SIR MODEL

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***Abstract*—The world is currently suffering deaths because of the COVID-19. Many things are changing, people are losing their jobs, people are getting sick and simply we do not see a well ending for this situation until there will be vaccines for this. Therefore in this project, a model called SIR will be explained in order to give you the ideas of how the coronavirus is spreading. This model is being applied in the Mérida, Yucatán population and the data is being taken from the Secretaria de Salud de Yucatan.**

***Index Terms*—R0, COVID-19, SIR, epidemic, pandemic, endemic, epidemic outbreak.**

I. Introduction

The situation we are currently experiencing is distressing, because many people have been dying from a new disease called Covid-19 (Coronavirus), in late 2019 the first outbreak began in the market in Wuhan, China [1]. The coronavirus is known to have originated from zoonotic transmission, from animals to humans, and has affected the entire world. However, many first world countries are already in the process of ending this pandemic, if not some have already eradicated this disease in their respective country. So there are different points of view such as:

- ¿Cómo es posible que China, siendo el epicentro de esta enfermedad, haya sido capaz de controlar esta enfermedad desde el inicio?
- How is it possible that China, being the epicenter of this disease, has been able to control this disease from the beginning?
- How is it possible that developing countries such as Honduras and Cuba have been able to control this epidemic?
- How is it possible that many people are infected and die with this disease?
- What measures did the different countries that had large numbers of people infected with this disease took to control it?
- What level of control do countries like China or Russia have compared to the United States?
- How is it possible that this disease spreads very fast?

That is why I gave myself the task of investigating the data obtained in our town, given that although it has already occurred worldwide, I am interested in knowing more about this disease in our immediate context, which is in the state of Yucatan, Mexico. Therefore, we must take into account different terms:

- Endemic
- Epidemic outbreak
- Epidemic
- Pandemic

- Endemic refers to the habitual presence of a disease in a specific place.
- Epidemic outbreak: is when there are more than 2 cases of the same disease associated in time, place and person. Or the significant increase in cases in relation to the values usually observed.
- Epidemic: It is the appearance, in a defined community or region, of cases of a disease (or an outbreak) with a frequency that clearly exceeds the expected normal incidence. The number of cases that indicates the existence of an epidemic varies according to the infectious agent, the size and type of the exposed population, their previous experience or lack of exposure to the disease, as well as the time and place where it occurs. •
- Pandemic: affectation of a disease of people throughout a geographically wide area. Technically speaking it should cover the entire world and affect everyone. For a disease to take the name of Pandemic, it must be so fast that people become infected and an easy transfer from one geographical sector to another.

Backgrounds

SARS-CoV-2 belongs to coronaviruses, this coronavirus is the current cause of the pandemic that the world is facing, COVID-19, it was discovered at the end of 2019, in Wuhan China. SARS-CoV-2 is of zoonotic origin [2], the mode of transmission or contagion between people is through droplets of saliva that are expelled, by coughing or sneezing [3] and air in the street [4]. The World Health Organization, the Centers for Disease Control and governments are currently making immense efforts to control this situation, such as:

- Frequent washing of hands.
- Cover up when coughing or sneezing
- Keep the distance between people.
- Do not touch your eyes, nose and mouth.
- Social isolation.
- Keep home, if you have symptoms.

These measures were some that the WHO has proposed to stop the advance and the contagions between people [5] Epidemiological models are an essential part of this effort since they allow predicting the probable course of a pandemic, as well as showing the most appropriate strategies to contain it. In this report we will talk about the SIR model, one of the most widely used epidemiological models in this type of situation.

II. Model

In this model, each subject within the affected population You can belong to one of these three groups. The susceptible ones, which are the individuals that are not immune to the disease, either because they have not been vaccinated or because they have not yet developed the infection, that is, they are the subjects that can be infected at any time, in the case of COVID- 19 and because it is a new virus, at the start of the pandemic practically the entire population of the world is part of this group. The infected, who are simply the people who have the disease and who can spread it to other people. The recovered who are the subjects who already had the infection and therefore cannot develop the disease or infect others. The idea of the SIR model is simple, each person can move from one group to another, a susceptible person can develop the disease if he comes into contact with an infected person after a certain time, an infected person can move to the group of recovered as the objects move between these groups the number of people in each compartment changes over time, but at any instant time the result of adding the number of individuals in each group will always be equal to the size of the population. To model these transitions, a system of differential equations is used:

$$\frac{\partial S}{\partial t} = -\beta S \frac{I}{N}$$

For the group of susceptibles, the rate of change with respect to time is primarily negative because the number of people in this group decreases with time, and it also depends on the number of susceptible people and the proportion of infected with respect to the population. Total, so in the equation these two quantities are multiplied, because the more susceptible and infected they interact, the greater this rate of change will be, but not all the susceptible ones will end up being infected. Therefore we include a beta constant that is known as the transmission rate and that depends on two variables, the contact rate, that is, the more daily interaction there is between susceptibles and infected, the higher the beta value and the transmission probability, that is, how likely is it that a susceptible person will become infected after coming into contact with an infected person.

$$\frac{\partial I}{\partial t} = \beta S \frac{I}{N} - \gamma I$$

The variation with respect to the time of the group of infected depends on 2 elements: on the number of susceptibles that enter this group each day, that is, the same term of the previous equation but positive and the number of infected that daily pass to the group of recovered. In this case we use the negative singo as they are no longer infected but we must also bear in mind that this transition does not occur immediately and that it takes a few days for the subject to recover or in the worst case die. We will model this behavior with the gamma recovery rate, which is the speed with which an individual passes from one group to another.

$$\frac{\partial R}{\partial t} = \gamma I$$

The variation with respect to the time to recover will be simply equal to the number of infected that pass to this last group, that is, it will be equal to the last term of the previous equation but positive. One of the first questions I want us to solve is: under what conditions will there be or not be a pandemic? For this we are going to focus on the second differential equation that of the group of infected, if the number of infected does not change over time, the disease is in endemic equilibrium, that is, it does not spread massively but it does not disappear either, if the rate of infected decreases over time ie less than zero there will be no spread. But if this rate increases over time, that is, if it is greater than zero, it is there that an epidemic will develop. When solving this last inequality using a little algebra we find that for there to be propagation the relationship between beta and gamma must be greater than 1. This relationship represents a very important parameter in any epidemiological model and is known as the basic number of reproduction or R0. This parameter is essential because it allows epidemiologists to measure how contagious a disease is, in simple terms R0 is the average number of people in the group of susceptibles that may be infected by a subject from the group of infected, for example a basic number of Reproduction equal to two is equivalent to saying that for each infected subject two susceptible subjects would end up developing the disease. So if everything starts with an infected subject, then there will be 2, then 4, 8, 16, and so on, and therefore a pandemic because the number of those affected will grow exponentially.

III. Results

Since we have finished defining the parameters of the SIR model, now we can start with the simulations. Many scenarios may or could have occurred if health and hygiene protocols had been taken correctly. A very important parameter in this model is R0, which is the basic reproduction number. This parameter is very important, since it allows us to know whether or not there will be a pandemic. Basically, it is telling us how many people on average will be infected by at least one infected person during their infection period. As we defined before, to move from one state to another, everything is through human interactions. A person may be susceptible to passing to the group of infected for certain times and then that same person, during her period of infection, is likely to infect a certain number of people on average. As your infection period is over, it goes into the removed state, as it will not give you this disease again. That is why while $R0 > 1$, then, the number of people infected will grow exponentially, while if $R0 < 1$, the number of infections will decrease exponentially and consequently, the epidemic outbreak will disappear quickly without many infections occurring. Although it is said that R0 can be calculated in the following way:

$$R0 = \frac{\beta}{\gamma}$$

Where, $beta$ is the transmission rate and $gamma$ is the recovery rate. Similarly, R0 can be calculated as follows [6]: $R0 = \frac{Number of cases of people infected today}{Number of people infected yesterday}$

That is why we will do simulations for tomorrow and Tuesday.

We will take the data from the Secretaria de Salud de Yucatan

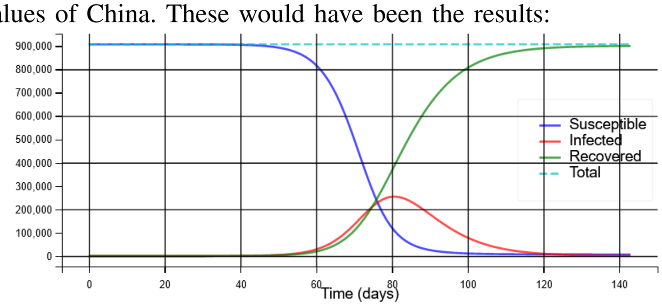
Since yesterday there were 215 new infections and on Saturday there were 211 new infections. If we follow the previous rule, we will have that $R0 = \frac{215}{211} = 1.01$ and if we multiply 215 * 1.01, we will have that on Tuesday they will make an average of 217 new infected and if we take the 217 and divide them with the 215 from the previous day, we will have that R0 is equal to 1.00 and if we do the same, we will obtain that by Wednesday, there will be approximately 216 new cases.

We can see the R0, number of cases and the expected in the following days:

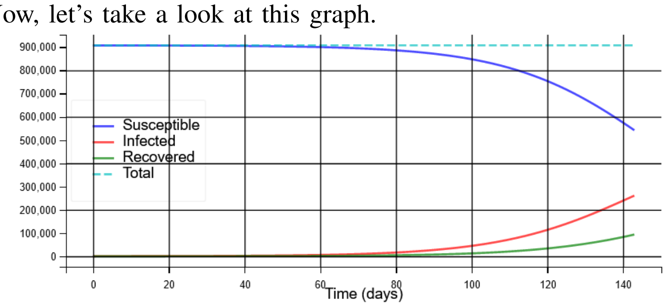
Date	Number of infected cases	R0
30-07-2020	244	1.22
31-07-2020	240	0.98
01-08-2020	211	0.87
02-08-2020	215	1.01
03-08-2020	217	1.00
04-08-2020	216	1.00

Now we will do a simulation regarding the parameters of China

If we take into account that the population of Mérida is approximately 907,020 people [7]. And if we had taken the values of China. These would have been the results:



Now, let's take a look at this graph.



This is the current situation at least in Mérida, Yucatán. The number of people infected are growing up exponentially. Therefore, the suceptible people is less, but the recovery is even less than the infected people. This is because most of the Merida population do not follow the rules of stay at home or the use of face masks

IV. Conclusion

In this work, the data published by the Health Secretariat of the State of Yucatan on the number of new daily confirmed cases of COVID-19 in Merida, Yucatan, were used to estimate the average number of people that an infected person transmits during their contagion period. (R0).

Although the data obtained is supposed to be the real data, I consider that the reality is different, since there are many lagging cases. Therefore, greater hygiene measures must be taken, since if these are ignored, the cases of infected will be greater and the medical capacity to treat them will be increasingly scarce.

The parameter that is telling us the number of daily infected is R0 and as long as R0 is not less than 1, this pandemic will continue to grow exponentially.

My expectations at the beginning of this project were that I had a little idea of how the SIR model was working in order of predecting the deaths and infections, but it is true that this model is really helpful for the correspondent authorities since this will tell which measure we should follow in order to not get infected until there is a vaccine for the coronavirus. After I finished the report I realized that this model is really complex and is useful and since as we studiend at the begging of the quarter, this might be simulated by using networks, but the thing that impressed me the most was that human interaction in this case is not recommendable since you would know if a person is infected and therefore you might be infected and you once that you own the illness, you might as well infect other until you pass to the recovery state and you no longer infect others. I really liked this project because I learned a lot, not only in the mathematical way but also in which all the hygiene protocols are done for something and if people obeyed those ones, the cases would be differents.

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