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An Analytical Model for Confronting the Omicron Variant During COVID-19 Pandemic: A System Dynamic Approach

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A B S T R A C T

The global outbreak of COVID-19 began in December 2019 in Wuhan, China, and affected the entire world in a short time. Over time, the emergence of new species of the disease, the pace of response to it has also strongly affected, and with the emergence of the newest species called Omicron. Knowing and reviewing the system and publishing publications in the community is essential for sound policies. It is necessary to investigate the spread of COVID-19 to make proper policies. System dynamic can be adopted as an approach to the behavior evaluation of the COVID-19 pandemic. The present study introduces a system dynamic model to explore the effects of different factors on the pandemic and therapeutic and non-therapeutic modalities. Vaccination is evaluated as the main approach to prevent the disease. The influential factors of pandemic prevention and control are examined based on the SEIR model and policies such as vaccination. The safest way to prevent this epidemic is vaccination. Therefore, a policy that benefits the entire population and will be necessary is producing and purchasing vaccines. From 19 July 2021, the rate of vaccine imports to Iran has increased significantly, and therefore it is predicted that by the end of 2022, Iran's general vaccination will end, after which the number of cases and mortality rates will decline. Vaccines are the ultimate solution to contagious diseases to control disease spread and provide safety to deal with the infection. The results suggested that the fatality rate of the susceptible population was reduced by vaccination and protective protocols. Thus, this paper aims to analyze factors influencing the spread of COVID-19 and prevent the disease.

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1. INTRODUCTION

A total of six human corona virus types were detected during 1960-2019, including HCoV-229, OC43, HKU1, and NL63 [1]. A large number of severe pneumonia cases were detected in December 2019 in Wuhan, China. They were the first infected people in Wuhan. Then, the seventh type of corona virus was identified and announced as SARS-CoV-2 (also known as COVID-19) [1]. Initial epidemiological research showed that the disease was rapidly spreading. As can be seen in Figure 1, COVID-19 spread throughout China in January and February 2019 and affected some other countries [2].

Flights between China, the United States, Europe, and some other parts of the world transmitted the virus to Asian countries and then to the other continents [3]. As SARS-CoV-2 spread in Wuhan, the Ministry of Health and Medical Education began to check passengers arriving from China in Iran. As of July 15, 2020, a total of 13,119,239 confirmed cases were reported in at least 213 countries, with a total of 573,752 deaths. The first SARS-CoV-2 death case was reported in Qom, Central Iran, in February 2020 [4, 5]. World Health Organization (WHO) announced the disease as the COVID-19 pandemic and requested all countries to enhance control attempts concerning the largest global health emergency condition in the modern era [6][1].

WHO stated that early diagnosis and treatment were crucial and effective factors to control the spread of the pandemic. Today, most studies focus on the clinical characteristics, epidemiology, nucleic acid diagnosis methods, gene sequencing, medication effectiveness, and

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[1] https://www.who.int/en/activities/tracking-SARS-CoV-2-variants

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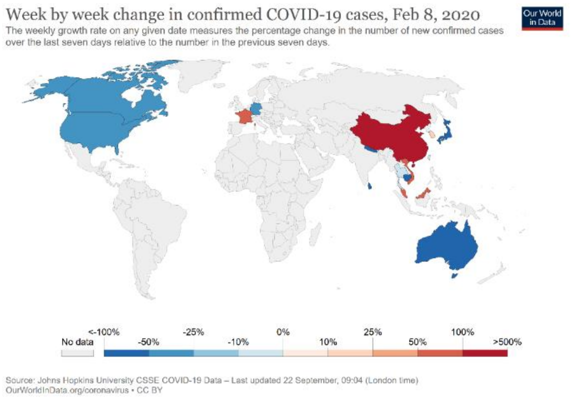

Figure 1. The first countries to be affected by the COVID-19 pandemic on February 8, 2020

other aspects of COVID-19 patients. However, there still is a need for the in-depth discussion of early diagnosis, early screening, early treatment, and early isolation and improvement concerning COVID-19 [7]. Thus, the present study seeks to evaluate factors influencing the spread of COVID-19 and prevent it by analyzing the data of COVID-19 infection and fatality rates.

COVID-19 is transmitted by breathing and touching, and its symptoms include fever, coughing, sore throat, tiredness, and digestive symptoms such as diarrhea, vomiting, and stomach ache. Digestive symptoms may appear earlier than respiratory symptoms [8]. The virus can be transmitted in different ways, depending on its type. In some cases, the virus is transmitted between humans through coughing and sneezing, as similar to flue virus. However, the probability of virus transmission is very small outdoors. The human-to-human transmission of COVID-19 has been found to occur in indoor places with long exposure to infected individuals (such as those who are in close contact with patients at hospitals). To cope with the COVID-19 pandemic, many countries have implemented preventive measures, such as isolation and social distancing, mainly to prevent the rate of hospitalization and reduce stress and pressure imposed on the healthcare workers. It also remains a crucial concern to protect healthcare workers from injections.

These measures, however, have resulted in the isolation of public life and induced many problems. The incomes of the population are a significant economic challenge imposed by the pandemic and have caused an economic gap between countries [9]. Thus, it is essential to shorten quarantine period[3].

The policy response of Iran to the COVID-19 pandemic indicates how countries that already have challenges deal with severe crises. The Iranian government had already been weakened economically by U.S. sanctions and had to consider short-term exchanges of public health and social stability with unemployment and food insecurity, which is used to justify a policy from economic decline to economic lasting. It has been revealed that explanations for the initially inefficient response of Iran to the COVID-19 pandemic included poor economic policies, a lack of public health coordination, treatment priority over prevention, and insufficient healthcare facilities.

At the beginning of the pandemic, a lack of vaccines led to a set of political interventions, such as travel bans, border restrictions, mandatory quarantine, screening protocols, mask regulations, and social distancing measures [10]. However, Iran experienced several waves of the COVID-19 pandemic as public protective protocols were not efficiently implemented. Although vaccination began on February 8, 2021, Iran underwent new waves of the pandemic due to the significantly slow rate of vaccination, as shown in Figure 2. Thus, the fatality and infection rates of COVID-19 did not decline in Iran.

The COVID-19 pandemic is a global crisis with adverse health, commercial, and social impacts. Vaccination is a safe, simple, and effective approach to diminish COVID-19 fatality [10]. Figure 3 depicts the shares of vaccinated populations until November 21, 2021, in different countries. As can be seen, more than 69% of the population was fully vaccinated in the UK and Germany, while 61% of the US population received full vaccination. Also, 47.6% of the world's population had been fully vaccinated. In the Middle East, 59.2% of the Iranian population was fully vaccinated. As shown in Figure 4 until December 19, 2021, over 100 million people received at least one vaccine dose in Iran.

Several vaccines have been developed and approved for emergency use since COVID-19 emerged. The current vaccines have shown effectiveness with a slight risk of side effects. However, some new variants of COVID-19 (such as the delta and lambda variants) may

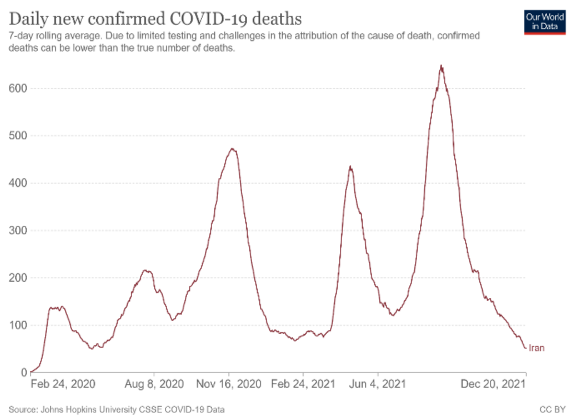

Figure 2. COVID-19 fatality and waves in Iran

[3] http://joc.kntu.ac.ir/article-1-824-en.html

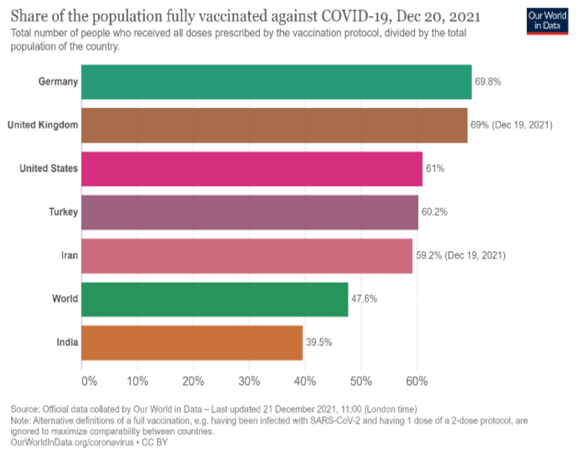

Figure 3. COVID-19 vaccination rates on November 21, 2021

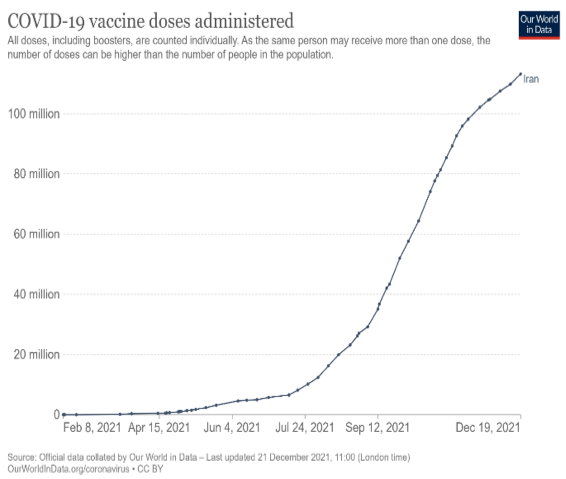

Figure 4. Vaccination in Iran

escape immunity extracted by the vaccines [10]. Having been one and a half years since the emergence of the pandemic, the mutations significantly facilitated the transmission of the disease compared to the initial virus detected in Wuhan in late 2019.

The delta variant of COVID-19 was recently detected in India and has been reported to be much more likely to be transmitted to individuals than its previous mutations. The delta variant infects a much larger number of individuals and increases the transmission chain. As a result, the fatality rate rises at a large rate compared to other viruses.

Researchers are still focused on the delta variant as the dominant COVID-19 variant in the world with increasing infected cases. Research has shown that the delta variant is more infectious than the alpha variant reported in the UK, representing the most transmittable variant of SARS-CoV-2 [11]. This has reduced the effectiveness of two doses of the Pfizer vaccine to 64%. Many countries have significant unvaccinated populations, and the delta variant has proved to infect a larger portion of the vaccinated population than the previous variants. WHO classifies the delta variant as a variant of concern (VOC); that has proved to increase transmutability, causing severer diseases or reducing the advantages of vaccines and treatments.

A more recent variant of COVID-19 was detected as the lambda variant in Peru. Infections with the lambda variant were reported in December 2020. The lambda variant has been considered to be a potential threat. However, some infectious disease specialists claimed that the lambda variant may be weakening as the number of lambda-infected cases reported to the GISAID database has been declining. The previous variant (Alpha, Beta, Gamma and Delta) resulted in a new wave of pandemic and thousands of deaths in more than one country and area, and even across the whole world[4]. On November 26, 2021, a new variant named Omicron immediately raised global concerns [12]. The present study proposes a system dynamic (SD) model to explore the effects of different factors on the spread of COVID-19 and therapeutic and non-therapeutic modalities and policies adopted to reduce the spread of the pandemic.

Dynamic modeling of the system has been used to study infectious diseases, such as human immunodeficiency virus (HIV) transmission [13, 14]. This environment is also used to study the disease on the economy [15] and the policy of migrant workers on the growth of the country under the influence of the COVID-19 epidemic [16]. In addition, dynamic system modeling has been simulated to explain the social effectiveness of COVID-19 laws in selected areas of Japan [17] and the spread of COVID-19 in Italy, India, South Korea and Iran [18]. Another study proposed a SEIR model to demonstrate the dynamic behavior of the disease at the regional level [19] and to model possible pathways resulting from Quid 19 and non-pharmacological interventions in the United States [20]. Due to the acceptable and low system dynamics, this study develops dynamic system modeling based on a model designed by Tom Fidaman to evaluate the various policies of the Iranian government.

2. LITERATURE REVIEW

A large number of studies have been conducted on cultural, economic, and medical aspects of the COVID-19 pandemic to prevent and mitigate it since late 2019. Researchers recently reported COVID-19 simulation models, such as SD for COVID-19, and the outcomes of possible interventions.

[4] https://www.who.int/en/activities/tracking-SARS-CoV-2 variants

Geier and Geier [21] in 2020 studied respiratory conditions of COVID-19. They proposed alternative treatments using the existing clinical methods, e.g., hyperbaric oxygen therapy, packed red blood cells, and anthroponosis stimulator treatment [21]. Ali and Alharbi [22] in 2020 investigated COVID-19 and its management, treatment, and social impacts. They suggested that the combined use of antiviral medications, hydroxychloroquine, and azithromycin as the most effective alternative to treat patients [22]. Bastos and Cajueiro [23] in 2020 predicted the primary evolution model of the pandemic using data from February 25 to March 30, 2020, in Brazil. They employed two susceptible-infected-recovered (SIR) models and simulated a parameter involving social measures. The SIR model divided the population in disease spread into three groups: (1) susceptible are those who are healthy but can be infected, (2) infected are those who are infected, and (3) recovered refers to people that have been recovered from the disease. They estimated the SIR model using the existing parameters and data [23].

Chanu and Singh [24] in 2020 studied public data of Indian COVID-19 patients and analyzed the possible impacts of quarantine and social distancing under the susceptible-exposed-quarantine-infected-recovered (SEQIR) to represent control policies. The SEQIR model divides the population into five groups: susceptible, exposed, and infected while not being test-detected, quarantined, hospitalized/reported/quarantined infected, and recovered people along with those who live in secured zones free of the pandemic. Pruyt and Hamarat [25] in 2020 developed an SD model of COVID-19 spread. The stringent age-structured model endogenously received disease transmission paths and significantly extended from the standard susceptible-exposed-infected-recovered (SEIR) model. The model was customized for India using a suitable population pyramid, contact matrix, foreign arrival, and some other calibration fractions based on the reported Indian COVID-19 cases. Through time-variant pyramids, they explicitly modeled the effects of testing, contact tracking, positive COVID-19 patients, quarantine, masks, and social distancing by reducing contact in certain places (e.g., home and workplace).

Ghaffarzadegan and Rahmandad [26] in 2020 proposed a dynamic, simple model of the epidemic in Iran to represent a more reliable image of the disease based on the existing data. They employed the SEIR model and incorporated behavioral and logistic considerations. First, they reported endogenous variations in contact (contact with people) as higher fatality. As a result, the number of reproductions endogenously changed in the model. Second, they distinguished the reported and real cases by simple formulations to detect only a fraction of the cases and how the fraction would change in response to epidemic progress. Sy et al. [27] in 2020 proposed policy recommendations through an SD approach. The developed model captured relationships, feedback, and delays in the disease transmission system. The dynamism of several policies was analyzed based on effectiveness in reducing infection and consequent economic pressure. Indeed, they are important to respond to the disease. Relationships were established between these factors in the SD framework and then were simulated as stock and flows. However, it is worth mentioning that SD values are not predictions. Instead, SD is used to represent the trends of variables with time under the existing feedback in the system.

Gkini [28] in 2020 examined the population-level coupled dynamics of COVID-19 infection and behavioral response in Norway. They developed an SD model that proposed alternations in the epidemiologic models of classical differential equations for more efficient use in the case of COVID-19. They sought to gather health behavior theories on individual responses to environmental well-being threats. The two components of the model were studied individually and collectively and were found to accurately replicate COVID-19 spread in Norway with rational assumptions. In particular, they constructed a simulation model capturing many common components in health behavior theories within a composite framework that could enable tests under various assumptions. Zia and Farooq [29] in 2020 simulated an SD model of epidemic progress that represented the mode dynamics of COVID-19 spread and handled population and mobility data. The model was calibrated based on epidemic data and particular incidents in Pakistan and could be generalized. The simulations produced disturbing results and revealed that the pandemic would significantly spread for a long time (even longer than a year), even under social distancing and testing strategies. In a specific scenario, they imitated 95% of the isolation of infected patients with symptoms. The 5% probability of infecting others was really lower (only 2.5%). Asymptomatic patients could infect people with a probability of 5% only due to the lockdown. The results indicated that 40% of the population was infected rather than being similar to cases in the previous group.

Hadiwibowo et al. [30] in 2020 analyzed the COVID-19 prediction peak by selecting scenarios. System dynamics prediction was enhanced by selecting scenarios to observe the prediction. Thus, the probability of COVID-19 cases in business could be typically found (including typical control, optimistic, and even uncontrolled situations). Medium conditions with precautious contact, implementing protective protocols (such as the healthy life movement), social distancing, disinfection, sufficient medical equipment and healthcare facilities, home settlement, and working at home could smoothly reduce the rate of infection.

Fathollahifard et al. [31] in 2021 examined the Home Health Care Supply Chain (HHCSC). This paper develops a bi-level programming model as a static Stalkberg game between nurses and patients within the HHCSC framework. From HHCSC's point of view, pharmacy location, nurses' scheduling and routing, and drug delivery rate have always been important issues, so this model considers the possibility of outsourcing demand and applies to emergencies such as the COVID-19 pandemic outbreak. In this situation, the demand for HHC services has increased and is beyond the capacity of the centers. In this regard, the proposed model can be used and outsourcing can be provided. In coronary conditions, vaccination is one of the most important factors to consider, for example, in order to expedite vaccination in Canada, vaccination services were provided in both pharmacies and hospitals [21]. In another paper, Fathollahifard et al. [32] in 2022, in this paper present a model for robust multi-objective optimization for a routing optimization problem and scheduling for the use of a home health care logistics network. The benefits of an efficient design are critical to responding to or responding to epidemics such as COVID-19. Due to the need for social distance during COVID-19, these services are very useful for reducing epidemic growth [32]. Due to the prevalence of COVID-19, Mosallanejad et al. [33] in 2021 have simultaneously developed a multi-objective, multi-product and multi-period model for the needs of personal protective equipment with the aim of optimizing total cost and scarcity.

Reviewing the literature on this subject, it was found that there are research gaps such as the lack of simultaneous study of the impact of quarantine and vaccination on the pandemic system using the systems dynamics approach. Therefore, this study investigates the effect of various factors on the prevalence of COVID-19 disease and ways to control or reduce its incidence and finally a system dynamics model is presented. The data required in this study to analyze the model are taken from official sources, the Ministry of Health of Iran, the World Health Organization and other articles presented in this field as Table 1.

TABLE 1. Research in the field of COVID-19

#	Authors	Year	Title	Approach	Case Study	Vaccine	Quarantine
1	Geier and Geier [21]	2020	Respiratory Conditions in Corona virus Disease 2019 (COVID-19): Important Considerations Regarding Novel Treatment Strategies to Reduce Mortaliy.				
2	Ali and Alharbi [22]	2020	COVID-19: Disease,Management, Treatment, and Social Impact.				✓
3	Bastos and Cajueiro [23]	2020	Modeling and forecasting the early evolution of the COVID-19 pandemic in Brazil.	Susceptible, Infected, Recovered (SIR)model	Brazil		
4	Chanu and Singh [24]	2020	Stochastic approach to study control strategies of COVID-19 pandemic in India.	Susceptible, Exposed, Quarantine, Infected, Recovered (SEQIR)model	India		✓
5	Pruyt and Hamarat [25]	2020	The Influenza A(H1N1) Pandemic: An Exploratory System Dynamics Approach.	Exploratory System Dynamics model	India	✓	
6	Ghaffarzadegan and Rahmandad [26]	2020	Simulation-based Estimation of the Spread of COVID-19 in Iran.	Susceptible, Exposed, Infected, Recovered (SEIR)model	Iran		
7	Sy et al. [27]	2020	Policy Development for Pandemic Response Using System Dynamics: a Case Study on COVID-19.	Susceptible, Infected, Recovered (SIR)model			✓
8	Gkini [28]	2020	Health Behaviour Theories and The Norwegian Response to COVID-19: A System Dynamics Modeling Approach.	SEIR model	Norway	✓	
9	Zia and Farooq [29]	2021	COVID-19 Outbreak in Pakistan: Model-Driven Impact Analysis and Guidelines.	Susceptible, Exposed, Infected, Recovered (SEIR)model	Pakistan		✓

10	Hadiwibowo et al. [30]	2021	A Policy Strategy Evaluation for Covid Pandemic in the City of Surabaya Using Vensim Ventana Dynamic System Simulation.	Susceptible, Exposed, Infected, Recovered (SEIR)model	Indonesia		
11	Fathollahi-Fard et al. [31]	2021	Sustainable and Robust Home Healthcare Logistics: A Response to the COVID-19 Pandemic,	multi-objective optimization model	Austria		
12	Mosallanezhad et al. [33]	2021	Disaster relief supply chain design for personal protection equipment during the COVID-19 pandemic,	multi-objective, multi-product, and multi-period model	Iran		
13	Fathollahi-Fard et al. [32]	2022	Bi-level programming for home health care supply chain considering outsourcing.	bi-level programming model	Iran		
14	Muniyappan et al. [34]	2022	Stability and Numerical Solutions of Second Wave Mathematical Modeling on COVID-19 and Omicron Outbreak Strategy of Pandemic: Analytical and Error Analysis of Approximate Series Solutions by Using HPM	homotopy perturbation method	India		
15	Present research	Under review	An analytical model for confronting the Omicron variant during COVID-19 pandemic: A system dynamic approach	System Dynamic, Susceptible, Exposed, Infected, Recovered (SEIR)model	Iran	✓	✓

The second part of this research reviews the literature and research background in this field, then in the third part, the method is explained, and in the fourth part, the result. The fifth part reviews Discussions and managerial insights and in the sixth part, conclusion is presented.

3. METHODS

The research method for developing prototypes and scenarios is dynamic system-based simulation with Vensim Ventana software. Dynamic systems simulation is a method used to transform real phenomena into clearer models whose systems will change over time. According to this method, this section is divided into 7 subsections, which first define the problem and provide a general explanation related to the simulation of dynamic systems, and then the data collection methods in this research are reviewed. In the continuation of this section, the existing initial model is developed and finally validation is performed.

3. 1. Problem Statement Contagious diseases pose essential impacts on the economy and physical and mental health of people. Many societies need to identify system behavior and disease spread to plan and cope with diseases. It is important to realize the behavior dynamic of disease spread to enhance healthcare systems and health workers. SD is a well-known, efficient approach to studying system behavior in the spread of diseases.

Infectious disease specialists view population composition, society culture, environment, and government responsiveness as the four major factors that potentially influence the spread of COVID-19 in a region. Also, personal protective measures, such as wearing a mask, consistently washing hands, and avoiding human crowds, can play a key role in preventing the spread of COVID-19[5]. The responsiveness of governments also plays an important role in COVID-19 spread, and countries that rapidly responded to the COVID-19 pandemic by implementing quarantine and social distancing experienced lower causalities.

The present study develops a model of vaccination based on the existing research gaps and a base model. To obtain a more realistic model, constant or auxiliary parameters were derived from the databases of the WHO and the Ministry of Health and Medical Education, drawing the stock-flow diagram of the key variables and reference behaviors and formulating the epidemic simulation model. The model was validated, and the sensitivity of the model to parameters, initial conditions, and boundaries was analyzed.

3. 2. System Dynamic System Dynamic (SD) is an aspect of systems theory and is used to understand dynamic and continuous behavior in complex systems. It is a methodology of simulation to determine frameworks and understand and discuss complex management, industrial, social, and even medical factors [33].

Due to the COVID-19 pandemic, researchers seek to realize how simulation instruments can help decision-

[5] https://www.who.int/en/activities/tracking-SARS-CoV-2 variants

makers deal with this very complex crisis [12]. Introduced by Foster, SD helps understand the relationships between the components of a system and represents dynamic behaviors through several feedback loops [34]. In particular, it is very beneficial as it enables policy-makers to accurately implement policies and detect their complex relationships, revealing the potential effects of alternative policies to make more efficient decisions [35].

In general, systematic mathematical models are an efficient framework to mitigate and control COVID-19, as with other contagious diseases. The spread of contagious diseases is very complicated and involves interconnected systems with feedback loops, delays, and nonlinear relationships. It is difficult to predict the behavior of such systems. Detailed modeling methods, such as SD, can be employed to illustrate spread dynamics and simulate spread behavior. Also, public health workers believe that systematic approaches such as SD are valuable in the design of effective policies [36]. The present study aims to develop an SD model and analyze the effects of factors on the spread of COVID-19 and therapeutic and non-therapeutic modalities and policies for the reduction of the pandemic.

3. 3. Data Collection Data from the onset of the pandemic in Iran to February 20, 2020, was introduced to the developed model. To obtain consistently varying data, such as disease progression rate, recovery rate, and fatality rate along with vaccination rate, the WHO database was utilized. It should be noted that the COVID-19-infected patients initially have no symptoms but gradually show symptoms. COVID-19 has an incubation period of 2-14 days (5 days on average). Furthermore, the rate of transmission in the incubation period is low. Recovery periods of 1-3 weeks have been reported. Research has shown that COVID-19 patients recover within 14 days on average [37].

3. 4. Modeling A SD simulation approach was adopted to develop the model and policy scenarios in Vensim. SD simulation is used to translate real phenomena into more explicit models of time-variant systems. The model was constructed for Iran based on the basic SEIR model and the framework of Hadiwibowo et al. [30] model. To obtain more realistic outputs, the vaccination rate and the effectiveness of government policies were incorporated into the model.

Modeling was implemented in the form of a causal loop diagram and then a stock-flow diagram. Once the causal loop diagram had been plotted, the stock-flow diagram was developed by applying formulations in Vensim. Figure 5 illustrates the causal loop diagram., whereas

3. 5. Base Model The SEIR model was employed as the base model to implement the SD analysis of COVID-19 spread. It is a well-known framework for investigating the spread of diseases. Figure 6 shows the SEIR framework. As can be seen, SEIR involves susceptible, exposed, infected, and recovered individuals [38]. The components of the SERI are described as:

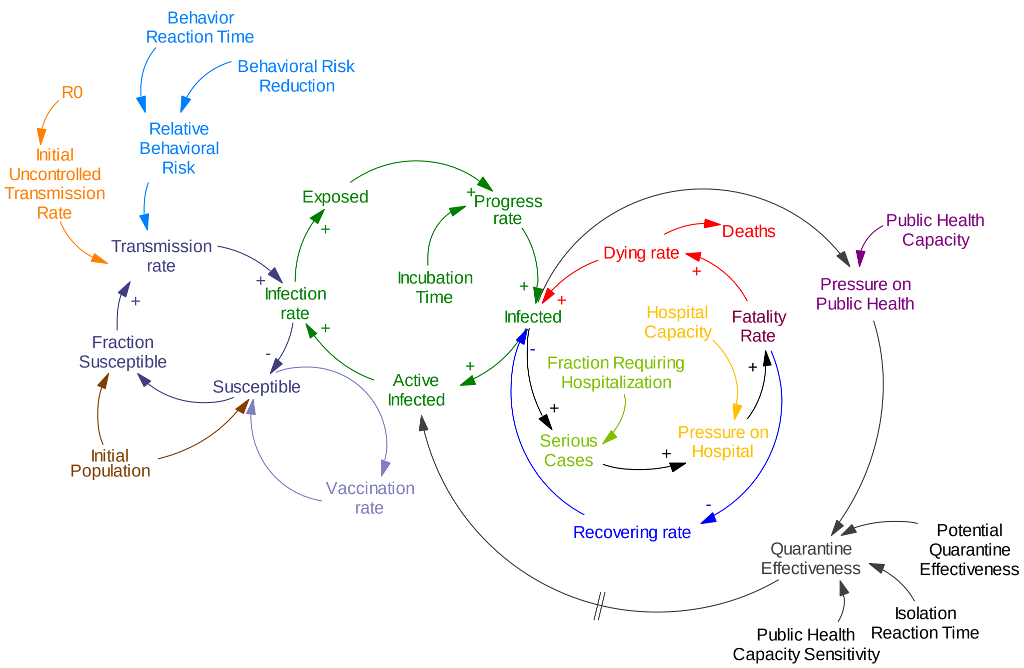

Figure 5. Causal loop diagram

Susceptible: Considering the nature of COVID-19, the initial population (the total Iranian population) was assumed to be susceptible. The infection rate in the base model was deducted from the susceptible population. Also, contact rate and infectivity influence the spread of COVID-19.

- Exposed: It refers to the accumulated rate of exposed people. However, the number of infected people is subtracted from the exposed people through the disease progression rate.
- Infected: It is the accumulated rate of infected arrivals into the country and progression rate. However, the recovery and fatality rates are subtracted from the infected people.

Recovered: It is the accumulated rate of patients recovering from the disease.

Figure 7 depicts the stock-flow diagram.

3. 6. Proposal Model As mentioned, the model introduced by Atun et al. [39] was utilized as the base model. Its major components include: 1-susceptible, a healthy population that is likely to be infected, 2-asymptomatic infected, infected people who show no symptoms of the disease, 3-symptomatic infected, those who are confirmed with COVID-19, 4-recovered, those who have recovered from the disease (either at home or treated by the healthcare system), and 5-fatality, those who die from the disease.

The loop of the transmission rate, fatality rate, and carriers was added to the SEIR model. Also, factors such as imported infections and behavior risk (e.g., protective protocols and social distancing) were incorporated into

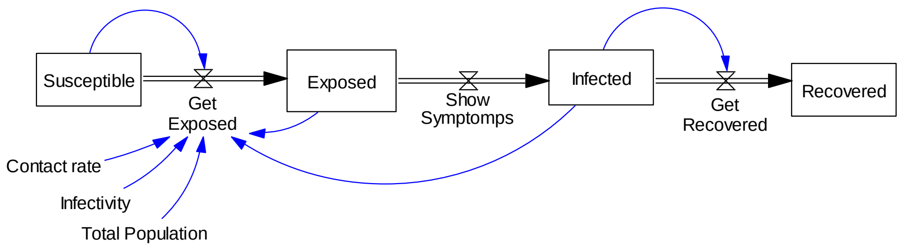

Figure 6. SEIR model

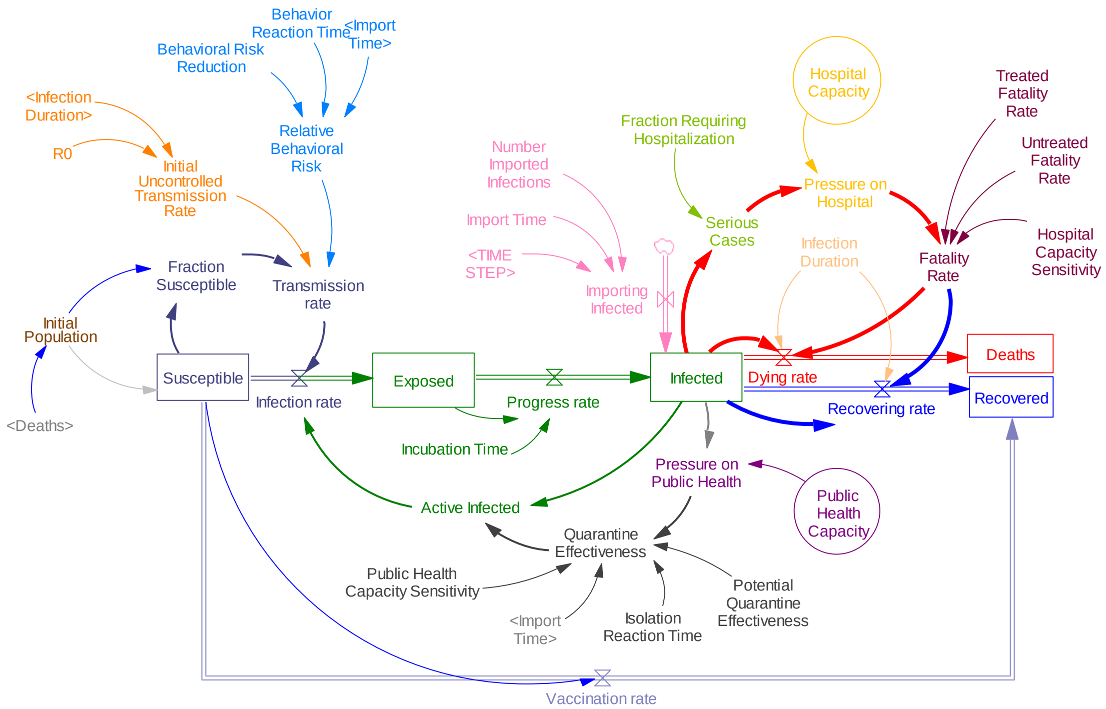

Figure 7. Proposed model

the base model. As it has a strong effect on COVID-19 spread, a quarantine loop was included in the model. The fatality rate consists of two components: 1-patients who were hospitalized and received sufficient healthcare services and 2-those who received no healthcare services. Also, the public healthcare system has a certain capacity that should be considered. Figure 7 depicts the proposed model.

The COVID-19 pandemic has become a huge challenge. To cope with the pandemic, it is required to make different policies, such as public vaccination. Therefore, the model was updated using Tom Fiddaman's model and Iran's requirements and measures, applying a number of such policies. The model was executed by introducing inputs and setting parameters based on the associated data of Iran. To obtain a more realistic model, parameters such as vaccination, hospital capacity, government policies, and personal protective protocols, were incorporated into the model.

Vaccination began in countries as some vaccines were developed. The susceptible population and even those who were infected and recovered should be vaccinated. However, only a small fraction of the population was initially vaccinated since the vaccines were limited, and the vaccination rate has been increasing. Thus, the vaccination loop and its effects were added to the proposed model, as shown in Figure 7.

3. 7. Validation

The structural and behavioral validity of the model was verified using different tests. A variety of references, such as papers and reports on COVID-19, were used to determine the input parameters. A period of almost one year was selected for the spread of COVID-19, and a reliable view of the disease in education and health was obtained by using the existing data and evaluating the number of the infected, recovered, and dismissed individuals under different policies. The data and parameters formulated in Vensim were used as inputs, and the model was constructed based on the real, calibrated available data. A lack of real data-imposed limitations on data-based calibration. However, the model is based on real input parameters and some validation tests to measure its efficiency and effectiveness.

The present work employed the initial output of the SEIR model and earlier works on Iranian citizens. Once the model is properly simulated, it should be validated. Validation is carried out by comparing the simulations results to ground-truth observations. Comparisons were performed for the early period of the COVID-19 pandemic, when the virus spread in the city on February 20, 2020. The comparison was implemented by two validation measures, i.e., mean and percentage error variance. Table 2 shows the means and percentage error variances. The model was validated using the real rates of COVID-19 infection and fatality in Iran and the model estimations.

TABLE 2. Model validation results

Variable	Actual value	Estimate	E_1	Actual value	Estimate	E_2
Infection rate	5442232	6585100	21%	5442232	5605498	3%
Fatality rate	117526	130453	11%	117526	172763	47%

Mean

A model is assumed to be valid based on the mean measure when E1≤5%.

$$E_1 = \frac{|\bar{S}-\bar{A}|}{\bar{A}} \quad (1)$$

where $\bar{S}$ is the average estimate, whereas $\bar{A}$ is the ground-truth quantity [31, 40].

Percentage error variance

A model is assumed to be valid based on the percentage error variance when E_2≤30%.

$$E_2 = \frac{|S_s-S_a|}{S_a} \quad (2)$$

where S_s is the standard deviation of the estimates, while S_a is the standard deviation of the ground-truth data [31, 41].

4. RESULTS

Policies and scenarios were examined based on the proposed COVID-19 spread model. The increased infection and fatality rates imposed heavy pressure on the healthcare sector due to a lack of adherence to protective protocols and social distancing in holidays, e.g., the Persian New Year, religious ceremonies, and inter-city travels. This decreased the effectiveness of quarantine from 80% to 40%. Thus, the government has to adopt policies to control the spread of COVID-19.

A comparison of government behavior in the "onset of spread," "pandemic," and "control" stages indicates that differences in the fatality rate between countries arise from the policies and policy implementation time; i.e., not only policies but also their implementation time and strictness determine the effectiveness of COVID-19 policy effectiveness.

4. 1. The Policy of Quarantine and Vaccination

Although almost all countries in the world, except for a few ones, banned social gatherings above ten in March 2020 (even earlier in some countries), there was no gathering ban in Iran until May 2020. Also, staying at home (or quarantine) has been a major control measure for the pandemic in countries. The policy of quarantine

was implemented at different levels, depending on the pandemic intensity [14, 42], in most countries. Although most countries adopted this policy at the peak of the pandemic (i.e., early April 2020), Iran was among the few countries that refused to strictly implement quarantine, despite a high fatality rate. However, the government finally decided to implement quarantine due to significant pandemic waves and numerous death cases.
To put an end to the COVID-19 pandemic, a large fraction of the global population should be immune to the virus. Vaccines are the most reliable solution. Thus, governments began to develop COVID-19 vaccines. Iran adopted a vaccine development approach while importing vaccines. The government should realize the particular conditions may strongly expose individuals to COVID-19 [43-45]. Therefore, some groups of people, e.g., pregnant and breastfeeding women, autoimmunity and immunodeficiency patients, diabetic patients, and people with respiratory and cardiovascular conditions, are in desperate need of vaccination [44]. The present study examined scenarios to realize how different scenarios, including early vaccination, could have influenced the infection and fatality rates. Different vaccination rates were applied, and the effectiveness of quarantine was evaluated in the form of different scenarios.

4. 1. 1. Scenario 1: Quarantine The COVID-19 virus was completely novel and had no effective treatment or medication for almost one year. Governments could reduce the infection and fatality rates only by policies such as quarantine and protective protocols. At the same time, researchers began to develop vaccines. The Iranian government was able to somewhat reduce the rate of infection by quarantine; however, quarantine was not consistently implemented in Iran, mainly due to the poor economic status of Iran. Thus, the government refused to strictly adopt public quarantine policies. Figure 8 defines quarantine conditions for the model and the output. The results suggest that quarantine would decrease the susceptible population over time.

4. 1. 2. Scenario 2: Beginning of Vaccination Iranian researchers were able to develop COVID-19 vaccines. These vaccines underwent clinical trials and were approved by the Ministry of Health and Medical Education. The government decided to vaccinate a majority of the Iranian population using domestic vaccines. Thus, the imports of vaccines were reduced, leading to a decreased rate of vaccination in Iran. As a result, Scenario 2 assumes a vaccination rate of 9% in a certain period (with vaccination being begun at a low rate after one year). According to Figure 9, vaccination diminished the infection rate and susceptible population, with the recovery rate increasing.

4. 1. 3. Scenario 3: Middle of Vaccination As mentioned, vaccination is the most efficient solution to prevent the pandemic. Despite vaccination in Iran, the spread of COVID-19 was not prevented in Iran, and the infection rate continued to rise, leading to new COVID-19 waves. This can be attributed to the slow vaccination rate and a lack of public adherence to protective protocols. Thus, the Iranian government began to import more vaccines to mitigate the pandemic. The vaccination rate began to rise on July 19, 2021, reaching 41%. These data were introduced to the model for a period until the end of 2021. The results indicated that the rise in the vaccination rate would more rapidly reduce the infection rate and susceptible population, as shown in Figure 10.

5. DISCUSSION AND MANAGERIAL INSIGHT

The present study developed an SD model to identify the factors influencing the COVID-19 epidemic. It was found that vaccination was the most reliable solution to prevent the epidemic. The fatality rate increasingly rose.

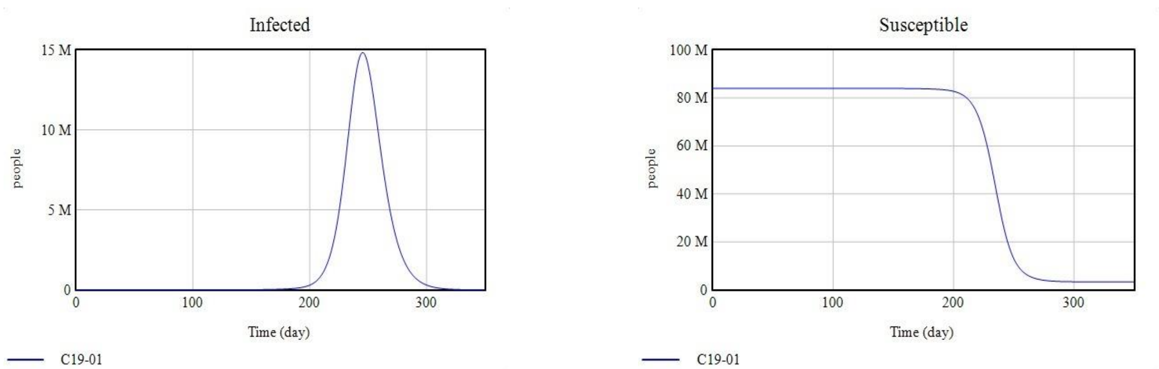

Figure 8. Quarantine scenario

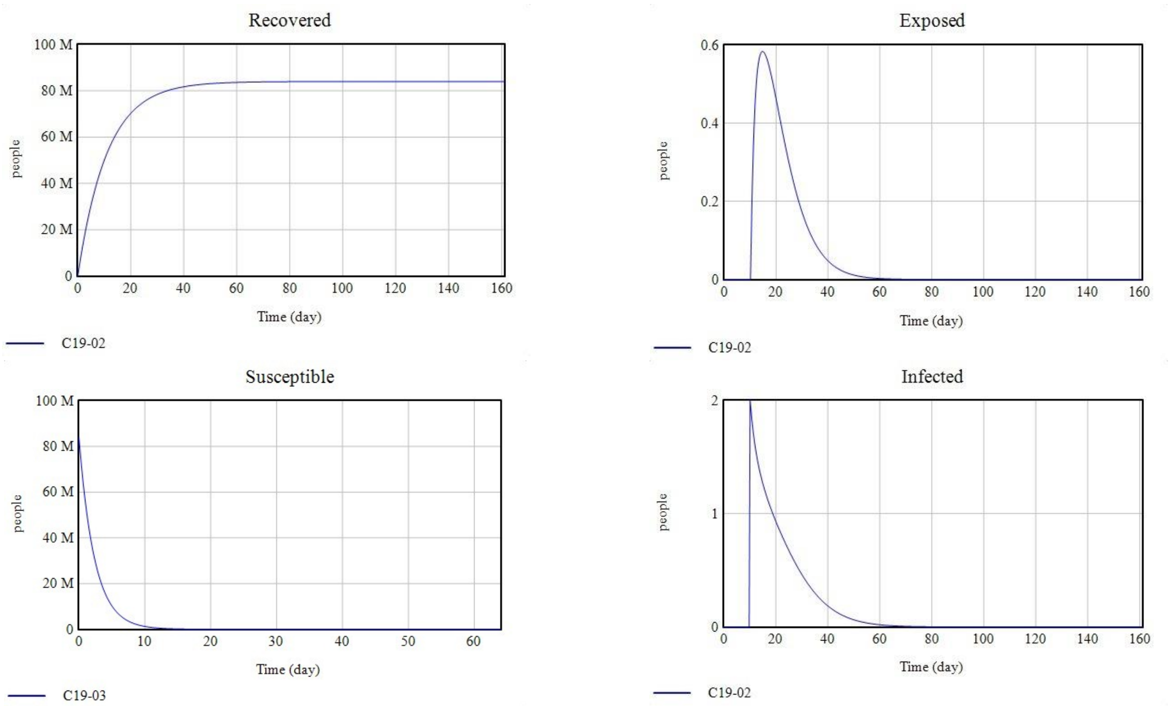

Figure 9. Vaccination scenario

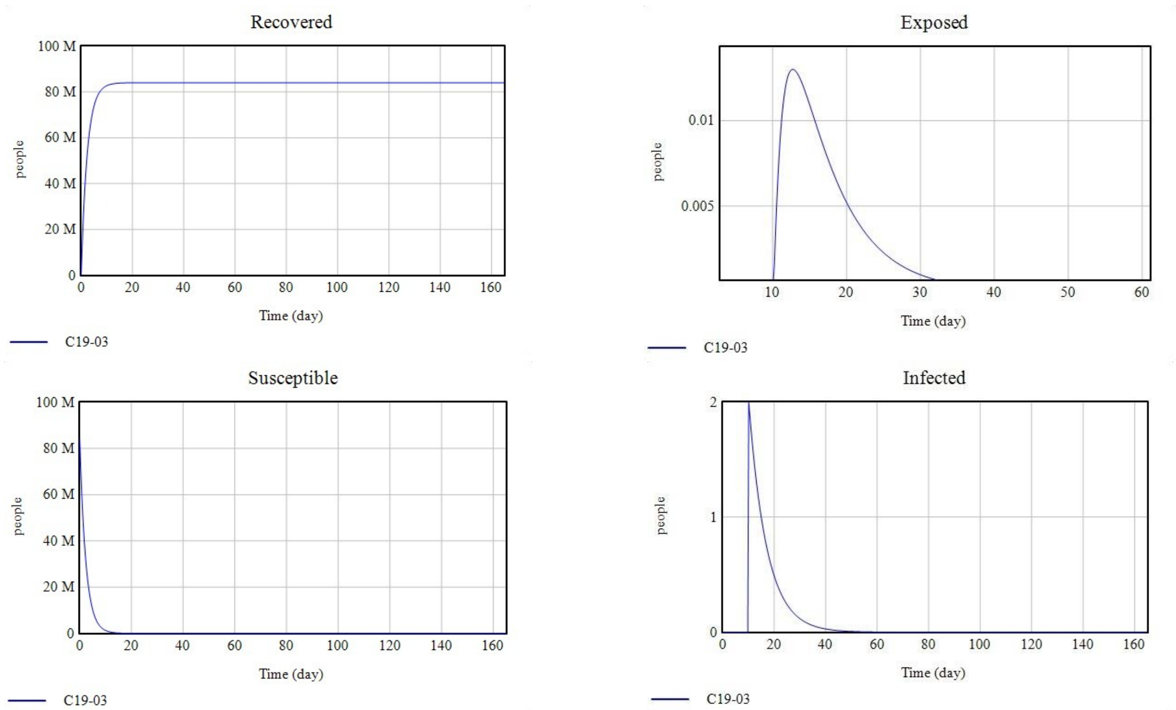

Figure 10. Vaccination scenario

However, the SD model predictions suggested that the rise in the vaccination rate would reduce the infection and fatality rates. Therefore, it is necessary to use domestic and imported vaccines to vaccinate the Iranian population. The people and the government must work together to prevent the next wave, as well as to control the disease. Today, the government has a significant role in controlling the disease by focusing on vaccinating individuals, which will vaccinate all members of the community as soon as possible by increasing access to vaccines. The imports of COVID-19 vaccines significantly increased since July 19, 2021. Thus, public vaccination is estimated to be completed by the end of 2021, leading to reduced rates of infection and fatality.

The present work focuses on governmental decisions and their outcomes. It has also been observed in the community that some people refuse to be vaccinated for unscientific reasons; Therefore, it is necessary for the national media, with the help of trusted and specialized people in the Ministry of Health, to increase public trust and proper awareness, and to encourage people to be vaccinated. Also, according to the data and results of sensitivity analysis and different scenarios, to control and reduce corona virus disease, it is necessary to focus on quarantine and vaccination. The government should continue to work to maximize injections of more vaccines and encourage people to follow health advice. Because the use of a vaccine is the shortest way to recovery, the vaccine can be considered a temporary solution. Therefore, encouraging the implementation of health recommendations can be considered as a basic solution, and finally, the two solutions should be considered as a complement to each other.

The SD methodology is of great importance in research since it helps analyze data, visualize outcomes through diagrams, and understand the behavior of systems. It also enables developing simulation models for future system planning. To enhance the COVID-19 spread model, future works can include further variables, such as economic impacts, government policies, and demographic characteristics (e.g., age) as auxiliary variables. Although this would increase the complexity of the dynamic model, more accurate and reliable results could be obtained. Moreover, the proposed model can be implemented in other countries or at the provincial scale.

Since the government has announced that an intelligent quarantine scheme and reduction of restrictions for vaccinated people will be implemented shortly, it is suggested that future research of this program be considered in the face of new mutations in the COVID-19 virus that have a higher transmission rate. Consider several coping policies and adopt the best policy by designing different scenarios and analyzing them.

6. CONCLUSION

The COVID-19 epidemic has plunged the world into a crisis in health and the economy, a crisis that is perhaps unprecedented in the world since 1918, when the Spanish flu spread. The virus was first detected in Wuhan, China in late 2019, and spread with multiple mutations around the world, turning COVID-19 disease into a pandemic.The COVID-19 pandemic has become increasingly rampant in Iran. To determine municipal government policies to be right on target, policy scenarios are simulated first with a dynamic system simulation. This study examines the factors affecting the spread and control of COVID-19 pandemic by developing the basic SEIR model and considering interventions and policies such as vaccination and quarantine. The developed model was simulated using Vensim software. The desired parameters and variables were formulated according to previous research. Based on different conditions, three scenarios were designed and implemented. According to the results, the most important factor in reducing the prevalence of this disease is the increase in vaccination and quarantine. Vaccines are the ultimate solution to contagious diseases to control disease spread and provide safety to deal with the infection. The results suggested that the fatality rate of the susceptible population was reduced by vaccination and protective protocols. Due to the fact that the Corona virus is changing, the information is constantly being updated, so obtaining information about COVID-19 is one of the Limitations. Also, in face of the Omicron variant, it remains a question, the transmission capacity, and the immune-escape potential of the variant. The continuous emergence of new SARS-CoV-2 variants has made it much harder to control the COVID-19 pandemic.Fortunately, we have accumulated a lot of experiences and methods to deal with the novel corona virus. Thus, this paper aims to analyze factors influencing the spread of COVID-19 and prevent the disease. However, for policies to be implemented properly, contributions from all society elements are required. This paper examined quarantine and vaccination factor, so for future research other policies can be added to the model.

Limitations of this article include changes in statistics and data due to the speed of change of variants and the prevalence of the disease and access to some databases. Also, by the system dynamic, the category of prediction can be done in the future. In connection with Covid 19, it is possible to use this method to use the prevalence and control of the disease in different dimensions in future research.

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Persian Abstract

چکیده

شیوع جهانی COVID-19 در دسامبر ۲۰۱۹ در ووهان چین آغاز شد و در مدت کوتاهی کل جهان را تحت تاثیر قرار داد. به مرور زمان ظهور گونه های جدید بیماری، آهنگ مقابله با آن را نیز به شدت تحت تأثیر خود قرار داده و با ظهور جدیدترین گونه با نام امیکرون، شناخت و بررسی سیستم و انتشار نشریات در جامعه برای سیاست های صحیح ضروری است. بررسی شیوع COVID-19 برای اتخاذ سیاست های مناسب ضروری است. پویایی سیستم (SD) را می توان به عنوان رویکردی برای ارزیابی رفتار بیماری همه گیر COVID-19 اتخاذ کرد. مطالعه حاضر یک مدل SD را برای بررسی اثرات عوامل مختلف بر بیماری همه گیر و روش های درمانی و غیر درمانی معرفی می کند. واکسیناسیون به عنوان رویکرد اصلی برای پیشگیری از بیماری ارزیابی می شود. عوامل مؤثر در پیشگیری و کنترل همه‌گیری بر اساس مدل SEIR و سیاست‌هایی مانند واکسیناسیون بررسی می‌شوند. مطمئن ترین راه برای جلوگیری از این بیماری همه گیر، واکسیناسیون است. بنابراین، سیاستی که به نفع کل جمعیت است و ضروری خواهد بود، تولید و خرید واکسن است. از ۱۹ جولای ۲۰۲۱ میزان واردات واکسن به ایران افزایش چشمگیری داشته است و از این رو پیش بینی می شود تا پایان سال ۲۰۲۲ واکسیناسیون عمومی ایران پایان یابد و پس از آن تعداد موارد و مرگ و میر کاهش یابد. واکسن ها راه حل نهایی برای بیماری های مسری برای کنترل شیوع بیماری و ایجاد ایمنی برای مقابله با عفونت هستند. نتایج نشان داد که میزان مرگ و میر جمعیت مستعد با واکسیناسیون و پروتکل های حفاظتی کاهش یافته است. بنابراین، این مقاله با هدف تجزیه و تحلیل عوامل موثر بر گسترش COVID-19 و پیشگیری از این بیماری است.