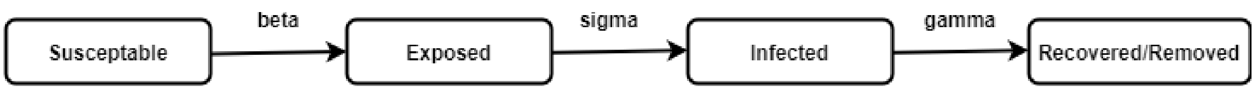
SEIR model has been used to model and depict the dynamics of the spread of COVID-19 in Spain. According to the compartmental models in epidemiology (Lopez & Rodo, 2020) the population can be divided into four distinct compartments namely, *Susceptible* [S] (population prone to the disease) *Exposed* [E] (population in the incubation period i.e. who are exposed to the disease but don't have symptoms yet), *Infected* [I] (population having the disease with symptoms and are infective) and *Recovered/Removed* [R] (population who have recovered and become immune or, dead suffering from the disease).

The transitions between the four compartments are depicted as shown in Figure 1 and the related differential equations are represented as follows:



$\frac{dS}{dt} = -\beta\frac{SI}{N}$ .... (1)

$\frac{dE}{dt} = \beta\frac{SI}{N} - \sigma E$ .... (2)

$\frac{dI}{dt} = \sigma E - \Upsilon I$ .... (3)

$\frac{dR}{dt} = \Upsilon I$ .... (4)

N = S + E + I + R .... (5)

$R0 = \frac{\beta}{\Upsilon}$ .... (6)

where **S** is the total susceptible population in this case population of Spain, E is the exposed population, **I** is the stock of the infected population, and **R** is the stock of recovered or, removed population. The four compartments add up to the total population of N and R_0 is the basic reproduction number for COVID-19.

We have proposed a customized SEIR model for the epidemic spread of COVID-19 based on grid-based population distribution with recurrent mobility patterns of the population between these grid-cells (Arenas et al., 2020) . The land surface of Spain excluding the dispersed islands have been divided into a mesh of 153270 grid-cells and treat each square as a separate location. For smooth mobility flow and computational ease, 3997 grids have been selected for the current study where the population is greater than 2000 and where we can apply the SEIR model individually. If a grid has exposed or infected cases, the outbreak will follow the dynamic described by the model using the mobility flow where the people will travel to other locations, carrying the disease with them and causing (additional) infection. The mobility dataset used in the current study as origin-destination flow matrix has been collected from the Instituto Nacional de Estadística (INE), Spain ("Spanish Statistical Office," 2020).

The transition between the four compartments mentioned above, are the epidemiological parameters controlling the dynamics of the epidemic. The transition rate between S and E is β, defined as the average number of contacts per person i.e. the effective contact rate estimating the probability of disease transmission in one contact between a susceptible and an infective subject. In the current study, the average contact rate has been calculated using the urban transport dataset from three busy cities of Spain, Madrid, Barcelona and Valencia. The transport dataset collected from INE, Spain provides number of commuters per hour using intercity train and metro services. The average number of contacts have been calculated as the number of commuters per 1000 population commuting per hour during the busiest time of the day (9:00 Hrs. to 17:00 Hrs.). The average contact of the three cities are Madrid (0.952), Barcelona (0.934) and Valencia (0.804) from which the mean value (0.89) has been used as the β value in the current study. The commuting data and time period used to calculate β value has been selected to maximize the mobility flow for the current model. The incubation period for COVID-19 reported by WHO, 2020 is 5 to 6 days in average (WHO, 2020), in some cases it was reported to be 14 days. In our formalism, we have considered 7 days as the average incubation period. The transition parameter (σ) between exposed and infective compartments used in the current model is thus, (1/incubation period) i.e. 0.142. Similarly, the transition rate between infected and recovered compartments is denoted by ϒ. During current study, there is no conclusive data to determine the value of ϒ for Spain. From recent literature from other countries, we estimate the period from ICU admission to death as an average 5 to 7 days (Wilson, Kvalsvig, Barnard, & Baker, 2020) and the stay in ICU for those overcoming the disease as 10 days (Ferguson et al., n.d.)But the values vary widely in different countries. An attempt was made to estimate the value of ϒ from the basic reproduction number R_0. The ratio between β and ϒ is usually denoted as R_0. To date, the WHO estimates that R_0 for COVID-19 is somewhere between 1.4 and 2.5 (WHO, 2020). Although other estimates from Europe and Spain give a range between 2 and 3 (Jonathan M. Read, Jessica R.E. Bridgen, Derek A.T. Cummings, Antonia Ho, 2014) even there are instances epidemic have been found to infect up to 16 people (Yuan, Li, Lv, & Lu, 2020). In a recent literature (Yuan et al., 2020) the reproduction number for Spain has been found be 3.95. Following the same trend, from the records of European Centre for Disease Prevention and Control (ECDC, 2020) we have calculated an average basic reproduction number, $R_0 \sim 2.96$. From the basic reproduction number, the value of ϒ is calculated to be 0.294. Again, at the time of the writing, we don't have enough data to determine this conclusively, but for the model the value for ϒ has been estimated from the R_0 value.

From the outbreak of the pandemic in Spain since the last week of February 2020, Spain has undergone two phases of lockdown imposed by the Government as a precaution to fight against the fatal virus. There was a complete lockdown imposed from 15 March 2020 till 12 April 2020 and another partial lockdown continuing from 13 April 2020 till date. During the complete lockdown phase, all sort of transport except emergency and healthcare facilities had been completely ceased in the country. In our model during this phase we have implemented the complete lockdown phase by completely stopping the mobility flow for the above time period. However, the β value has not been reduced immediately from the starting day of the complete lockdown. As mentioned above, an average 7 days of incubation has been imposed on the β value reducing it to 0.19, collected from the mobility matrix in (Arenas et al., 2020) from 22 March 2020. Similarly, during the partial lockdown phase when the mobility gets relaxed to some extent, the value of β has been updated to a comparatively higher value 0.25 (one forth of actual β value). Both β values during the complete and partial lockdown have been selected considering previous literature from Spain (Arenas et al., 2020) and actual intercity communication available during the mentioned time period. During the partial lockdown phase the mobility flow has been reduced to half of the actual mobility matrix values. The values for ϒ and σ are kept unchanged throughout the study period.

In the current study we have simulated four different scenarios, one the real scenario of a combination of complete followed by a partial lockdown, another proposed scenario if the complete lockdown has been imposed from 6 March 2020 followed by partial lockdown from 13 April 2020. Other two scenarios are without lockdown and partial lockdown for the complete time period. Detail of the transmission rates and mobility matrix for each scenario used in the current study are reported in **Table 1**.

Few assumptions are made while designing the epidemiological models. They are mentioned as follows:

- Based on the COVID-19 pandemic reports by World Health Organization (WHO, 2020) we have considered whole population of Spain to be susceptible to the ongoing virus attack.
- The last compartment (Recovered/Removed) is no more susceptible to the disease.
- During the lockdown phases, depending on the reduced daily number of train or, other intercity transport facilities β and mobility matrix values have been updated.
- We have used the average R_0 ~ 2.96, which lies in the higher end of the global range of estimates by scientists (Wilson et al., 2020) for COVID-19. But this value close to other estimates specifically for Spain (Yuan et al., 2020).
- R0 value has been used to estimate the ϒ value.
- The seed of COVID-19 in Spain with number of infected as 8 has been set at Madrid from 26 February 2020.
- The model has been executed for a total time period of 91 days, starting from 26 February 2020 to 25 May 2020.

Scenario	Type	Start Date	End Date	Parameters	Mobility
	No Lockdown	26-Feb-20	14-Mar-20	**beta = 0.89** **sigma = 0.14** **gamma = 0.3**	Full

Scenario 1	Complete Lockdown	15-Mar-20	12-Apr-20	**beta = 0.19 sigma = 0.14 gamma = 0.3**	Zero
	Partial Lockdown	13-Apr-20	25-May-20	**beta = 0.25 sigma = 0.14 gamma = 0.3**	Half
Scenario 2	No Lockdown	26-Feb-20	14-Mar-20	**beta = 0.89 sigma = 0.14 gamma = 0.3**	Full
	Complete Lockdown	6-Mar-20	12-Apr-20	**beta = 0.19 sigma = 0.14 gamma = 0.3**	Zero
	Partial Lockdown	13-Apr-20	25-May-20	**beta = 0.25 sigma = 0.14 gamma = 0.3**	Half
Scenario 3	No Lockdown	26-Feb-20	14-Mar-20	**beta = 0.89 sigma = 0.14 gamma = 0.3**	Full
Scenario 4	No Lockdown	26-Feb-20	14-Mar-20	**beta = 0.89 sigma = 0.14 gamma = 0.3**	Full
	Partial Lockdown	15-Mar-20	25-May-20	**beta = 0.25 sigma = 0.14 gamma = 0.3**	Half

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