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Human Behaviors against COVID-19: A game theory approach

Mansour Abedian[a, *], Maryam Hejazy[b], Sayad Mohammad Davoodi[c]

[a]*Department of Management, Financial Position, Najafabad Branch, Islamic Azad University, Najafabad, Iran*
[b]*Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran*
[c]*Associate Professor, Department of Management, Dehaqan Branch, Islamic Azad University, Dehaqan, Iran*

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Abstract

Human choices and prevention and control measures during the outbreaks of infectious diseases play an important role in mitigating the spread and burden of the diseases and the negative impact of such phenomenon on societies. In this study, we developed a static game theoretical approach to assess the impact of human responses to the personal protection strategies of vaccination, self-quarantine, wearing face masks and social distancing on the evolution of the COVID-19 pandemic burden. The model was set up such that an individual can choose multiple strategies to strike a balance between reducing the burden of the pandemic and not overrunning down their economies. A kind of static game analytics approach has been developed for this issue, and the proposed model has been implemented to design optimal intervention strategies for a sample of Iranian people in two critical phases in a serious battle against the COVID-19 pandemic. The results revealed that social distancing of exposed, susceptible, and recovered humans, self-quarantine of susceptible and infectious humans, and vaccination of exposed and recovered humans were more effective in mitigating the burden of the COVID-19 pandemic and limiting the transmission rate. The analyses also indicated that for a substantial reduction in disease burden, adopting several strategies and performing them with a high level of compliance by a major proportion of the population was crucial.

***Keywords*:** COVID-19; Quarantine; Social-distancing; mask; Human behavior; Game theory; Nash equilibrium;

1. Introduction

The emergence of an unprecedented severe respiratory infection, COVID-19. COVID-19 as a new member of the family of coronaviruses about its nature and treatment there was not sufficient and reliable information at first months of its outbreak has been a shocking reality for the people of our globe. The spread of the virus worldwide has been rapid so that as of 27 May 2021, there have been 168,040,871 confirmed cases of COVID-19, including 3,494,758 deaths, and administration of a total of 1,545,967,545 vaccine doses that have been reported to WHO. Among the countries hit the first and most by COVID-19 was Iran so that from 3 January 2020 to 27 May 2021, there have been 2,865,864 confirmed cases of COVID-19 with 79,219 deaths, and administration of a total of 3,141,577 vaccine doses that have been reported to WHO (Figure 1 and Figure 2). Although case numbers have been declining in some parts of the world due to vast vaccination and observing healthcare protection techniques against this severe respiratory disease, the staggering statistics about the number of confirmed cases and deaths in Iran indicate that the COVID-19 pandemic is still a major health problem in this country that is still experiencing severe economic sanctions, very low speed of vaccination, late implementation of healthcare protection principles, late restriction on international arrivals, and late implementation and premature relaxation of lockdown measures. Iran has experienced four waves of pandemics (from 3 January 2020 to 27 May 2021,). Iran went through a strict lockdown phase between March and April 2020, which contributed to reducing disease burden and pressure on the healthcare system but it cannot manage to keep its disease numbers low, as it started re-opening the economies after the first pandemic wave due to severe economic sanctions and problems. Hence, it is important to understand the transmission dynamics of the virus and the potential impact of various control and mitigation strategies concerning human behavior and adoption during the pandemic.

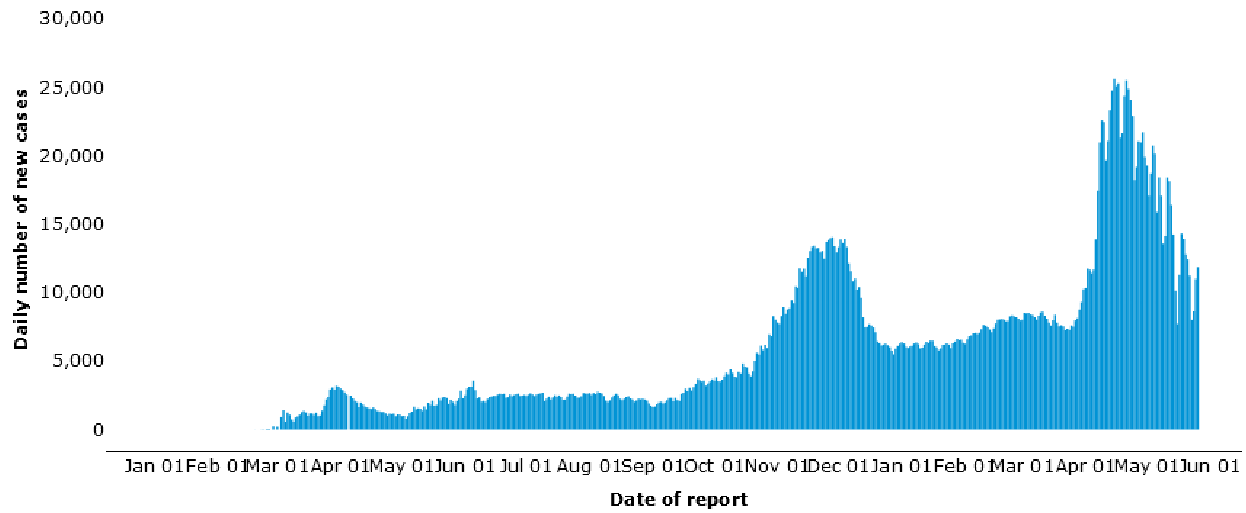

Fig 1: *Daily number of COVID-19 confirmed cases from 3 January 2020 to 27 May 2021in Iran*

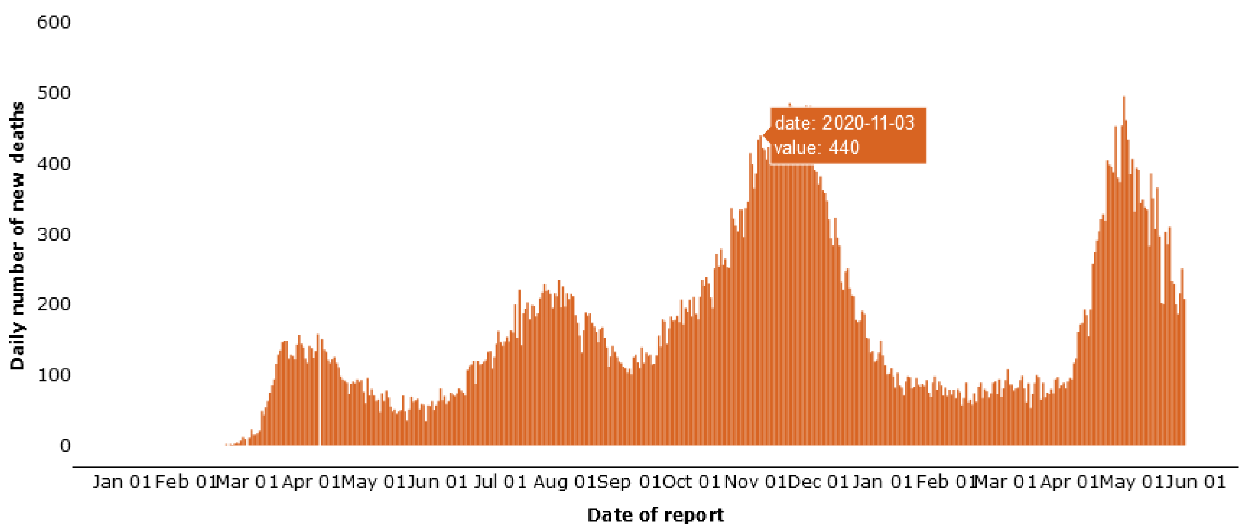

Fig 2: *Daily number of COVID-19 deaths from 3 January 2020 to 27 May 2021in Iran*

As of mid-September 2020, there was no effective and reliable treatment or vaccine for COVID-19. The World Health Organization (WHO) advises the use of masks, hand hygiene, the physical distancing of at least 1 meter, avoidance of touching one's face, respiratory etiquette, adequate ventilation in indoor settings, testing, contact tracing, self-quarantine of suspected and infectious cases (to stay away from others at home or in designated facilities), and social-distancing (shelter-in-place, community lockdowns, closure of schools, university and non-essential businesses, avoiding crowded gatherings such as wedding or funeral, staying about six feet apart in public, isolation of confirmed cases, evacuation) as parts of a package of self-protection and control measures to reduce the spread of SARS-CoV-2, the virus that causes COVID-19. None of these measures, even when it is used correctly, is sufficient to provide adequate protection or source control. Irrespective of the control measure that a country adopted, individual and collective responses to the measure, as well as the timing of the measure, are important in disease containment. Many mathematical and computational models have been developed and used to study COVID-19 transmission in the population, the impact of different control measures on the spread and burden of the virus, the potential magnitude of the epidemic, and the key factors that characterize the severity of the outbreak (Flaxman et al., 2020; Ferguson et al., 2020; Gumel et al., 2021; Ngonghala et al., 2020). An age-structured compartmental model was employed to study COVID-19 transmission in the population of Ontario, Canada (Tuite et al., 2020). They investigated the impact of different lockdown durations on the dynamics of COVID-19. Some mathematical model developments demonstrated that late implementation and premature relaxation of lockdown measures may trigger a resurgence of COVID-19 with a more devastating impact (Ngonghala et al., 2020; Dickens et al., 2020). Some studies have analyzed the combined impact of an imperfect vaccine and NPIs such as SD and face mask use in public on COVID-19 (Gumel et al., 2021; Iboi et al., 2020). Human choices and prevention and control measures during the outbreaks of infection diseases play an important role in the spread and burden of infectious diseases and mitigating the negative impact of such phenomenon on society, meaning that adapting new behaviors and taking preventive measures and precautionary actions, such as wearing face masks, hand washing, and avoiding public transportation and crowded areas conducted by a significant proportion of the population contributed to reducing the rate transmission in societies (Beutels et al., 2009; Lau et al., 2004; Jones and Salathe, 2009; Rubin et al., 2009; d'Onofrio et al., 2016; d'Onofrio and Manfredi, 2020; Shim et al., 2020). So, the behavioral epidemiology of infectious diseases has been studied to shed more light on the relationships between behavioral changes and the dynamics of infectious diseases. (Onofrio and Manfredi, 2020; Onofrio et al., 2016; Funk et al., 2010a; Manfredi and D'Onofrio, 2013; Manfredi et al., 2009; Wang et al., 2016; Choi and Shim, 2020; Ngonghala, Goel, Kutor, and Bhattacharyya, 2021). Agent-based modeling using a fine-grained computational simulation of the ongoing COVID-19 pandemic was conducted in Australia (Chang et al., 2020). This study showed that the effectiveness of school closures was limited (under the assumptions on the age-dependent symptomatic fractions and the infectivity in children). Another implication was related to the SD strategy, which showed little benefit for lower levels of compliance (at 70% or less), these levels do not produce epidemic suppression for any duration of the SD restrictions. Only when the SD compliance levels exceed 80%, there is a reduction in incidence and prevalence. The feasibility of controlling COVID-19 outbreaks by implementing isolation of cases and contacts was studied (Hellewell et al., 2020). In the absence of a COVID-19 vaccine, the potential impact of a number of public health measures (non-pharmaceutical interventions) to reduce COVID-19 mortality and healthcare demand was investigated in two countries: the UK (Great Britain) and the US. The results demonstrated that the effectiveness of any one intervention in isolation is likely to be limited, requiring multiple interventions to be implemented to have a substantial impact on reducing contact rates in the population and transmission of the virus (Ferguson et al., 2020).

Game theory was originally construed by von Neumann and Morgenstern (1944) as an application of mathematics to social situations wherein rational individuals strive for the best possible outcomes under given circumstances. It can be defined as a collection of mathematical models formulated to study decision-making in situations involving conflict and cooperation for finding optimal solutions or stable outcomes (Lucas, 1972). The main intellectual attraction of the game theory is essentially a question of how to act in gaming situations against highly rational opponents (Harsanyi, 1982). The theoretical domain of game uses applied mathematics and economic logic to analyze the interplay of informed, calculating actors in a precise way. The practical domain of game theory concerns the application of its principles to actual human behavior and interactions. The game theory approach, as a decision-making tool in conflict situations, is suggested for planning and adopting optimal prevention strategies against a severe disease infection. Compartmental epidemiological models were combined with the concept of behavioral dynamics from evolutionary game theory (EGT) to investigate the impact of the individual economic costs of public-health measures and the real risk of infection on the spread of an epidemic (Kabir and Tanimoto, 2020). An integrated framework of the COVID-19 transmission dynamics and a multi-strategy evolutionary game approach of individual decision-making was developed to characterize the evolution of human choices in social isolation as the disease progressed and public health control measures such as mandatory lockdowns were implemented. The results illustrated that social distancing (SD) played a major role in reducing the burden of the disease compared to self-quarantine (SQ) and the effectiveness of these strategies in controlling the spread of infections depended on the type of isolation, and the time and period of implementation of the selected isolation measure during the outbreak (Ngonghala, Goel, Kutor, and Bhattacharyya, 2021).

A game-theoretic approach was developed to model the application of the COVID-19 vaccine market with two manufacturers Pfizer-BioNTech and Moderna in the United States. The results indicated that the government can negotiate prices with the manufacturers to keep public sector prices as low as possible while meeting demand and ensuring each manufacturer earns a target profit even in the context of very high production and distribution costs. (Martonosia, Behzad, and Cummings, 2021). A game-theoretic approach was applied to check the impact of vaccination and social distancing as management intervention methods that people pursue the maximization of payoffs on the natural event of COVID-19 (Choi and Shim, 2020). The optimal strategies based on the Nash strategy were determined when both strategies were available and when only one strategy was available. Furthermore, the relative costs of control strategies at which individuals preferentially adopt vaccination over social distancing (or vice versa) were studied. A generalized equilibrium model with stochastic demands was constructed to model competition among organizations at demand points for medical supplies. The model included multiple supply points and multiple demand points, along with prices of the medical items and generalized costs associated with transportation (Nagurney and Salarpour, 2020). Several studies within the soft computing literature used theoretical and empirical approaches to research multiple aspects of the COVID-19 pandemic. These aspects embrace modeling the fast diagnosing (Gianchandani et al., 2020; Murugan et al., 2021), correct detection of Covid‑19 patients management (Mansour et al., 2021)), the importance of carrying high-quality masks (Rosenstrom et al., 2020), ventilator inventory management (Mehrotra et al., 2020), deep transfer learning model (Kumar et al., 2021), COVID-19 classification (Saad et al., 2021)), the impact of COVID-19 on international provide chain performance and food provide chain (Ivanov, 2020; Singh et al., 2020), and plasma donations throughout the COVID-19 pandemic (Nagurney and Dutta, 2020).

In the present study, a kind of static and finite game analytics approach has been developed as an application of mathematics to the social situation of the COVID-19 pandemic in Iran wherein rational individuals strive for the best possible outcomes under the given circumstance. The proposed model has been implemented to design optimal behavioral strategies for Iranian people. The game theory seeks to achieve mathematical behavior through strategic or game conditions in which the success of one's choice depends on the choice of others (Sohrabi and Azgomi, 2020). The players, strategies or moves available to the players, and the payoffs (outcomes) associated with each strategic combination are three key elements of a game. The main assumption of a game-theoretical approach is that all players act rationally to maximize the minimum possible gain or maximize the security level which is called the Mini-max principle. Winning every game is not just about helping luck, it has its own rules and principles. The main rationale for applying a game-theoretical model to study human choices in a battle against COVID-19 is that it can provide an approach to modeling, describing, and documenting the likely outcomes of the adoption of different strategies. The main contribution of game theory is its consideration of rationality, both on the part of the decision-maker and competitors. In recent years the game theory has been used as an analytical tool to gain strategic intelligence and insight into the competitive intentions and behaviors involved in managerial decision-making processes. The main significance of the present study is to develop a discrete game theory model to optimize human self-protection strategies. To this end, a new approach to modeling and forming components of a game is presented by defining the profit and loss functions of each player in adopting specific intervention strategies. Vaccination, self-quarantine, wearing face masks, and social distancing were among the human intervention choices that were adopted in the present study as strategies to control and limit the spread of COVID-19 transmission. The game-theoretic model was developed so as to consider both the costs and benefits associated with disease intervention strategies to identify the individually optimal strategy. By using the game-theoretic models, one can not only examine the impact of human prevention and control measures on the transmission rate of infectious diseases but also determine how individual choices are influenced by the perceived costs of actions and the resulting benefits.

The contribution of current work is:

1) In times of pandemics, people activate ancestral behavioral mechanisms to reduce the risk of infection , also impacting social life
2) Game-theoretical approaches suggest that a significant (and as the pandemic continues) and growing number of people with fail to comply with social rules to keep infection rates low.
3) Accordingly, almost certainly second and third waves of COVID-19 will occur, unless an efficient vaccine will be available on a mass scale.
4) Antisocial punishment poses a threat to public health, as it undermines efforts to control the disease.

The rest of this paper is organized as follows. Section two reviews the proposed mathematical model and the process of data collection and analysis. Section three provides the results, and finally, section four discusses the conclusions and implications of the present study.

2. Methodology

Game theory is a complex, dynamic elaboration of decision theory (Murnigham, 2015). It is an investigation of the interdependent interaction of rational decision-makers or highly strategic parties who are acting in their own best interests (Bazerman 2000). More recently, it has expanded its goals towards the general analysis of potentially conflictual interactions (Murnigham, 2015). Gibbons (1992) identified the players (i.e. stakeholders), information (e.g. records and messages), action (i.e. applied strategy), process (i.e. a sequence of actions), and utility (i.e. payoff or profit) as five elements of the model. There are three ways to represent games: the extensive form, the normal form, and the characteristic function form (Laraki, Renault, and Sorin, 2019; Lucas, 1972). The choice among them stems from the requirement of analysts and researchers. The extensive form focuses on the rules of the game to represent all possible outcomes for all possible plays of each player and to represent the sequential play of the game. The normal form focuses not on the rules of the game and the game tree, but the strategies available to each player and the resulting payoffs. So, a game in normal form is typically represented by a payoff matrix. The strategies available to each player appear as rows and columns of the matrix. The characteristic function form focuses on the formation of possible coalitions among players and the payoffs each coalition could obtain if the players agreed to cooperate (Laraki, Renault, and Sorin, 2019). The formal way to represent the game in this study is the normal form since the focus is not on the rules of the game and the game tree, but on the strategies available to each player and the resulting payoffs. The game theory includes the concept of utility, which concerns a mathematical measure of player satisfaction (Von Neumann and Morgenstern, 1944). In games that involve a settled perform between call and outcome, there is a utility price allotted to the result of every call. An equilibrium (Nash, 1951) considerations a scenario once the sport players cannot improve their payoff by severally dynamic their strategy. This suggests that it's the simplest strategy forward the opposite game player has chosen a technique and cannot modification it (Goldfarb et al., 2012). The equilibrium is going to be reached once the simplest rewards are obtained once the sport happens (Neslin and Greenhalgh, 1983; Sanchez Torres et al., 2018). Before solving the game theory problem, it is necessary to identify the components of the game. These components include the players involved, the strategies available to them, and the payoffs associated with each strategic combination. The main assumption of the proposed model as a game-theoretical approach is that all players act rationally which is taken to mean that they maximize the minimum possible gain or maximize the security level (Bacharach, 1997). The players of the present proposed model were: susceptible humans S, exposed humans E, infectious humans I, and recovered humans R. The susceptible and exposed populations can further be subdivided into non-quarantined and quarantined susceptible humans. The infectious human population can be also subdivided into infectious asymptomatic humans (those who transmit the virus without showing symptoms after the incubation period), infectious symptomatic humans (clinically ill individuals, i.e., individuals who exhibit disease symptoms after the incubation period), and isolated infectious humans (identified symptomatic humans who are self-isolating or who have been placed in isolation in a health care facility. In the present study, these subdivisions were not considered so as not to make the computations so complicated. Vaccination, self-quarantine, wearing face masks and hand washing, and social distancing were among the human behaviors that were adapted in the present study as strategies to limit the spread of infectious diseases, and these strategies were incorporated into a game theory approach.

Table 1: *Human group strategies*

Players	symbols	strategies	symbols
infectious humans(A)	S	Vaccination(S1)	V
exposed humans(B)	E	self-quarantine(S2)	SQ
susceptible humans (C)	I	wearing face masks(S3)	FM
recovered humans(D)	R	social distancing(S4)	SD

Fig 3*: strategies of players*

It was possible for every player to adopt one strategy, two strategies, three strategies or four strategies simultaneously in encountering three other players in a game situation (table 1 and figure 3). So, the total possible number of strategy combinations of any player equaled 16 and as a result, the total possible number of strategy combinations and interactions of four players equaled 256 (4 × 4 × 4 × 4) in the proposed model. The number of players and strategic options of any player were limited to four so as not to trap a high-complicated model. It should be noted that the proposed model is also easily applicable to cases in which more than four strategic option is available but the mathematical computation becomes more complex. The research methodology of the present study can be described in five, main steps. In the first step, the human behaviors and prevention and control measures proposed by World Health Organization during the COVID 19 outbreak and infection to curtail the spread of this infectious disease and mitigating the negative impact of it were taken as the basis to define the as the main strategies of the proposed game theoretical approach. In the second step, the normal form was selected to represent the game since the main focus of the proposed model of this study was not on the rules of the game, and the game tree, but on the strategies available to each player and the resulting payoffs. So, a payoff matrix was designed to represent the game in normal form. A questionnaire was used as the main source of data collection process. The questionnaire was designed according to accepted strategies and principles proposed by World Health Organization and completed by a random sample of population of 384 persons with different gender, age, social, educational, professional, and health background in Isfahan province in Iran. The responders were selected according two criteria from an available random sample. The first criteria were that they had to have the possibility of adopting vaccination as one of their strategies. The other criteria were that the responders had to be selected among those who had been infected by COVID-19 so as to be able to response to all the questionnaire's questions as susceptible, exposed, infectious, and recovered humans. The data analyses of these questionnaires were used as the inputs of the matrix. The strategies available to each player appeared as rows and columns of the matrix. In the third step, a mathematical model, based on the Nash solution, was proposed for a four-player game to specify the interaction of players and determine the equilibrium points of these interactions. In the fourth step, the proposed model was solved using the Taguchi method. In this paper, the proposed model was based on a general finite-discrete game model with multiple players and multiple strategies for which a common equilibrium point is obtained. All players should bargain and should be provided with a security level of d_i (disagreement utility for player i). Nash Bargaining game, proposed by Nash (1950), adapts a cooperative approach to the bargaining problem. In cooperative games, agents bargain before the game is played. If an agreement is reached, agents act according to this agreement; otherwise, agents act non-cooperatively. Nash Bargaining game aims to analyze how agents should cooperate when non-cooperation leads to Pareto-inefficient results, i.e., the case where the results are dominated by other alternatives. A Nash equilibrium concerns a situation where the game players cannot improve their payoff by independently and unilaterally changing their strategy (Nash, 1950). Harsanyi (1959) used the Nash solution for an n-player game that can be presented through what follows.

$$\max \prod_{i=1}^{n} (f_i - d_i) \tag{1}$$

subject to

$$f_i \geq d_i \qquad \forall i \in \{1,\dots,n\} \tag{2}$$

$$f_i \in F_i \qquad \forall i \in \{1,\dots,n\} \tag{3}$$

Where f_i is the utility of player i, d_i is named breakdown point for player i, and F_i is a feasible set of the model. Based on the above model and discussion, the following model is proposed. In order to facilitate the understanding of the mathematical model, sets, parameters, and the decision variables are introduced in the following sections.

2.1 Assumptions

The model in this study has been proposed on the basis of some assumptions that seems necessary to be specified to run the model in real-word situation. These assumptions are presented here:

1- All the parameters are deterministic.
2- The number of strategies is finite.
3- All players act rationally and intelligently.
4- There is conflict of interest between the players.
5- The rules of play are known to all the players.

2.2 Sets and Indexes

$i \in \{1,2,\cdots,n\}$	Index of players (Group of Humans)
$j \in \{1,2,\cdots,m\}$	Index of all pure strategies (V, SQ, FM, and SD)
$j_i \in \{1,2,\cdots,m_i\}$	Index of strategies available to player (Group of Humans) i

2.3 Parameters

d_i	Security level (disagreement utility) for player (Group of Humans) i
$A_{i,j_1,j_2,\dots,j_n}$	Utility of player (Group of Humans) i if the players $1,2,\cdots,n$ choose their strategies as $j_1, j_2, \dots, j_n$

2.4 Variables

f_i	The payoff for player (Group of Humans) i
$t_{j_1,j_2,\dots,j_n}$	Is 1 if the players $1,2,\cdots,n$ choose their strategies as $j_1, j_2, \dots, j_n$

2.5 Mathematical model

$$max\ Z = \sum_i \ln(f_i - d_i) \tag{4}$$

Subject to

$$f_i \geq d_i \qquad \forall i \in \{1, \dots, n\} \tag{5}$$

$$f_i - M * \left(1 - t_{j_1, j_2, \dots, j_n}\right) \leq A_{i, j_1, j_2, \dots, j_n} \qquad \forall i \in \{1, \dots, n\}, \forall\, j_i \in \{1,2, \cdots, m_i\} \tag{6}$$

$$f_i + M * \left(1 - t_{j_1, j_2, \dots, j_n}\right) \geq A_{i, j_1, j_2, \dots, j_n} \qquad \forall i \in \{1, \dots, n\}, \forall\, j_i \in \{1,2, \cdots, m_i\} \tag{7}$$

$$\sum_{j_1} \sum_{j_2} \dots \sum_{j_n} t_{j_1, j_2, \dots, j_n} = 1 \tag{8}$$

$$t_{j_1, j_2, \dots, j_n} \in \{0, 1\} \qquad \forall i \in \{1, \dots, n\}, \forall j \in \{1,2, \cdots, m\}, \forall\, j_i \in \{1,2, \cdots, m_i\} \tag{10}$$

In this model, the objective function is to maximize the total payoff. Constraint (5) states that the payoff of each player (Group of Humans) must be greater than the corresponding security level. Constraints (6) and (7) determine the payoff for each Group of Humans considering the strategies of all groups. Constraint (8) imposes the fact that only one combination of indicators must be selected. Finally, Constraint (9) determines the type of the variables.

3. Result

Based on the research objectives specified above, a two-part questionnaire was used as an instrument to collect data. The first part used a nominal scale, while the rest use a 5-point Likert scale. The first part of the questionnaire was designed to collect information about the respondent's characteristics including gender, age, education, occupation, and health condition. The second part of the questionnaire was designed to measures human intervention choices and preferences of respondents as susceptible humans S, exposed humans E, infectious humans I, and recovered humans R. Vaccination, self-quarantine, wearing face masks, and social distancing was among the human intervention choices that respondents could adopt in the present study as strategies to control and limit the risk of COVID-19 infection and spread of COVID-19 transmission. Each one of the four main strategies was subdivided further and identified in terms of their indicators that were specified by the World Health Organization. As a result, each strategy contained four items and the questionnaire contained 48 questions about the main and subdivided strategies. The questionnaire was reviewed by several researchers and experts to be validated. Expert recommendations were incorporated into the questionnaire. This was done before and after pre-testing. Necessary corrections and adjustments were made before they were used in the actual collection of data in the field. Cronbach's alpha coefficient was used to examine the reliability of the questionnaire. The results showed that the calculated alpha coefficient for the whole questionnaire was 0.82. Considering that the calculated reliability coefficient was more than 0.70, it could be concluded that the questionnaire used had the necessary research reliability. The appropriate sample size was considered to be 384 people according to Cochran's formula with an error of 0.05. 384 questionnaires were given to the responders in two phases. In the first phase, the questionnaires were given to determine the control intervention strategies that individuals pursue the maximization of payoffs at the landing of the COVID-19 pandemic from May 2020 to September 2020. In the second phase, the questionnaires were given to determine the control intervention strategies that individuals pursue the maximization of payoffs at the peak of the COVID-19 pandemic from March 2021 to May 2020. The total number of 384 questionnaires (100%) were completed and analyzed at each phase. The payoff matrix of the four-person game-theoretical model at the landing of the COVID-19 pandemic was given in Table 2. The Layout of the L16 orthogonal array of the Taguchi method at the landing of the COVID-19 pandemic was given in Table 3. Calculate Maximum payoffs at the landing of the COVID-19 pandemic was given in Figure 4. As depicted in these tables and figure, the equilibrium point of this model at the landing of the COVID-19 pandemic was (5, 5, 5, 4) that was acquired when player 1 selected the second strategy (self-quarantine), player 2 selected the fourth strategy (social distancing), player 3 selected the fourth strategy (social distancing), and player 4 selected the fourth strategy (social distancing) to play the game.

Table 2*: payoff matrix of four-person game theory at the landing of COVID-19 pandemic in Iran*

player 1(infectious humans)	player 3 (susceptible humans)	player 2(exposed humans)															
		I				II				III				IIII			
		player 4 (recovered humans)															
I		(2,5,2,2)	(4,1,4,2)	(3,5,5,5)	(4,5,1,1)	(3,5,5,5)	(3,5,5,4)	(1,3,5,1)	(4,3,5,3)	(3,1,3,2)	(2,3,4,1)	(3,5,5,5)	(1,3,5,1)	(3,1,3,2)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)
		(5,2,4,1)	(1,3,4,2)	(4,2,4,1)	(5,2,4,3)	(4,2,4,1)	(2,3,2,2)	(1,3,5,4)	(1,1,3,1)	(3,5,4,1)	(1,1,5,3)	(4,2,4,1)	(1,3,5,4)	(3,5,4,1)	(1,1,5,3)	(1,3,4,2)	(1,3,5,4)
		(1,2,4,4)	(4,1,1,4)	(4,4,2,1)	(1,4,2,4)	(4,4,2,1)	(1,1,2,1)	(2,2,3,2)	(4,3,2,2)	(4,5,3,1)	(1,4,3,2)	(4,2,4,2)	(2,2,3,2)	(4,5,3,1)	(1,4,3,2)	(4,2,2,4)	(2,2,3,2)
		(3,1,3,3)	(3,5,4,2)	(2,3,1,4)	(2,4,1,3)	(2,3,1,4)	(3,5,3,1)	(2,5,3,5)	(2,2,5,4)	(1,3,1,2)	(5,4,3,2)	(2,3,1,4)	(2,5,3,5)	(1,3,1,2)	(5,4,3,2)	(3,5,4,2)	(2,5,3,5)
II		(5,3,1,2)	(3,3,2,1)	(1,1,2,4)	(2,5,4,1)	(1,1,2,4)	(4,1,3,2)	(4,2,4,3)	(3,5,4,2)	(4,1,1,2)	(1,5,4,4)	(1,1,2,4)	(4,2,4,3)	(4,1,1,2)	(1,5,4,4)	(3,3,2,1)	(4,2,4,3)
		(5,2,4,1)	(1,3,4,2)	(4,2,4,2)	(5,2,4,3)	(4,2,4,1)	(2,3,1,2)	(1,3,5,4)	(1,1,3,1)	(3,5,4,1)	(1,1,5,3)	(4,2,4,1)	(1,3,5,4)	(3,5,4,1)	(1,1,5,3)	(1,3,4,2)	(1,3,5,4)
		(1,3,3,3)	(4,1,2,5)	(1,1,1,2)	(1,4,3,3)	(1,1,1,2)	(5,3,2,4)	(4,3,5,3)	(2,3,1,3)	(3,1,1,5)	(3,2,5,5)	(1,1,1,2)	(4,3,5,3)	(3,1,1,5)	(3,2,5,5)	(4,1,2,5)	(4,3,5,3)
		(5,2,4,1)	(1,3,4,2)	(4,2,4,1)	(5,2,4,3)	(4,2,4,1)	(2,3,1,2)	(1,3,5,4)	(1,1,3,1)	(3,5,4,2)	(1,1,5,3)	(4,2,4,1)	(1,3,5,4)	(3,5,4,1)	(1,1,5,3)	(1,3,4,2)	**(5,5,5,4)**
III		(1,3,5,4)	(2,4,1,3)	(1,1,4,1)	(1,2,5,3)	(1,1,4,1)	(1,2,1,5)	(4,4,2,3)	(3,1,3,2)	(3,1,2,3)	(2,5,2,2)	(1,1,4,1)	(4,4,2,3)	(3,1,2,3)	(2,5,1,1)	(2,4,1,3)	(4,4,2,3)
		(2,5,1,2)	(4,1,4,2)	(3,5,5,5)	(4,5,1,1)	(3,5,5,5)	(3,5,5,4)	(1,3,5,1)	(4,3,5,3)	(3,1,3,2)	(2,3,4,1)	(4,5,4,5)	(5,4,5,5)	(2,5,2,2)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)
		(3,3,4,2)	(4,1,4,1)	(1,1,3,3)	(2,3,5,2)	(1,1,3,3)	(3,1,2,3)	(4,4,3,5)	(3,5,4,3)	(1,3,3,3)	(3,4,3,4)	(1,1,3,3)	(4,4,3,5)	(1,3,3,3)	(3,4,3,4)	(4,1,4,1)	(4,4,3,5)
		(2,5,1,2)	(4,1,4,2)	(3,5,5,5)	(4,5,1,1)	(3,5,5,5)	(5,3,5,4)	(2,3,5,2)	(4,3,5,3)	(3,1,3,2)	(2,3,4,1)	(3,5,5,5)	(1,3,5,1)	(3,1,3,2)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)
IIil		(4,3,4,1)	(2,4,1,3)	(1,1,4,1)	(1,2,5,3)	(1,1,4,1)	(1,2,1,5)	(4,4,2,3)	(3,1,3,2)	(3,1,2,3)	(2,5,1,1)	(1,1,4,1)	(4,4,2,3)	(3,1,2,3)	(2,5,1,1)	(2,4,2,3)	(4,4,2,3)
		(2,5,1,2)	(4,1,4,2)	(3,5,5,5)	(4,5,1,1)	(3,5,5,5)	(4,5,5,4)	(1,3,5,1)	(4,3,5,3)	(3,2,3,2)	(2,3,4,1)	(3,5,5,5)	(3,2,3,2)	(3,1,3,2)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)
		(3,3,4,2)	(4,1,4,1)	(1,1,3,3)	(1,2,5,3)	(2,3,3,2)	(3,1,2,3)	(4,4,3,5)	(3,5,4,3)	(1,3,3,3)	(3,4,3,4)	(1,1,3,3)	(4,4,3,5)	(1,3,3,3)	(3,4,3,4)	(4,1,4,1)	(4,4,3,5)
		(2,5,1,2)	(4,2,2,4)	(3,5,5,5)	(4,5,1,1)	(3,5,5,5)	(5,4,5,4)	(1,3,5,1)	(4,3,5,3)	(3,1,3,2)	(2,3,4,1)	(3,5,5,5)	(1,3,5,1)	(3,1,3,2)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)

Table 3 *The Taguchi method for validity: Layout of L16 orthogonal array at the landing of COVID-19 pandemic in Iran*

A	B	C	D	y
1	1	1	1	1.38629
1	2	2	2	0.69315
1	3	3	3	2.19722
1	4	4	4	3.46574
2	1	2	3	2.19722
2	2	1	4	3.17805
2	3	4	1	3.17805
2	4	3	2	3.46574
3	1	3	4	2.07944
3	2	4	3	2.07944
3	3	1	2	1.38629
3	4	2	1	1.38629
4	1	4	2	2.19722
4	2	3	1	1.38629
4	3	2	4	1.38629
4	4	1	3	1.79176

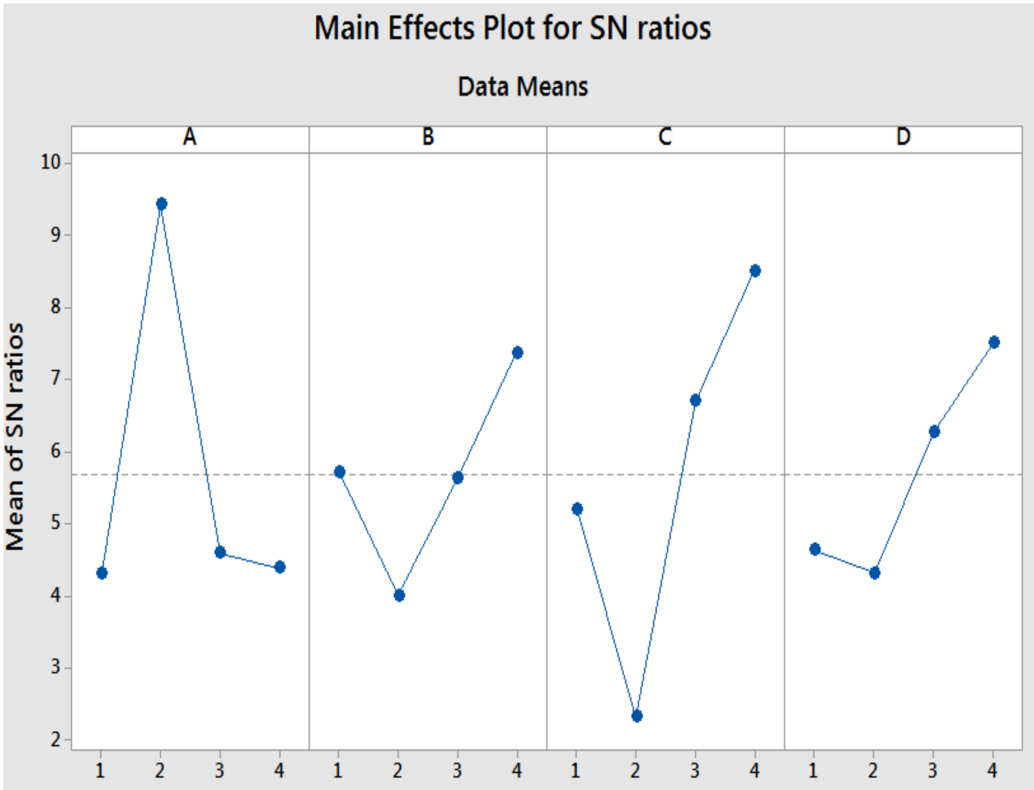

Fig4 calculated Maximum payoffs *at the landing of COVID-19 pandemic in Iran*

Table 3*: payoff matrix of four-person game theory at the peak of COVID-19 pandemic in Iran*

player 1 (infectious humans)		player 3 (susceptible humans)	player 2 (exposed humans)															
			I				II				III				IIII			
			player 4 (recovered humans)															
	I		(2.3,2,2)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)	(3,5,5,5)	(5,5,5,4)	(1,3,5,1)	(4,3,5,3)	(3,1,3,2)	(2,3,4,1)	(3,5,5,5)	(1,3,5,1)	(3,1,3,2)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)
			(3,5,4,1)	(1,1,5,3)	(1,3,4,2)	(1,3,5,4)	(4,2,4,1)	(4,2,2,4)	(1,3,5,4)	(1,1,3,1)	(3,5,4,1)	(1,1,5,3)	(4,2,4,1)	(1,3,5,4)	(3,5,4,1)	(1,1,5,3)	(1,3,4,2)	(1,3,5,4)
			(4,5,3,1)	(1,4,3,2)	(4,2,2,4)	(2,2,3,2)	(4,4,2,1)	(1,1,2,1)	(2,2,3,2)	(4,3,2,2)	(4,5,3,1)	(1,4,3,2)	(5,5,5,4)	(2,2,3,2)	(4,5,3,1)	(1,4,3,2)	(4,2,2,4)	(2,2,3,2)
			(1,3,1,2)	(5,4,3,2)	(3,5,4,2)	(2,5,3,5)	(2,3,1,4)	(3,5,3,1)	(2,5,3,5)	(2,2,5,4)	(1,3,1,2)	(5,4,3,2)	(2,3,1,4)	(2,5,3,5)	(1,3,1,2)	(5,4,3,2)	(3,5,4,2)	(4,2,2,4)
	II		(5,3,1,2)	(3,3,2,1)	(1,1,2,4)	(2,5,4,1)	(1,1,2,4)	(4,1,3,2)	(4,2,4,3)	(3,5,3,5)	(4,1,1,2)	(1,5,4,4)	(1,1,2,4)	(4,2,4,3)	(4,1,1,2)	(1,5,4,4)	(3,3,2,1)	(4,2,4,3)
			(5,2,4,1)	(1,3,4,2)	(4,2,2,4)	(5,2,4,3)	(4,2,4,1)	(2,3,1,2)	(1,3,5,4)	(1,1,3,1)	(3,5,4,1)	(1,1,5,3)	(4,2,4,1)	(1,3,5,4)	(3,5,4,1)	(1,1,5,3)	(1,3,4,2)	(1,3,5,4)
			(1,3,3,3)	(4,1,2,5)	(1,1,1,2)	(1,4,3,3)	(1,1,1,2)	(5,3,2,4)	(4,3,5,3)	(2,3,1,3)	(3,1,1,5)	(3,2,5,5)	(5,5,5,5)	(4,3,5,3)	(3,1,1,5)	(2,2,4,5)	(4,1,2,5)	(4,3,5,3)
			(5,2,4,1)	(1,3,4,2)	(4,2,4,1)	(5,2,4,3)	(4,2,4,1)	(2,3,1,2)	(1,3,5,4)	(1,1,3,1)	(2,2,3,5)	(1,1,5,3)	(4,2,4,1)	(1,3,5,4)	(3,5,4,1)	(1,1,5,3)	(1,3,4,2)	(5,5,5,4)
	III		(3,1,2,3)	(2,5,2,2)	(1,1,4,1)	(4,4,2,3)	(1,1,4,1)	(1,2,1,5)	(4,4,2,3)	(3,1,3,2)	(3,1,2,3)	(2,2,3,5)	(1,1,4,1)	(4,4,2,3)	(3,1,2,3)	(2,5,1,1)	(2,4,1,3)	(4,4,2,3)
			(3,1,3,2)	(2,3,4,1)	(4,5,5,5)	(1,3,5,1)	(3,5,5,5)	(5,5,5,4)	(1,3,5,1)	(3,5,3,5)	(3,1,3,2)	(2,3,4,1)	(4,5,5,5)	(1,3,5,1)	(2,4,2,3)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)
			(1,3,3,3)	(3,4,3,4)	(1,1,3,3)	(2,2,3,5)	(1,1,3,3)	(3,1,2,3)	(4,4,3,5)	(3,5,4,3)	(1,3,3,3)	(3,4,3,4)	(1,1,3,3)	(4,4,3,5)	(1,3,3,3)	(3,4,3,4)	(4,1,4,1)	(4,4,3,5)
			(3,1,3,2)	(2,3,4,1)	(3,5,5,5)	(1,3,5,1)	(3,5,5,5)	(5,3,5,4)	(2,2,3,5)	(4,3,5,3)	(3,1,3,2)	(2,3,4,1)	(3,5,5,5)	(1,3,5,1)	(3,1,3,2)	(2,3,4,1)	(4,1,4,2)	(1,3,5,1)
	IIiI		(4,3,4,1)	(2,4,1,3)	(1,1,4,1)	(1,2,5,3)	(1,1,4,1)	(1,2,1,5)	(4,4,2,3)	(3,1,3,2)	(3,1,2,3)	(2,5,1,1)	(1,1,4,1)	(2,2,3,3)	(1,1,4,1)	(1,2,1,5)	(2,2,3,3)	(3,1,3,2)
			(2,5,1,2)	(4,1,4,2)	(3,5,5,5)	(4,5,1,1)	(3,5,5,5)	(5,5,5,4)	(1,3,5,1)	(4,3,5,3)	(3,2,3,2)	(2,3,4,1)	(3,5,5,5)	(4,2,5,3)	(3,5,5,5)	(5,5,5,4)	(1,3,5,1)	(4,3,5,3)
			(3,3,4,2)	(4,1,4,1)	(1,1,3,3)	(1,2,5,3)	(2,2,3,3)	(3,1,2,3)	(4,4,3,5)	(3,5,4,3)	(1,3,3,3)	(3,4,3,4)	(1,1,3,3)	(4,4,3,5)	(2,2,3,3)	(3,1,2,3)	(4,4,3,5)	(3,5,4,3)
			(2,5,1,2)	(2,2,3,3)	(3,5,5,5)	(4,5,1,1)	(3,5,5,5)	(5,4,5,4)	(1,3,5,1)	(4,3,5,3)	(3,1,3,2)	(2,3,4,1)	(3,5,5,5)	(1,3,5,1)	(3,5,5,5)	(5,4,5,4)	(1,3,5,1)	(4,3,5,3)

Table 4: *The Taguchi method for validity: Layout of L16 orthogonal array at the peak of COVID-19 pandemic in Iran*

A	B	C	D	Y
1	1	1	1	0.69315
1	2	2	2	2.19722
1	3	3	3	5.2575
1	4	4	4	2.19722
2	1	2	3	2.19722
2	2	1	4	4.15888
2	3	4	1	2.07944
2	4	3	2	2.48491
3	1	3	4	2.07944
3	2	4	3	2.07944
3	3	1	2	2.07944
3	4	2	1	1.79176
4	1	4	2	1.38629
4	2	3	1	1.38629
4	3	2	4	1.38629
4	4	1	3	1.38629

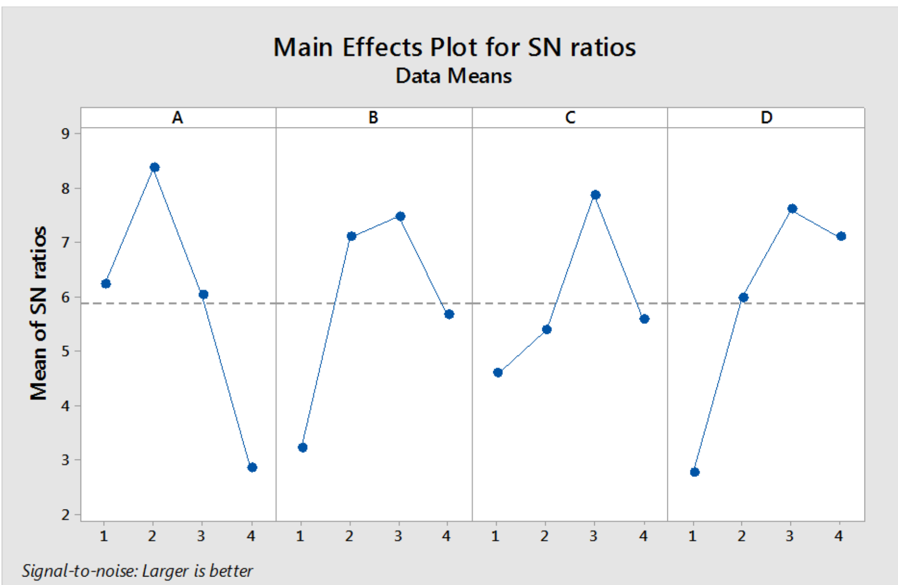

Fig5 calculate Max payoff *at the peak of COVID-19 pandemic in Iran*

The payoff matrix of the four-person game-theoretical model at the peak of the COVID-19 pandemic was given in Table 3. The Layout of the L16 orthogonal array of the Taguchi method at the peak of the COVID-19 pandemic was given in Table 4. Calculate Maximum payoffs at the peak of the COVID-19 pandemic was given in Figure 5. As depicted in these tables and figure, the equilibrium point of this model at the peak of the COVID-19 pandemic was (5, 5, 5, 5) that was acquired as an optimal point when player 1 selected the second strategy (self-quarantine), player 2 selected the third strategy (wearing face masks), player 3 selected the third strategy (wearing face masks), and player 4 selected the third strategy (wearing face masks) to play the game.

4. Conclusions

Game theory was developed by mathematical and economic theorists in an attempt to examine and explain choice behavior among competing individuals. Game theory has the potential for application to strategic choices made by decision-makers, as it explicitly considers the strategic interplay among competitors, their behavioral intentions, and the obtainable payoffs (Lucas, 1972). In this study, we developed a theoretical model to assess the impact of human response to certain personal intervention strategies (i.e., vaccination, self-quarantine, wearing face masks, and social distancing) on the evolution of the COVID-19 pandemic burden in two phases, once at the peak of epidemic and one another at the landing of the epidemic. The model was set up such that individuals could choose multiple strategies to strike a balance between reducing the burden of the pandemic (e.g., reducing the transmission of the disease and consequently the daily number of confirmed cases, hospitalizations, and deaths), and not overrunning down their economies. The human choice of intervention measures has a direct impact on the success of the measure as it can influence the outbreak size and duration of the pandemic. The optimal choices of each player in the gaming situation of the proposed model at the peak of COVID-19 pandemic to reach an equilibrium point was determined when the infectious human I as the first player selected the self-quarantine strategy, the exposed human E as the second player selected the mask-use strategy, the susceptible human S as the third player selected the mask-use strategy, and the recovered human R as the fourth player selected the mask-use strategy. The optimal choices of each player in the gaming situation of the proposed model at the landing of COVID-19 pandemic to reach an equilibrium point was determined when the infectious human I as the first player selected the self-quarantine strategy, the exposed human E as the second player selected the social distancing strategy, the susceptible human S as the third player selected the social distancing, and the recovered human R as the fourth player selected the social distancing strategy. Parameters like the efficacy of vaccination, social distancing, wearing face masks, and self-quarantine, high level of vaccination, social distancing, wearing face masks, and self-quarantine compliance, and the detection rate of exposed asymptomatically infectious individuals play crucial roles in reducing the basic reproduction number. Our analysis indicates that for a substantial reduction in disease burden, adopting several strategies and performing them with a high level of compliance by a major proportion of the population is crucial.

Our study revealed that social distancing of exposed, susceptible, and recovered humans, self-quarantine of susceptible and infectious humans, and vaccination of exposed and recovered humans were more effective in mitigating the burden of the COVID-19 pandemic and limiting the transmission rate. As reported in previous studies (Chang et al., 2020; Ngonghala et al., 2020), social distancing with a high level of compliance was very effective in reducing the number of effective contacts in the population and the size of the peak of the pandemic, and also delaying the time at which the peak occurs, thereby protecting healthcare systems from being overwhelmed, while pharmaceutical interventions, e.g., antiviral drugs and vaccines are being developed. The perceived cost of each strategy was a critical point in adopting that strategy. It seems that people prefer to adopt social distancing and mask-use strategies than self-quarantine and vaccination to reduce the cumulative incidence at lower individual cost (Chang et al., 2020; Ferguson et al., 2020; Ngonghala et al., 2020). The results of the present study also indicated that Individuals with a higher risk of severe complications from COVID-19, individuals who are more than 60 years old, and those with underlying conditions such as cardiovascular disease or diabetes mellitus, chronic lung disease, cancer, cerebrovascular disease or immunosuppression observed these prevention and control measures especially social distancing with high levels of compliance.

The most relevant issue is continuing medical education of the public about Covid 19 to minimize the risk of defection and the spread of false information. • Regulation of social distancing and other measures that prevent virus transmission (e.g. compulsory face masks) is imperative. A lesson learnt from game theory is that this must entail punishment for non-compliance. Preparation for a second (and third) wave is warranted, as well as for secondary health issues that may affect vulnerable or at-risk populations most, including psychological problems following prolonged social isolation.

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