915	1	3.1175	1.12	3.0425	0.206688	4
ECF3	0.69869	0.32077	1	0.3825	1.7925	0.212881	1
ECF4	0.342027	0.892857	2.614379	1	0.36375	0.16448	5
ECF5	0.425306	0.328677	0.55788	2.749141	1	0.206781	3

Table 6: Pairwise Matrixfor OPF

Criteria	OPF1	OPF2	OPF3	OPF4	OPF5	OPF6	OPF7	Weights	Ranking
OPF1	1	1.78125	1.59	5.88875	1.785	4.88875	3.53875	0.144877	3
OPF2	0.561404	1	0.4975	2.1425	1.28125	3.1425	1.455	0.143501	4
OPF3	0.628931	2.01005	1	1.81625	4.5	1.42375	2.75	0.140425	6
OPF4	0.169815	0.466744	0.550585	1	0.34375	2.1975	3.65	0.144975	2
OPF5	0.560224	0.780488	0.222222	2.909091	1	1.28875	0.47	0.146399	1
OPF6	0.204551	0.318218	0.702371	0.455063	0.775946	1	2.9	0.141223	5
OPF7	0.282586	0.687285	0.363636	0.273973	2.12766	0.344828	1	0.1386	7

Table7: Pairwise Matrixfor AMF

Criteria	AMF1	AMF2	AMF3	AMF4	AMF5	Weights	Ranking
AMF1	1	0.8475	1.9425	0.98125	0.5175	0.201972	2
AMF2	1.179941	1	0.42625	1.6925	1.475	0.185556	3
AMF3	0.514801	2.346041	1	4.25	4.16625	0.144445	5
AMF4	1.019108	0.590842	0.235294	1	2.7	0.173984	4
AMF5	1.932367	0.677966	0.240024	0.37037	1	0.285567	1

Table 8: Pairwise Matrixfor GPF

Criteria	GPF1	GPF2	GPF3	GPF4	GPF5	Weights	Ranking
GPF1	1	3.15	1.725	2.0425	3.1175	0.204196	2
GPF2	0.31746	1	4.15	2.65	1.4825	0.226604	1
GPF3	0.57971	0.240964	1	3.66625	3.30875	0.185665	4
GPF4	0.489596	0.377358	0.272758	1	1.725	0.180495	5
GPF5	0.32077	0.674536	0.302229	0.57971	1	0.194564	3

Table 9: Final Ranking for Specific Factors

Factors	Rank	Weights	Sub-Factors	Rank	Weights	Global Rank	Global Relative Weights
ECF	2	0.25147	ECF1	2	0.20917	4	0.047852
			ECF2	4	0.206688	6	0.0472843
			ECF3	1	0.212881	3	0.048701
			ECF4	5	0.16448	21	0.0376283
			ECF5	3	0.206781	5	0.0473056
OPF	1	0.258665	OPF1	3	0.144877	11	0.0460078
			OPF2	4	0.143501	12	0.0455708
			OPF3	6	0.140425	14	0.0445941
			OPF4	2	0.144975	10	0.0460388
			OPF5	1	0.146399	8	0.0464912
			OPF6	5	0.141223	13	0.0448475
			OPF7	7	0.1386	16	0.0440146
AMF	3	0.248022	AMF1	2	0.201972	9	0.0462053
			AMF2	3	0.185556	18	0.0424499
			AMF3	5	0.144445	22	0.0330449
			AMF4	4	0.173984	20	0.0398024
			AMF5	1	0.285567	1	0.0653295

GPF	4	0.241843	GPF1	2	0.204196	7	0.0467141
			GPF2	1	0.226604	2	0.0518405
			GPF3	4	0.185665	17	0.0424747
			GPF4	5	0.180495	19	0.041292
			GPF5	3	0.194564	15	0.0445106

The final rankings are shown in Table 9, which were identified and evaluated using the MCDM technique. The table shows that the distribution of vaccines in the Indian scenario can be assessed in terms of the Operational, Economic, Administrative, and Geopolitical factors. The study ranks these dimensions in the order of importance: Operational, Economic, Administrative, and Geopolitical factors. The Operational factors were ranked the most important when compared to all the other three factors as per the survey conducted and it weighs the most of all the factors as shown in Table 4. Putting the operational factors foremost will help the government plan for a cost-effective distribution of vaccines by maintaining the factors that can lead to vaccine wastage and unnecessary costs. Especially in the current condition that our government is put in to provide vaccines to each and everyone in the country free of cost and to make sure that it reaches to the last one. So operational factors should be considered first. Next comes the Economic factors with the second rank, the factors that will support carrying out the operational factors. Administrative factors rank the third and Geopolitical ranks the fourth where both are interdependent.

The subfactors of each of these dimensions are also ranked in Table 9. Of all the subfactors License approval process ranks always first, once the vaccine is ready it goes for the License approval and in the present case of the COVID-19 vaccine it is the Emergency Use Listing Procedure. The rankings of the factors are determined by multiplying the sub factor's relative weights (0.285567) with its respective dimension's weight (0.248022), giving it a global relative weight of 0.0653295 making AMF5 rank 1. Geographical prioritization (GPF2) of how and where to supply the vaccines first on availability comes the second most important factor which is categorized under Geopolitical factors. Indian topography consists of plains, deserts, and Himalayan mountains are quite diversified. A continuous power supply is a must when it comes to the storage of vaccines as it requires temperature control which is categorized as an economic factor. Therefore, the uninterrupted power supply ranks 3. Infrastructure maintenance cost (ECF1), Quality of equipment (ECF5), Vaccine price (ECF2) comes under Economic factors that rank 4, 5, and 6 respectively. Access to the vaccines to all the citizens without any discrimination on gender, religion, caste is one of the factors that should be noticed in order to stop the further spread and improve the present conditions. Access is categorized under Geopolitical factors as GPF1 and ranks 7. Once access is also prioritized, the quantity of vaccines that is required for the country comes next. Order quantity that is categorized under operational factor as OPF5 ranks 8. After the Order quantity processing the order is the next step, which is categorized as administrative factors as AMF1, ranks 9. Transport network (OPF4), Storage infrastructure (OPF1), Cold chain temperature (OPF2), Inventory (OPF6), Temperature monitoring mechanism (OPF3) ranks 10, 11, 12, 13, 14 that comes under operational factors as shown in Table 10. Policies (GPF5) involved in the vaccine distribution ranks 15 which is a geopolitical factor. Packaging (OPF7) of the vaccines is important to avoid vaccine wastage, which ranks 16. Political will (GPF3) depends on the political condition of the area, Regulatory system (AMF2), Hesitancy and awareness (GPF4), Counterfeit control mechanism (AMF4), Vaccine wastage (ECF4) ranks 17, 18, 19, 20, and 21. AMF 3 is ranked the last which is security as the vaccines are of utmost importance for the government is giving more importance than any other programs going on in order to bring back the economy.

5. Conclusions

Widespread vaccination would almost certainly be needed to end the COVID-19 pandemic. To ensure that every subsequent allocation strategy advances the expected public health goals for COVID-19 vaccination: namely, to mitigate morbidity and mortality loss, avoid economic damage from the pandemic, and narrow unfair health disparities, strategic preparation for the ethical Distribution of vaccines against COVID-19 is essential. To ensure that the vaccine can be used worldwide, rigorous production and distribution policies and protocols will be required. India lacks effective policies for healthcare rationing, as well as the required discussions in academia. Infectious diseases pose a global challenge to public health, and vaccines provide a secure and effective remedy. The cost of transporting vaccines can be reduced by optimizing the vaccine supply path, lowering the total cost. The optimization and management of the vaccine supply chain is currently a hot topic of study. The cold stage infrastructure of the country has always been challenging for perishable goods including health care supplies. Capacity and maintenance have been major issues facing the perishables Distribution. The experts at the district level and state-level are required to identify adequate cold storage requirements based on Vaccine centers. Sustainable and affordable models of storage units are required at district levels. The vaccine cold chain management is strongly associated with health care workers' profession and knowledge of handling the same. The Vaccine pricing in the country has been under criticism. This is due to differential pricing allowed under procurement by state and central governments. The vaccine manufacturers have been allowed to sell at a lower price to central governments contracts whereas state and private bodies purchase contracts have allowed for higher prices respectively. This has led to greater chaos and mismanagement of purchases and inventory controls. Of late, the central government has reviewed that the whole procurement would be taken by themselves under a single price and has a fixed upper limit for private players. This is showing better results in supply and effective vaccination drive. Training and educating the health workers for the appropriate handling of vaccine cold chain logistics is the immediate need of the hour. This could also lead to reduced vaccine wastage. This is one of the factors for denying permission to Pfizer vaccine usage in India as this requires storage at -70o C. There is a need for a more advanced and optimized system that can meet the growing demand for vaccines while also resolving issues that previous systems could not. The COVID-19 pandemic has focused all policymakers' attention on one long-term goal: the ability to effectively navigate the next global health crisis. This will necessitate a medical equipment supply chain that is both resilient and adaptable. Governments' ability to define and execute both pre-planned and ad hoc steps, forge organizational alliances, sustain supply and logistics infrastructure, gain real-time visibility along the supply chain, and create a core response unit empowered to respond quickly and effectively will all be critical to their success. In the context of the Indian situation, the factors evaluated and confirmed in the current study can be useful in developing a system, as the study evaluates and confirms the relative importance of factors that may affect vaccine Distribution. From this study, policymakers, supply chain partners, Public-private partnerships, Government-to-government partnerships, or any organization related to Distribution vaccines should benefit from this study by prioritizing the factors for efficient and effective Distribution of vaccines.

Limitations and scope of the study: The study has been limited to vaccine Distribution in India only. However, a similar method could be deployed to study in other countries for more effective vaccine Distribution.

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