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ORIGINAL RESEARCH

Analysis and Evaluation of Major COVID-19 Features: A Pairwise Comparison Approach

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Abstract

The COVID-19 pandemic is a major health threat and its global spread has led governments worldwide to take a series of public health and social measures and restrictions, aiming to reduce its transmission. As COVID-19 outbreak continues, there is a crucial need for further analysis and evaluation of the main features that seem to affect the clinical status of a patient infected by SARS-CoV-2. In this context, the present paper introduces a Covid Patient Assessment Analysis (CPAA) based on operational research, which examines the patient profile, taking into consideration characteristics like gender and age, and also categorizes the experiencing COVID-19 symptoms and the dependency of patient's clinical status from potential comorbidities. Finally, evaluating all the aforementioned features, CPAA ranks COVID-19 cases based on the severity of each case in low-, medium-, and high-risk groups. For the modeling and the implementation of the CPAA, the Pairwise Comparison (PWC) has been used as an integral part of a decision-making process. The outcomes of the paper are the first step towards an overall operational research framework that would be used to evaluate the clinical status of patients and take automate decisions for their potential hospitalization.

Keywords COVID-19 · Pairwise Comparison · Covid Patient Assessment Analysis

1 Introduction

The COVID-19 or SARS-CoV-2 pandemic, also known as the coronavirus pandemic, is an ongoing global pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The novel virus was firstly identified as an outbreak

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in the Chinese city of Wuhan in December 2019 and was spread all over the world [1]. This major global health threat has proved that the diseases arising from a single country may also affect other countries and the health risks are over the national borders. The global spread of the pandemic has led governments around the world to take a series of public health and social measures and restrictions, aiming to reduce the COVID-19 transmission.

As the COVID-19 outbreak continues, there is a crucial need for further research in the wider impacts of this crisis on the society. Numerous mathematical and prediction models have been adopted to help medical, government and public services to respond to the COVID-19 pandemic by performing decisions about pandemic planning, resource allocation and implementation of social distancing measures and other interventions.

Infection by COVID-19 has been associated with various features such as symptoms, comorbidities, age and gender. The frequency, variety and severity of the symptoms are difficult to be distinguished in a patient with COVID-19. The present paper introduces a Patient Assessment Analysis (CPAA), which examines the patient profile, taking into consideration characteristics like gender and age, and also categorizes the experiencing COVID-19 symptoms and the dependency of patient's clinical status from potential comorbidities. Finally, evaluating all the aforementioned features, CPAA ranks COVID-19 cases based on the severity of each case in low-, medium-, and high-risk groups. CPAA aims to help health professionals, decongest the health system offering guidance to patients. It is pointed out that in COVID-19 cases the frequency of a symptom is not highly related to the severity of a case, thus frequency is not taken into account. For the modeling and the implementation of CPAA, the Pairwise Comparison (PWC) has been used as an integral part of a decision-making process. Such methods are used in operational research as problem-solving techniques applied in the pursuit of improved decision-making and efficiency, such as decision analysis and the analytic hierarchy process. The proposed CPAA is the first step towards an overall operation research framework that would improve the health systems related to COVID-19 pandemic and more specifically the evaluation of patients' clinical status taking automated decisions for their potential hospitalization.

The rest of the paper is organized as follows: Section 2 presents the related work, while Sect. 3 introduces the motivation of the paper. In addition, Sect. 4 describes the PWC method, Sect. 5 defines the COVID-19 features considered in this paper. Section 6 presents and analyses the outcomes of this research. Finally Sect. 7 concludes the paper.

2 Related Work

There are several papers that discuss health assessment analysis, adopting decision-making methods such as the pairwise comparisons. In this context, the body of the relevant literature includes studies that address health care decision-making.

In [2] a telehealth system for Parkinson's disease was introduced. The work described a tool called PERFORM that offered a preliminary assessment of

Parkinson patients. In [3] authors addressed a health assessment analysis and a multi-criteria analysis was implemented through a simulation model. The evaluation of two biological prostheses for incisional infected hernias was presented, assessing the effectiveness of the model. In [4] a disease risk analysis and prediction model was introduced, supporting chronic disease management and clinical research for schizophrenia patients. Based on metal health information and intelligent data processing platform, an automatic framework was designed that analyzed and predicted the disease risks of schizophrenia patients.

In addition in [5] a complex decision-making process was carried out through selection, rating, weighting and analyzing of multiple criteria. Spacial analysis was also integrated in the proposed approach. The present study used 10 decisions making factors that were chosen based on their relative importance in mosquito growth and diseases. The Analytic Hierarchy Process (AHP) was adopted for the implementation of the decision-making approach.

After the COVID-19 outbreak, several papers introduced decision-making approaches and predictions tools for this pandemic. Towards this direction, in [6] the authors established laboratory predictors of mortality in COVID-19 disease, which can help to identify high-risk patients. This approach can dynamically predict mortality risk in patients admitted to hospital due to SARS-CoV-2 infection in different occasions during the hospital stay.

In [7] an effective model using risk monogram was introduced that aimed to early identification of cases at high risk. Through this study 372 non-severe COVID-19 patients during hospitalization were followed for more than 15 days after their admission. Finally in [8] a tool based on machine learning monogram was developed, predicting the risk of getting severe coronavirus disease. In this study, 590 COVID-19 patients during hospitalization were enrolled and using two machine learning methods in the training set, 5 out of 31 clinical features were chosen into the model building to predict the risk for severe COVID-19 disease.

Several papers examine and prediction of COVID-19 impact on hospitalized patients. The present paper proposes COVID-19 CPAA (CPAA) and fills a gap in previous literature, since it evaluates the patients' symptoms combined with their demographic profile, their potential comorbidities and ranks the patients in low-, medium-, or high-risk case. The evaluation of each COVID-19 case by CPAA enables patients to self-assess their clinical condition throughout quarantine days, offering personalized diagnosis.

3 Motivation

On January 30th, 2020, the World Health Organization (WHO) announced the outbreak of COVID-19 in China as a public health emergency, raising global concern, especially for countries with vulnerable health systems. The Emergency Committee stated that the spread of COVID-19 can be stopped by early detection, isolation, immediate treatment and implementation of a powerful case detection system have come in contact with the coronavirus [9].

The most common symptoms are fever, dry cough and fatigue. Less common symptoms that may affect some patients are: loss of taste or smell, nasal congestion, conjunctivitis, sore throat, headache, muscle or joint Pain, different types of skin rash, nausea or vomiting, diarrhea, chills or dizziness. The severe symptoms of COVID-19 include breathing difficulty or shortness of breath, loss of appetite, confusion, persistent chest pain or pressure, high temperature. Other less often symptoms are irritability, confusion, anxiety, depression, and sleep disorder [10].

With more that 437 millions confirmed cases of coronavirus worldwide [9], it is obvious that symptoms are varied and strange, they can be mild or debilitating, and the disease may progress in unpredictable ways. Despite the hundreds of published studies on COVID-19 symptoms, any given symptom depends on the patient group examined. Patients in hospitals typically have more severe symptoms. Older patients are more likely to have cognitive problems. Younger patients are more likely to have mild disease.

In this context, the proposed CPAA examines the profile of each patient based on specific characteristics such as gender and age, and also categorizes and ranks patients' experiencing symptoms. Eventually, CPAA evaluates the symptoms combined with patient profile and categorize the patient in low-, medium-, or high-risk case. The purpose of the proposed framework is to decongest the health system and health professionals, but also provide guidance to patients being in home isolation. Figure 1 illustrates CPAA concept.

Even though the Scientific Community created effective vaccines against SARS-CoV2, with the aim of reducing the evolution of pandemic, the number of COVID cases is constantly increasing, since new mutations have reduced the vaccines' effectiveness. WHO states, in its instruction to patients with mild symptoms, that the initial treatment of the disease starts individually at patient's home. In case of more symptoms are appeared or the existing ones worsen, the patient is asked to contact a health care professional for appropriate guidance.

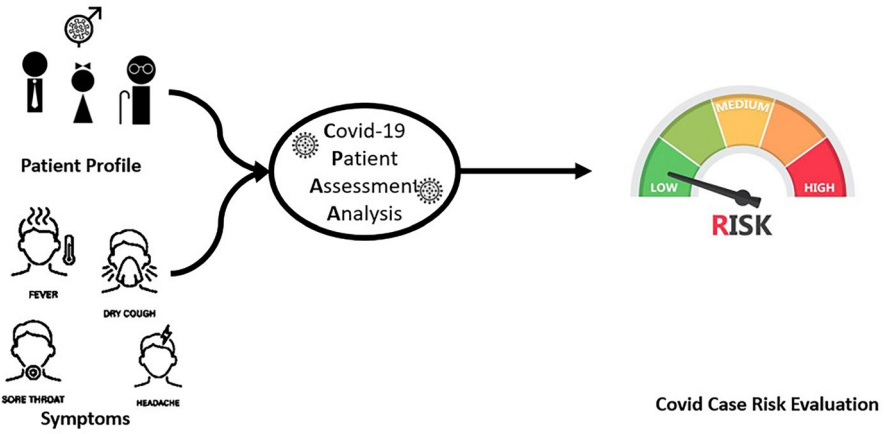

Fig. 1 Covid Patient Assessment Analysis

Therefore, the evaluation of each COVID-19 case by CPAA could enable patients to self-assess their clinical condition during home isolation days. In addition, health professionals could use CPAA and offer to their patient a correct diagnosis. CPAA can be an innovative operational research proposal in the field of Telemedicine and could be used as a first step to develop a patient evaluation system based on operational research to improve health care systems related to COVID-19.

4 Pairwise Comparisons Framework

A fundamental problem in decision-making is to grade the importance of a set of attributes and assign a weight to each of them. Their importance usually depends on several criteria which can be evaluated within the decision-making processes. Pairwise comparisons are widely used in multi-criteria decision analysis (MCDA) and have successfully been applied in many practical decision-making problems either as a standalone method or as an essential ingredient of MCDA processes, such as the AHP [11], the Weighted Product Method (WPM) allowing the Preference ranking organization method for enrichment evaluation (PROMETHEE) and the Analytic Network Process (ANP) [12]. PWC provides a structured process for the effective ranking of attributes, aiming at identifying their importance of influence on a general goal [13, 14].

The PWC framework enables the ranking of attributes by allowing a number of end-users, say M, to compare the various attributes A_i, $(1 \leq i \leq N)$ in pairs, instead of assigning their priorities in a single step [11]. This reduces the influence of subjective point of views, associated with eliciting weights directly. According to PWC, each end-user compares all possible combinations of A_i and A_j. The outcome of these judgments for the m^{th} end-user are stored in a square $N \times N$ reciprocal matrix $\mathbf{P}^{(m)} = [P_{ij}^{(m)}]$, which will henceforth be referred to as a PWC matrix. The value of the element $P_{ij}^{(m)}$ reflects the importance of attribute A_i over A_j. The end-user needs to complete only the upper triangular elements $(i < j)$ of $\mathbf{P}^{(m)}$ since by definition we have $P_{ij}^{(m)} = 1/P_{ji}^{(m)}$ and $P_{ii}^{(m)} = 1$ for a reciprocal matrix. The weights $w_i^{(m)}$ of attribute A_i according to end-user m can be calculated with various ways. The most widely adopted approach is to solve the eigenvalue problem $P^{(m)}x_q^{(m)} = \lambda_q x_q^{(m)}$, where λ_q are the eigenvalues of $\mathbf{P}^{(m)}$ and $x_q^{(m)} = [x_{pq}^{(m)}]$ are the corresponding eigenvectors. Assuming that the eigenvalues are ordered so that λ_1 is the largest eigenvalue, then the weight of attribute A_i is estimated by normalizing the elements of the principal eigenvector $x_1^{(m)}$ as follows [11]

$$w_i^{(m)} = x_{1i}^{(m)} \sum_{i=1}^{N} (x_{1i}^{(m)}) \tag{1}$$

In order to further simplify the comparisons, introduced the nine-level scale shown in Table 1.

One way of measuring the inconsistency of a pairwise comparison matrix is to calculate the Consistency Ratio (C.R.) defined as $C.R. = C.I./R.I.$, where C.I.

Table 1 The nine-level fundamental comparison scale

$P_{ij}^{(m)}$	**Explanations**
1	A_i and A_j are equally important
3	A_i is slightly more important than A_j
5	A_i is strongly more important than A_j
7	A_i is very strongly more important than A_j
9	A_i is absolutely more important than A_j
2,4,6,8	intermediate values
Reciprocals of above	used in analogous manner when A_j is more important than A_i

$= (\lambda_1 - N)/(N-1)$ is the Consistency Index and R.I. is an average random consistency index derived from a sample of randomly generated reciprocal matrices with elements scaled according to [11]. If C.R. is smaller or equal than 0.1 is considered acceptable and in this case, the matrix is said to be nearly consistent [11]. After all the comparisons have been completed, the average weight wk for each attribute A_k is calculated by averaging out the weights $w_k^{(m)}$ obtained by the M end-users, F

$$w_k = \frac{1}{M}\sum_{i=1}^{M} w_k^{(m)} \tag{2}$$

The weights w_k define the priorities of the attributes and hence the outcome of the PWC process.

In this paper, in order to rate the features of COVID-19, one must first evaluate the weights of the primary features and sub-features, denoted by w_k and f_{jk}, respectively, affecting the health status of a patient being infected by SARS-CoV-2. Towards this end, each expert m performs a series of PWCs according to the aforementioned procedure and the weights are finally estimated.

5 Analysis of COVID-19 Features

The health status of a patient infected by SARS-CoV-2 is assessed based on the following primary features: **Gender, Age, Symptoms** and **Comorbidities**. We define as Comorbidities the potential underlying diseases that a patient may have. According to the PWC framework, each feature is further analyzed into further sub-features. Present health studies for disease prevention and treatment should include future analyses related to gender. However, there are only few literature references so far that deal with gender disproportion in the impact and progress of COVID-19 disease and there is no clear analysis of the underlying causes. The Independent Gender Equality Initiative in Global Health 50/50 presents an overview, from countries worldwide, with COVID-19 cases depending on gender. The result of this research showed that there was a similar number of COVID-19 cases in women and men, but increased mortality in men. In cases there are the same

COVID-19 cases in women and men, there is a higher frequency of the disease in older men, given that older men are numerically less than older women due to their shorter life expectancy [15].

In a sample of 262 patients in Beijing, the mean age of the patients was 47.5 years, of which 48.5% were male [16]. In Shanghai, from a total number of 249 patients, the mean age of patients was 51 years and 126 (50.6%) of them were men [17]. The collection of data by the Emergency Medical Service of Beijing showed that of a sample of 60 elderly patients, 56.7% were men. However there was no significant difference between men and women in the age group of "50-64'' and "65–79'' years old [18]. Other studies report that the larger age and some comorbidities are associated with higher rates of infection and mortality, explaining in part the deaths observed in men. It is likely twice higher the risk for men to die due to COVID-19, compared to women according to [19].

A study of European Commission (EC) states that gender differences in relation to immune system have been observed in infectious diseases, autoimmune diseases and inflammations. Women seem to respond more strongly to viral infections and produce more antibodies in response to infection and vaccination [20]. The mechanisms that lead to these differences may be hormonal, that is the different effects of testosterone, estrogen or progesterone, or may be related to differences in the intestinal flora. A stronger immune system may cause a higher risk of autoimmune diseases in women, but also better ability to fight the infection. Other studies mentioned that there are more antibodies, called IgG, in women rather than in men after the SARS-CoV2 infection [21]. In fact, mortality is rising depending on the age and it was observed to be higher in male patients [22].

Gender is a controversial factor that has not yet been described as COVID-19 evaluation criterion, however in this paper it has been introduced as a feature, based on its importance and its role in the disease of COVID-19, according to previous literature. The doubt if the gender finally influences the COVID-19 infection is the reason why there is no comparison between men and women, in this paper, in order to determine the importance of each sex for the disease. The weight of gender importance on COVID-19 is estimated from its comparison with the other features.

- **Age**. In many demographic studies, the patient's age has been identified as one of the key factors of high concern for the progress of clinical status of patients infected by SARS-Cov-2, including rate mortality and severity of symptoms. However, the way the disease of COVID-19 can affect different age groups of patients has not been thoroughly investigated yet. A thorough impact analysis of this kind requires a sequence of thousands samples in different nationalities and age groups.

  In this paper, age is divided into five (5) sub-features (age groups) as presented in Fig. 2. The age group between 0 and 20 was considered of major importance in order for the study to capture all the age range and be more reliable [23].
- **Symptoms**. The feature of Symptoms consists of twenty-one (21) sub-features. The symptom of Oxygen Saturation is examined only if it is lower than or equal to 93%, which leads to a serious clinical status of the patient. Typically, the NPHO gives the following guidelines for dealing with a confirmed

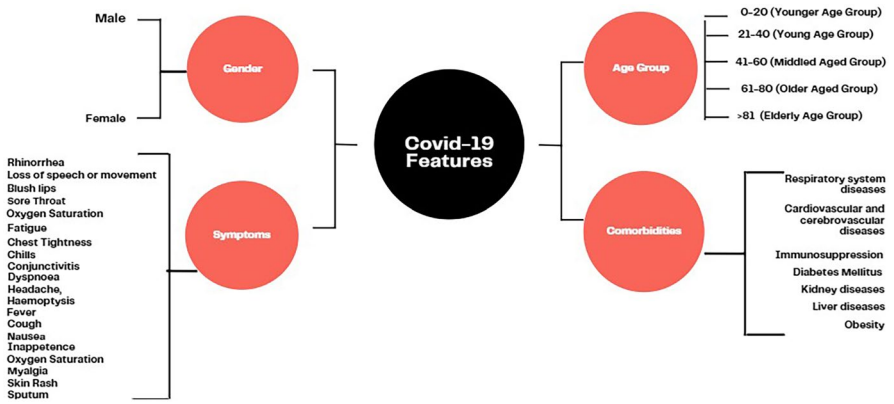

Fig. 2 Covid-19 Features

case out-of-hospital: "If the patient is experiencing respiratory distress or has O2 ≤ 93% saturation, regardless of risk group has to go to the hospital [24].

In March 2020, a meta-analysis was performed analyzing twenty-one (21) surveys, in a total of 47,344 patients, of whom 24,419 were men and 22,925 women. It was observed that the most predominant clinical symptoms were Fever with rate of occurrence 85.6%, Cough with 65.7%, Fatigue 42.4% and Difficulty breathing, i.e., Shortness of breath with 21.4% [25]. In a total of 249 patients, the most common symptoms were Fever in 217 patients with a rate of 87.1%, Cough in 91 people with 36.5% and Fatigue in 39 patients with a rate of 15.7%. Less common symptoms were Dizziness and Headache, Shortness of breath, Rhinorrhea, Sore throat, Diarrhea and Anorexia [26]. Similarly in a review of 43 studies with 3600 patients, Fever (83.3%), Cough (60.3%) and Fatigue (38.0%) were the most common clinical symptoms, followed by increased Sputum production, Dyspnoea and Myalgia [27]. Another research shows that the most common symptoms at the beginning of COVID-19 infection are Fever, Cough and Fatigue, while other symptoms include Sputum production, Headache, Hemoptysis, Diarrhea, Dyspnoea and Lymphopenia (laboratory result not examined in the present study) [28].

A study examining 303 people of all ages mentions that Fever was the most common clinic symptom (80%), followed by Cough (69%), Dyspnoea (45%), Fatigue (30%), Diarrhea (17%) and Anorexia (12%). More specifically, for the age group between 20 and 40, Chest pain was more common (13%), Dyspnoea (22%), less common, while about 13% of young people had no clinical symptoms. In the Middle Age group (41–60) the most common symptoms were Cough (80%), Dyspnoea (58%), Fatigue (39%), Diarrhea (21%), Myalgia (15%) and Gastroenterology. In older people (61–80), Gastrointestinal symptoms (Diarrhea, Nausea and Vomiting) were more common. In the elderly, the most common symptoms were Fever (75%), Cough (53%), Shortness of breath (38%), Fatigue (34%) and Anorexia (25%) [23].

Loss of taste and smell is a clinical condition that resembles symptoms of a single influenza and has been observed in individuals diagnosed with COVID-19 [29, 30]. The existence of this symptom in combination with Fever and Shortness of breath could signal worsening of the patient's health status and lead to severe pneumonia [22].

It is not yet clear if COVID-19 is related to Conjunctivitis. Further studies stressed the importance of recognizing possible early ocular symptoms and draw attention in the examination of Conjunctivitis as a symptom [29, 31]. The World Health Organization (WHO) has ranked it among the lowest common Symptoms along with Skin Rash [9].

At the moment, there are limited data on skin manifestations after SARS-CoV-2 infection. Given the importance of early diagnosis of COVID-19 during a global pandemic, it is necessary to highlight the possible dermatological events and characterize their morphology. In fact, there is a variation in the clinical presentation of dermal findings after SARS-CoV-2 infection [32].

Loss of speech and movement is considered by the WHO to be one of the most important symptoms of the disease, along with Shortness of breath and Tightness/Pain/Pressure in the chest [9]. Cyanosis is considered, according to the Centers for Disease Control and Prevention (CDC), as one of the symptoms that ring the bell for COVID-19 patients. Immediate medical care is recommended, as Cyanosis indicates poor oxygen circulation in the bood and hence may lead to blue discoloration of the skin [33].

Based on the aforementioned analysis, the symptoms considered as sub-features are depicted in Fig. 2.

- **Comorbidities**. The most demanding and at the same time complex part of the research, was the feature of Comorbidities. This feature refers to the underlying diseases that the patients with COVID-19 may have and it is the most important feature to consider, because it highly affects the clinical condition of the patient, as revealed from the evaluation of features, using PWC, as shown in Fig. 2 presented in the following Section.

  The completion of the pairwise comparison matrices was considered a challenge for the doctors participating in the research, because the underlying diseases cannot be examined separately, as one comorbidity may be unbreakable connected to another. Therefore, a disease of a vital organ may lead to multiple organ dysfunction. Every health professional performed the comparisons, based on his academic knowledge, his personal experience from the cases that dealt with, following the instructions of the WHO.

  A review study of 27 articles revealed that in a total of 22,753 patients with COVID-19, from major centers worldwide, the main comorbidities were Cardiovascular disease with a rate of 8.9%, Hypertension with 27.4%, Diabetes Mellitus with 17.4%, Chronic Obstructive Pulmonary disease with 7.5%, Cancer or Malignancy with 3.5%, Chronic Kidney Disease with 2.6% and other diseases with a rate of 15.5% [30]. In mortal cases, it was estimated that 84.1% had one or more comorbidities. Significant mortality occurred in patients with Cardiovascular Diseases (34.9%), Hypertension (35.2%) and Diabetes Mellitus (33.2%). Comparatively lower mortality was observed in people with Chronic Obstructive Pulmonary

Disease (13%), Chronic Renal Disease (8.3%), Cancer (9.6%) and other diseases (11.6%). According to the statistics of WHO for chronic diseases, the aforementioned diseases are the most common and major causes of mortality worldwide, for patients with COVID-19. Therefore, health professionals believe that the presence of any comorbidity puts the patient with COVID-19 in a high risk [30]. There are also other studies on comorbidities statistics related to COVID-19 cases as [34–36].

In the present paper, the categorization of comorbidities was based on the data of NPHO (NPHO Out-of-Hospital Case Management, 2020). As revealed in previous studies, Hypertension is one of the most dominant factors of health status worsening or even a factor of high mortality. However, it is a subset of Cerebrovascular disease and may cause Cardiovascular and Nephrological diseases [37]. The examination of individual diseases increases the complexity of the research and for this reason the diseases that affect vital organs of the human will be considered as a whole (e.g., Cardiovascular Diseases). Most diseases have multisystemic nature, meaning the pathology that regardless of its origin may affect the stability of more than one body systems. The Diabetes is the only disease that will be considered as a unit, because is a multisystem disorder that affects the functions of different systems of the human body. Therefore, it is important to take into account the total level of systemic instability caused by Diabetes [38].

Therefore the present research takes into account the comorbidities depicted in Fig. 2.

6 Evaluation of COVID-19 Features

6.1 Surveys Design

The number of experts participating in the surveys was equal to twelve (12), which constitutes a sufficient group size according to the literature [39]. The experts are health professionals (doctors) working at the National Health System (NSS). They participated in the surveys based on their professional experience and knowledge gained from their daily involvement with COVID-19 disease.

The specialities of doctors include the Pathological sector (5 of them belong to Pulmonology - Tuberculosis, 1 in Endocrinology, 2 in Cardiology, 1 in Gastroenterology and 3 in Special Pathology). Moreover, among the participants there were eight (8) men and four (4) women.

The surveys carried out were the following:

- Evaluation of COVID-19 features.
- Evaluation of sub-features

6.2 Evaluation Results

In this section the results of the pairwise comparisons are presented and analyzed. All the features were pairwise compared and the results are presented in Fig. 3.

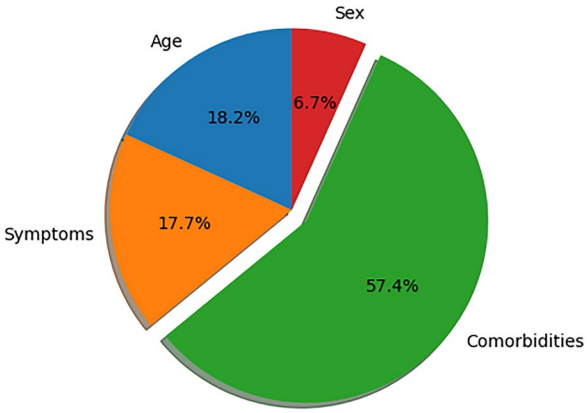

Fig. 3 Features Evaluation

The outcomes reveal that Comorbidities is the most dominant feature that seems to have the major impact on the health status of a patient influenced by SARS-CoV-2. It is interesting to notice that based on the analysis performed in Sect. 5, patients with comorbidities are more prone to COVID-19 disease and their clinical status may impair based on the type of their comorbidity.

Regarding the feature of Age, the different age groups were pairwise compared. The mean weights are shown in Table 2.

Inspection of the results reveals that the most affected age group is the elderly over 81 years with a weight of 48.23%. The older age between 61 and 80 years follows with a weight of 26.78%. The middle-aged group is ranked with a weight of 14.25%, while young people ranged between 21 and 40 years old have a weight of 6.75%. Finally the younger ones belonging to the age group 0–20 have a weight of 3.99%. The ranking of the age groups is presented in Fig. 4.

As far as the Symptoms are concerned, the PWC results are presented in Table 3.

Inspection of the results reveals that the Loss of speech and movement is the most dangerous symptom for patient's health with a weight of 21.16%. The Cyanosis follows with 17.31%, Oxygen Saturation $\leq$ 93% with a weight of 13.32%, and Tightening/Pain/Chest Pressure with 10.58%, while Dyspnoea was ranked with a weight of 9.74%. In the sixth place we may find Hemoptysis with 7.06%, in the seventh the Fever with weight of 3.6%, and Ptyella, Diarrhea follows with 2.43% and 1.99%,

Table 2 Age Groups

Age Groups	Age Groups Mean Weight %
0–20	3.99
21–40	6.75
41–60	14.25
61–80	26.78
$\geq$ 81	48.23

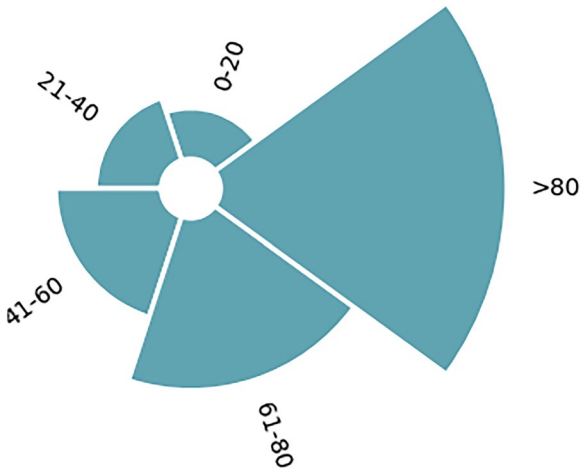

Fig. 4 Age Groups Evaluation

respectively. It is observed that Cough and Nausea/Vomiting are in the tenth position, with a total weight of 1.79%. Similarly, the Skin Rash or Finger Discoloration and Conjunctivitis have the same weight of 1.04%, while the other symptoms are

Table 3 Symptoms

Symptoms	Symptoms Mean Weight %
Loss of speech or movement	21.16
Bluish lips or face	17.31
Oxygen Saturation<= 93%	13.32
Chest Tightness	10.58
Dyspnoea	9.74
Haemoptysis	7.06
Fever	3.6
Sputum	2.43
Diarrhea	1.99
Cough	1.79
Nausea/Vomiting	1.79
Skin Rash/Finger or Toe Discolouration	1.04
Conjunctivitis	1.04
Loss of taste and smell	0.98
Headache	0.95
Rhinorrhea	0.91
Sore Throat	0.9
Fatigue	0.88
Myalgia	0.85
Chills	0.85
Inappetence	0.84

below < 1%. In more detail, Loss of Taste and Smell has a weight of 0.98%, Headache around 0.95%, Catarrh 0.91%, Pharynx 0.9%, Fatigue 0.88%, Chills and Myalgia 0.85% and finally Anorexia has a weight of approximately 0.84%. The ranking of the symptoms is presented in Fig. 5.

Regarding the important feature of Comorbidities, results are presented in Table 4.

The predominant disease that aggravates the health status of a patient with COVID-19 and leads to high mortality rates is Obesity with a weight of 24.05%, followed by Cardiovascular Diseases and Cerebrovascular Disease with rates around 22.48%. The latter diseases are closed to Diabetes which has a weight of 20.73%. The Chronic Respiratory Disease participates with a weight of 13.94%, Liver Diseases with a weight of 6.44%, Immunosuppression with 6.35% and finally Kidney Disease almost 6%.

Although it is stated in the literature that the main comorbidities aggravating the condition of a patient are Hypertension, Cardiovascular Diseases and Diabetes, we could not overlook the doctors points of view, derived from real cases of patients they have been treated. We have also to consider that the present research is related to the case study of Greece. In a previous Greek study examining 90 patients in critical condition, mean age 65.5 years old, 80% of them being men, it turned out that Obsesity and Diabetes Type 2 were the predominant comorbidities that may worsen the health status and lead to mortality as well [40]. Therefore, with Obesity in Greece being the second risk factor after smoking and with an obesity rate of 17% [41], it is correctly confirmed that the underlying disease of Obesity is the dominant comorbidity according to the results of the present study for the case study of Greece. The graphical illustration of the results is presented in Fig. 6.

Fig. 5 Symptoms Evaluation

Table 4 Comorbidities

Comorbidities	Comorbidities Mean Weight %
Respiratory system diseases	13.94
Cardiovascular and cerebrovascular diseases	22.48
Immunosuppression	6.35
Diabetes Mellitus	20.73
Kidney diseases	6.00
Haemoptysis	7.06
Liver diseases	6.44
Obesity	24.05

6.3 Categorization of Symptoms

Based on the estimated weights of the present study and according to previous literature, Symptoms are classified in three categories, Mild, Moderate and Severe.

Fever is a symptom that may belong to the three categories. Regarding Mild and Moderate categories, Fever is considered to be less than 38.5 °C, while in the Severe category the fever is equal to or greater than 38.5 °C [24]. However, Fever is not examined separately (<38.5 °C and ≥ 38.5 °C) in the present study, since the scientists indicated that the level of Fever that is important to be evaluated is the one that is greater than or equal to 38.5 °C and is persistent for many days. In the same context, Fever smaller than 38.5 °C is considered minor for COVID-19 disease. However, in an attempt to gradually examine (≥ 38.5 °C), additional questions arose from doctors on how many days the fever remains, what is the general clinical status of the patient, what other symptoms appear etc. This symptom is characterized by a multi-variant complexity and therefore it was decided to participate without grading, like all other symptoms (with the exception of Oxygen Saturation).

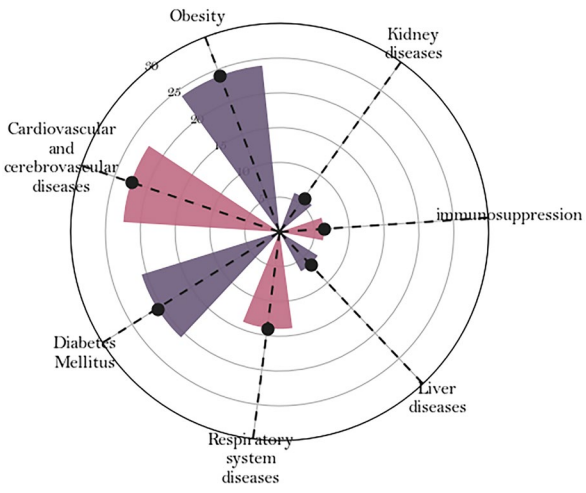

Fig. 6 Comorbidities Evaluation

Mild symptoms include those that have a low impact on the clinical status of patients and indicate the possibility of SARS-Co-V2 infection. They usually give the feeling of a "simple flu" or a cold. The category with Mild symptoms is characterized as a **Low-Risk Group** and home monitoring is recommended. In case of no improvement or worsening of the symptoms, medical assessment is recommended and probably hospitalization [24]. The symptoms belong to the mild category: Anorexia, Myalgia, Chills, Fatigue, Pharynx, Catarrh, Headache, Loss of taste and smell, Skin rash or discoloration of fingers, Conjunctivitis, Cough, Nausea/Vomiting and Diarrhea.

Moderate symptoms include those that have a greater impact on patient's health than mild symptoms and look like severe influenza. We cannot overlook the fact that some of the mild symptoms get worse and hence the clinical status of the patient may aggravate. Some of them may be the stubborn Dry Cough, Chills, intense Myalgia etc. However, in this category, these mild symptoms are not included, because it was no possible to create a percentage range that indicates the worsening of a symptom over time. After all, not all symptoms get worse in the same way for every patient, as they are not expressed with the same seriousness in everyone. The category with the moderate symptoms is classified as an **Intermediate-Risk Group** and in this case home monitoring in conjunction with clinical and laboratory monitoring is recommended (General blood, CRP examination). In case of no improvement or worsening of the symptoms, medical assessment is recommended in order to assess the possibility of hospitalization [24]. In the category of moderate symptoms we may find Sputum, Fever and Hemoptysis.

Severe symptoms are those that burden the patient's health. In this case, the clinical status of the patient is very bad and there is a need for immediate medical treatment in order to avoid the worst consequence of death. The category with severe symptoms is characterized as a **High-Risk Group** and immediate hospitalization is recommended [24]. The severe symptoms are Shortness of breath, Tightening/Pain/Chest pressure, Oxygen Saturation, Cyanosis, Loss of speech and movement.

An overall categorization of the symptoms is presented in Fig. 7.

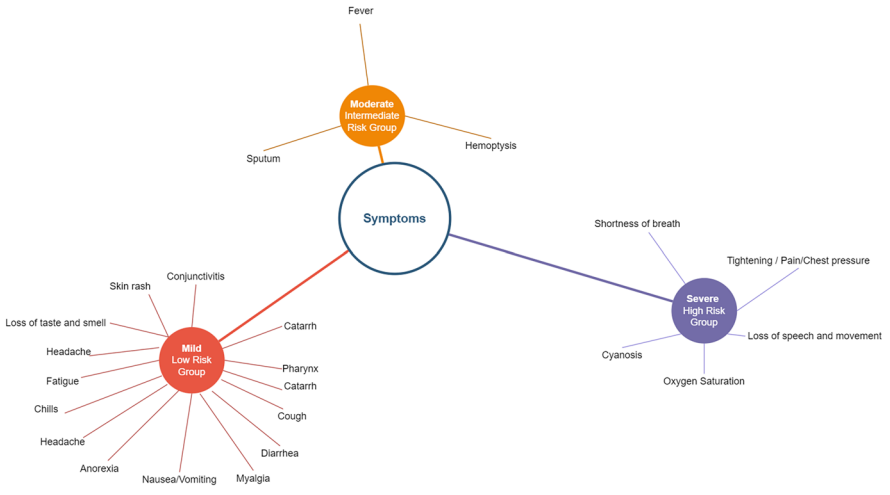

Fig. 7 Symptoms Categorization

7 Conclusions

The present paper introduces a CPAA examining the patient profile, taking into consideration the features of age, gender, symptoms and comorbidities. In this context, the importance of the COVID-19 features has been evaluated using the PWC approach. It is interesting enough that the frequency of occurrence of a feature does not automatically rank it in the same scale of importance. There are symptoms which appeared in a small portion of the population but they had significant impact on the clinical status of a patient infected by SARS-CoV-2.

Inspection of the evaluation outcomes reveals that Comorbidities is the feature with the highest importance, since it significantly affects the health status of the patient. A potential comorbidity not only complicates the patient's condition, but it is also associated with high rates of mortality, mainly for specific underlying diseases.

Regarding comorbidities, Obesity seems to be the dominant comorbidity according to the results of the present study for the case study of Greece. Obesity is closely followed by Cardiovascular and Cerebrovascular diseases. As far as the age feature is concerned it turns out that the most risky age group for SARS-CoV-2 are the elderly people over 81 years old.

Regarding the feature of symptoms the predominant symptoms that affect the patient's clinical condition are the Loss of speech and Movement, Cyanosis, Dyspnoea, Tightening/Pain/Chest Pressure and finally Satiety Oxygen.

Finally, evaluating all the aforementioned features, CPAA ranks COVID-19 cases based on the severity of each case in low-, medium-, and high-risk groups.

The present paper is an operation research application in the health sector using a decision-making method. The outcomes of this study are the first steps towards the development of an operational research system/framework that evaluates the clinical status of the patients with COVID-19 and take decisions related to their health status and the potential hospitalization. This system may give the appropriate guidelines to the patients and inform them if they have to go to the hospital or not, according to the features related to each patient. The framework proposed is based on operational research and provides a decision-making system that assesses the situation of positive patients, who monitor the disease at home and inform them about whether and when they should be hospitalized. The development of such an operational research framework would be of paramount importance for improving the outcome of health care systems related to COVID-19 pandemic.

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Data Availability The datasets generated during and/or analyzed during the present study are available as supplementary material.

Declarations

Conflict of Interest The authors declare no competing interests.

References

1. Marik PE, Iglesias J, Varon J, Kory P (2021) A scoping review of the pathophysiology of COVID-19. Int J Immunopathol Pharmacol 35:20587384211048026
2. Cancela J, Fico G, Arredondo Waldmeyer MT (2015) Using the analytic hierarchy process (AHP) to understand the most important factors to design and evaluate a telehealth system for Parkinson's disease. BMC Med Inform Decis Mak 15(3):1–11
3. Improta G, Russo MA, Triassi M, Converso G, Murino T, Santillo LC (2018) Use of the AHP methodology in system dynamics: modelling and simulation for health technology assessments to determine the correct prosthesis choice for Hernia diseases. Math Biosci 299:19–27
4. Tan W, Weng H, Lin H, Ou A, He Z, Jia F (2021) Disease risk analysis for schizophrenia patients by an automatic AHP framework. BMC Med Inform Decis Mak 21(9):1–12
5. Ali SA, Ahmad A (2019) Mapping of mosquito-borne diseases in Kolkata Municipal Corporation using GIS and AHP based decision making approach. Spat Inf Res 27(3):351–372
6. Antunez Muiños PJ, López Otero D, Amat-Santos IJ, López País J, Aparisi A, Cacho Antonio CE, Catalá P, Gonzalez Ferrero T, Cabezón G, Otero Garcia O et al (2021) The COVID-19 lab score: an accurate dynamic tool to predict in-hospital outcomes in COVID-19 patients. Sci Rep 11(1):1–9
7. Jiao G, Jingyi Q, Xueping Q, Yusheng J, Yaqiong C, Lianxiong Y, Jing C, Mingkai T, Wenxiong X, Fang Z et al (2020) A tool to early predict severe coronavirus disease 2019 (COVID-19): a multicener study using the risk nomogram in Wuhan and Guangdong. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7184338/pdf/main.pdf
8. Yao Z, Zheng X, Zheng Z, Wu K, Zheng J (2021) Construction and validation of a machine learning-based nomogram: a tool to predict the risk of getting severe coronavirus disease 2019 (COVID-19). Immun Inflammation Dis 9(2):595–607
9. WHO: Coronavirus disease (COVID-19). https://www.who.int. Accessed 2 Mar 2022
10. WHO. https://www.who.int/westernpacific/emergencies/covid-19/information/asymptomatic-covid-19. Accessed 2 Mar 2022
11. Saaty TL (2003) Decision-making with the AHP: Why is the principal eigenvector necessary. Eur J Oper Res 145(1):85–91
12. Brans J-P, Vincke P, Mareschal B (1986) How to select and how to rank projects: the Promethee method. Eur J Oper Res 24(2):228–238
13. Triantaphyllou E, Shu B, Sanchez SN, Ray T (1998) Multi-criteria decision making: an operations research approach. Encyclopedia of Electrical and Electronics Engineering 15(1998):175–186
14. Yager RR (2004) Modeling prioritized multicriteria decision making. IEEE Trans Syst Man Cybern B Cybern 34(6):2396–2404
15. Gebhard C, Regitz-Zagrosek V, Neuhauser HK, Morgan R, Klein SL (2020) Impact of sex and gender on COVID-19 outcomes in Europe. Biol Sex Differ 11(1):29
16. Tian Y, Liu Y, Wang T, Zhou N, Kong J, Chen L, Snitow M, Morley M, Li D, Petrenko N, Zhou S, Lu M, Gao E, Koch WJ, Stewart KM, Morrisey EE (2015) A microRNA - Hippo pathway that promotes cardiomyocyte proliferation and cardiac regeneration in mice. Sci Transl Med 7:279–38
17. Chen J, Qi T, Liu L, Ling Y, Qian Z, Li T, Li F, Xu Q, Zhang Y, Xu S et al (2020) Clinical progression of patients with COVID-19 in Shanghai, China. J Infect 80(5):1–6
18. Niu S, Tian S, Lou J, Kang X, Zhang L, Lian H, Zhang J (2020) Clinical characteristics of older patients infected with COVID-19: a descriptive study. Arch Gerontol Geriatr 89:104058
19. Ya'qoub L, Elgendy IY, Pepine CJ (2021) Sex and gender differences in COVID-19: More to be learned! American Heart Journal Plus: Cardiology Research and Practice 3:100011
20. Klein SL, Flanagan KL (2016) Sex differences in immune responses. Nat Rev Immunol 16(10):626–638
21. Zeng F, Dai C, Cai P, Wang J, Xu L, Li J, Hu G, Wang Z, Zheng F, Wang L (2020) A comparison study of SARS-COV-2 IGG antibody between male and female COVID-19 patients: a possible reason underlying different outcome between sex. J Med Virol 92(10):2050–2054
22. Cartocci A, Cevenini G, Barbini P (2021) A compartment modeling approach to reconstruct and analyze gender and age-grouped COVID-19 Italian data for decision-making strategies. J Biomed Inform 118:103793
23. Liu X, Lv J, Gan L, Zhang Y, Sun F, Meng B, Jheon A, Yan F, Li B, Xuan Z et al (2020) Comparative analysis of clinical characteristics, imaging and laboratory findings of different age groups with COVID-19. Indian J Med Microbiol 38(1):87–93

24. National Public Health Organization. https://eody.gov.gr/. Accessed 2020.
25. Bhakta Bahadur KC (2020) COVID-19 pandemic: time to focus quitting tobacco use in Nepal and globally. Population Medicine 2(September):1–2
26. Chen Y, Zhou X, Yan H, Huang H, Li S, Jiang Z, Zhao J, Meng Z (2021) CANPT score: a tool to predict severe COVID-19 on admission. Front Med 68
27. Fu L, Wang B, Yuan T, Chen X, Ao Y, Fitzpatrick T, Li P, Zhou Y, Lin Y-F, Duan Q et al (2020) Clinical characteristics of coronavirus disease 2019 (COVID-19) in China: a systematic review and meta-analysis. J Infect 80(6):656–665
28. Rothan HA, Byrareddy SN (2020) The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. J Autoimmun 109:102433
29. Esakandari H, Nabi-Afjadi M, Fakkari-Afjadi J, Farahmandian N, Miresmaeili S-M, Bahreini E (2020) A comprehensive review of COVID-19 characteristics. Biol Proced Online 22(1):1–10
30. Bajgain KT, Badal S, Bajgain BB, Santana MJ (2021) Prevalence of comorbidities among individuals with COVID-19: a rapid review of current literature. Am J Infect Control 49(2):238–246
31. Bacherini D, Biagini I, Lenzetti C, Virgili G, Rizzo S, Giansanti F (2020) The COVID-19 pandemic from an ophthalmologist's perspective. Trends Mol Med 26(6):529–531
32. Rivera-Oyola R, Koschitzky M, Printy R, Liu S, Stanger R, Golant AK, Lebwohl M (2020) Dermatologic findings in 2 patients with COVID-19. JAAD Case Rep 6(6):537–539
33. Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html. Accessed 2021
34. Pranata R, Huang I, Lim MA, Wahjoepramono EJ, July J (2020) Impact of cerebrovascular and cardiovascular diseases on mortality and severity of COVID-19-systematic review, meta-analysis, and meta-regression. J Stroke Cerebrovasc Dis 29(8):104949
35. Singh AK, Misra A (2020) Impact of COVID-19 and comorbidities on health and economics: focus on developing countries and India. Diabetes Metab Syndr Clin Res Rev 14(6):1625–1630
36. Alimohamadi Y, Sepandi M, Taghdir M, Hosamirudsari H (2020) Determine the most common clinical symptoms in COVID-19 patients: a systematic review and meta-analysis. J Prev Med Hyg 61(3):304
37. Iadecola C, Davisson RL (2008) Hypertension and cerebrovascular dysfunction. Cell Metab 7(6):476–484
38. Ewing GW, Parvez SH (2010) The multi-systemic nature of diabetes mellitus: Genotype or phenotype? N Am J Med Sci 2(10):444
39. Dede G, Kamalakis T, Sphicopoulos T (2015) Convergence properties and practical estimation of the probability of rank reversal in pairwise comparisons for multi-criteria decision making problems. Eur J Oper Res 241(2):458–468
40. Halvatsiotis P, Kotanidou A, Tzannis K, Jahaj E, Magira E, Theodorakopoulou M, Konstandopoulou G, Gkeka E, Pourzitaki C, Kapravelos N et al (2020) Demographic and clinical features of critically ill patients with COVID-19 in Greece: the burden of diabetes and obesity. Diabetes Res Clin Pract 166:108331
41. Hellenic Statistical Authority. https://www.statistics.gr/en/home/. Accessed 2020

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