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Application of OR techniques on government planning during the COVID-19 pandemic

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ABSTRACT

In this paper we try to suggest models to optimize actions and policies which attempt to benefit the Government as well as people during the Covid-19 pandemic. We make use of game theory and a modified SEIR model. These models are important because of the adverse effects the Covid-19 pandemic has brought on, such as strict stay-at-home orders and economic shutdowns. Our game theory model studies the decision-making behavior of people and Government during the current pandemic. We also suggest a modified SEIR model to represent the movement of people between states of a country.

Keywords— *Game theory, Operations research, Government, SEIR model, Covid-19*

1. INTRODUCTION

The novel coronavirus was first identified in Wuhan, China in December, 2019 and on March 11, 2020 a state of pandemic was declared by WHO. This, brought the whole world to a standstill. The ongoing Covid-19 pandemic has been caused by the SARS-CoV-2 virus. This virus has mutated into several infectious variants such as Delta, Alpha, Beta and currently even Delta plus. As on September 14, 2021, there have been 225,024,781 confirmed cases of Covid-19, including 4,636,153 deaths, reported by WHO (World Health Organization, 2021). By population impact it is the 8th deadliest pandemic and has impacted about 0.04% of the world's population (Ang, 2021). With the onset of the pandemic many countries and Governments started to take precautions by implementing lockdowns, restricting international travel, closing their borders, etc. This in turn led to a suspension in all social and economic activities all around the world (Pandey & Saxena, 2020).

In this paper we have used OR methods such as game theory and simulation – a modified SEIR model. Game theory is defined as an OR technique which assesses the decision-making process in various situations of conflict. Game theory is concerned with the analysis of strategies for dealing with competitive situations where the outcome of a participant's choice of action depends critically on the actions of other participants. The emergence of this theory is credited to the World War II period (Özkaya & İzgi, 2021). Furthermore, we also utilize a modified simulation model to analyse the spread of Covid – 19. We use the SEIR (Susceptible, Exposed, Infected, and Removed) model as our base framework and build upon it by inserting variables to improve its results (Ghaffarzadegan, 2021).

The Governments have used SIR, SEIR, SAIR, curve fitting models and a combination of several mathematical models to understand the spread and propagation of Covid-19 infections. The SEIR model is a modified version of the SIR model which has an extra compartment called Exposed (E). To overcome the limitations of the SEIR model, researchers came up with a new model SAIR. It includes the following: susceptible (*S*), asymptomatically infected (*A*), symptomatically infected (*I*) and removed (*R*) individuals (Liu, Wu, Niu, Wu, & Fan, 2020). These models have been used to predict several things like the duration of a pandemic,

the expected number of infection cases, and estimate various epidemiological parameters such as the reproductive rate of infection. Such models can show how different public health interventions may affect the outcome of the epidemic (Wikipedia, 2021). The Government of India with help from researchers has used the SUTRA model – a compartmental model and a modified version of the SAIR model (Koshy, 2021). Furthermore, researchers have used game theory to analyse the effects of general or self-quarantine to the spread of the first wave of the Covid-19 pandemic (Özkaya & İzgi, 2021).

In this paper we propose two models which shows the effect of Government policies and plans implemented related to Covid-19 on the people. We illustrate a game theory model which studies the decision-making behavior of people as well as the Government during the pandemic. We are hence able to analyse the relation between Government implemented lockdowns and people's sustenance or quality of living. With the use of this model, there is a possibility of controlling the spread of the disease more effectively. Additionally, we illustrate a modified SEIR model which models the movement of people between states of a country during the pandemic. This upgraded model provides suggestions regarding factors that can be included to achieve more accurate predictions.

2. LITERATURE REVIEW

The worldwide spread of COVID-19 has elicited dramatic public health measures. These include stringent stay-at-home orders and shutdown of economies throughout countries. In some countries Governments have refrained from such measures in the belief that naturally attained shield immunity could decrease the spread of the virus. In the absence of ample data in this area, we look towards the research done by analysts and Governmental agencies in gaining information and insight into these problems (Kabir & Tanimoto, 2020).

2.1 Operation research methods applied by different Governments

India: A study funded by ICMR and researched by the team of National COVID Task Force -Operation Research Group members is assessed. The model they have used is Susceptible - Exposed - Infectious - Recovered - Susceptible model (SEIRS) (IDM, n.d.).

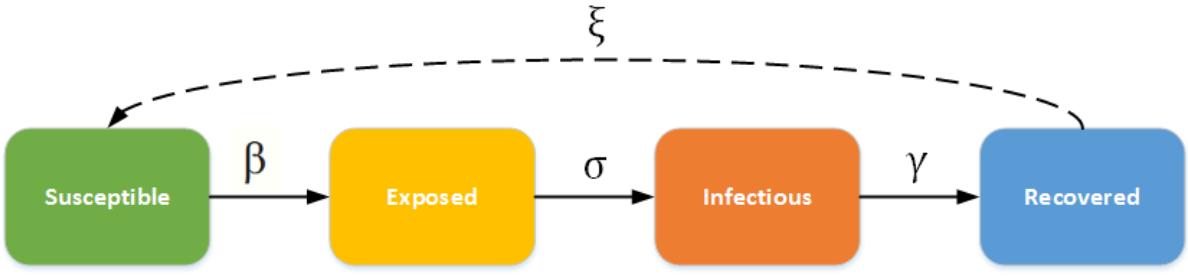

Figure-1: SEIR model

Source: https://docs.idmod.org/projects/emod-hiv/en/latest/model-seir.html#seir-and-seirs-models

Limitations of the SEIR model:

(a) Assumes that transmission occurs only through the human to human infected channel. In reality, it is spread throughout asymptomatic, symptomatic and even from the surroundings (Wang, 2020).
(b) The models need to include varying degrees of arbitration across different regions.
(c) Non-inclusion of the obedience of guidelines imposed (Chen, Robinson, Janies, & Dulin, 2020).

The Government of India has also used a model proposed by researchers from IIT Kanpur and Hyderabad called the SUTRA model to predict the Covid graph in India (TheTribune, 2021). The researchers developed on models like SAIR, SEIR, etc. The SAIR model is used to analyse and determine how to contain the spread of Covid-19. SAIR stands for Susceptible, Infected but asymptomatic, Symptomatic and Removed (Liu, Wu, Niu, Wu, & Fan, 2020). The problem with the SAIR model is that it is assumed that all individuals (symptomatically infected) are symptomatic which is not true. Because of contract tracing a new group of asymptomatic patients are also identified which would go unnoticed under the SAIR model. It was found that a good number of asymptomatic patients are undetected and not accounted for. Therefore a new model was proposed (Agrawal, Kanitkar, & Vidyasagar, 2021). This is the SUTRA model which divides patients between detected and undetected. Also, other improvements were made which included the stability of methods used to forecast.

The limitations of the model include: (a) Depending on too many parameters; (b) Lack of accounting for social and geographic heterogeneity; (c) It does not account for the reason behind the change in its values; (d) The virus mutates quickly and is unstable (drishti, 2021). Furthermore, it predicted the second wave peak in the third week of April 2021 which was again proven false as the peak was on the 8th of May, 2021 (TheEconomicTimes, 2021).

In UK, the MRC Centre for Global Infectious Disease Analysis at Imperial College, London collaborated with the World Health Organization to develop a model. Due to this model the Government decided to implement policies stating strict social distancing and lockdowns. Its concept is built upon the SIR framework. The objectives were to understand the impact of Government policy interventions and determine the actual number of infections. Since the main focus of this model is on the epidemical process of transmission, infection and deaths, the capacity of the healthcare system and treatment choices are not taken into decision. Its limitations include: (a) The continuous development of the model creates biases towards those countries where Covid-19 spread earlier (b) Fitting the model only to the number of deaths suggests that other intermediary parameters that are not directly associated to the death rate are estimated depending on it.

In Austria, researchers have suggested a model that is a descriptive simulation model that is built upon from an existing population model based on the SIR methodology. The limitation is that it suffers from model propagation error and is a big and comprehensive model (Eker, 2020).

In **USA**, The Institute of Health Metrics and Evaluation, at University of Washington (USA) also came up with a different approach that is known as the "Curve Fitting Model." The outbreak in USA lagged behind those in some countries. Hence it was assumed that the USA's Covid-19 curve would resemble them. The main objective was to predict the number of cases (Hutson, 2020). Although, there were certain limitations of the model. It had only one objective which was to predict the number of cases. According to the model the cases should have peaked in mid-April, but it did not happen. The projections are based on a purely statistical model having no epidemiologic basis (Foley, 2020).

2.2 Operation research methods applied by researchers to analyse the Government's policies and decisions

In this study, the authors have analysed the effects of general or self-quarantine to the spread of the first wave of the Covid-19 pandemic. They have applied game theory to evaluate the effects of quarantine on the three different stages of the pandemic – the beginning, the spread, and the end. Three countries are chosen for this analysis – South Korea, Italy and Turkey. To find the optimal strategy, the use of the repeated game approach is followed in the analysis. To apply this model, the authors have used number of cases diagnosed, number of deaths, and the dates on which lockdown has started and ended in each country (Özkaya & İzgi, 2021).

Limitations of Game theory:

The assumptions are that there are a limited number of rational actors that participate in an isolated game. Also, the rules of the game, the players' preferences and utility functions are clearly defined. The practical application of game theory models is hindered by the different indications of bounded rationality and irrational behaviour. Additionally, analysing pay-off structures for different actors is difficult without knowing their actual preferences from their stated preferences. Lastly, players in a game are dynamic beings (Hermans, Cunningham, & Slinger, 2014).

In this literature, the authors have combined compartmental epidemiological models with the theory of behavioural dynamics derived from evolutionary game theory (EGT). This model shows how compliance with an economic lockdown might decline over time, as people consider the trade-off between the risk of infection and the economic cost of staying at home. Increasing Government funding at the individual level is effective in reducing the time and overall economic cost of a pandemic. The behavioural model adopted by the author's works on the assumption that the players in a game have to make a decision whether they will follow a stay-at-home order made to stop the spread of the pandemic. The researchers have built upon the SEIR model by adding terms for quarantined and hospitalized people to form a SEQIHR (Susceptible-Exposed-Quarantined-Infected-Hospitalized-Recovered) model. To arrive at an optimal solution, they have presented the outcomes of all these models. The conclusion is that the Government can take measures to reduce the economic cost of staying at home and that the effectiveness of shield immunity is not clearly known (Kabir & Tanimoto, 2020).

With the use of data envelopment analysis and stochastic frontier models, the researchers introduced a new country-month index of efficiency of Government policy to deal with Covid-19 problems. The framework proposed assumes that Governments enforce stringent policies with the main objective of saving people's lives. Countries that have firm democratic institutions, justice system, and political stability are more efficient. Also, efficient countries have more faith in public healthcare spending and their level of economic inequality is low (Delis, Iosifidi, & Tasiou, 2021).

Limitations of DEA:

(a) Ignores statistical errors
(b) Does not mention methods to improve efficiently
(c) Difficulty in performing statistical tests with solutions (Pablo Jordá & Monzón, 2012).

3. METHODOLOGY

In game theory models the basic concepts are as follows:

(a) Players: The players in a game can include people, Governments, Organizations, etc.
(b) Actions and strategies: Players in a game each have a number of possible actions to consider. The course of actions that players choose are their strategies. Usually, strategies are selected on the basis of the decisions of the other players.
(c) Outcomes: The outcome is determined by the combination of strategies chosen by the players.
(d) Preferences and payoffs: Among the possible outcomes, players have distinct preferences. Payoffs are generally used to show the value of these outcomes.
(e) Rules: Games are directed by rules that define actions and strategies that are permitted or prohibited.

The advantages of game theory includes (a) giving insight into lesser-known aspects, which occur in situations of conflicting interests; (b) developing a framework for evaluating decision making in situations where interdependence between firms is considered (Hermans, Cunningham, & Slinger, 2014).

We construct a game-theoretic model where the two players are the People and the Government, which we henceforth will denote as P_1 and P_2 respectively. The objective of P_2 is to reduce infections among people by implementing lockdowns. Whereas the objective of P_1 is to maintain a sustainable living by reducing the opportunity cost of staying home. The payoff for P_2 is calculated by the probability of a person being infected in a certain period. The payoff for P_1 is the opportunity cost of going out or not staying at home during the pandemic. We assume that if the opportunity cost of people staying home is less than that of them going out, then they achieve high sustenance and thereby will be less likely to break lockdown. On the other hand, if the opportunity cost of

staying home is more than that of going out, then we assume that people are in a state of low sustenance and would thereby be more likely to break lockdown. This model also assumes that each player will choose the strategy that gives them the highest payoff.

Let x_1 denote the payoffs of P_1 and x_2 the payoffs of P_2 under each strategy. The payoff matrix is given by:

Table-1: Payoff matrix

PEOPLE \ GOVERNMENT	Lockdown	No lockdown
Low Sustenance	A (x_1, x_2)	B (x_1, x_2)
High Sustenance	C (x_1, x_2)	D (x_1, x_2)

The modified SEIR model adheres to the similar aspects of infectious disease compartmental modelling. For the modified SEIR model we build upon the framework by adding additional variables and representing the same in a graphical manner. This includes both administrative and behavioural reactions to changes in the count of Covid – 19 cases.

4. OBJECTIVES

1. Given the limitations of various models used by different Governments mentioned above, recommend better and more accurate OR techniques to curb the pandemic.
2. Given the analyses of various researchers, assess and select/form a method that seems to best solve these problems.
3. Assist associations and Governments to become aware and/or prepare for a possible 3rd wave.
4. Understand the benefits of Operations Research in Government policies and decisions during the Covid-19 pandemic.

5. ANALYSIS AND FINDINGS

5.1 First Proposed Model – Application of Game Theory

Game theory is a logical and mathematical method of strategic decision making. With its application, we can introduce more effective Government policies and plans through a better comprehension of how people's decisions change depending on the situation. The public and Government have different interests. Hence, we need some kind of settlement or accommodation in the incentives, strategies, and behaviors for the both of them. Our aim here is to:

(a) Propose a possible model that can analyze the relation between Government implemented lockdowns and people's sustenance or quality of living.
(b) Show that game theory can be useful in understanding people's response to policies implemented during Covid-19, especially specific to lockdown.
(c) Identify the optimal strategy – dominant equilibrium where the strategy used by both the players is the one which gives them the highest payoff

Problem Statement:

- To establish an optimal strategy for the Government who is engaged in the decision making of plans to be enforced during Covid-19.
- To establish an optimal strategy for the people who are engaged in reducing their opportunity cost of staying home to achieve high sustenance.

We assume theoretically that the highest payoff achieved by a player is 2 and the least payoff is -1. This is done based on the possible effect of a strategy chosen by a rational player. With reference to Table 1:

- The position A (x_1, x_2) denotes the situation where the Government implements lockdown, but the people have low sustenance. Assuming that most people have no choice but to break lockdown in this case, the Government will not be able to reap the benefits of lockdown. Thereby, the rate of infections will increase. Here, the payoff will be A (0, 1).
- The position B (x_1, x_2) denotes the situation where the Government does not implement lockdown, and the people have low sustenance. Due to this there will be a possible phenomenal increase in infections among people. Moreover, due to the high opportunity cost of staying home the people are more likely to risk themselves in the outside world. Both these strategies result in severe losses to the players involved. Here, the payoff will be B (-1, -1).
- The position C (x_1, x_2) denotes the situation where the Government implements lockdown, and the people have high sustenance. In this situation, both players achieve the highest payoff. This is because people are least likely to break lockdown or go out because their opportunity cost of staying home is way lesser than that of going out. Furthermore, the lockdown is able to effectively control the spread of infection. In this case, the payoff will be C (2, 2).
- The position D (x_1, x_2) denotes the situation where the Government does not implement lockdown, but the people have high sustenance. Since, the Government has not implemented a lockdown there will be a possibility of a greater number of infections. However, the low opportunity cost of staying home signifies that people are less likely to go out. This means that the number of cases will still be comparatively lesser in spite of no lockdown. The payoff here is D (1, 0).

The final payoff matrix:

Table-2: Final payoff matrix

PEOPLE \ GOVERNMENT	Lockdown	No lockdown
Low Sustenance	A (0, 1)	B (-1, -1)
High Sustenance	C (2, 2)	D (1, 0)

To achieve the dominant strategy equilibrium, we examine the payoffs individually for each player and choose the strategy which is dominant (giving highest payoff) for each (Policonomics, n.d.). In this case, the dominant strategy for P_1 is – High sustenance with a payoff of 2 and the dominant strategy for P_2 is – Lockdown with a payoff of 2. As both players are playing their dominant strategy – the dominant strategy equilibrium is C (2, 2).

5.2 Second Proposed Model – Modified SEIR Model

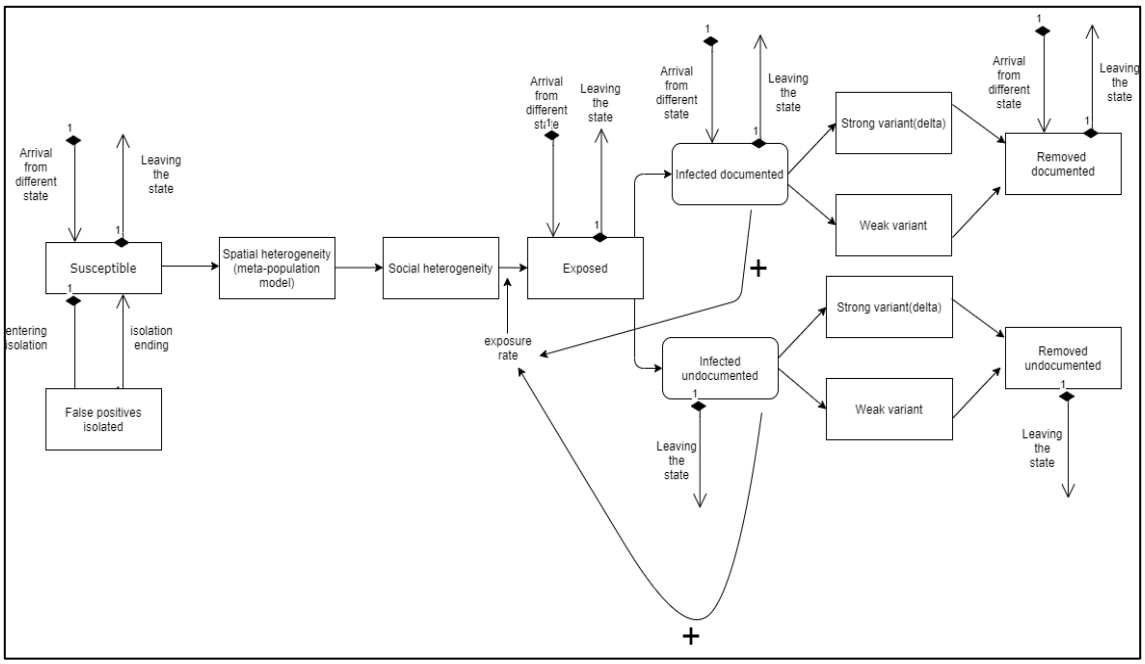

Figure 2: Modified SEIR model
Reference: (Ghaffarzadegan, 2021)

We create a modified SEIR model which can be applied to the movement of people travelling inter-state in a country. This model is a step further as more variables and processes have been added in order to overcome the limitations of the basic SEIR/SUTRA model. Suggested variables to improve the model:

1) Geographical heterogeneity: The SUTRA model used by the Indian Government does not account for geographical heterogeneity. Such models assume that every person has the same chance of being susceptible to a particular virus irrespective of their geographical location. Over the course of the pandemic, we have seen that certain areas have had higher infection rates than others. Due to the differences in the characteristics of the location (e.g.: size/density), people do not have the same chance of being infected. In this, a model known as the meta-population model is introduced. Metapopulation models are a type of spatial model which investigate interactions and movements among different subpopulations of (usually) the same species across time and space (Chen, et al., 2019). Therefore, this variable divides the population into subgroups which have different geographical characteristics and studies them to better compartmentalize and predict future infections.
2) Mutation Factor: Most epidemiologic operations research models do not factor in mutations. The centres for disease control and prevention state that, "As expected, multiple variants of SARS-CoV-2 have been documented in the United States and globally throughout this pandemic." Therefore, as you can see in figure 2, infected individuals have been divided into a strong variant and a weak variant. A strong variant is one which has a high impact on the contact rate which affects the exposure rate. In this case the strong variant is the delta variant which is, at the time of this writing, considered the deadliest. This classification is important because it has an impact on the exposure rate and takes into account future mutations that can develop over time. It can be updated as and when new mutations occur. Social heterogeneity: The SUTRA/SEIR model also doesn't account for social heterogeneity. As mentioned above, the model assumes an equal chance of being infected. But that is not the case as covid has taken 230 times the lives of individuals who are 75 and above compared to the 18-29 year age category (Centers for Disease Control and Prevention, 2021). This means that age, along with various other social factors, affect the impact of covid. Therefore, this factor divides the population in order to account for the different social factors and behaviours.

After suggesting all these factors, we have combined the SEIR model with the above additional parameters in order to better predict and simulate interstate travel in India as seen in Figure 2.

6. LIMITATIONS

The game theory model assumes that if people break lockdown, the infection rates will increase. It does not account for the other ways in which people can be infected while staying at home. Moreover, in this model the players are supposed to have knowledge of each other's strategies and are rational. It assumes that in a state of low sustenance, people will break lockdown which is just one definite course of action (generalisation) whereas people behave irrationally and there can be innumerable actions to maintain the quality of living. Furthermore, the opportunity cost of staying home is very subjective and would be difficult to quantify.

With regards to the modified SEIR model, additional variables that could overcome the initial limitations might increase the complexity of the model. It is possible that certain variables are interconnected and therefore the calculations might be inaccurate. Also, the improved model only considers two mutations, while it has been observed that there have been multiple mutations affecting people in the same region. For underdeveloped countries, a model as complex as this is not feasible as collecting the required data can be expensive and time consuming. Real life data has to be used in order to test the viability of these models.

7. RECOMMENDATIONS

The game theory model suggests that the most ideal situation would be that the Government decides to implement lockdown and that the people are in a high state of sustenance. We hence recommend that the Government should consider imposing lockdown while also ensuring the sustenance or good quality of living of individuals. This will effectively control the spread of coronavirus and will help them build more effective policies and plans that people are more likely to follow in the future.

Another existing drawback during the current pandemic has been to account for the delay in notification and the fact that its transmission varies with time in the existing models. To overcome this, we suggest a semi-mechanistic model of infectious disease dynamics that was used in real time during 2013-2016 West African Ebola epidemic and shows fits to an Ebola forecasting challenge conducted in late 2015 with simulated data mimicking the true epidemic. Modelling the time-varying transmission rate as a random walk means it is auto-correlated: the transmission rate on any day is most likely to be the same as on the previous one (Purkayastha, et al., 2021). Our second recommendation is that the Government should consider using this model for forecasting numbers and keeping track of a possible 3rd wave and frame appropriate policies for the same. Additionally, more research in this area using operations research can prove to be beneficial during the Covid-19 pandemic.

8. CONCLUSION

The OR techniques we have recommended can be utilized by the Government to make decisions and frame policies during the Covid-19 pandemic. The game theoretic approach attempts to assess the decisions and the outcomes of the public and the Government concerned with the lockdowns. The modified SEIR model approach attempts to represent the effect of movement of people between states in a country during a pandemic.

From the findings of the game theoretic approach, we have established that we achieve the optimum dominant payoff at C (2, 2). This means that the dominant strategy equilibrium is when the people are in a high state of sustenance and the Government implements a lockdown. We can infer from this that during the Covid-19 pandemic if the Government wishes to reduce the number of infections it needs to make sure that the public has high sustenance. This will reduce the chances of people breaking lockdown. The Government needs to make sure that in addition to implementing lockdowns it needs to care of the people's needs and provide the resources they may need to maintain a stable sustenance during the pandemic.

Furthermore, we can conclude from the modified SEIR model that the addition of variables such as geographical heterogeneity, mutation factor, social heterogeneity can improve the accuracy and practicality of the model. In conclusion, from the combined findings of these two models we recommend that with support from Government and consideration of the additional variables in the modified SEIR model, the Government can reduce the spread of Covid-19 effectively.

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