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Optimization-based strategic interventions for public health crises using Delphi and mathematical modeling

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Abstract

Global lockdowns brought about by the pandemic upset economies and created serious problems in a number of areas, most notably employment. Traditional qualitative research techniques like focus groups, community studies, and observations were rendered impractical by social distancing policies, which compelled a switch to internet platforms. To assure expert participation, preserve anonymity, and reduce biases, this study uses the Delphi technique in a fully virtual manner. Prior to their involvement, experts were made aware of the study's goals and procedures, and their formal e-consent was acquired. A scoping review that divided individual competency units into two clusters was the first step in the multi-round Delphi process. Despite regional variations and clinical prejudices, this iterative process made sure that a range of viewpoints were included and made reaching an agreement easier. A high consensus level of 99.775%, as determined by a Likert scale, backed the final choice that was made at the end of the process with few interruptions. Experts were able to analyze inputs at their convenience and contribute independently due to the asynchronous nature of online responses. A competency matrix was also created as a result of the process, which strengthened team-based decision-making. This study shows that the Delphi procedure is a useful tool for strategic intervention in public health emergencies when paired with optimization techniques.

Keywords: Intervention; Health Crisis; Optimization; Delphi Method; Linear Programming

1. Introduction

After converting real-world problems into mathematical ones, assumptions are made and mathematical models (equations, graphs, LPP) are identified or constructed. This allows for the interpretation of data-based answers and prepares the way for the right solution in the real world. This paper mainly emphasis on trans-disciplinary decision-making using a scientific/medical approach. The methodology is provided by the construction and manipulation of models. By integrating the systems, it enhances decision quality and yields the best solution while fostering analytical objectivity. Reduce time and expense while increasing profit and hygiene quality. It means exactly that the creation of a model, the display of significant variables in the model, the symbolization of the model, the quantification of the model, and particularly the use of mathematical devices, all contribute to the attainment of the objective. The goal of the Delphi procedure is to ascertain how much laypeople or professionals agree on a certain topic, with one another, and in areas where they disagree, reach a consensus. Typically, the Delphi procedure is carried out using questionnaires. We translate our real-world issue into a mathematical model through linear programming. It involves linear inequalities that are subject to constraints and an objective function. In other words, the process is defining the issue, creating a mathematical model, then interpreting the outcome by contrasting it with reality.

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2. Review of Literature

The last twenty years have seen a major increase in the use of optimization models in public health decision-making. Resource allocation and epidemic modeling were the main areas of early applications [1]. In testing intervention scenarios and replicating illness dynamics, mathematical models such as SEIR have demonstrated efficacy [2]. Stochastic and agent-based models have been used in more recent studies to account for heterogeneity and uncertainty [3]. Cost-effective systems for vaccination distribution and hospital resource management have been developed through the use of optimization techniques, including linear and integer programming [4]. Particularly in quickly developing crises like COVID-19, the Delphi technique has proven to be an effective instrument for obtaining expert consensus [5]. In order to align expert opinion with quantitative outputs, a number of studies have combined Delphi with modeling [6]. This hybrid approach improves transparency and stakeholder engagement in policymaking. Additionally, multi-objective optimization has made it possible to balance health outcomes with economic and social factors [7]. The integration of scenario analysis and real-time data enhances model adaptability, but literature highlights challenges in data availability, model validation, and stakeholder coordination [8]. Despite these issues, optimization-based strategies have shown strong potential for improving public health preparedness, and the inclusion of expert insight through Delphi adds a layer of contextual relevance. Ongoing research emphasizes interdisciplinary collaboration for robust, scalable interventions. Studies on SARS outbreak in Ontario, Hong Kong and Singapore and the role of diagnosis and isolation as a control mechanism are discussed in [9], [10] and Introduction to Mathematical Epidemiology [11] were reviewed. Mathematical Models in Population Biology and Epidemiology were discussed in [12],[13]. The Delphi Method: Techniques and Applications were given in detail in [14]–[17]. The Improvement and extension of the Delphi process are studied by [18],[19] and [20]. Regression models are used to solve real time problems [21] and [31]. Statistical studies and analysis are done to understand complex problems [22],[23],[24], [29] and [33]. Cubic equation are formed and various forms of it are derived in [25], [39]. Other related works are referred in [26], [30]. Real time problems are solved and optimization is done through Transportation and transshipment techniques. [27], [28], [36], [40], [42], [43]. Mathematical modeling for worldly problems is solved using mathematical techniques [32]. Decision making models facilitates decision makers at arriving conclusions quickly [34], [41]. Fuzzy multi criteria models were formulated in [35]. Differentiation and computational methodology is also a technique to solve problems [37]. Linear programming for cost effectiveness is studied by [38].

3. Methodology

3.1. Delphi Method

There was no need for anyone to meet during the COVID-19 epidemic because the entire Delphi process was carried out online. In the first round, the consent is obtained via Google forms. In subsequent iterations, the spreadsheet templates were shared and stored on Google Drive. All correspondence took place through the mail. Panelists' input was saved on internet data storage disks.

3.2. First Round Consensus

A questionnaire survey was utilized to incorporate the competency factor into the baseline framework. It used a Likert scale with three categories: (1) desirable, (2) essential, and (3) most essential. The baseline framework would comprise all competency elements that received a score of 3 or 4 from at least 75% of experts. Because the specialists on the Delphi panel had a wide range of knowledge, a 75% cutoff was established.

3.3. Final Round Consensus

An agreement level of at least 95% was determined for validation and approval of the competency document.

3.4. Stability of Agreement

The number of panelists who reported differently for the competency unit (in the form of yes/no) between Rounds 3 and 4 varied by less than 10%. Based on the scoping review, the individual competency units were grouped into two clusters at the start of the next round. This ensures that a variety of viewpoints are included in the final decisions and is appropriate for a number of reasons, as it helps overcome clinical conflicts and biases in different geographical locations. With little problems, we were able to reach the final conclusion at the end of the procedure. They had easy access to a wealth of independent reviews and comments due to the non-synchronized pattern of responses over the internet. In addition, it results in the creation of a competency matrix for each team member. Thus, with uniformity in the vocabulary on a Liker scale, we can get to superior precision, as demonstrated by the consensus level of 99.775%.

3.5. Delphi Flowchart

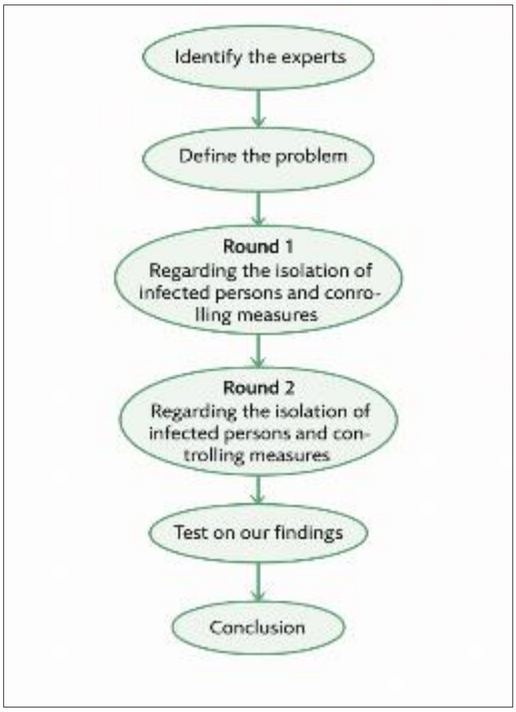

Figure 1 Delphi Flowchart

3.6. Delphi Method Algorithm

Let $DM_1, DM_2, DM_3, DM_4, DM_5, DM_6$ denote the six types of decision makers.

Let $q_1, q_2, \dots, q_n,$ denote the questions.

Let $I_1, I_2, \dots, I_n$ denote the Ideas.

Let S represent the summarize input.

Let D denote the distribute summary.

Let R denote the revise, refine, prioritize earlier input and

Let C_i denote the repetition of the process.

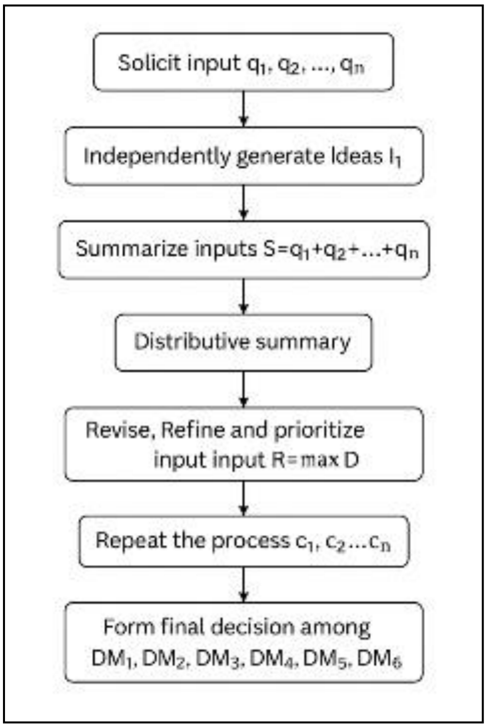

Figure 2 Delphi Method Algorithm

The linear programming problem of the objective function is

$$\max Z = C_1R_1 + C_2R_2 + C_3R_3 + C_4R_4 + C_5R_5 + C_6R_6$$

Subject to

$$DM_1I_1 + DM_2I_1 + DM_3I_1 + DM_4I_1 + DM_5I_1 + DM_6I_1 \geq q_1$$

$$DM_1I_2 + DM_2I_2 + DM_3I_2 + DM_4I_2 + DM_5I_2 + DM_6I_2 \geq q_2$$

$$DM_1I_3 + DM_2I_3 + DM_3I_3 + DM_4I_3 + DM_5I_3 + DM_6I_3 \geq q_3$$

$$DM_1I_4 + DM_2I_4 + DM_3I_4 + DM_4I_4 + DM_5I_4 + DM_6I_4 \geq q_4$$

$$DM_1I_5 + DM_2I_5 + DM_3I_5 + DM_4I_5 + DM_5I_5 + DM_6I_5 \geq q_5$$

$$DM_1I_6 + DM_2I_6 + DM_3I_6 + DM_4I_6 + DM_5I_6 + DM_6I_6 \geq q_6$$

4. Linear Programming Technique

In a relatively short amount of time, the current new corona virus has caused a global emergency that is rapidly spreading around the world. However, there is no antiviral medication or vaccination for this type of illness. Therefore, how to contain the pandemic is currently a big global issue. India is a country with a dense population and a high rate of human-to-human contact. Therefore, significant action must be taken sooner. Mathematical models and decision-making are used to analyze the dynamics of the disease, pinpoint the key variables, and determine the best preventative measures to minimize the size of outbreaks. Controlling the asymptotic class is crucial since, in comparison to other classes, they are the most harmful because they do not exhibit clinical signs. Because of their lack of concern for the disease, those who interact with them must be kept apart, and it is crucial that they take the screening test. In the absence of antiviral treatment, it is unavoidable for concurrently exposed individuals to be placed in quarantine and to continue social separation in order to recover from the infection. There are several preventative measures like keeping social distance, donning masks, and regularly washing hands with soap and sanitizers, can be used appropriately. During this endemic period, social distance should be at least six feet, and raising awareness is crucial to reducing the disease's incidence.

Let s represent the number of susceptible persons, $s = 1,2,..S$

Let e represent the number of exposed persons, $e = 1,2,...$

Let a represent the number of persons asymptomatic infected, $a = 1,2,..A$

Let I represent the number of persons symptomatically infected $I = 1,2,\dots,i$ but not quarantined.

Let Q represent the number of persons symptomatically infected and quarantined $Q = 1,2,..,q$

Let h represents the number of persons hospitalized and isolated infected,$H = 1,2,\dots,h$

Let R represent the number of persons recovered from the disease, $R = 1,2,\dots,r$

Let $\mu_s, \mu_e, \mu_i, \mu_q, \mu_a, \mu_h, \mu_s$ represents the natural death rate of susceptible, exposed, symptomatically infected not quarantined, symptomatically infected and quarantined, asymptomatically infected and hospitalized persons.

Let π represents constant recruitment rate in S. Let k_1 *and* $k_2$represent the quarantine and isolation individuals obey the rules of quarantine and isolation centre properly and $(1 - k_1)$*and* $(1 - k_2)$ does not obey the rules properly. After getting infection due to an individual from s-class with interaction of A, I, Q and H (exposed class). Let proportion d maintains a safe distance from one another, personal awareness and difference awareness programmes.

Exposed individuals move to 3 difference compartments $\sigma_a, \sigma_i, \sigma_q$respectively.

Infected and quarantined infected individuals have been detected and hospitalized at the rate η_i, η_q

Asymptomatically infected, symptomatically infected but not quarantined, symptomatically infected but quarantined individuals recover from the infection $\gamma_a, \gamma_i \gamma_q, \gamma_h$respectively. Let δ denote the COVID-19 induced mortality rate.

The first objective function is to minimize the overall infected persons,

$$Min\, T^1 = \pi - [\textstyle\sum_{s=1}^{S}(\lambda_s\ (1-d) + \mu_s) + \sum_{e=1}^{E}(\lambda_s\ (1-d) - e(\sigma_a + \sigma_i + \sigma_q + \sigma_e) + \sum_{a=1}^{A}[\sigma_a E - (\gamma_a + \mu_a)] + \sum_{i=1}^{I}(\sigma_i E - (\eta_i + \gamma_i + \mu_i + \delta) + \sum_{q=1}^{Q}(\sigma_q E - (\eta_q + \gamma_q + \mu_q + \delta) + \sum_{h=1}^{H}(h\,\eta_i\, I + h\,\eta_q\, Q - (\gamma_h + \mu_h + \delta) + \sum_{r=1}^{R}(r\ (\gamma_a A + \gamma_i I + \gamma_q Q + \gamma_h H) - \mu_r R) \text{ -------- (1)}$$

$$\text{where } \lambda_s(S, E, A, I, Q, H) = \frac{\beta(I + \rho A + (1 - k_1)Q + (1 - k_2)H)}{N}$$

$N = S + E + A + I + Q + H + R$ and β *and* $\rho$are transmission rate of covid 19.

Let T denote the transportation time.

Let A denote the ambulance.

Let n denote the number of patients.

Let denote the location point of the patient's area.

Let W represent the type of patients in the category of S, A, E, Q, H, R respectively.

Let X_{Anwl} denote the number of trips by the ambulance.

$\min T^2 = \sum Anwl\ (X_{Anwl} C_{Anwl})$ ---------------------- (2)

Subject to the constraints,

$\sum_{Anwl}(X_{Anwl}) \geq N_i, N_i$ denote the total number of infected persons. ---------- (3)

$X_{Anwl} \leq t_n \sigma_i \sigma_q$ ----------(4)

Let us denote the vehicle type V by $v = 1, 2, \dots, V$and the volume of vehicle type be V_v.

Let D be the generalDistributive time of masks and sanitizers to the various areas which are filled with W type of patients.

Let M and F denote the quantity of masks and sanitizers respectively.

Let $D_{VSMF}, D_{VEMF}, D_{VAMF}, D_{VIMF}, D_{VQMF}, D_{VHMF}$denote the particular distributive time of masks and sanitizers to the susceptible persons, Exposed persons, Asymptomatically infected persons, symptomatically infected persons but not quarantined and Hospitalized persons respectively.

Let$X_{VSMF}, X_{VEMF}, X_{VAMF}, X_{VIMF}, X_{VQMF}, X_{VHMF}$denote the number of trips made by the vehicle to distribute the masks and sanitizers to the particular category of patients as mentioned above.

The objective function is

$\min T^3 = \sum_{VSMF}(D_{VSMF}X_{VSMF}V_v) + \sum_{VAMF}(D_{VAMF}X_{VAMF}V_v) + \sum_{VEMF}(D_{VEMF}X_{VEMF}V_v) + \sum_{VIMF}(D_{VIMF}X_{VIMF}V_v) + \sum_{VQMF}(D_{VQMF}X_{VQMF}V_v) + \sum_{VHMF}(D_{VHMF}X_{VHMF}V_v)$ --------(5)

Subject to the constraints,

$\sum_{VSMF} X_{VSMF}V_v + \sum_{VAMF} X_{VAMF}V_v + \sum_{VEMF} X_{VEMF}V_v + \sum_{VIMF} X_{VIMF}V_v + \sum_{VQMF} X_{VQMF}V_v + \sum_{VHMF} X_{VHMF}V_v \geq q_M F$, M = F =1,2, ... -----------------(6)

$X_{VSMF}V_v \leq t_n \lambda_s$ -----------------(7)

$X_{VEMF}V_v \leq t_{ne} (\sigma_a + \sigma_i + \sigma_q)$ -----------------(8)

$X_{VAMF}V_v \leq t_n \sigma_a$ -----------------(9)

$X_{VIMF}V_v \leq t_n \sigma_i$ -----------------(10)

$X_{VQMF}V_v \leq t_n \sigma_q$ -----------------(11)

$X_{VHMF}V_v \leq t_n (\eta_i + \eta_q)$ -----------------(12)

$X_{VSMF} \geq 0$ -------------(13)

$X_{VEMF} \geq 0$ -------------(14)

$X_{VAMF} \geq 0$ -------------(15)

$X_{VIMF} \geq 0$ -------------(16)

$X_{VQMF} \geq 0$ -------------(17)

$X_{VHMF} \geq 0$ -------------(18)

The Objective function is to minimize overall timing T

$\min T = T^1 + T^2 + T^3$ --------------(19)

5. Results and Discussion

In order to reduce the total number of infected people as well as the time it takes to transport and distribute masks and sanitizers among the large number of people, careful planning has been done above. Since there is no vaccine, the aforementioned tactics can be very helpful in raising public awareness of the COVID-19 outbreak and encouraging people to exercise greater caution. It is also clear that isolating those who are infected or at risk of contracting the virus, particularly those who are asymptomatically infected, is crucial, as is quickly distributing masks and sanitizers throughout different locations to prevent the pandemic. Therefore, even though there is no specific vaccination or antiviral treatment, simultaneous minimization enables us to survive against the corona virus more successfully.

6. Conclusion

We have developed a deterministic compartmental model using the Delphi and Linear Programming approach to analyze the dynamics and future trend of the epidemic in India and to forecast future outbreaks. Our results indicate that increasing the percentage of populations that keep a safe distance from one another at a given level and the percentage of asymptomatic populations that are identified and isolated from the other susceptible populations at a given level can significantly reduce the overall outbreak size and peak prevalence.

Compliance with ethical standards

Disclosure of conflict of interest

No Conflict of interest

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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