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COVID-19 Patients Analysis using SuperHeat Map and Bayesian Network to identify Comorbidities Correlations under Different Scenarios

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Abstract

Background: Given the exposure risk of comorbidities in the Mexican society, the new pandemic involves the highest risk for the population in history.

Objective: This article presents an analysis of the COVID-19 risk for the regions of Mexico.

Method: The study period runs from April 12 to June 29, 2020 (220,667 patients). The method has an applied nature and according to its level of deepening in the object of study, it is framed in a descriptive and explanatory analysis type. The data used here has a quantitative and semi-quantitative characteristic because they are the result of a questionnaire instrument made up of 34 fields and the virus test. The instrument is of a deliberate type. According to the manipulation of the variables, this research is a secondary type of practice, and it has a factual inference from an inductive method because it is emphasizing the concomitant variations for each region of the country.

Results: Region 1 and Region have the highest percentage of hospitalized patients, while Region 2 has the minimum of them. The average age of non-hospitalized patients is around 40 years old, while the hospitalized patients' age is close to 55 years old. The most sensitive comorbidities in hospitalized patients are: obesity, diabetes mellitus, and hypertension. The patients who needed the mechanical respirator were in range from 7.45% to 10.79%.

Conclusions: There is a higher risk of people losing their lives in the Region 1 and Region 4 territories than in Region 2, this information was dictated by the statistical analysis.

Keywords: Risk; COVID-19; Statistic; Covariance; SuperHeat map.

Introduction

The city of Wuhan in China got the world's attention due to a new disease outbreak of respiratory illness called COVID-19. It has been widely considered the origin of this new epidemic started in early December 2019 from the Huanan Seafood Wholesale Market in the Hubei Province. The World Health Organization (WHO) received notifications about this new disease by the Chinese authorities until December 31 [1].

Coronaviruses are a large family of viruses that can cause diseases in animals and humans. In the case of humans, as far as it is known, several of these coronaviruses induce usual signs of the cold and in severe cases give rise to a respiratory diseases such as Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS) [1].

As of March 11, the 118,000 infection cases were reported globally in 144 countries with 4,291 people who had lost their lives, thus the WHO Director declared that COVID-19 could be characterized as a pandemic [2]. As a consequence of this situation, on March 16, Mexico's health ministry announced the implementation of "healthy distance" to avoid infection. Measures to stop the spread of the coronavirus were temporary restrictions to all non-essential activities; essential activities included the provision of medical services and supplies, assurance of public safety, maintenance of fundamental economic functions, and others essential categories [3].

One of the main measures established by the Mexican government was that the population stay at home to prevent an increased risk of infection. Within in the priority sectors to protect were older adults as well as those people with chronic conditions such as cardiovascular disease, diabetes, chronic respiratory diseases, hypertension, and cancer. The presence of certain comorbidities may represent potential risk factors and death among patients who were infected by the virus [3]. It is important to mention the previous risk scenario in Mexico before the arrival of the COVID-19. In 2018, 722,611 deaths were reported in Mexico, of which 56.4% were men, approximately 43.5% were women, and the rest of the 376 cases the sex was not specified. Of the total deaths, 88.4% were health-related diseases, while 11.6% were due to other causes, mainly to accidents, homicides, and suicides. The three leading causes of death for both men and women are heart disease, diabetes mellitus, and malignant tumors. Homicides were the fourth cause of deaths in men [4]. The aim of the research refers to analyzing the behavior of COVID-19 in Mexico from a period of 79 days (April 12 to June 29, 2020). The study project report is a statistical analysis that is based on a comparison of the contagion population with the chronic diseases of the patients, and their exposure risk to the virus. The paper is structured as follows: Summary, Introduction, Sections 2, 3, and 4, and Discussion. The Section 2 is a brief overview of the arrival of COVID-19 in Mexico. Section 3 presents a statistical analysis descriptive research of the database reported by the Mexican authorities. Section 4 shows the results obtained from the statistical data, which are discussed in the last section.

COVID-19 arrives in Mexico

COVID-19 arrived in Mexico at the end of February 2020. On

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Thursday, February 27, 2020, it was announced at the media that a patient had been tested positive for the coronavirus. This patient went to the National Institute of Respiratory Diseases (INER) where he mentioned that he had traveled to Bergamo, Italy; there he had contacted with an infected person [3]. On Friday, February 28, 2020, the Dr. Manuel Martinez Baez Institute of Epidemiological Diagnosis and Reference (InDRE), confirmed the first case of COVID-19 in Mexico. They found four other cases with suspicious symptoms in people who had traveled to Italy, of which three of them had mild symptoms. Following this up, two of these patients were citizens of Mexico City and the last one was a resident of Sinaloa State. The fourth patient did not show coronavirus symptoms; he was reported as a virus carrier. Perhaps this was the first Mexican case registered of an asymptomatic patient [3].In the following days, there were confirmed new cases of the pandemic. On Saturday, February 29, 2020, it was reported a female patient, which lived in Torreon, Coahuila, Mexico, tested positive after returning from Italy. Her symptoms were mild and she stayed at home for her care. The next case showed up in Tuxtla Gutierrez, Chiapas, it was an 18-year-old female patient, who also arrived from Italy and had been in contact with Torreon's patient. Until March 1st, all the COVID-19 Mexican cases were imported [3].

Material and Methods

COVID-19 data analysis

This section presents a COVID-19 risk analysis for the regions of Mexico. For the record, it is important to point out that the database origin is from the official government web page created by the Secretary of Health in Mexico.

The Mexico COVID-19 database has the following hierarchical variables (Figure 1): 1) positive and negative patients, 2) symptomatic patients, and 3) hospitalized and non-hospitalized patients.

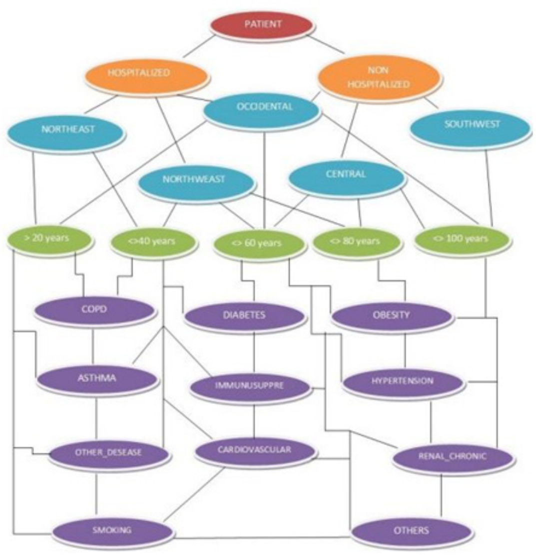

Figure 1: Network database was constructed with hierarchical variables identified by 5 different colors as follows: maroon, orange, blue, green, and purple.

Symptomatic patients are characterized by presenting the major COVID-19 symptoms, these cases show symptoms such as cough, sore throat, fever, or shortness of breath. Once the viral detection test has been applied, if the patients are tested positive they were classified as positive patients and assume to have the virus, otherwise, they were consider as negative patients. At the first position on the hierarchical variables are positive patients; for these cases are following subsections: the symptom onset date, clinic admission date and clinic exit date [5]. At the second place on the hierarchical variables are symptomatic patients, whose are sub sectioned as hospitalized patients and non-hospitalized patients. For symptomatic patients with severe to critical disease or those who are severely immunocompromised, the health experts admitted them at the clinic immediately and were classified as hospitalized patients in our database.

For symptomatic patients with mild to moderate disease and not severely immunocompromised, the health experts recommended that they must keep a strict quarantine at home and were classified as non-hospitalized patients in our database. The study project report is based on a comparison of the hospitalized and non-hospitalized patients with the comorbidities of the patients and their exposure risk to the virus in different regions of Mexico. In these statistical analyses, the principal comorbidities on patients are detailed, such as diabetes (D), COPD (CO), asthma (A), immunosuppression (IM), hypertension (HY), cardiovascular (CA) problems [5], chronic kidney disease (RE), obesity (OB), and others diseases (OD) [6,7]. People suffering from any comorbidities are at increased risk of severe COVID-19 infection [8], the diseases mentioned above play an important role in the possible recovery of patients who have acquired the virus [9,10]. Figure 1 describes the Mexico COVID-19 database extraction and their hierarchical variables. It should be emphasized that the period of analysis of the database corresponds from April 12 to June 29, 2020 (220,667 patients), giving a total of 79 daily record files.

Statistical analysis

Parameters analysis of the regions of Mexico: For the risk analysis of the regions of Mexico on patients with COVID-19, 5 regions were selected, for a more adequate analysis and information management [11,12]. It must not forget that Mexico has 32 states, as a whole each is a sovereign jurisdiction, each one with a particular political division, economic entity, specific culture, and also population with a different social situation. The states grouped by separate regions allow an efficient and certain descriptive analysis of statistical information. The regions are named as follows: United Mexican States of Northwest Region (R1), United Mexican States of Northeast Region (R2), United Mexican States of West Region (R3), United Mexican States of Central Region (R4), and United Mexican States of Southeast Region (R5).

The United Mexican States of Northwest Region (R1) consists of the following federal entities: Baja California, Baja California Sur, Chihuahua, Sinaloa, and Sonora. The United Mexican States of Northeast Region (R2) incorporates: Coahuila, Durango, Nuevo Leon, San Luis Potosi, and Tamaulipas. The United Mexican States of the western Region (R3) involves: Aguascalientes, Colima, Guanajuato, Jalisco, Michoacan, Nayarit, Queretaro, and Zacatecas. The United Mexican States of the Central Region (R4) contains: Mexico City, State of Mexico, Guerrero, Hidalgo, Morelos, Puebla, and Tlaxcala. Finally, the United Mexican States of Southeast Region (R5) includes the states of Campeche, Chiapas, Oaxaca, Quintana Roo, Tabasco, Veracruz, and Yucatan.

Age Analysis of the regions of Mexico: In order to perform the age analysis of the regions of Mexico, the database of age was divided into five ranges (bins), where each bin corresponds to the following categories: 0-20 years old, 21-40 years old, 41-60 years old, 61-80 years old, and 81-100+ years old (Figure 2). The age distributions analysis compared the hospitalized (H) and non-hospitalized (NH) patients in the 5 regions of Mexico where they were registered daily [13]. The age distribution has been adjusted to obtain a normal distribution [13, 14]. The first analysis contains the mean and standard deviation per day and then these analyses were calculated per groups for the consequent 79 days in the five geographical regions. Figure 2 shows only 10 days of the 79 days, for more details visit our repository on GitHub.

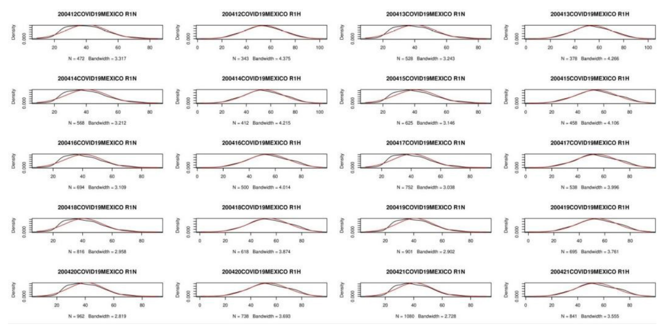

Figure 2: Age distribution plots of H and NH patients in R1 for 10 days.

It is important to mention that the following numbers are referring to the standard deviation age from the patients. In R1, the age of non-hospitalized patients was about 40.88 years old (standard deviation), while in the case of hospitalized patients it was almost 55.25 years old. In R2, NH patients were almost 40.64 years old and 54.64 years old for hospitalized patients. For R3, NH patients the age was 41.08 years old and for hospitalized patients was 55.46 years old. In R4, NH patient's age was 42.42 years old and H patients were about 53.71 years old. For R5, the age of non-hospitalized patients was 42.22 years old and for hospitalized patients was 54.18 years old. It is notable in the age distribution that two bins accumulate the major density of age, in 20-40 years old range and 40-60 years old age ranges. For the bin with age range between 20 to 40 years old, our analysis shows that the major density was with NH COVID-19 patient cases, who were recommended by the health experts to keep a strict quarantine at home for their recovery. In contrast, for the bin with age range between 40 to 60 years old, our analysis shows that major density was with H patient cases. Figure 2 carries the empirical evidence of these results, it is extraordinary that each region has independence between them, and it is amazing to discover that age average numerical and its age standard deviation value are similar in all regions.

Regions of Mexico comorbidity analysis: Regarding the comorbidity of the regions of Mexico and its analysis, it is necessary to notice that these analyses were carried out only in H patients due to the huge information that can be obtained from them in the hospitals, even each patient were monitored all day. As we mentioned in the previous subsection, the age of these patients is between 40-60 years old. The total number of patient registered in R1 are about 28,769 in these 79 days (NH=18,526;H=10, 243), in R2 there were 20,178 patients (NH=16,752;H=3, 426), for R3 there were almost 26,359 patients (NH=19,544;H=6,815),in R4 there were 105,744 patients (NH=69,807;H=35,937), and R5 there were 39,617 patients (NH=27,737;H=11,880). Chronic degenerative diseases have been a risk factor in patients with COVID-19. Depending on the condition of the patient with comorbidity, it is their scenario when the coronavirus shows up; with fatal scenarios the risk is too high that they may even die. The comorbidity scenarios registered by the Secretary of Health in Mexico are: patients with asthma, cardiovascular problems, COPD, diabetes mellitus, Hypertension, immune problems, obesity, kidney problems, and others. Figure 3 has two graphs with the box plot where were compared the 5 regions of Mexico and their morbidities, patients were divided into hospitalized and non-hospitalized [15]. In a critical observation, at least three more frequent degenerative comorbidities stand out among H and NH patients, i.e., obesity, diabetes mellitus, and hypertension. It should be noted that the R4 has more density and variety of comorbidities in cases of patients than in the R2. In the next analysis is presented the Relative Frequency of the Total number of comorbidities patients with COVID-19 for each one of the regions Mexico with the following formula: Region={Non-hospitalized;Hospitalized}.

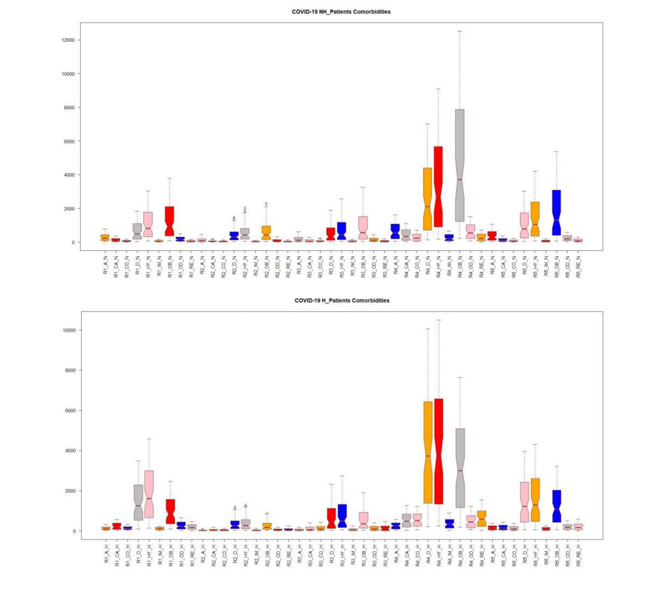

Figure 3: Box plot of the 5 regions of Mexico, grouped by the 9 comorbidities, the top graph is from NH patients values and the bottom graph is from H patients.

Asthma disease had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1 = {4.18%;3.16%}, R2 = {2.72%;2.65%}, R3 = {3.12%;2.71%}, R4 = {2.31%;1.60%}, and R5 = {3.82%;3.11%}. Cardiovascular disease had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1 = {1.92%;5.62%}, R2 = {1.07%;5.42%}, R3={1.45%;5.82%}, R4={1.59%;3.52%}, and R5={1.33%;3.62%}. Hypertension disease had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1={16.35%;44.56%}, R2={12.26%;37.53%}, R3={13.12%;40.04%}, R4={13.01%;29.17%}, and R5={15.14%;36.17%}. COPD disease had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1={0.93%;3.13%}, R2={0.68%;3.53%}, R3={1.11%;6.17%}, R4={0.99%;3.37%}, and R5={0.81%;3.11%}. Diabetes mellitus disease had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1={9.83%;33.95%}, R2={8.85%;34.55%}, R3={9.65%;33.82%}, R4={10.04%;27.97%}, and R5={10.87%;33.21%}. Immunosuppression disease had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1={0.86%;2.21%}, R2={0.71%;3.38%}, R3={0.86%;3.40%}, R4={0.93%;2.47%}, and R5={0.68%; 2.13%}. Obesity disease had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1={20.34%;23.93%}, R2={13.81%;25.27%}, R3={16.56%;27.82%}, R4={17.90%;21.27%}, and R5={19.32%;26.91%}. Kidney disease had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1={0.92%;4.45%}, R2={0.82%;7.03%}, R3={1.01%;6.76%}, R4={1.02%;4.25%}, and R5={1.07%;4.86%}. Others diseases had a relative frequency in patients with COVID-19 in the regions of Mexico as follows: R1={2.63%;6.45%}, R2={1.90%;5.34%}, R3={2.23%;5.91%}, R4={2.16%;3.38%}, and R5={2.07%;4.15%}.

It is worth noting that the major comorbidities densities that are presented in patients with COVID-19 are obesity, diabetes mellitus, and hypertension diseases. Table I is summary of patients form the 5 regions of Mexico; it shows the percentage of patients for each region who tested positive for COVID-19, but they were not having any type of comorbidities. Of these patients, 61%-69% is NH patients while 29%-41% required hospitalization i.e., H patients.

Region	Ambulatories	Hospitalized
R1	61.36	30.56
R2	69.97	33.12
R3	65.69	29.93
R4	64.74	41.71
R5	61.24	33.23

Table 1: Records of the patients for each regions of Mexico who did not report having any comorbidity when tested positive for the virus.

Covariances Analysis of the regions of Mexico: This subsection gives out an analysis of the dependencies of comorbidities with the different regions and the ages of their patients. The correlation network is constructed by hierarchical variables that are grouping; at the first level is the patient that tested positive for COVID-19; at second level it is divided into hospitalized and non-hospitalized patients; in a third level are the five geographic regions of Mexico; at fourth level there are five age ranges of the patients and finally, in the fifth level there are nine types of comorbidities (Figure 1). The correlation matrix of these comorbidities was generated by Pearson's correlation coefficients whose values are between the interval $\rho \in [-1;1]$ [16,17]. The correlation matrix obtained is a square matrix of 91 by 91 elements. For a better visual analysis of these matrices, it was divided into two sub-matrices (Figure 4). Each sub-matrix shows the positive or negative correlation between those conditions [18].

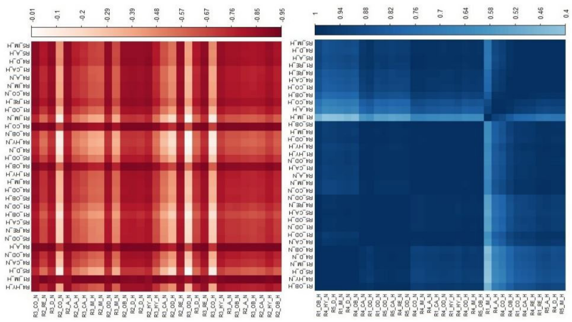

Figure 4: Correlation sub-matrices, the top matrix constitutes the positive correlation and the bottom matrix the negative correlation.

Figure 4 has 2 sub-matrices, the top matrix contains the highest positives correlations that the analysis found in the original matrix, i.e., the values were almost 1. In favor of the last affirmation, it must be noted that its correlation is high because there are several hierarchical levels of the correlation network where the comorbidities are coincident and this has a positive effect on this relationship between H and NH patients. That means, that the linear correlation is high due to the patients in R5 with diabetes has a similar density of H patients to R1 with obesity. In contrast, Figure 4 in the bottom has the matrix that represents the sub-matrix with the highest negative correlation that the analysis was found in the original matrix, which means, this sub-matrix has the inverse linear correlations between the hierarchical levels of the network. Figure 5 shows a correlogram map [19]. This kinds of maps synthesize all the information analyzed in the previous sections. Supporting the last sentence, this correlogram has in its vertical axis the scale that represents the number of days (that is, all recorded database from day one to day 79). On the below horizontal axis are the NH and H patients. The correlogram map contains the entire matrix correlation that has been described in previous sections, left vertical and upper horizontal axes describe the 5 hierarchical levels of the correlation function in a kind of ramp palette. The colors of the correlogram are the result of correlation patterns and are determined by the density of the accumulated number of patients [20, 21].

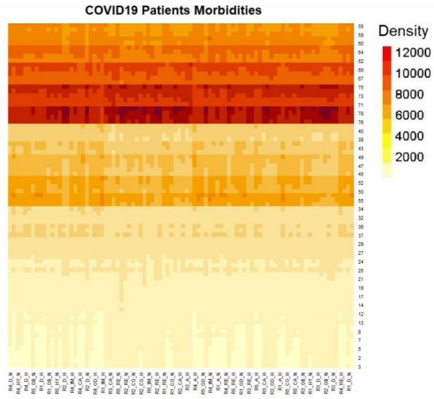

Figure 5: SuperHeat map describing the density relationship between the comorbidities, N and NH patients in the regions of Mexico during the 79 days with the pandemic.

Probability analysis: This section proposes a method for the analysis of the probabilities that uses the 9 subset comorbidities summary and their intersections for each region of Mexico throughout the 79 days of analysis. The calculation of each probability is Equation 1, Equation 2, and Equation 3; this section also contains the description of the DAG plot and its relationship between the children nodes and its leaves, where were calculated the Bayesian probability Analysis. In the first case, it is important to note the direct relationship between the P (patients) and its type classification NH and H. Then the hierarchical classification is under 5 regions (R1, R2, R3, and R4). Subsequently, the dependent event between the 9 comorbidities is calculated in two more hierarchical classifications (Comorbidities(H) and Comorbidities(NH)).

It is important to highlight that the depend events are calculated by the probabilities of comorbidities and their intersections between each of them. It must be taken into account that the patients do not necessarily suffer only one comorbidity, in the majority of the situations, they are suffering more than one comorbidity, see Figure 6. This phenomenon can be possible to resolve as it is presented in Figure 6. Note: There are two separate analyses, NH and H patients.

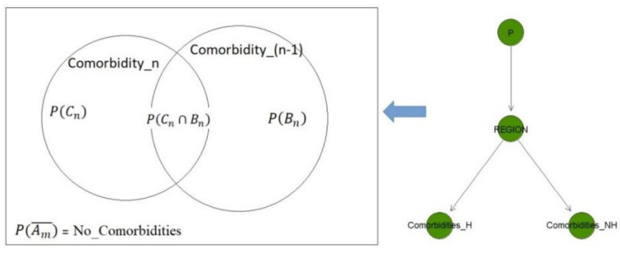

Figure 6: Bayesian Network configuration for calculating the Probability Analysis.

Defined to $P(A_m)$ as the probability of a patient with COVID-19 for the m={1,….,5} region. Therefore, $P(A^{-}_{m})$ is defined as the complement probability, which is a patient in another region.

$$P(A_m)=1-P(A^{-}_{m}) \quad (1)$$

The intersection between regions and comorbidities is defined as:

$$P(A_m \cap B_n)=P(A_m) * P(B_n \mid A_m) \quad (2)$$

where P(Bn|Am) is the region probability given at least one comorbidity n={1,...,9}. As consequence, the probability of each comorbidity is obtained by:

$$P(B_n)=P(A_m)-P(A_m \cap B_n)=P(A_m)-P(A_m) * P(B_n|A_m) \quad (3)$$

Based on the last equations, these data results are entered in the Bayesian network that it uses the bnlearn and Rgraphviz libraries (in R programming) [22], for generating the probabilities outputs that are shown in Figures 7 and 8, for NH and H Patients.

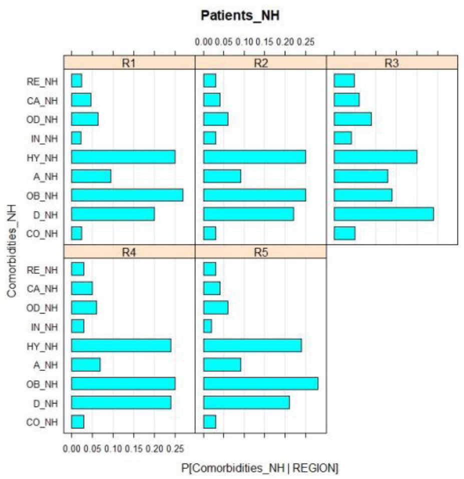

Figure 7: Network output for the Non-Hospitalized patients and their coefficients from comorbidity probabilities for the 5 regions of Mexico in 79 days of COVID-19 registration.

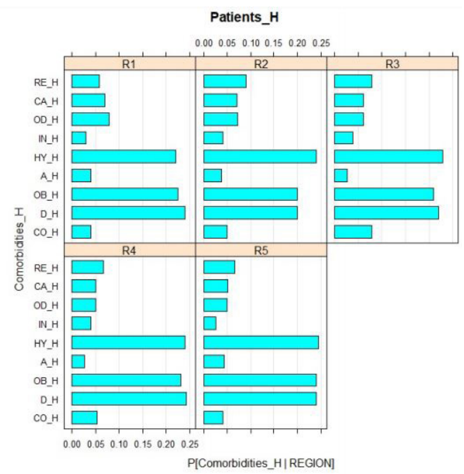

Figure 8: Network output for the Hospitalized patients and their coefficients from comorbidity probabilities for the 5 regions of Mexico in 79 days of COVID-19 registration.

Results and Discussion

The last sections have described the study project report overview of the pandemic situation since the COVID-19 arrived in Mexico. The United Mexican States has a population of 125 million people. Its largest concentration of the population is young and adult persons; as a consequence the elderly people are a lesser percentage. Accordingly, there is a high probability that people who have been tested positive for COVID-19 are in the age range of 20-60 years old. In view of the fact that comorbidities occur in adults, the patients who have required hospitalization (H) are in the range about of 40-60 years old while patients who have not required hospitalization (NH) stay in the younger population of 20-40 years old (Figure 2).

In R1, 35.61% of the patients have been hospitalized and 64.39% have not required hospitalization. For R2, 16.98% was H and 83.02% was NH; in R3, the proportion of H was about 25.86% and NH with 74.14%; R4 had 33.99% of H while 74.14% were NH patients, and in R5, it was about 29.99% of H patients and 70.01% of NH patients.

On the other hand, the Mexican population has stood out in the comorbidities such as diabetes, COPD, asthma, immunosuppression, hypertension, cardiovascular problems, chronic kidney disease, obesity, and others diseases. These conditions and COVID-19 have played an important role in determining whether or not patients require hospitalization. It is redeemable to mention that in R5, asthma, diabetes mellitus, kidney problems, and obesity had the highest relative frequencies among H and NH patients. In R1, the cardiovascular problems, hypertension, and other diseases were the most frequent comorbidities in their patients, while in R4, the immunosuppression was the mainly frequent comorbidity in their patients, and COPD was in R3. Some percent of H patients have been required mechanical ventilators in the Intensive Care Unit (ICU) in these 79 days. As a result, the accumulated relative frequency of invasive ventilator employed in H patients by region is as follows: 9.27% in R1, 10.47% in R2, 8.08% in R3, 7.45% in R4, and 10.79% in R5. It should be emphasized that the patients whose needed the ICU services unfortunately died. The accumulated relative frequency in 79 days and their relationship is as follows: R1 of 48.42%, in R2 of 33.14%, R2 of 46.46%, for R4 of 56.49%, and in R5 of 49.45%. Therefore, the risk of people losing their life being H patients and ICU hospital services in R1 is about 41.34%, R2 concerning 27.23%, 28.55% for R3, in R4 is 36.06% and R5 almost 35.31%. As claimed by the probability analysis, it can be possible to point out that there is a high probability that a good number of H patients are suffering from obesity, hypertension, or diabetes disease.

This research proposes a regional analysis of the risk of patients who tested positive for COVID-19 and its relationship in a huge country like Mexico. This study also analyzed the risk exposure of patients with comorbidities in Mexican society by regional territory and it is notable the different risk values that involves the population. The evaluation period runs from April 12 to June 29, 2020 (almost 220,667 patients). The most densely populated regions, R1 and R4, represent the largest number of positive cases that have required hospitalization. In R2, the major density of patients has recovered at home. As a result of the age analysis distribution, the average age in NH patients is around 40 years old, while in H patients it is close to 55 years old. While regions R1 and R5 have a higher proportion of H patients, region R2 have higher proportion of NH patients. On the other hand, H patients were shown to be more sensitive due to suffering comorbidities. And the previous scenario is more dramatic because, after the arrival of COVID-19, many have developed obesity, diabetes mellitus, and hypertension. and other diseases. It is remarkable that those H patients who have needed a mechanical respirator had ranges about 7.45% to 10.79% for all the regions of Mexico. Given the above scenario the risk of people losing their life in the hospital is the highest due to the aforementioned comorbidities, particularly in the regions R1 and R4 with the major propensity to die with COVID-19 patients, while R2 is less vulnerable than others, information obtained from the database statistical analysis. On the report of the analysis of probabilities (Figure 6) in all regions, there is almost a 70% probability of being hospitalized if one has COVID-19 and suffers any type of the 9 comorbidities (Figures 7 and 8), on the other hand, there is a probability of almost 30% if one does not suffer any of the 9 comorbidities. Faced with this Mexican national scenario, it is intended to generate a more detailed regional statistical analysis, particularly in Mexico City (in R4), this state has the most densely populated territory in the country. This aforementioned study will allow the Mexican population to take the necessary care to reduce the number of infections, and therefore, the cases of deaths.

Conclusion

In front of this national Mexican scenario, it is intended at work to generate a more detailed regional statistical analysis particularly in Mexico City (into R4); this state has the most densely populated territory of the country. This mentioned study allows to the Mexican population to take the necessary care to reduce the number of infections and therefore, the cases of deaths.

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