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COVID-19 Vaccine Ranking Using ANP Method

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ABSTRACT

Wuhan Province in China reported the first case of novel corona virus as pneumonia outbreak during December 2019. The novel coronavirus was soon declared a pandemic by the World Health Organization. On 16th of July 2021, the number of COVID-19 confirmed cases was 188,128,952 globally, out of which 4,059,339 individuals succumbed to this deadly virus. In a short span of time, eight vaccines were approval for emergency use in different nations. The selection of vaccine depends upon many criteria. Concepts from multi-criteria decision making (MCDM) are appropriate to compare and rank them. The paper proposes analytical network processing (ANP) method to rank the eight vaccines according to seven criteria. The study proposes a decision tool to select the best vaccine among the candidate vaccines. A mathematical model based on ANP approach with three clusters having interrelationships within and among the clusters is proposed.

KEYWORDS

Analytical Network Processing (ANP), Clusters, Corona Pandemic, COVID-19, Limit Matrix, Multi-Criteria Decision Making (MCDM), Pair Wise Comparisons, Vaccine, WHO

INTRODUCTION

China reported the outbreak of a novel corona virus, by December 2019, which was later declared as a pandemic by WHO on 11th March 2020. Across the globe, this "pneumonia-causing Severe Acute Respiratory Syndrome Corona virus 2 (SARS-CoV-2)" has affected millions of people though its origin was first identified in Wuhan, China. Global nations suffered huge losses due to this pandemic, both in terms of health and economic perspectives. The outbreak of COVID-19 pandemic instigated fear among people for lives across the globe while nations started face severe economic crises, low GDP, tremendous increase in unemployment rate, disastrous burden on healthcare system etc., Confining

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person-to-person interaction, to the best possible limits, was the only response of many countries when pandemic struck the lives, since there is no established or universally-accepted treatment protocols available. Workplaces were closed down with announcements made for curfews, lockdown and restricting people movement and mass gathering to ensure social distancing.

COVID-19, caused by novel corona virus, is an extremely dangerous, life-threatening disease that is characterized by respiratory, hepatic, gastrointestinal and neurological complications (WHO,2021). When COVID-19 infections started receding, countries went back to normal life. However, this disastrous decision brought the second wave of COVID-19. Though the second wave of COVID-19 badly hit India, there is no standard drugs or protocol designed to treat the disease.

In this scenario, globally nations started prioritizing the research on developing a vaccine to fight COVID-19 since only a vaccine can be a life saver and its optimal distribution within best possible time is the key factor to save from the deadly disease. Quickly after China reported the outbreak of novel corona virus, governments and global pharma companies worked tirelessly to find a vaccine that can fight the disease. But as time went, without promising results, the data regarding corona virus is disseminated to global researchers. After the publication of first gene sequence of COVID-19, the race for vaccine development got picked up. Lurie (Lurie,2020) cited that mRNA-based SARSCoV-2 vaccine, produced by Moderna, underwent phase-1 clinical trials on 16thMarch 2020, a miracle turn-around time of mere 10 weeks, after the publication of first genomic sequence. This is phenomenal since a vaccine development may usually take up to 10-15 years. It is evident from literature that mumps vaccine is the fastest candidate developed so far within a timeline of 4 years (Moreira,2020). It is matter of pride, as researchers developed a COVID-19 vaccine in less than 1 year without compromising safety.

In a short span of time eight vaccines got permission of emergency use in different countries. Selection of best Covid-19 Vaccine depends upon various criteria thus tools from Multi criteria decision making can be applied to compare these vaccines. Analytical Network process (ANP) is one of the most popular MCDM method that works by making pair wise comparisons. Candidate vaccines are grouped in cluster “alternatives” whereas seven deciding criteria are placed in cluster “Criteria”. The inter relationships between various members of clusters and between various clusters is also considered.

The present study proposes a mathematical model that uses analytical Network process (ANP) to rank eight vaccines according to seven criteria. The ranking of the ranking of vaccines becomes all the more important as more than one vaccine got approval in many countries . The vaccine ranking help people to select vaccine that suits their requirements.

BACKGROUND OF THE STUDY

Literature Review

Year 2020 and 2021 witnessed lot of research in Corona pandemic using MCDM tools. Nazi et al. compared various vaccines with focus on AZD1222, BNT162b2, and mRNA-1273 vaccines (Moreira,2020). The management of smart hospital using deep learning algorithms was proposed by Lee et al. (Lin,2020). Kayapinar in their study, suggested two methods such as WASPAS (Weighted Aggregated Sum Product Assessment) and MABAC (Multi-Attributive Border Approximation Area Comparison) to analyze damage caused by pandemic on sustainable development of developing and developed nations (Kayapinar,2020). Samanlioglu et al. evaluated the crucial role played by intervention strategy alternatives that are being used by different countries in the management of COVID-19 pandemic (Samanlioglu,2020). Their study used hesitant fuzzy Analytic Hierarchy Process. Lee proposed DEMATEL-Based ANP in analyzing the Taiwan’s experience for preventing COVID-19 (Lee,2020).

TOPSIS method was used by Majumder et al.to find out the various risks of Corona virus infections and continuous monitoring of number of casualties that occurred due to this virus(Majumder,2020). Multi-Criteria Decision Making techniques (MCDM) such as WSM, WPM, WASPA and TOPSIS were utilized by Arul et al. to rank every country that managed COVID-19 health crisis(Arul,2020). Abdel-Basst applied BWM and TOPSIS methods to distinguish the novel corona virus i.e., COVID-19 from rest of the four viral chest diseases in case of uncertain conditions (Abdel-Basst,2020). The study used signs and symptoms of COVID-19 along with CT scan reports to perform this action. By combining entropy and TOPSIS approaches, Mohammed et al. solved benchmarking and selection problems that are associated with diagnostic models of COVID-19 (Mohammedi,2020).

Manupatiet al. compared fuzzy VIKOR and fuzzy AHP methods to identify the optimal Healthcare Waste (HCW) disposal technique (Manupati,2021). Thus, such a technique can be applied in treating the medical waste generated during and after COVID-19, in an effective manner. Mzougui proposed integration of Best Worst Method (BWM) Fuzzy TOPSIS method to rank and prioritize risks affecting suppliers in supply chain management during COVID times (Mzougui,2021). Guhathakurata et al. used AHP in analysis of various factors that causes uneven distribution of COVID-19 deaths in world (Guhathakurata,2021).Ibrahim et al. in their proposed an integrated approach combining TOPSIS and AHP to find priority groups so as to allocate vaccine doses for COVID-19 (Ibrahim,2021).

Aydin proposed a hybrid method integrating Best Worst Method (BWM) with fuzzy numbers and TOPSIS methods that can select the most optimal location for isolation of patients diagnosed with COVID-19 and who exhibit mild-to-moderate symptoms (Aydin,2021). Improta et al. made use of fuzzy PROMETHEE and VIKOR methods to assess the available COVID-19 treatment options (Improta, 2021). Ghorui et al. proposed an integrated approach combining Fuzzy AHP and TOPSIS technique to assess the risk factors, primarily responsible in the spreading of corona virus (Ghorui,2021).

Available Covid -19 Vaccines

By January 11th 2020, the "genetic sequence of SARS-CoV-2" was published, subsequently the research and collaboration between scientists and biopharmaceutical manufacturers quickly followed (Cennimo,2021). This resulted in the rapid development of a various types of vaccines from different players such as academia, industry and government sectors (Naji,2021). Pfizer, a New York-based pharma giant and BioNTech, a German firm announced that their vaccine has an efficacy rate of 90 per cent, one of the historical and most-needed announcements ever made. The vaccine manufactured by Boston-based Moderna got emergency-use authorization from FDA by 18th December 2020 (Zimmer,2021). This was only the second vaccine, next to the vaccine developed by Pfizer and BioNTech in the previous week. In this scenario, a joint-collaboration between the University of Oxford and AstraZeneca, a British-Swedish pharma giant, led to the development of a vaccine that plays a crucial role in meeting global vaccine demand (Katella,2021). Vaxzevria showed 76 per cent efficacy while it is manufactured at affordable rates in huge quantities since it only needs refrigeration, not frozen temperature setup (Cennimo,2021). So, this vaccine can be widely used compared to mRNA vaccines. Argentina and the United Kingdom authorized the vaccine for emergency use by 30th December 2020. The same vaccine, in the name of Covishield, was given emergency-use approval by the Government of India on 03rd January 2021.

Having been manufactured by Serum Institute of India, this vaccine was approved by WHO on 16th February 2021 for emergency-use in adults aged 18 and above. Brazil approved the vaccine, in full, by 13th March. Covax's international delivery was started in the month of March to developing and under developed nations. FDA approved Johnson and Johnson 's vaccine for emergency-use on 27th February 2021 and it became the third vaccine available in the United States. Further, its safety and efficacy were proved such that one dose is sufficient rather than two doses.

Brief introduction of corona vaccine is as follows:

- PfizerBioNTech Vaccine

PfizerBioNTech was first COVID-19 vaccine to receive Emergency use permission in USA and European Union on 11th Dec, 2020. It offered 95% efficacy against covid-19 (Branswell,2021). Biggest challenge with this vaccine was, its ultra cold freezing requirements for storage and transportation. People aged twelve years 12 or older can get this vaccine. Two doses at interval of three weeks are administered. It is mRNA vaccine where proteins stimulate "an immune response, producing antibodies and developing memory cells that will recognize and respond if the body is infected with the actual virus" ("A comparison of all COVID-19 vaccines ",2021).

- Moderna Vaccine

It was the next vaccine after Pfizer-BioNTech which receives permission for emergency use in the U.S.A. and European Union. Like Pfizer, Moderna vaccine is also mRNA vaccine. The vaccine should be given in two doses. The ideal time duration between two doses is 4 weeks . Moderna's vaccine is easy to store and transport than Pfizer vaccine. It needs standard refrigeration of -25 to -15 degree Celsius. Moderna vaccine can be given to adults i.e. 18 years or above. It offers 94.1% protection against symptomatic covid-19 (Branswell,2021). It was slightly less, 86% effective in people who are 65 and older.

- Johnson & Johnson Vaccine

It is the thirds vaccine that was allowed by USA for emergency use. It is virus vector vaccine which offers 86% efficacy (Branswell,2021). In Europe it is available under trade name "Janssen". However, soon after use of this vaccine is halted because of blood clotting side effect. In April the ban was lifted with a warning label about blood clotting disorder. Unlike Pfizer and Moderna vaccines, Jhonson & Jhonson vaccine needs relaxed storing requirements. It can be stored in refrigerator temperature. The biggest advantage of this vaccine over other vaccines is that it can be administered in a single dose.

- Oxford-AstraZeneca

It is "a carrier vaccine, made from a modified version of a harmless adenovirus" (Katella,2021). It is allowed in United Kingdom, India and some other countries (not USA). In Europe, it is sold under the brand name Vaxzevria. It is cheaper than other vaccines. It can be stored in normal refrigeration of 2 to 8 degree Celsius. The relaxed storage requirements made this vaccine easy to transport and distribute. It can be given to adults (18 year or older) in form of two shots with gap of 12 weeks. It is 93% effective against hospitalization arises sure to COVID ("A comparison of all COVID-19 vaccines", 2021). This AstraZeneca-Oxford University vaccine is allowed to be manufactured by the Serum Institute of India (SII), under the brand name Covishield.

- Sputnik Vaccine

Russia authorized use of this vaccine in august before entering into Phase III of clinical trial. Sputnik vaccine is Adenovirus-based(Katella,2021). It claims to have 92% efficacy (Cennimo,2021). Russia's Gamaleya research institute focused on potentially marketing their vaccine worldwide with cost no more than $10 i.e. half of cost of Pfizer vaccine. It is allowed in India, Korea, Brazil, China, and Hungary.

- Sinovac Biotech

In January 2021, China-based Sinovac Biotech introduced vaccine having 50.38% efficacy (Cennimo,2021). The company's clinical trials are demonstrates 50.38% to 91.25% varying efficacy rates in different countries. It is an inactivated vaccine that uses inactivated SARS-CoV-2 viruses (Katella,2021).

- Bharat Biotech

In April 2021, India introduced Covaxin with 100% efficacy claims against severe infection. Being a highly purified and inactivated virus, this vaccine is manufactured using Whole-Virion Inactivated Vero Cell platform technology (Katella,2021). With stability in 2-8°C, Covaxin is a ready-to-use liquid vaccine available in multi-dose vials without any need to reconstitute or storage in sub-zero temperature ("A comparison of all COVID-19 vaccines ",2021). Covaxin is under consideration of WHO and 60 more countries including US, Brazil and Hungary for regulatory approvals. However, it has been already approved in 13 countries.

- Sinovac vaccine

CoronaVac was developed by Sinovac, a Chinese bio-pharma company. Being an inactivated virus-based vaccine, it consists of killed viral particles and when exposed to human body, the immune system responds in prior, without any serious complications (Katella,2021). This vaccine again does not require sub-zero temperature and can be stored in 2-8°C regular refrigerator ("A comparison of all COVID-19 vaccines ",2021). It is manufactured from a genetically-engineered virus that causes common cold in chimpanzees.

COVID-19 VACCINE RANKING USING ANP METHOD

Introduction of Analytical Network Process

ANP was introduced by Thomas L. Satty in 1970. "ANP is more general form of AHP" .Both of the models made pair wise comparisons using Satty's scale. A network in ANP model consists of following:

- Elements: Elements are the nodes in the network that interact with each other.
- Clusters: Clusters are the groups of element having similar characteristics.
- Inter relationship between elements within a cluster.
- Inter relationship between clusters.

In ANP, "A network can incorporate feedback and complex inter-relationships within and between clusters which means all the elements in the network can be related in a possible way" (Saaty,1999). Matrix is used to represent network system of ANP .The matrix is consisting of all nodes horizontally as well as vertically. Each non-zero entry in the matrix corresponds to the weight from one node to another node in the network.

ANP method is consisting of following steps:

Step 1: Analysis of the problem

The goal of the problem is clearly identified and stated

Step 2: Identification of criteria and sub criteria

Seven criteria were identified: Efficacy, WHO approval, minimum age, price, storage conditions, side effects, number of doses.

Step 3: Selection of alternatives.

Eight alternatives were identified: Bharat biotech, Jhonson & Jhonson, Modena, Oxford, Pfizer, Sinopharm, Sinovac, Sputnik. Novax vaccine

Step 4: The network control hierarchy is determined.

Influences that a criteria made on other criteria in a cluster i.e. inner dependence and relationships between different clusters i.e. outer dependences are identified. Feed backs from the clusters are also analyzed to design the network control hierarchy. Figure 1 shows control structure.

Step 5: Computation of unweighted supermatrix

Unweighted supermatrix is a square matrix of all nodes in the decision-making problem (goal, criteria, sub criteria and alternatives) and contains local priorities. As in AHP, pairwise comparisons are made using Saaty's fundamental scale. To ensure rational judgments by decision maker inconsistency ratios were calculated. Inconsistency ratio is a measure of inconsistent decisions while making pairwise comparisons. Both AHP and ANP models permits less than 10% inconsistency ratio. Following four types of pairwise comparisons at node level are made to fill the unweighted supermatrix with priorities.

Following types of comparisons were made:

a. Comparisons of the criteria with respect to the goal - Comparisons of criteria in cluster Vulnerabilities with respect to Goal .Local priorities will be put into the super matrix at rows system, software and column Goal.
b. Comparisons of criteria with respect to other criteria - Comparisons of the criteria that influence the criterion from the same cluster with respect to it.
c. Comparisons of alternatives with respect to each criterion - Comparisons of criteria in each cluster with respect to each of the alternatives were made.
d. Comparisons of criteria in each cluster with respect to each alternative.

Step 6: Unweighted super matrix of step 5 will be converted into weighted super matrix. All the elements in a component of the unweighted super matrix are multiplied by their respective cluster weight to get weighted super matrix.

Following two types of comparisons were made:

a. All criteria clusters pairs are compared with respect to the Goal.
b. All clusters (Criteria and Alternatives) pairs are compared with respect to each cluster.

Step 7: Calculating the limiting super matrix.

The Limit Matrix is the weighted Super matrix, taken to the power of k+1, where k is arbitrary number. The super matrix will be steady state by multiplying the weighted super matrix by itself until the super matrix's row values converge to the same value for each column of the matrix. In this step normalized super matrix with local weights is synthesized.

Application of ANP Method in COVID-19 Vaccine Ranking

The problem is modeled into network model with three clusters namely, Goal, Criteria and Alternatives. All deciding criteria are kept in cluster Criteria and all the candidate vaccines are in cluster Alternatives. Cluster named criteria contains seven nodes namely, efficacy, cost, side effects, WHO approval, Storage conditions, number of doses and minimum age. Cluster called alternatives has eight elements: Bharat biotech, Jhonson & Jhonson, Modena, Oxford, Pfizer, Sinopharm, Sinovac, Sputnik. Novax vaccine though promising, is not included in study as it is not yet approved by any nation. Fig. 1 shows elements and clusters along with their inter relationships.

The study took into consideration eight vaccines those are currently administered in various countries. The information about these vaccines (Branswell,2021), (Katella,2021), (Cennimo,2021),("A comparison of all COVID-19 vaccines ",2021) is summarized in Table1.

First, Pairwise comparison of criteria with respect to Goal were carried out using Satty's scale, Pairwise comparisons are shown in Table 2.

The Eigen vector for criteria comparison with respect to Goal is shown in Table 3. The inconsistency ratio is 0.09434 .

Next, Pair wise comparisons for the nodes in alternatives cluster with respect to each of the criteria will be made. Pair wise comparisons of alternatives with respect to criteria efficacy is shown in Table 4.

Priorities with respect to criteria Efficacy were calculated as shown in Table 5. The Inconsistency ratio is 0.09917.

Now, Pairwise comparisons of alternatives will be made with respect to next criteria i.e. cost

Figure 1. Network design for vaccine selection problem

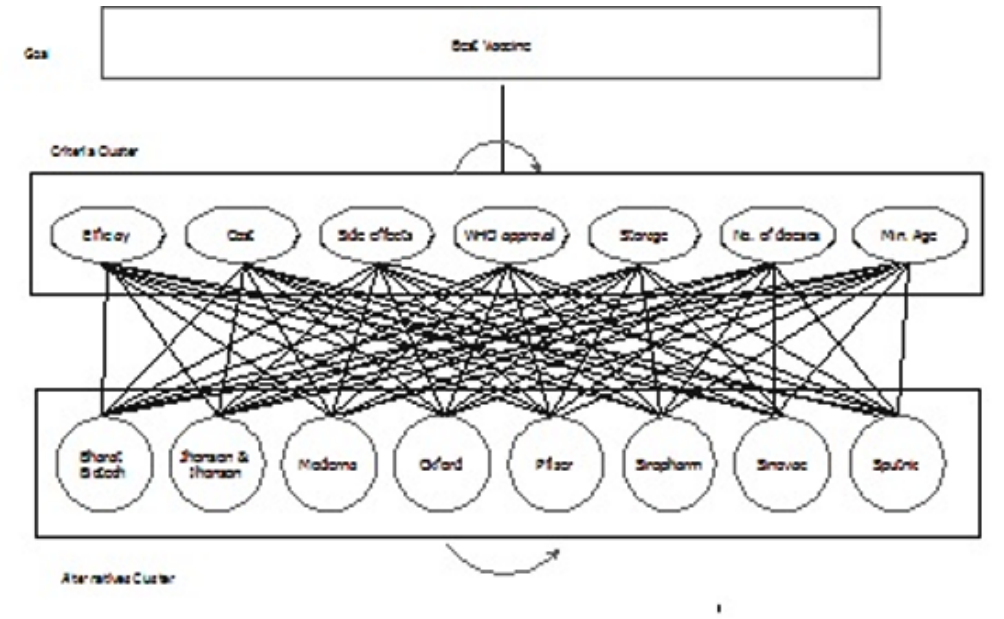


Table 1. Summary of vaccines approved for emergency or regular use

Company name	No of dose	Cost ($)	Min age	Storage (°C)	WHO approval	Efficacy	Side affects
Pfizer-BioNTech	2	19.5	12	-80 to -60	Yes	95%	Mild
Moderna	2	32	18	-25 to -15	Yes	94.1%	Mild
Johnson & Johnson	1	10	18	2 to 8	Yes	72%	Rare blood clots
Oxford-AstraZeneca	2	3	18	2–8	Yes	90%	Rare blood clots
Bharat Biotech	2	2	18	2–8	NO	81	Mild
Russia's GamelyaCenter	2	10	18	-18 to 8	NO	91.6	Mild
Sinopharm Group	2	75	18	2–8	yes	79	Mild
Sinovac Biotech Ltd	2	27	18	2–8	yes	50	Mild

Table 2. Pairwise comparison of criteria with respect to Goal

Criteria	Efficacy	Cost	Side affect	Approvals	Storage	No of doses	Min age
Efficacy	1	5	6	6	7	7	7
Cost	1/7	1	4	5	5	6	6
Side affect	1/6	¼	1	3	3	4	5
Approvals	1/6	1/5	1/3	1	3	2	4
Storage	1/7	1/5	1/3	1/3	1	2	4
No of doses	1/7	1/6	1/4	1/2	1/2	1	2
Min age	1/7	1/6	1/5	1/4	1/4	1/2	1

Table 3. Normalized weights of criteria under consideration

Criteria Name	Normalized Priority
Efficacy	0.461
Cost	0.232
Side effects	0.117
WHO approval	0.074
Storage	0.053
Number of doses	0.037
Minimum Age	0.026

Table 4. Pairwise comparisons of vaccines with respect to efficacy criteria

W.r.t. Efficacy	Bharat	J& J	Moderna	Oxford	Pfizer	Sinopharm	Sinovac	Sputnik
Bharat	1	4	1/5	1/4	1/6	3	6	1/6
J & J	1/4	1	1/8	1/5	1/8	1/4	6	1/6
Moderna	5	8	1	3	1/2	6	9	2
Oxford	4	5	1/3	1	1/3	4	7	1/2
Pfizer	6	8	2	3	1	7	9	2
Sinopharm	1/3	4	1/6	1/4	1/7	1	6	1/5
Sinovac	1/6	1/6	1/9	1/7	1/9	1/6	1	1/7
Sputnik	6	6	1/2	2	1/2	5	7	1

Priority vector is calculated with Inconsistency ratio 0.09711. The priority vector with respect to criteria cost is shown in Table 7.

Next, Pair wise comparisons of alternatives will be made with respect to criteria side effects. All vaccines reports mild side effects like chills, fever, itching, fatigue, headache, diarrhea, muscle pain, pain at the injection site. However, some rare cases reported blood clot issues with Jhonson &Jhonson and Oxford vaccines.

The priority vector with respect to criteria side effects is shown in Table 9.

Table 5. Priorities of vaccines with respect to efficacy criteria

Vaccine	Normalized Priority
Bharat	0.066
J & J	0.031
Moderna	0.238
Oxford	0.125
Pfizer	0.294
Sinopharm	0.049
Sinovac	0.016
Sputnik	0.182

Table 6. Pairwise comparisons of vaccines with respect to cost criteria

W.r.t. Cost	Bharat	J& J	Moderna	Oxford	Pfizer	Sinopharm	Sinovac	Sputnik
Bharat	1	4	8	2	6	9	7	4
J & J	¼	1	6	1/4	4	8	5	1
Moderna	1/8	1/6	1	1/7	1/4	6	1/2	1/6
Oxford	½	4	7	1	6	9	7	4
Pfizer	1/6	¼	4	6	1	9	3	1/3
Sinopharm	1/9	1/8	1/6	9	1/9	1	1/5	1/9
Sinovac	1/7	1/5	2	7	1/3	5	1	1/4
Sputnik	1/4	1	6	4	3	9	4	1

Table 7. Priority vector with respect to cost criteria

Vaccine	Normalized Priority
Bharat	0.326
J & J	0.130
Moderna	0.031
Oxford	0.274
Pfizer	0.068
Sinopharm	0.015
Sinovac	0.038
Sputnik	0.120

Similarly, Pair wise comparisons of alternatives will be made with respect to criteria, WHO approval (Table 10). The emergency use listing (EUL) of WHO approves some of the candidate vaccines. Some vaccines those are not listed in EUL list of WHO are approved by nations. Indian vaccine developed by Bharat Biotech, Covaccine is approved by India, Brazil, Mexico, Iran etc. Russian Gamelya Center's vaccine, Sputnik is approved for emergency use in Russia, India, Brazil, China, Iran, Italy .

Table 8. Pairwise comparisons of vaccines with respect to side effects criteria

W.r.t. Side Effects	Bharat	J& J	Moderna	Oxford	Pfizer	Sinopharm	Sinovac	Sputnik
Bharat	1	5	1	5	1	1	1	1
J & J	1/5	1	1/5	1	1/5	1/5	1/5	1/5
Moderna	1	5	1	5	1	1	1	1
Oxford	1/5	1	1/5	1	1	1	1	1
Pfizer	1	5	1	1	1	1	1	1
Sinopharm	1	5	1	1	1	1	1	1
Sinovac	1	5	1	1	1	1	1	1
Sputnik	1	5	1	1	1	1	1	1

Table 9. Priority vector with respect to side effects criteria

Vaccine	Normalized Priority
Bharat	0.156
J & J	0.031
Moderna	0.156
Oxford	0.031
Pfizer	0.156
Sinopharm	0.156
Sinovac	0.156
Sputnik	0.156

Table 10. Pairwise comparisons of vaccines with respect to who approval criteria

W.r.t. WHO approval	Bharat	J& J	Moderna	Oxford	Pfizer	Sinopharm	Sinovac	Sputnik
Bharat	1	1/5	1/5	1/5	1/5	1/5	1/5	1
J & J	5	1	1	1	1	1	1	5
Moderna	5	1	1	1	1	1	1	5
Oxford	5	1	1	1	1	1	1	5
Pfizer	5	1	1	1	1	1	1	5
Sinopharm	5	1	1	1	1	1	1	5
Sinovac	5	1	1	1	1	1	1	5
Sputnik	1	1/5	1/5	1/5	1/5	1/5	1/5	1

The priority vector with respect to criteria side effects is shown in Table 11.

Similarly, pairwise comparisons of alternatives will be made with respect to criteria, Storage condition. Pfizer vaccine requires ultra-cold freezing conditions of -80 to -60 degree Celsius, Moderna vaccine need very cold freezing conditions of -25 to -15 degree Celsius. Sputnik vaccines also need

Table11. Priority vector for WHO approval criteria

Vaccine	Normalized Priority
Bharat	0.031
J & J	0.156
Moderna	0.156
Oxford	0.156
Pfizer	0.156
Sinopharm	0.156
Sinovac	0.156
Sputnik	0.031

very cold freezing temperature -18 to 8 degree Celsius. Other vaccines need normal refrigeration of 2 to 8 degree Celsius.

The priority vector with respect to criteria Storage condition is shown in Table 13. The inconsistency ratio is 0.03334.

Next, pairwise comparisons of alternatives will be made with respect to criteria, Number of doses (Table 14). Apart from Jhonson & Jhonson vaccine, all other vaccines under consideration needs two doses to be effective against covid-19. Vaccine with lesser number of dose is better than vaccine with multiple doses, if other criteria are same.

The priority vector with respect to number of doses is shown in Table 15. The inconsistency ratio is 0.

Next, pairwise comparisons of alternatives will be made with respect to criteria, minimum age (Table 16). Apart from Pfizer vaccine, all other vaccines under consideration can be administered on people with 18 years or older. Pfizer vaccine can be given to twelve years or old people.

The priority vector with respect to minimum age is shown in Table 17. The inconsistency ratio is 0.

After making pair wise comparisons, Unweighted super matrix can be constructed. Eigenvector of the comparison matrix forms the local priorities (Saaty,1999). These local priories are stored as column vectors in the super-matrix. Resultant matrix is normalized by scaling sum of all columns to 1.Super decisions package is used for making calculations (SuperDecisions,2021). Screen shots for unweighted super matrix is shown in Fig.2

The Weighted super matrix is computed using unweighted super matrix by multiplying all the elements in a component of the unweighted super matrix by the corresponding cluster weight. The resulting weighted super matrix is shown in Fig 3.

Table 12. Pairwise comparisons of vaccines with respect to storage condition criteria

W.r.t. Storage	Bharat	J& J	Moderna	Oxford	Pfizer	Sinopharm	Sinovac	Sputnik
Bharat	1	1	5	1	9	1	1	4
J & J	1	1	5	1	9	1	1	4
Moderna	1/5	1/5	1	1/5	5	1/5	1/5	1/4
Oxford	1	1	5	1	9	1	1	4
Pfizer	1/9	1/9	1/5	1/9	1	1/9	1/9	1/7
Sinopharm	1	1	5	1	9	1	1	4
Sinovac	1	1	5	1	9	1	1	4
Sputnik	1/4	¼	4	1/4	7	1/4	1/4	1

Table 13. Priority vector with respect to storage condition criteria

Vaccine	Normalized Priority
Bharat	0.176
J & J	0.176
Moderna	0.037
Oxford	0.176
Pfizer	0.016
Sinopharm	0.176
Sinovac	0.176
Sputnik	0.065

Table14. Pairwise comparisons of vaccines with respect to number of doses criteria

W.r.t. Number of doses	Bharat	J& J	Moderna	Oxford	Pfizer	Sinopharm	Sinovac	Sputnik
Bharat	1	1/7	1	1	1	1	1	1
J & J	1	1	7	7	7	7	7	7
Moderna	1	1/7	1	1	1	1	1	1
Oxford	1	1/7	1	1	1	1	1	1
Pfizer	1	1/7	1	1	1	1	1	1
Sinopharm	1	1/7	1	1	1	1	1	1
Sinovac	1	1/7	1	1	1	1	1	1
Sputnik	1	1/7	1	1	1	1	1	1

Table 15. Priority vector with respect to number of doses criteria

Vaccine	Normalized Priority
Bharat	0.143
J & J	0.50
Moderna	0.143
Oxford	0.143
Pfizer	0.143
Sinopharm	0.143
Sinovac	0.143
Sputnik	0.143

As final step, Weighted super matrix is converted into Limit matrix by synthesizing the model. The Limit Matrix is the weighted Super matrix, taken to the power of k+1, where k is an arbitrary number (Saaty & Cillo, 2008).

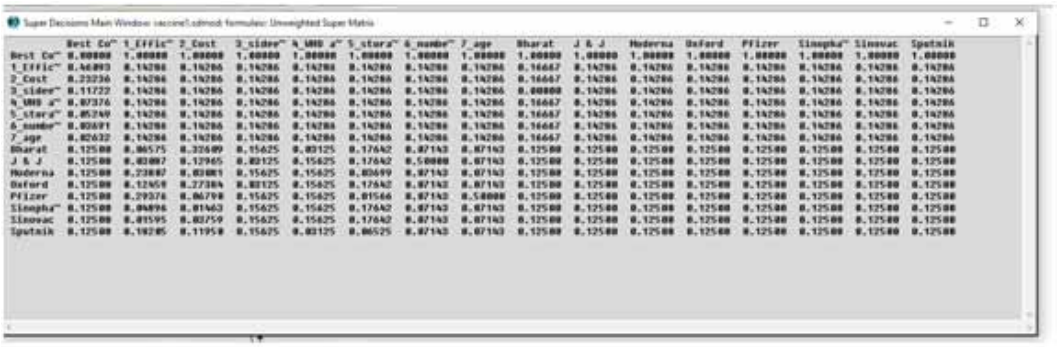
Table 16. Pairwise comparisons of vaccines with respect to minimum age criteria

W.r.t. Minimum age	Bharat	J& J	Moderna	Oxford	Pfizer	Sinopharm	Sinovac	Sputnik
Bharat	1	1	1	1	1/7	1	1	1
J & J	1	1	1	1	1/7	1	1	1
Moderna	1	1	1	1	1/7	1	1	1
Oxford	1	1	1	1	1/7	1	1	1
Pfizer	7	7	7	7	1	7	7	7
Sinopharm	1	1	1	1	1/7	1	1	1
Sinovac	1	1	1	1	1/7	1	1	1
Sputnik	1	1	1	1	1/7	1	1	1

Table 17. Priority vector with respect to minimum age

Vaccine	Normalized Priority
Bharat	0.143
J & J	0.143
Moderna	0.143
Oxford	0.143
Pfizer	0.50
Sinopharm	0.143
Sinovac	0.143
Sputnik	0.143

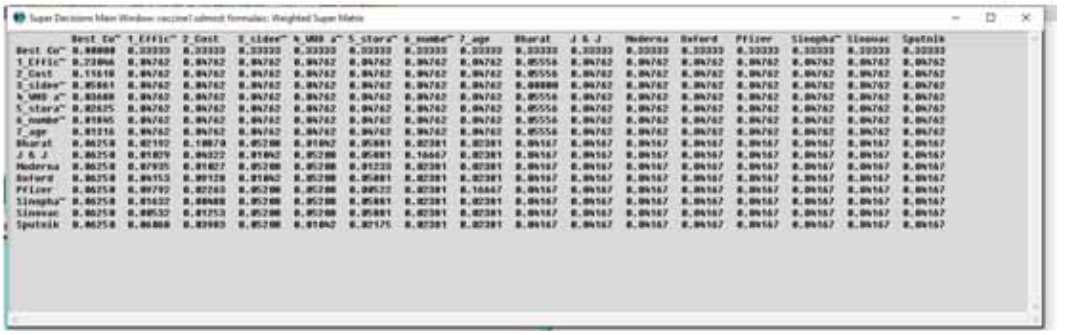
Figure 2. Unweighted super matrix



The weighted super matrix is raised to limiting power such to get the global priority vectors as in Eq(1).

$$\lim_{k\to\infty} W^k \tag{1}$$

Figure 3. Weighted super matrix



If the super matrix has the effect of cyclicity, there may be two or more limiting super matrices" (Adams,2011). In this case, the Cesaro sum is calculated as in Eq. (2) to get the average priority weights.

$$\lim_{k\to\infty}\left(\frac{1}{N}\right)\sum_{i=1}^{N} W_i^k \tag{2}$$

Screen shot of Limit matrix from super decisions software is shown in Fig 4.
The Priories corresponding to alternatives were computed and shown in Table 18.

RESULT

The need for vaccine is inevitable to control the rapid spread and manage the disease effectively so as to reduce high mortality rate. In the proposed study Eight vaccines were analyzed on the basis of seven criteria. Pairwise comparisons were made and unweighted super matrix was generated. Unweighted super matrix was used as a basis for computations of weighted super matrix and limit matrix. The Final rankings of alternatives are shown in Figure 5. Pfizer vaccine tops the list, with high efficacy and fact that it can be administered on people with minimum age12 years. Oxford vaccine's second ranking can be attributed to its low cost and normal refrigeration storage requirements. Sinovac is ranked last because of high cost and low efficacy.

Figure 4. The Limit Matrix

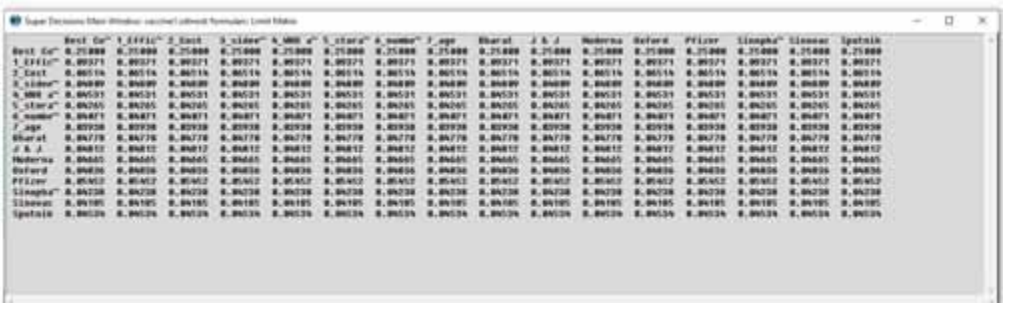
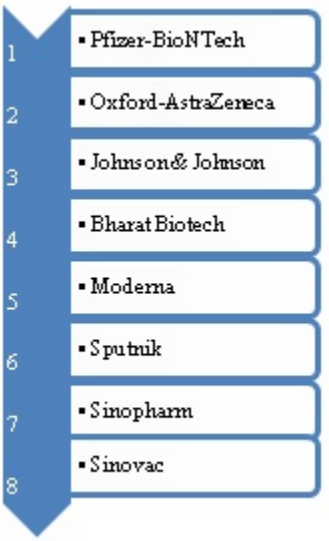


Table18. Final priorities of alternatives

Alternatives	Priority	Ranking
Bharat Biotech	0.1274	4
Jhonson& Jhonson	0.1283	3
Moderna	0.1244	5
Oxford-AstraZeneca	0.1290	2
Pfizer-BioNTech	0.1454	1
Sinopharm	0.1130	7
Sinovac	0.1116	8
Sputnik	0.1209	6

Figure 5. Final ranking of alternatives



CONCLUSION AND FUTURE SCOPE OF THE WORK

In order to stop further spread and end COVID-19 pandemic, it is inevitable to have equitable access to safe and affordable vaccines. At present, there are numerous vaccines in pipeline while many candidates are waiting for approval as well. In this scenario, the tiresome effects of WHO, in partnering with global team to develop, manufacture and deploy effective, efficient and affordable vaccines, are bearing fruits. With a milestone on administering 3,402,275,866 vaccine doses as on July 16, 2021 ("Corona Virus Dash Board",2021), nations need to overcome the pandemic quickly. Although every vaccine for COVID-19 is unique, but all candidates help in bringing herd immunity. Corona virus made mask-wearing and social distancing practices, a new norm in life. It also promoted cooperation among nations in vaccine research and its sensible distribution. Multi criteria Decision making approach can assist consumers, corporates and governments to select best vaccine in a scenario when vaccines from many brands were freely available in open market. Analytical Networking process can assist decision makers in ranking of covid-19 vaccines, Thus enabling people to take informed decision.

Future scope of work includes:

- Considering more candidate vaccines that got approval in near future for ranking.
- Study can be carried out with other popular MCDM methods like AHP, Topsis and their results can be compared .

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