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Modeling Spread of COVID-19 in Pakistan and Policy Interventions to Mitigate its Spread

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A B S T R A C T

COVID-19 has been a pandemic, a communicable disease that presented as atypical pneumonia with an unclear clinical spectrum. The first case in Pakistan was reported on February 26, 2020. Sind provincial government showed seriousness in initiating the containment measures. The outbreak progression was multiplying day by day. Fear and spread were dominating the areas increasing the number of detected infections and cumulative deaths. The demand for serious containment measures was increasing and highlighting the issues regarding public health capacity. This paper aims the development an epidemic model using the system dynamic architecture. The research aims to unveil the underlying structure that caused the spread of this contagious disease and identify the containment measures as policy levers to mitigate the spread of this deadly novel corona. Experimentation with the model highlighted that the model performed better in replicating the detected infections and cumulative deaths than the recovered people. Simulation results for varied simulation lengths under the combination of policy levers exactly traced the future trajectory of infected and dead people. Horrible numbers of future predictions demanded seriousness from the public and the government to mitigate its emerging outbreak with rational and plausible policies.

Keywords

COVID-19, Epidemic model, System dynamics, Policy design, Pakistan.

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1. Introduction

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the pathogen that causes COVID-19 infection. COVID-19 is a leading cause of death worldwide due to a lack of preparedness and scarcity of health care capacity around the globe. Researchers and epidemic modeling experts are exploring the implicit strategies to reduce its transmission rate and effectively manage the disease burden. In this battle with COVID-19, all human and technological resources are being consumed, and global economic activity has completely ceased, which has stressed the global economy, which is expected to experience an unprecedented recession alleviating poverty, creating hunger, and lowering employability. In order to lessen the drastic effects of this disease, there is a dire need to explore a set of policies that can reduce the accelerated blowout of this disease.

In our research, the standard dynamic epidemic model (SIR) provides the foundation stone of our model while capturing the structures grounded in experiential information and real-life setting (Bostanudin, et al., 2020). Our model is developed in simulation-based software STELLA; professional version 1.1.2 using system dynamics modeling framework (Cori et al., 2013). In our study, our simulated model (SIDIRD) is a policy regime tool that not only predicts the trajectory of this disease in Pakistan in the upcoming time but also establishes different policy levers that can flatten the curve of this disease and can dramatically reduce its spread and disease mortality. It also illustrates a list of possible limitations halting the productiveness of these policies and proposes an action plan to limit not only the infection rate of this disease but also the fatality rate associated with it.

2. Literature review

On December 31, 2019, an epidemic of atypical pneumonia (Forrester, 1968) was reported to WHO in Hubei, a city of Wuhan in China. An intensive investigation program was initiated in china which revealed the novel Coronavirus, SARS-CoV-2, as the causative agent, and the disease was afterward named on February 11, 2020, by the world health organization as COVID-19. It is a zoonotic disease with human-to-human transmission. Based on transmission dynamics, numerous policies were introduced in China, not only for local people but for health care workers as well. Owing to its exponential spread and global outbreak world health organization declared it a public health emergency of international concern on January 31, 2020. On February 26, 2020, the rate of increase in infected patients in other countries superseded China. A significant increase in infected cases was noticed in Italy, Iran, and many other countries. Till March 1 2020, WHO had confirmed 87137 cases of COVID-19 globally. By March 11, 2020, this disease had affected 113 countries and territories, with the number of infected cases reaching 118162, the number of deaths reaching 4990, and the WHO had declared it a Pandemic due to a thirteen-fold increase in cases in two weeks. The basic reproduction number for Coronavirus is estimated to be around 2.2 (range from 1.4 to 6.5) (Ghaffarzadegan and Rahmandad, 2020).

Based on published data from the Chinese center for disease control and prevention, the case fatality rate for COVID-19 is 3.64. Since many infected patients are asymptomatic carriers, the number of confirmed cases is just the tip of the iceberg, and these officials are not a reliable gauge to estimate the extent of the disease.

Pakistan is a developing country with a population of 197 million people as per the national census survey report 2017 in the country. Pakistan is a close friend of China, and there are many travelers from Pakistan to China and vice versa. The outbreak started in Wuhan city, and its spread was so fast that it got jet momentum covering 178 countries worldwide. The progression of COVID-19 was astonishing; the rapid rise in reported cases in many countries dimmed the hopes of containing the contagion at the origin.

The problem is multi-faceted in nature. The nature of the epidemic is not properly detected, the virus mutates quickly, and many mutations have been observed by virologists'; unlike other viruses, it is resistant to temperature partially (Lane, 2007), and no one has a clue about its vaccination. Pakistan, being a CPEC stakeholder, has strong ties with China, and Chinese products have flooded the Pakistani market with a good share. Price fluctuation in many products is the outcome of anything that happens in China. The Pakistani government, the business community, and even the common man have an eye on the news of COVID-19, especially concerning China and neighboring countries like Iran, Afghanistan, and India. Iran is the second neighboring country affected by COVID-19 after China and Pakistan have a close religious tie with the Iranian people (Qudrat-Ullah, 2012).

Table 1. Information related to the events of different periods of COVID-19

Time Period	Event Description
Period 1	The first case of the Coronavirus was highlighted in Sind Province at Taftan Border people coming from Iran.
Period 2	Till March 15, 53 cases were reported in Pakistan, and an awareness campaign has been started in all media houses.
Period 3	Educational institutes, schools, colleges, and universities have been closed till the next order.
Period 4	For the first time, two deaths were reported in Sind Province.
Period 5	The infection Fatality rate was one person died out of 151 infected people
Period 6	The government enforced two and a half days partial lockdown due to a rise in infected people
Period 7	The government enacted a full lockdown for the next 15 days
Period 8	The government extended the lockdown duration for the next 15 days to exert pressure on lockdown effectiveness and social distancing, etc.

During that timeframe, the paper "Hell is coming: here is a mathematical proof" by Dogan (2020a), (2020b) got the attention while mentioning that by April 15, 2020, 2 million Americans will be infected. Another article was written by Khan (2020), published in Business Recorder on March 27, 2020, sharing the horrifying findings like 90 million Pakistani will get infected in the next 40 days (Till May 6, 2020). Both researchers claim that mathematical modeling is the science behind these calculations. The odds are stacked against us, and it is a ticking time bomb. There was a motivation to develop the system dynamics model to understand the true magnitude of the epidemic. The information in Table 1 provides data for researchers to know how far this epidemic will go and what policies should be implemented to push down the infection rate and flatten the curve. What have policy levers been deployed to mitigate the spread of contagious diseases and lower the death toll?

Alarming news and a rising number of cases around the globe may be underestimating the actual size of the pandemic. Errors in data reporting and limiting health capacity in testing and screening lead to underestimation of its exponential growth. The patient's types are broadly classified as symptomatic and asymptomatic. It is said that at least 80% of the cases have symptoms not very different from common cold or flu (Novel Coronavirus Pneumonia Emergency Response Epidemiology 2020) (Ghaffarzadegan and Rahmandad, 2020). The following statistics show the ratio of deaths to those recovered at the beginning of March was 6.3% (Worldmeters 2020). However, most reports put the death rate at lower rates, indicating that approximately 70% of cases go undetected (Forrester, 1968).

3. Methodology

System Dynamics is a computer-aided simulation technique that addresses the complex, non-linear, time-delayed, feedback-dominant, and dynamic models of various disciplines (Raouf and Yusuf, 2011). System Dynamics masterly attempts to combine the key concepts like feedback controls, mutual causality, non-linearity in the functions, cybernetics, complexity, counterintuitive behavior, deviation correcting and deviation amplifying processes like goal-seeking, external resource production process, and many more to the organizational systems (Richardson, 2011).

Disease epidemiological modeling is an interesting research domain for modelers and researchers. Most of the mathematical and simulation models are grounded in the well-known epidemiological model SIR (Susceptible, Infected, and Resolved). Fiddaman's (2020) work on COVID-19 added another variable and renamed the SIR model as SEIR (Susceptible, Exposed, Infectious and Recovered). Lazovic-Lønningen (2020), inspired by Tom Fiddaman, has adopted his model to the community of Serbia. The results of this study indicate an inextricable link between implementation of combined policy of masks and social (physical) distancing and control of infection transmission, thus – total deaths caused by the infection. COVID-19 simulator by Eberlein (2020) is an abstract model generic in nature and valuable input in the epidemic research area, but all these models and simulators are not replicating the spread of the epidemic in Pakistan. There is a dire need to develop the simulated dynamic epidemic model to understand the mechanics of the spread of infectious disease and gain insight into the effectiveness of the measures adopted by the government to reduce its spread. The followings are the research questions:

1. What are the underlying structures that cause the undesirable spread of the infectious disease Covid-19?
2. What are the policy interventions that can reduce the spread of the virus and generate plausible outcomes?

3.1. Model structure

Stock and Flow diagram of Epidemic Model is shown in Figure 1. Saturation loop **(S)**, reinforcing loop **(R)** and balancing loops **(B)** are in play simultaneously. Their interactions generate the model behavior. The model consists of these loops.

As the transmission rate increases due to an increase in infected people, there is a decline in susceptible people (people who are healthy but are at risk), and it is going to saturate till all the susceptible persons become infected people.

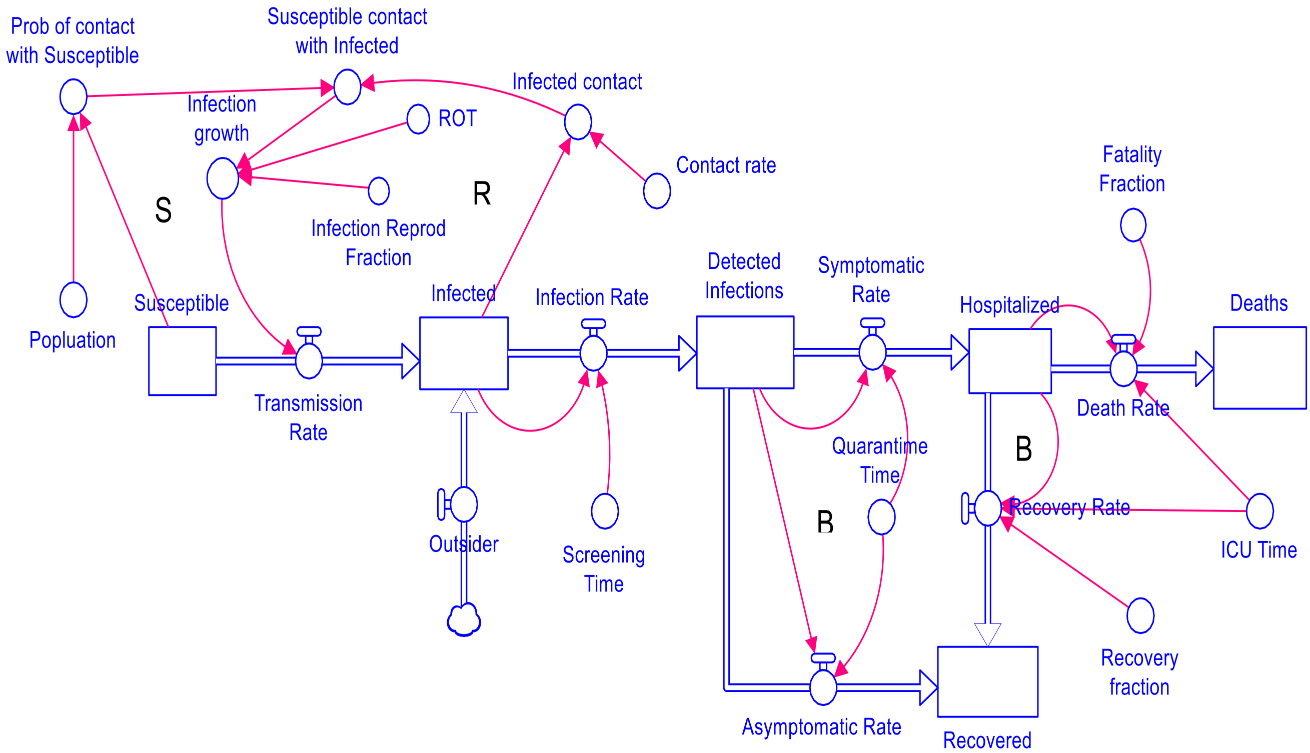


Figure 1. Simplified representation of the epidemic model

The reinforcing loop regulates the spread of disease. The susceptible are in contact with the infected people. They give exponential growth from susceptible to infected people, who are ultimately considered part of the stock of detected infections (Richardson and Pugh, 1981). Practically, it is impossible to test and screen all the infected people. Detected infections depend upon the availability of kits, quality of testing kits, and testing and screening to be conducted daily. The infected persons are quarantined for 14 days in quarantine centers.

Around 65 % of the infected are asymptomatic and stay in quarantine centers and become part of the stock of recovered persons. The other 35 % are symptomatic and can be categorized as symptomatic by mild, symptomatic by moderate, and the last category is symptomatic by severe. See details in Table 2.

Table 2. Types of patients and level of treatment

Patient Type	Description	Treatment
Type I	Asymptomatic and contagious	Isolation and staying in Quarantine
Type II	Contagious and Symptomatic by mild	Isolation and basic medicine
Type III	Contagious and Symptomatic by moderate	Isolation, medicine, and oxygen, having breathing difficulty
Type IV	Contagious and Symptomatic by severe	Isolation, medicine, and oxygen, ventilator, and plasma treatment

Type I patients are all recovered and stay alive. Type II, type III, and type IV patients either recover or die. The recovered persons become part of the stock of recovered patients, and the people who die become part of the death stock. Type II, III, and IV patients require hospitalization and sometimes an Intensive care unit (ICU), depending upon the symptom. It is empirically observed that type II, III, and IV patients are hospitalized for around 7 days, so the total resolution time is approximately 21 days. Special cases do not prove the rule, and resolution times slightly vary in various parts of the country. The resolution period varies from 21 days to 30 days. The model is the seventh-order differential equation with associated flows (Saeed, 1992). The order of the model depends upon the number of levels and the number of delays (Saeed, 2017). In our epidemic model, there is no delay function, so the number of levels decides the order of the model. Lockdown duration, social distancing, awareness campaigns, and government policies are non-linear and vary as the days pass. The number of infected persons and deaths in different parts of the country and world news about the spread of the Coronavirus is the added controller to regulate and control people's behavior. These non-linearities are captured through graphical functions. Graphical functions have been used in the model to translate the ground realities based on secondary sources of data and researcher empirical information (Saeed et al., 2018).

The range of the different variables in the graphical functions and their curvilinear patterns are discussed and approved by the domain experts. Interactions of the positive and negative feedback loops generate behavioral patterns. The system consists of major positive and negative feedback loops (Sterman, 2000). Model structure and interactions of dynamic variables generate multiple patterns that are understandable, interesting, and surprising for some variables. The dominance of the polarity and its shift from positive to negative and negative to positive adds complexity; the mechanisms of change from one pattern to another can be searched through experimentation (Sushil, 1993).

The simulation experiments conducted with our model are designed to understand the behavioral patterns arising out of the model structure rather than point prediction of future deaths and recoveries (Sweeney and Sterman, 2007). Figure 2 demonstrates the stock and flow diagram of the model showing all the policy levers.

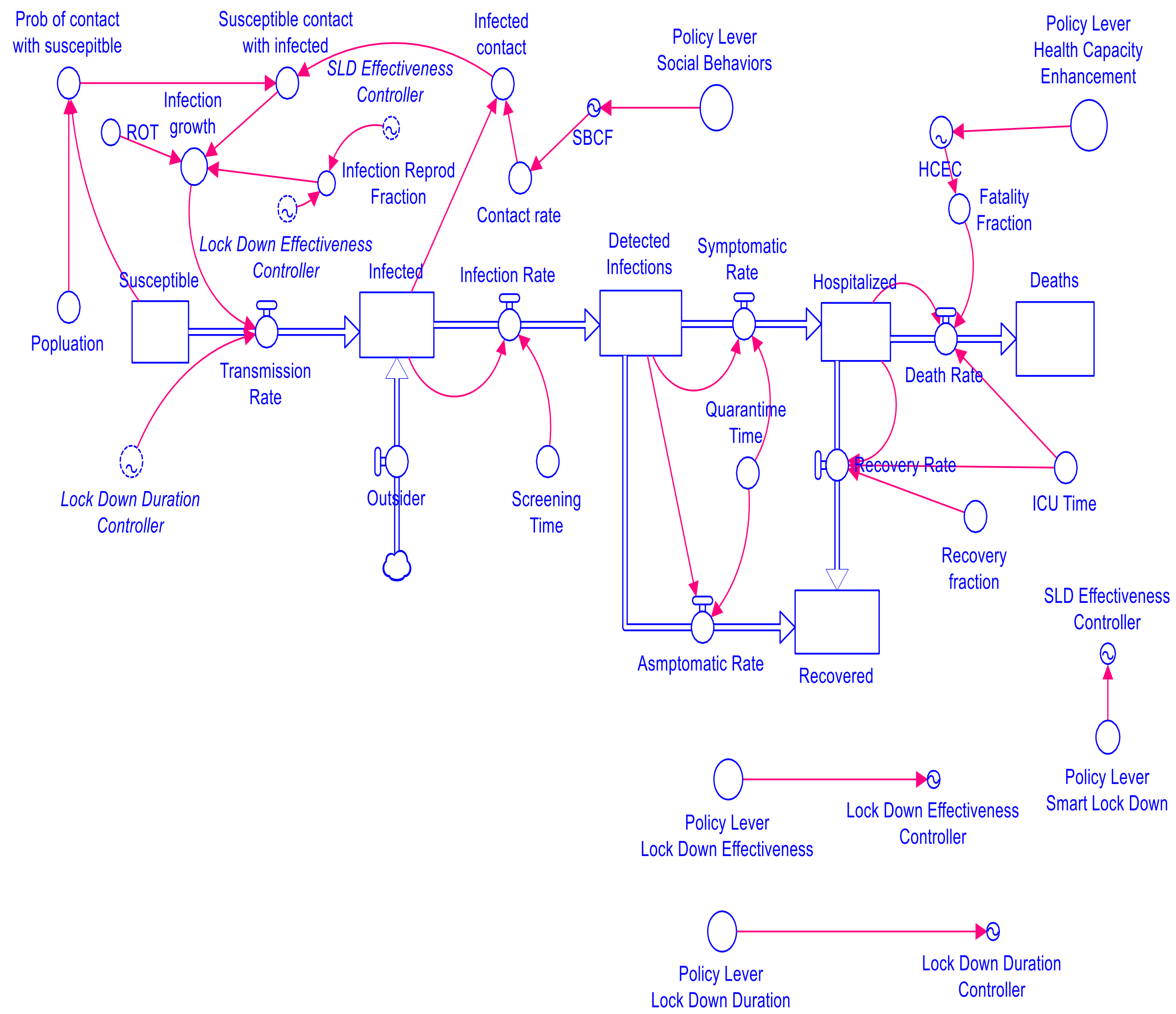


Figure 2. Stock and flow diagram of COVID-19 model

3.1.1. Base line model equations

Our baseline model has seven integral equations 1 to 7.

Susceptible = INTEGRAL (- Transmission rate) * dt (1)

Infected = INTEGRAL (Transmission rate – infection rate + outsider inflow) * dt (2)

Detected Infections = INTEGRAL (Infection rate – symptomatic rate – asymptomatic rate) * dt (3)

Hospitalized = INTEGRAL (symptomatic rate – death rate) * dt (4)

Deaths = INTEGRAL (Death rate) * dt (5)

Recovered = INTEGRAL (Recovery rate + Asymptomatic rate) * dt (6)

Annual COVID Death rate = INTEGRAL (Daily deaths – Deaths info discard) * dt (7)

Transmission rate = Infection growth (8)

Infection growth = Infection reproduction fraction * susceptible contract with infected / Reproduction Time (ROT) (9)

Susceptible contact with infected = prob of contact with susceptible * infected contact (10)

Infected contact = Contact rate * Infected (11)

Prob of contact with susceptible = Susceptible / population (12)

Infection rate = Infected / screening time (13)

Outsider Inflow = One person per day (Constant) (14)

Asymptomatic rate = 0.65 * Detected Infections / quarantine time (15)

Symptomatic rate = (1-0.65) *Detected Infections / quarantine time (16)

Death rate = fatality fraction * Hospitalized / ICU Time (17)

Recovery rate = Hospitalized / ICU Time * Recovery fraction (18)

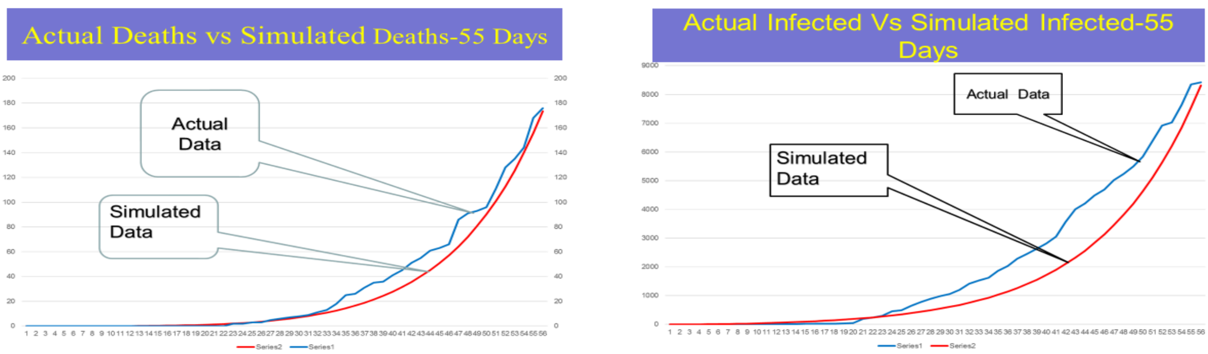
Daily deaths = Death rate (19)

Death info discard = Annual COVID Death rate / Time of info residence (20)

3.2. Model assumptions

Dynamic balance (Sweeney and Sterman, 2007) in this model prevails; the summation of all the stock and rates is equal to the total population. The person who is part of a healthy population lies somewhere in the system, either part of flow or stock. There are a few assumptions that have been taken into consideration while developing the model, which is as under:

1) There is no information about the immunity loss period.
2) An infected person is not to be infected again.
3) The Serio type of virus in Pakistan is less dangerous, or here the people have healthy immunity systems.
4) COVID-19 is temperature resistant; hot weather has no impact
5) Post-mortem testing is not allowed.



a. For deaths b. For detected infections

Figure 3. Actual and simulated data source:www.covid.gov.pk and www.worldometers.info/coronavirus

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Table 3. Base case values of policy levers and model calibration

	Days since first case reported 55 Days					
			Detected Infections		Deaths	
Policy Levers	**Base Case Values**	**UOM**	**Actual**	**Simulated**	**Actual**	**Simulated**
Social Distancing	15	%				
Lockdown Duration	30	Days				
Lockdown Effectiveness	30	%				
Health Capacity Enhancement	15	%				
Smart Lockdown	0	%	8418	8400	176	174

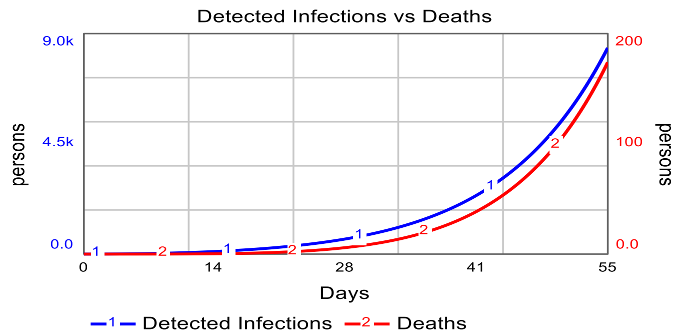
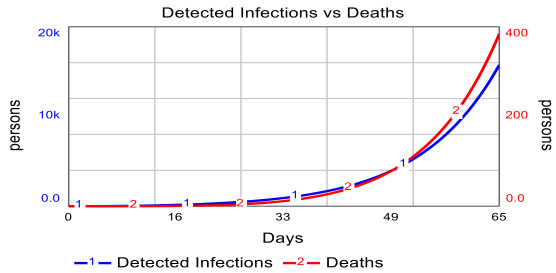


Figure 4. Detected infections and deaths for a simulation length of fifty-five days source:www.covid.gov.pk and www.worldometers.info/coronavirus

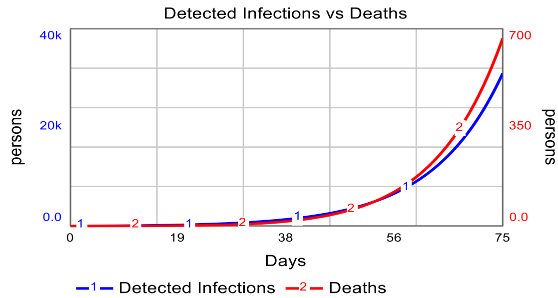
Experimentation with the model not only allows us to understand the diversity of patterns (Wu and McGoogan, 2020) of detected infections and deaths under the influence of policy interventions and various combinations of the policies as shown in Table 4 and Figure 5 .

Table 4. Tracing the detected infections and deaths with a mix of proposed values

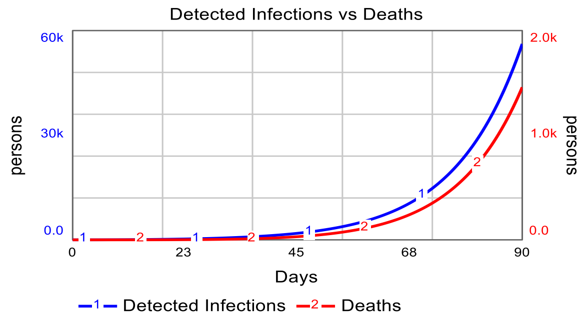
Policy Levers		**UOM**	**65 Days**	**75 Days**	**90 Days**	**180 Days Period of Six Months Duration**
			Mix of Proposed Values	**Mix of Proposed Values**	**Base Case Values**	**Base Case Values**
Social Distancing		%	35	35	39	39
Lockdown Duration		Days	40	50	65	65
Lockdown Effectiveness		%	45	50	40	40
Health Capacity Enhancement		%	25	85	90	90
Smart Lockdown		%	0	10	30	30
Detected Infections	**Actual**		16817	30334	56349	Not Known
	Simulated		16000	31000	56000	5.9 Million
Deaths	**Actual**		385	659	1167	Not Known
	Simulated		384	666	1400	648,000



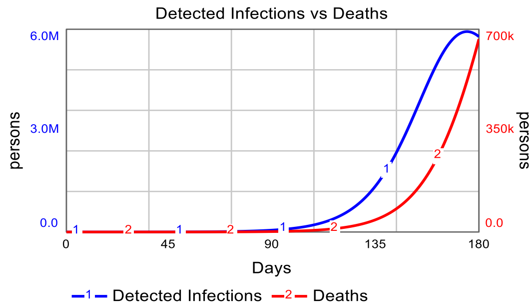
a. simulation length of sixty five days days



b. simulation length of seventy-five days days



b. simulation length of seventy-five days days



a. simulation length of next ninety days days

Figure 5. Detected infections and deaths

3.3. Model behavior

On the basis of the actual time series data, unofficial medical community estimates and the literature support providing building blocks of the SIR modeling paved the path for developing the system dynamics model to capture the true picture of COVID-19 spread in Pakistan. The model is calibrated, having a time series data of fifty-five days highlighted in Figure 3, considering the government measures shown in Table 3 and Figure 4.

Other model parameters like contract rate, infection fatality ratio, and the infection growth derived from the time series data and world statistics on COVID-19 and tracing the behavioral pattern for various simulation periods validated the estimations. We analyze the model for the future trajectory of the disease up to 90 days of actual data of detected infections and deaths with the simulated pattern having a mix of policy measures offered by the government.

Experimentation with the model has highlighted several scenarios**,** which are as under:

1) A positive change in social behaviors reduces the transmission of susceptible people into infected people (Tuite et al., 2020).
2) Infected people have a direct link with the Detected infections. The more infected people are prone to appear in testing and screening,
3) Lockdown effectiveness reduces the speed of spread of infectious disease, causing reduced detected infections and reduced deaths.

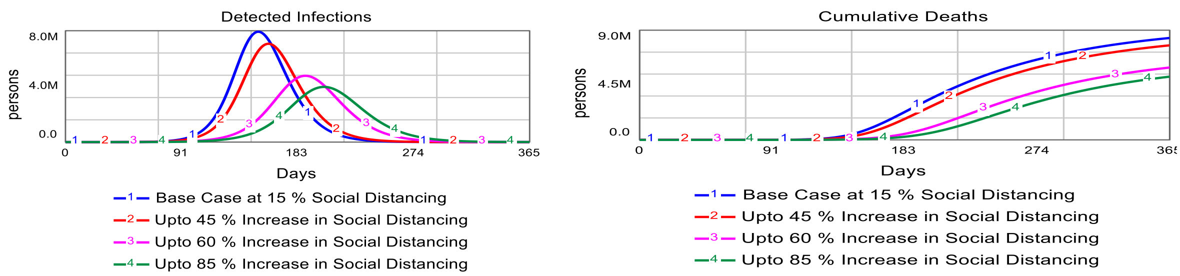
4) Enhancement in health care capacity lowers the death rate.
5) Lockdown duration just shifts the peak creating economic recession and having no effect on the reduction in infected people and deaths. An embedded reality is that lockdown duration has an effectiveness of almost less than half percent per day (estimation).

These scenarios are translated into policy measures that can change the model's behavior. A combination of various policy measures generates the various modes of behavioral patterns at different periods. These policies are guidelines for policymakers and government officials to reduce the spread of infectious diseases.

4. Results

4.1. Testing the scenarios

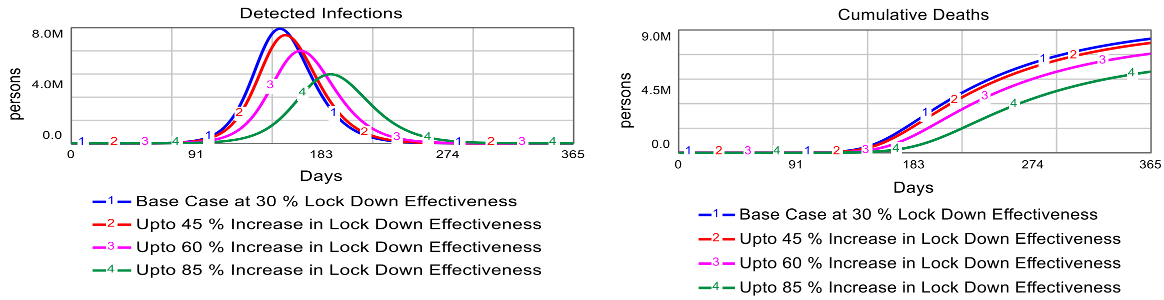
Social Distancing is a non-pharmaceutical prevention policy intervention that relates to people's behavior and attitude (Wang et al., 2020). Knowledge, understanding, and attitude of medical students (Waris et al., 2020) about health issues play a vital role in educating people around them. Education, religious beliefs, social norms, and awareness campaign are the deciding factors in lowering the detected infections and deaths. Figure 6 depict the same story.



a. For detected infections b. For cumulative deaths

Figure 6. Testing scenario social distancing

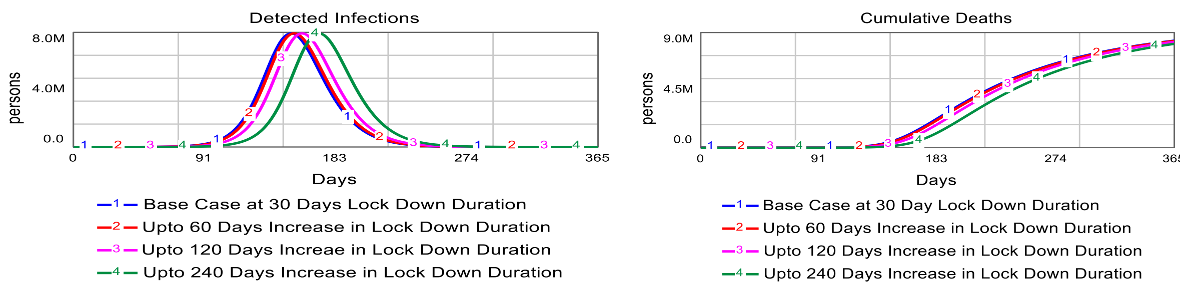
Lockdown effectiveness is the outcome of law enforcement agencies. How masterly do they go for Lockdown of the shops, shopping malls, hotels, restaurants, and other market places, get-togethers, official meetings, marriage parties, and funerals? Government has to enforce the effectiveness of the closure of factories and all public places. Figure 7 indicate the power of Lockdown effectiveness in lowering the spread of infectious disease.



a. For detected infections b. For cumulative deaths

Figure 7. Testing scenario lockdown effectiveness

Lockdown duration just shifts the peak and does not contribute to reducing deaths and detected Infections. They just announced that the province is in a Lockdown state and everyone is free to move as the Punjab government did in her first Lockdown, and they openly declared, "It is not curfew, so people are free to move". No doubt that the Lockdown duration created fear about infectious disease and created awareness of social distancing while closing the offices and public places see the behavioral pattern in Figure 9.

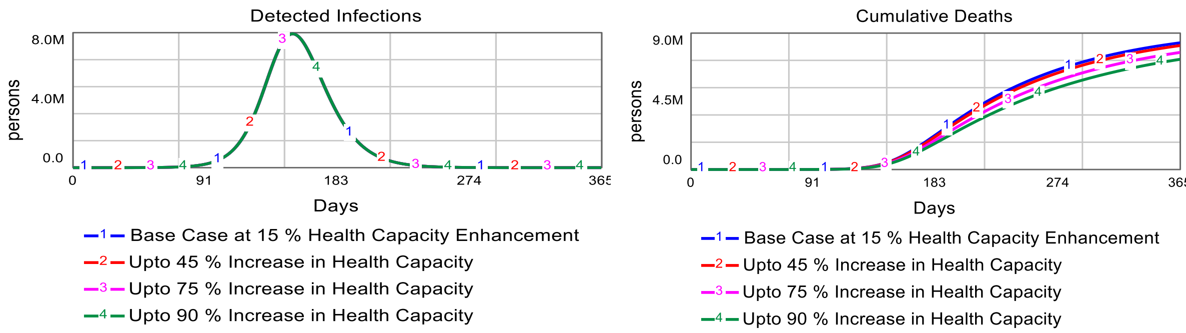


a. For detected infections b. For cumulative deaths

Figure 8. Testing scenario lockdown duration

Currently, the health capacity of the country is around thirty thousand beds, including all the quarantine centers and public hospitals. The government of Pakistan has progressively established metropolitan-wide quarantine centers (non-healthcare facilities) (Wu et al., 2020) all over the country. Expo centers, hotels, and schools are the key places for the quarantine centers. In the beginning, the detected person was forced to go quarantine center even though he was asymptomatic and seemed to be quite normal and healthy. Nowadays government is encouraging people to home isolation due to the scarcity of beds. The unclear clinical spectrum of disease and testing capacity with quality issues is still a question mark.

Ventilators are very limited, and private hospitals are charging so high that even the upper-middle-class family cannot afford to stay there. Enhancement in health capacity has no contribution to detected infections shown in Figure 9 (a) but reduces the death toll shown in Figure 9 (b). Figure 9 indicates that only health capacity cannot be reduced much unless we strengthen it with other policy levers, like Lockdown effectiveness, social distancing, and Lockdown duration.



a. For detected infections

b. For cumulative deaths

Figure 9. Testing scenario health capacity enhancement

The term smart Lockdown was borrowed from Sweden Model. The idea was brilliant. It can reduce poverty alleviation, job unemployment, and lay off of people from companies.

Smart Lockdown means opening every shop, public place, restaurant, factory, and intuitions in compliance with strict standard operating procedures (SOPs). Ensure effective contact tracing and territorial Lockdown where ever the case is reported. The outcome is very encouraging, as shown in Figure 10. But the hindrance point is awareness of the SOPs, the degree of seriousness of the people for its implementation, and passion for adhering to SOPs. It was observed that as the shops were opened near the Eid festival, women were there with small kids, ignoring the corona effect.

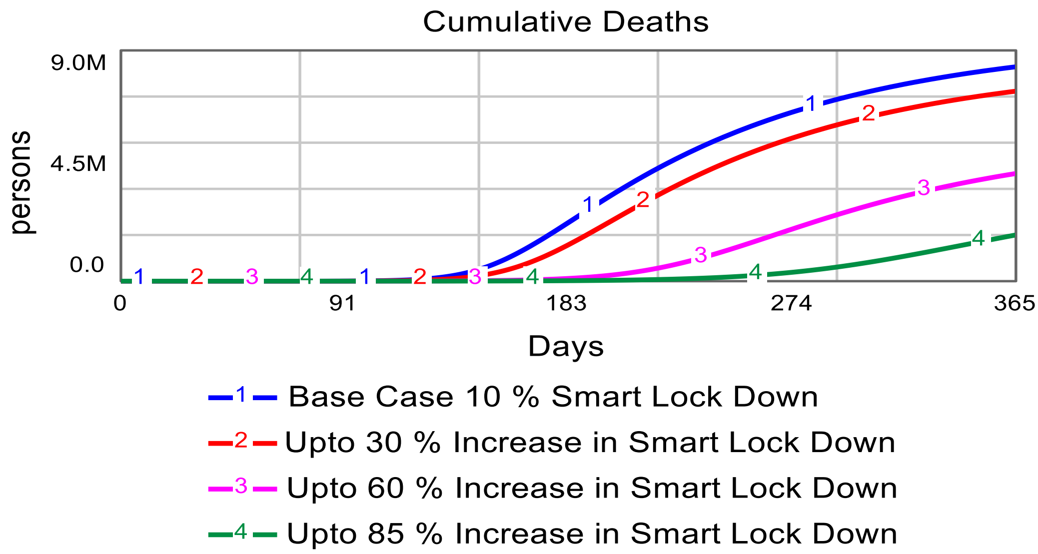


Figure 10. Testing scenario smart lockdown for cumulative deaths

The figures above clearly demonstrate the benefits of social distancing, the effectiveness of the Lockdown, Lockdown duration, enhancement in health capacity, and smart Lockdown. The role of law enforcement agencies in the effectiveness of the Lockdown seems harsh but helps to avoid a complete collapse of healthcare infrastructure.

5. Conclusion

Experimentation with the model (Yusuf and Azhar, 2018) and usage of various policy levers have given the guidelines for policymakers to mitigate the spread of Coronavirus. Lack of implementation of the policy lever not only builds up the stock of detected infections but as well the cause of the rising death toll. It is indispensable to keep on monitoring the data and playing with the policy levers to reduce the spread. Government should keep on working to enhance the health capacity and screening capacity. Contact tracing and territorial Lockdown effectiveness can contribute to its reduction and lower the pressure on health care services. Exploring the underlying feedback system structure for organizing the explicit and tacit knowledge about the system (Saeed et al., 2018) opens up other policy interventions to control this deadly communicable disease. Social distancing, Lockdown duration, Lockdown effectiveness, Health care capacity, and Smart Lockdown are the few control measures that were opted for in various countries depending upon their ground realities. There was a need to study these measures and foresee the impact in terms of reduction in infected and deaths as an outcome of these policies. Social distancing (based on education and literacy rate of the country) showed more impact than Lockdown effectiveness (Lockdown effectiveness depicts supremacy of the law enforcement agencies). Lockdown duration just shifted the peaks; otherwise, there was no impact while reducing the infected and deaths. Health care capacity seems to be very good in developed countries as compared to developing countries, but the model indicates that its impact is not significant, as shown in Figure 9. The initial focus was on the policies developed that should be used in Pakistan. Nevertheless, the results are so generic that they can be implemented in various countries as a control measure to mitigate the spread of COVID-19.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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