COVID-19 outbreak and the role of digital twin

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Abstract

COVID-19 has transformed the life of human beings and digital twin infrastructure can facilitates working remotely during COVID-19 outbreak by reducing burden on services and infrastructure. Currently, many organizations are installing and developing devices such as thermal cameras, sensors aiming to minimize human contact and so forth, in addition to enforcing social distancing resulting in reducing the risk of transmission. Due to economic reasons, lockdown restrictions are being relaxed/lifted in many countries and Pakistan which is one of the most densely populated countries in the world with a population of 220+million is no exception. Though, Pakistan contained the first two waves of coronavirus infections reasonably well but the country is struggling to contain the third wave of the spread due to violations of social distancing norms. While our predictions may deviate from official statistics due to lack of mass testing and existence of asymptomatic infections, the described approach predicts the possible actual burden of infection over times. In view of the unique demographics, our data quantify the efficacy of social distancing as an effective measure to forestall the infection. We highlight few areas where digital twins can be created/deployed to provide services and essential facilities to citizens as COVID-19 is expected to have permanent impact on the way we work.

Keywords Digital twin · Disease spreads · Healthcare system · Control · COVID-19

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1 Introduction

Digital twins are digital replicas of an object, process or system and becoming increasingly popular in various domains ranging from smart cities to remote equipment control to detecting heart anomalies in patients [37]. A recent study highlights that the current digital twin business market of 5.1 billion dollars in 2020 is estimated to reach 115.1 billion dollars by 2035 [36]. One of the critical tools in realization of smart cities concept is adoption of digital twins [7, 19, 23, 27, 28] which is powered by latest technologies such as Internet of Things (IoT) and Artificial Intelligence (AI). Enabling digital twins facilitate in automating many services and assists in unforeseen situations such as disaster management and mitigate pandemic spread.

Coronavirus disease 2019 (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 [31]. The COVID-19 disease was first identified in the Chinese city of Wuhan in December 2019. Since then, the disease has spread globally in more than 200 countries and territories. The World Health Organization (WHO) declared the disease as 2019 Novel Coronavirus Disease (2019-nCoVID) on January 30, 2020, and later announced the disease as coronavirus pandemic on March 11, 2020 [17, 31]. By May 9, 2020, the number of confirmed COVID-19 cases had been predicted to reach4 million across the globe [49] and the economic impact is estimated to be in trillions. Initial estimates suggest that COVID-19 could cost the world economy more than 8.5 trillion in next two years [8] with tourism sector alone facing an output decrease as high as 50–70% [5]. IMF reports project the global economy to be contracted by −3 percent in 2020 [9]. Even 3–4% is considered optimistic and there are projections up to 8% shrink in global growth for year 2020. As per Food and Agriculture Organization report, COVID-19 may cause a loss of Rs-600 billion to Pakistani economy if no prior steps are taken to control the disease [35].

To slower the spread and devise policies such that the disease dies out eventually, many countries applied strategies of lockdown which have been found very effective. Lockdowns have been implemented on various scales. For instance, full lockdowns were imposed initially in Italy, Saudi Arabia, France, India, Bahrain, and Pakistan etc. On the other hand, relaxed lockdowns were observed in USA, South Korea, and Iran, while no official lockdowns have been imposed in Brazil. While lockdowns have slowed the spread of COVID-19 spread across the globe, the economic cost associated these strategies is very high, especially for developing counties. Due to aforementioned reasons, countries are considering removal/relaxation of lockdowns which can potentially lead to increased number of infections.

Even with vaccinations, many countries have been hit by 3rd and 4th waves of COVID-19 and hence we must learn to live with it. Insights on a disease's spread from mathematical modeling can help authorities in making necessary arrangements, thus preventing avoidable deaths. For a disease like COVID-19 where effective drugs and vaccination are not available at present, a mathematical model of Susceptible, Exposed, Infectious, Recovered (SEIR) can provide directional insights on the spread in a large population like Pakistan [49]. SEIR has previously been used to predict the spread of a range of diseases such as HIV/AIDS, swine flu, dengue fever and more. Literature shows that it can effectively be used to simulate COVID-19 spread as well [2, 12, 17, 25, 30, 39, 40]. To reduce the support rate and support activities, the role of digital twins is of particular importance today and is expected to become more important in post COVID-19 era as well.

In the presence of COVID-19 pandemic or even endemic, the role of digital twin becomes of paramount importance for reducing the disease spread by enabling contactless scanning of patient's temperature, intelligent traffic management, and understanding long term post COVID-19 impact on patient's health, and COVID-19 mass vaccination centers [10] and so forth. Advancements in virtualization technologies, popularity of IoT, and Industry 4.0 pave the way to implement digital twins at various levels ranging from contact-less temperature scanning to traffic management to shipment of goods etc. The application of digital twins in pandemics is even more vital as its use not only results in cost reduction, performance enhancement, and convenience at various levels but also reduces the risk of spreading disease. The impact of COVID-19 on patients and drugs can also be studied by generating digital twins of patients as a system as well as at individual patient's organs level. In this work, we explore a high-level model of digital twin that is applicable to pandemics.

We provide background work in Section 2 and COVID-19 spread using SEIR model in Section 3. The implications of digital twins are highlighted in Section 4. The paper is concluded in Section 5.

2 Background

Initially, the transmission rate for COVID-19 was reported with 1-5% among 38,000 people in China who were in close contact. The number was even higher within a family and estimated to be 10% during the start of the pandemic. With isolation and lockdowns, the number was quickly lowered to 3% [46]. In mathematical modeling of disease spread, Ro is of vital importance which represents the probability of transmitting a disease from an infected to a susceptible individual. Figure 1 shows disease spread with various values of Ro for diseases like COVID-19, Influenza, Ebola, and Sars. When Ro is 1, the disease remains stable (1 person can infect only one), while less than 1 suggests that the disease dies out ultimately. Unfortunately, Ro is very high for COVID-19 and hence the disease spreads at a higher rate. Attempts are being made for Covid-19 to lower its Ro to 1 and eventually less than 1 in ideal scenarios. Similarly, series interval or the rate of latent (exposed) individuals becoming infectious is also an important factor that explains how quickly a disease can spread. For COVID-19, Ro is in the range 2.6–3.0 while series interval is the range

Fig. 1 Role of Ro in the disease spread
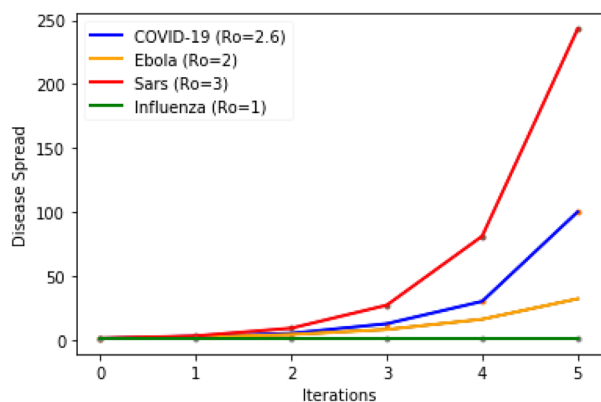
of 5–7.5 days [17, 20, 50]. Some studies suggest Ro in the range of 1.5–3.8 [18]. Just to understand the role of Ro in COVID-19 spread, let us assume Ro = 3, and series interval of 5 days, patient zero can infect 27 persons within 22 days. For a disease such as influenza, the value for the series interval is 2 days. The larger is the series interval value, the slower is the spread. For instance, assuming Ro = 3 and the series interval of 2 days, the patients zero can infect 30 individuals within 6 days while with series interval of 7 days, the patient zero will take 21 days to infect the same number of people. The value of Ro varies from county to country. For instance, Ro for UK is in the range of 0.7–1 with lockdown [3].

For Ro, a value of 2.6 was used in Imperial College report released on January 22, 2020 [32]. In a recent work, infected-suspected ratio was found to be 2–3 based on the data available till January 20, 2020 [50]. At such rate, the spread poses a big challenge to countries and attempts are being made to slow down this spread and flatten the peak so that a country's healthcare system does not crumble down under the pressure of overwhelming infected cases which can very easily surpass the number of hospital beds, doctors, nurses, and ventilators available for critical cases. It is worth mentioning as per 2016 study there were only 118,869 hospital beds in Pakistan [14] while another report published in 2014 shows 0.6 hospital beds (including public, private, general, and specialized hospitals and rehabilitation centers) per 1000 people in Pakistan [44]. Figure 1 reflects the spread rate for virus that spread from Wuhan, while on the other hand the spread rate becomes almost double in some parts of the world for delta variant. Though COVID-19 vaccinations help in preventing spread and Ro has been reduced significantly in many countries but still 100% protection is still not possible against COVID-19 like flu. For instance, data shows that with two doses of approved vaccines in UK can offer 96% protection against hospitalization [11]. Fortunately, with vaccination of large population in various countries, improving hygiene, following social distancing and other preemptive measures have reduced the spread significantly in many countries.

Pakistan shares a long border with two most populous countries in the world i.e., China and India. Additionally, Pakistan also has a border with Iran which is a religious tourism attraction for many in Pakistan. On February 26, 2020, two COVID-19 positive cases were confirmed in Pakistan and both cases had a travel history to Iran. By May 10, there are now 29,465 confirmed cases and 639 deaths where the most affected province is Punjab followed by Sindh [29]. At present, the Government of Pakistan has established several quarantine facilities at various part of the country. Like other countries, Pakistan has imposed travel restrictions and suspended all transport/flights except special flights to repatriate citizens to their home countries. On arrival, all passengers in Pakistan must comply with Government of Pakistan's quarantine and isolation requirements. A detailed discussion on health resources, healthcare system, and quarantine facilities can be found in [47]. Pakistan has a long border with Afghanistan, People's Republic of China, India, and Iran with multiple crossing points. The famous silk route between Pakistan and China was the first crossing point closed immediately with COVID-19 cases were reported in China, however, the border was reopened after a few days when cases came under control in China. In Pakistan, patient zero was traced to Iran who visited Iran on religious tourism.

Digital twin is a replica of an entity, which provides information on characteristics, conditions and processes occurring in the model [11, 45]. Digital twin technology has been inspired by advancement in IoT and virtualization tools which are the driving force behind making it applicable and popular in various domains. The realization of smart cities and campuses is incomplete without digital twins. Today, digital twins can be used to identify and recognize individual using face recognition techniques. In smart cities, similarly, the safety of infrastructure can be assessed using the digital twins. Even multimedia and other

services can be tested on using digital twins. Similarly, in the medical filed, digital twins are being used to create body organs that can be used for training purposes related to a surgery as well as to study the post-surgery behavior of an organ. Authors in [45] discussed digital twins that consist of a smart patch with integrated technology for collecting a range of data such as blood oxygen levels, and body temperature etc.

3 Modified SEIR model for COVID-19 spread predictions

In this section, evaluate the impact of lockdown on disease spread in Pakistan using modified Susceptible, Exposed, Infectious, Recovered (SEIR) disease spread model for the 3rd wave of disease spread in the country. Our analysis shows that around 14 million infections with current spread of 10.2% positive cases are estimated within 45 days starting from March 26, 2021. With strict degree of lockdowns and social distancing, the number can be lowered to 2 million and the spread can be delayed for 3 months.

SEIR model has been used to make predictions for HIV/AIDS spread with reasonable accuracy. There exist many derivatives such as SIR, SIS, SIRS, and others [4, 8, 15, 26, 41, 50]. Recently authors in [2, 8, 12, 13] used SEIR for COVID-19 spread as infected persons can pass on the infections without displaying any symptoms [30]. Many variants of SEIR have been proposed in literature to predict COVID-19 cases [8, 25, 39] and more are expected as many dynamics of the disease are yet to come. We studied the impact of lockdown on SEIR model in [8]. In this work, we analyze the data for Pakistan using the modified model established in [8]. Many assumptions of SEIR remain valid for COVID-19 at abstract level such as the population size remains fixed. However, some assumptions of SEIR cannot be applied to COVID-19 disease such as once a person has recovered, the person has received immunity. Cases have been reported where a person has become COVID-19 positive for the 2nd time after recovery. SEIR also overlooks many disease dynamics such as herd immunity where it has been reported that some COVID-19 patients recovered without showing symptoms. With this discussion, there is a need to establish a model that incorporate factors such as population ages, population density, death cases, lifestyle of the community, limiting number of people in social gatherings, social distancing and relevant parameters for making coherent predictions.

SEIR model is very much applicable to large populations such as the population of Pakistan which is 224,336,070 on April 23, 2021. We have estimated other parameters as follows:

1. $\propto$: denotes the probability of transmitting the disease from an infected to a susceptible individual. For Pakistan, Ro is calculated as 1.5 and 1.2.
2. μ: is the rate of latent (exposed) individuals becoming infectious. It is equivalent to 1/Y where Y is average incubation duration. (simulation uses Y = 5.2 [12])
3. $\beta = 1/D$, where D is the average duration of recovery D of the infection.

It can be seen in Fig. 2 there would be 14 million infections while 33 million population will be in Exposed compartment of day 60 starting from March 11, 2021, on which cases in 3rd wave started increasing. The Government of Pakistan has lifted total lockdowns currently and the trends shows that social distancing measures should be respected in religious ceremonies, shopping, sports and other activities to control in spread in the country. Our analysis shows that when a partial lockdown is imposed, the spread can be lowered as
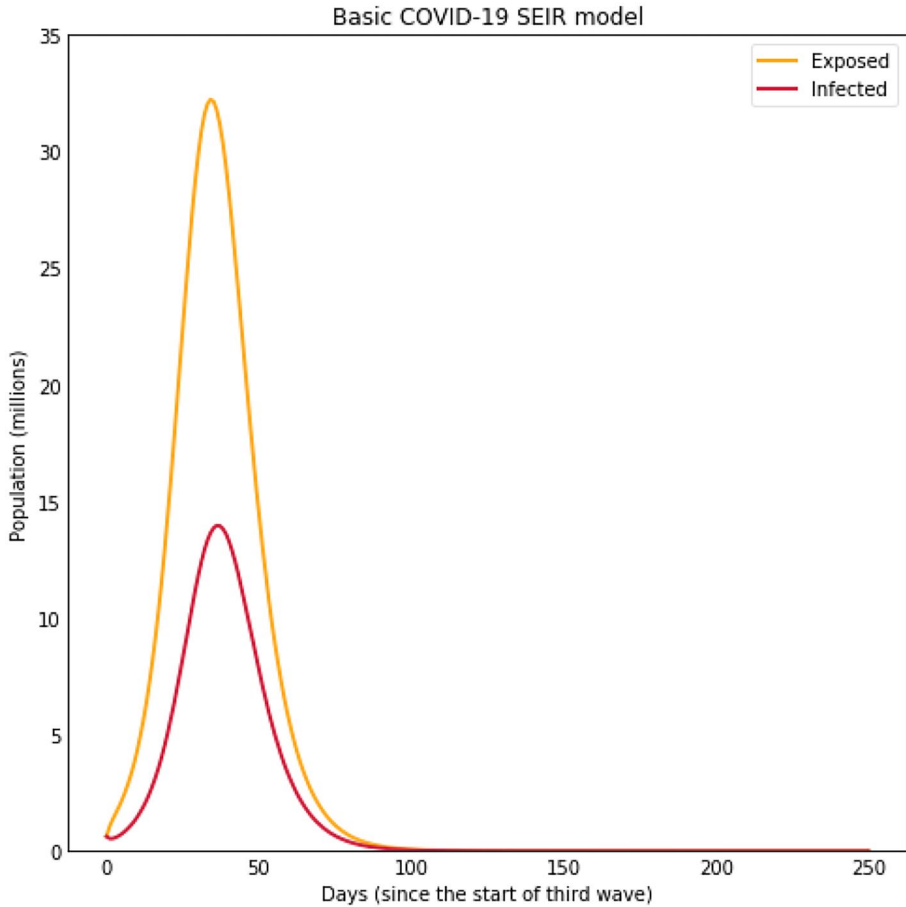
Fig. 2 COVID-19 spread predictions with no lockdowns

shown in Fig. 3 to be around 7 million. Furthermore, under partial lockdowns, around 18 million peak cases are expected. Under smart lockdowns a city, town, village, or specific areas can be cordon off in case of disease spread. If implemented, the smart lockdowns can lower the spread, reduce cases, and flatten the curve. With strict lockdown, the situation can be further controlled. As shown in Fig. 4, when lockdown is imposed strictly, Infected cases would be lowered to 1.3 million with 4 million exposed cases after an anticipated peak delay of 3 months. The aforementioned discussion suggests a strict lockdown for controlling the cases and flattening the curve even with higher Ro which is very likely after relaxing the lockdowns in the country.

We understand that our analysis can assist a country in back to business without overwhelming their health services. Like many countries, universities and schools are closed at present in Pakistan while it is very unlikely that things with change much in next 6 months. Lifting lockdowns restrictions fully can results in more COVID-19 cases. Based on our analysis, gradual removal of lockdown can be a good strategy as it will reduce the number of exposed population and consequently confirmed cases. However, any increase in spread rate can make a huge impact on the spread and hence much care is needed to lower the
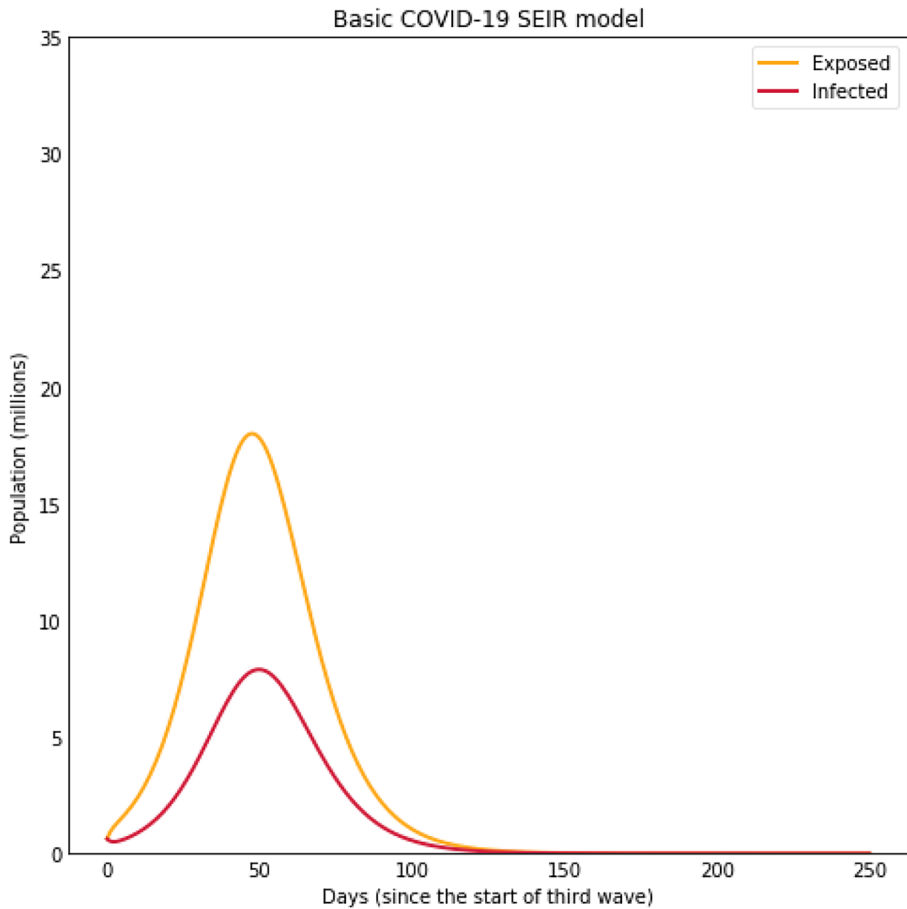
Fig. 3 COVID-19 spread predictions partial lockdowns

contact rate so that the disease dies out as soon as possible. Our projection are based on current official data and there is a chance that actual cases might be more than officially released number and hence predictions may deviate accordingly. In addition, many cases go undiagnosed and hence the actual spread can be higher. There exist a lot of uncertainty as many disease dynamics of CVOID-19 are still not known. Also, some parts of the world deaths are more than others. For instance, as of May 9, there were 29, 465 confirmed cases and 636 deaths in Pakistan as compared to Sweden with similar infections of 26,322 with 3225 deaths. Even in the region, deaths associated with COVID-19 in Sweden is 3–7 time higher. Except quarantine of infected and aged population, majority of the business are open in Sweden. When compared the deaths rate of Pakistan and Saudi Arabia, the deaths in Saudi Arabia is around 1% while in Pakistan the COVID-19 death rate is around 5%. Similarly, many other factors such as social gatherings, cultural activities, sports events, religious gatherings, and other human factors can also stimulus spread predictions. In Pakistan, initially, there were 1122 beds reserved for COVID-19 patients which were increased to 3000 and with the addition of field hospitals, the number of beds for COVID-19patients has increased to 19,000 in total [34]. As per BBC report [3], it was anticipated that there
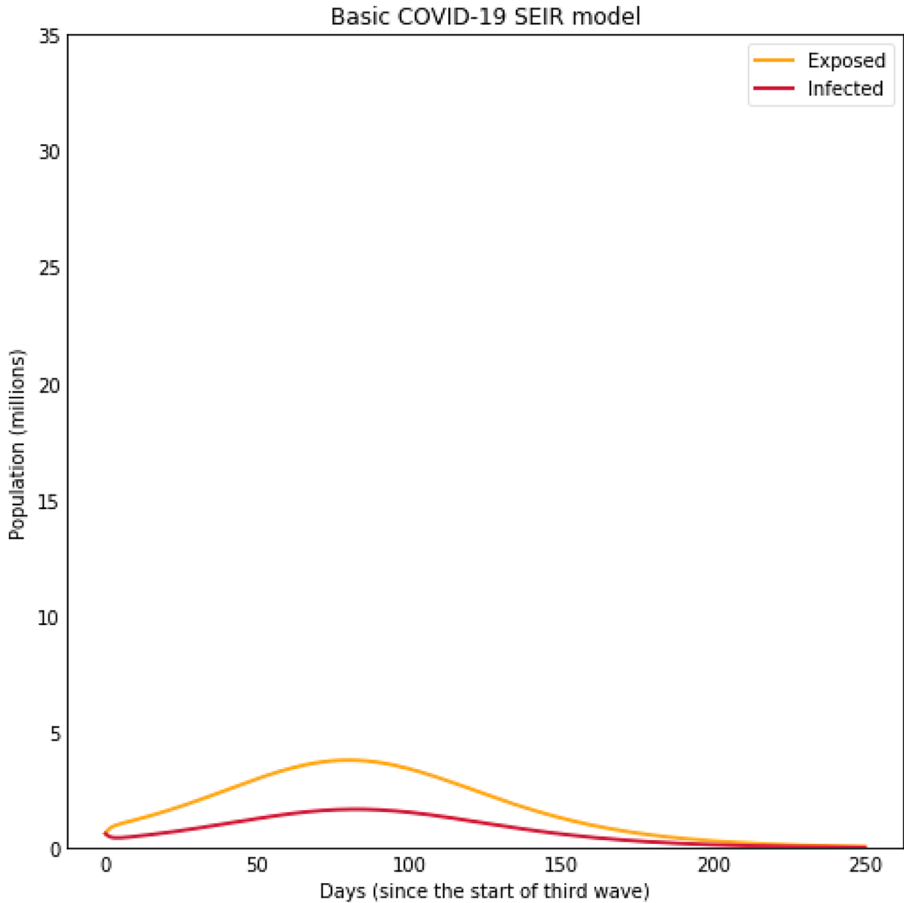
Fig. 4 COVID-19 spread predictions adhering to social distancing

will be a need of 50,000 beds by mid July 2020. With stricter lockdown, the disease spread can be controlled more effectively, and cases will be around 60,000 which seems manageable for a country like Pakistan as many of them might not need hospitalization. The mindset of the large populations in Pakistan was not pandemic sensitive and such attitude resulted in higher contacts and spread rate, however situation has been controlled effectively in recent months but the third wave a a serious threat to the health infrastructure in the country. Our study shows that under current scenario, infections could be 7 times lowered depending on the nature of lockdowns imposed. With current official spread ratio for Pakistan, the infection is projected to be less than 2 million with limited social distancing by end of summer 2021. However, the number can be further lowered with implementing smart lockdowns and respecting social distancing in Pakistan. In both cases, the spread is well below the initial projection made in May 2020 with Ro = 2.399 as shown in Fig. 5. Similarly, Fig. 6 shows the spread when Ro = 1.5 while Fig. 7 shows infections for based on the data available in August 2020 when Ro was calculates as 1.2.

Pakistan is the 5th-largest country in terms of population and 23rd largest in the world in terms of purchasing power with a GDP per capita of $1357[43]. It is worth mentioning
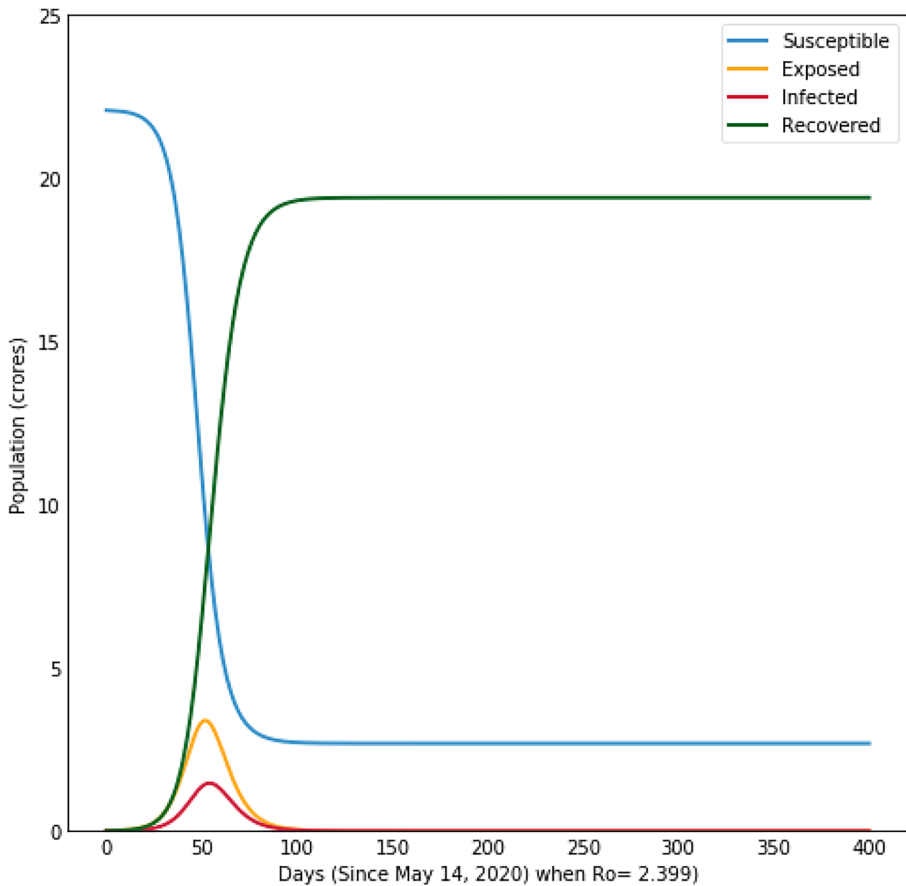
Fig. 5 COVID-19 spread predictions with Ro = 2.3

that 36% of its overall economy is undocumented and hence not counted towards per capita income [42]. To control COVID-19 spread in the country, Pakistan imposed lockdown in March 2020 in major cities which helped in lowering the spread. Recently, the 3rd wave which started on March 11 seems more dangerous and COVID-19 is spreading since then. With neighbor countries namely Afghanistan, People's Republic of China, India, and Iran, Pakistan shares a border of 6975 km in length with multiple entry points. For instance, there are 18 crossing points on Pakistan-Afghan border. This border as sealed since Mar 13, 2020, with exceptions such as temporarily lifting restrictions on allowing stranded Afghan nationals to return home etc. The Government of Pakistan has decided to fully open the said border from May 15. It is worth noting that Afghanistan is a landlocked country and heavily depends on border with Pakistan. According to [43], exports to Afghanistan from Pakistan were Rs128 billion in FY19 as compared to the exports of Rs122 billion in FY18 and around 2000 trucks cross the border on average. Currently, the trade between Pakistan and Afghanistan is $2 billion, however there is a potential of $10 billion trade which is not tapped due to various reasons. Closing this border for one day has a significant impact on the business community on both sides of the border. By utilizing digital twins,
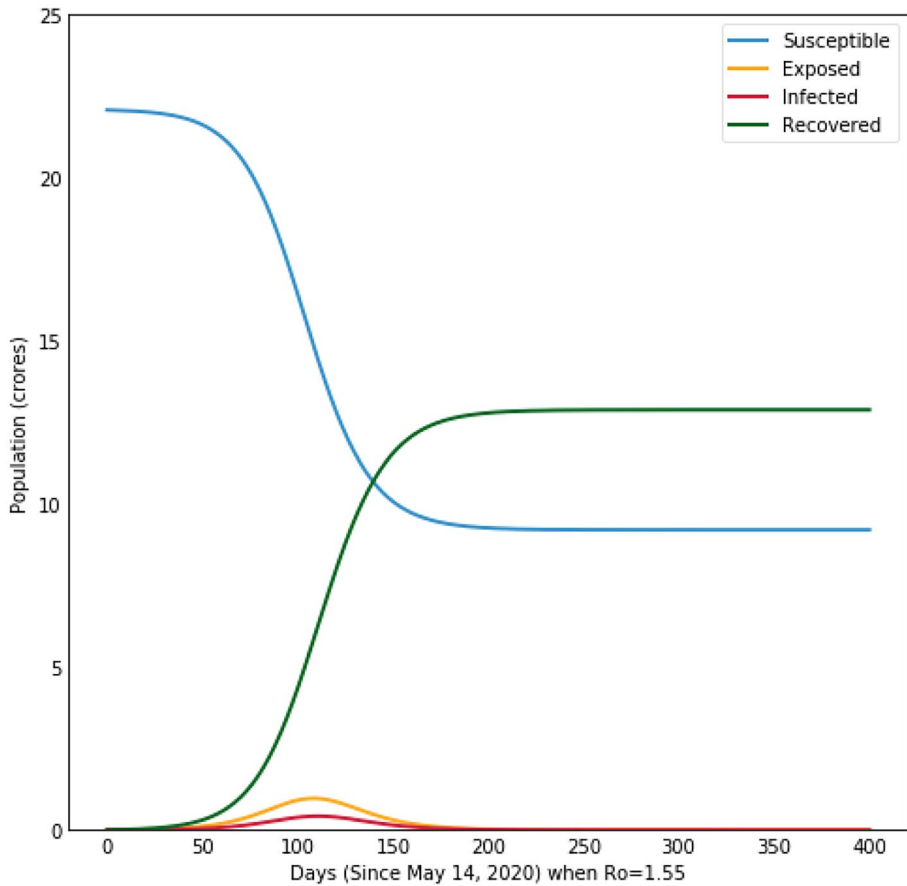
Fig. 6 COVID-19 spread predictions adhering to social distancing

robotics, and machine vision algorithms many activities can be facilitated on borders. This is another opportunity where digital twins can be deployed for smooth flow of goods and services. Installing digital twins at such places reduces chances of person-to-person contacts and hence prevent virus transmission to another country on border crossings.

4 Implications for digital twins

Despite lockdown and closures, the COVID-19 and its variants are on the rise, and this highlights that the world must live with this and transform the way of living [38]. With emergency of industry standard 4.0, the role of digital twin is more useful during the COVID-19 spread prevention and to navigate the potential crisis such as optimizing the use of ventilators for critical patients. In addition to its uses in in pre-COVID-19 era, digital twins are equally important to medical professionals in post COVID-19 era as well to analyze available data and study the impact on various body organs. For instance, by integrating artificial intelligence techniques with digital twins of lungs, respiratory products
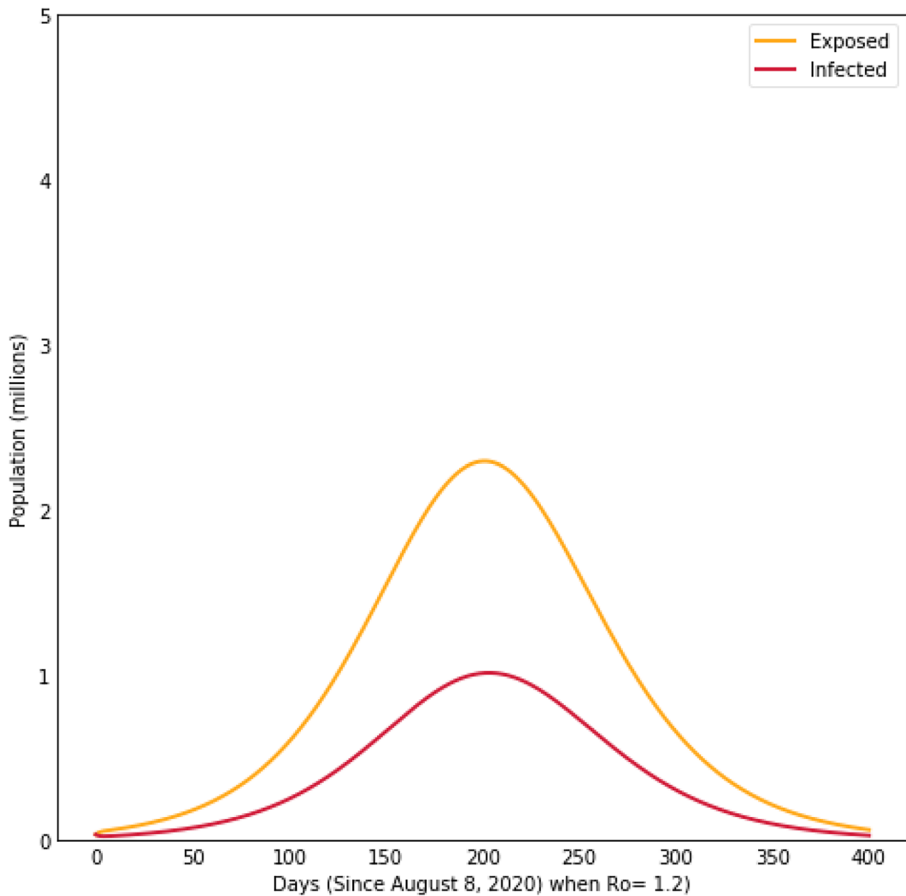
Fig. 7 Predictions with current slower spread rate and partial lockdowns

can be studied for predicting blood flow and oxygen supply in a patient's lungs. Digital twins can also help in drug trials as more data is now available for COVID-19 patients and this process can help in speeding up antiviral drugs, antibodies and on other treatments. These models can also facilitate physicians to make more informed decisions and assist in personalized medications for patients. Implementation of digital twins can assist governments to be well prepared for such unforeseen crises. To continually track specific biomarkers, data can be obtained in real-time form nano sensors [45].As shown in Fig. 8, there are four important layers in our model which are categorized under four levels as individual, organizational, e-governmental, and strategic. To integrate digital twins and provide a better environment, there is need for collective actions at all four levels. The individuals need to be connected with other entities so that the monitoring of COVID-19 can be done effectively in real time. In case of any alerts, these can be transmitted to individuals from higher levels. At organizational level, institutions like offices, hospitals, factories are placed together as they need to have a closer surveillance of COVID-19 symptoms and infections of all individuals relevant to their organization. These organizations act as bridge between individuals and e-governmental entities regarding risks, information, strategies,
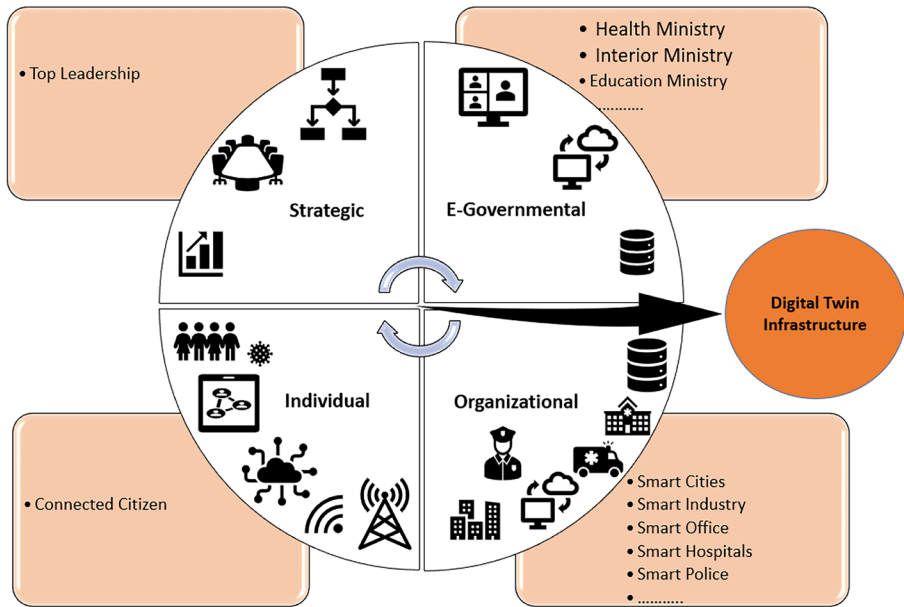
Fig. 8 Digital twin-based e-government framework

monitoring, policies and so on forth relevant to them. At the third level, governmental entities like health ministry, interior ministry etc. are placed. Each governmental entity deals with COVID-19 related data such as patient record, incoming travelers record, vaccinated patients etc. Such information exchange enables these entities to work closely with each other as well as communicate with strategic layer for future planning at higher level (country level) and forwarding relevant information to lower layers as well.

5 Conclusion

Applications of digital twins in epidemics has been discussed to minimize the disease spread and at the same time providing needed services to citizens. Projections for COVID-19 spread for Pakistan were shown based on the 3rd wave of disease spread. We quantified the impact of social distancing and lockdowns and made predictions for the number of infected cases under various degrees of social distancing and lockdowns in Pakistan. It was concluded that due to asymptomatic infections and limitation of testing facilities the current spread in many countries might be much higher, especially in developing countries. We showed that predicting the spread of COVID-19 might allow authorities to plan the resources accordingly. We further demonstrated that with observing social distancing, the COVID-19 curve can be effectively flattened. We explored the opportunities where digital twins can be deployed for supporting business continuity. Our layered approach provides guidelines for technologists, governments, and public policy managers to deploy digital twins to better enable new normal life in a relatively secure environment.

Declarations

Conflict of interest The authors declare no conflict of interest.

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