Use of Fuzzy Logic to demonstrate possibility of health system collapse due to Coronavirus Pandemic

Uso da Lógica Fuzzy para demonstrar a possibilidade de colapso do sistema de saúde devido à pandemia de coronavírus

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ABSTRACT
Introduction: At the end of 2019, contamination caused by an unknown virus affected the population of Wuhan, China. The virus, known as SARS-CoV-2, was found to cause flu-like symptoms, such as fever, cough, among others. Objective: using the fuzzy logic method graphically demonstrated the Risk of Collapse of the Health System, with the availability of beds /equipment to increase the number of infected, from the Sars-CoV-2 pandemic. Methods: Modeled a fuzzy system with a Mamdani model, later defined the physical variables of entry (Number of infected people and number of beds/equipment available) and output (Risk of collapse of the health system), then inserted the nine rules and the pertinence functions in the trapezoidal and triangular type graph, generating from this information a three-dimensional graph with the results. Results: From the three-dimensional graph, it can be seen that the results were consistent and demonstrate that countries must prevent the number of infected people from increasing, because when this situation occurs, the risk of collapse of the health system is high due to the unavailability of beds /equipment, in addition, this modeling of fuzzy logic along with the generated three-dimensional graph can be used to demonstrate a health crisis in countries. Conclusion: Concluded that the fuzzy logic technique allows many realistic predictions of possible crises and collapses of the health system, but to obtain good results in it, having the knowledge of what is expected will generate the necessary notion to make the insertion of information accurately in the software.

Keywords: Coronavirus, SARS-CoV-2, pandemic, Fuzzy logic, health system collapse.

RESUMO
Introdução: No final de 2019, a contaminação causada por um vírus desconhecido afetou a população de Wuhan, na China. O vírus, conhecido como SARS-CoV-2, causou sintomas semelhantes aos da gripe, como febre, tosse, entre outros. Objetivo: utilizou-se do método da lógica fuzzy demonstrando graficamente o Risco de Colapso do Sistema de Saúde, com a disponibilidade de leitos/equipamentos com o aumento do número de infectados, decorrentes da pandemia Sars-CoV-2. Métodos: Modelou um sistema fuzzy com o modelo Mamdani, posteriormente definiu as variáveis físicas de entrada (Número de pessoas infectadas e número de leitos/equipamentos disponíveis) e saída (Risco de colapso do sistema de saúde), a seguir inseriu as nove regras e a função de pertinência no gráfico do tipo trapezoidal e triangular, gerando a partir dessas informações um gráfico tridimensional com os resultados. Resultados: A partir do gráfico tridimensional, pode-se perceber que os resultados foram consistentes e demonstram que os países devem evitar que o número de infectados aumente, pois quando essa situação ocorre, o risco de colapso do sistema de saúde é alto devido à a indisponibilidade de leitos/equipamentos, além

disso, essa modelagem de lógica fuzzy juntamente com o gráfico tridimensional gerado pode ser usada para demonstrar uma crise de saúde nos países. Conclusão: Concluiu-se que a técnica de lógica fuzzy permite muitas previsões realistas de possíveis crises e colapsos do sistema de saúde, mas para obter bons resultados nela, ter o conhecimento do que se espera vai gerar a noção necessária para fazer a inserção das informações com precisão no software.

Palavras-chave: Coronavírus, SARS-CoV-2, pandemia, Lógica Fuzzy, Colapso do Sistema de Saúde.

1 INTRODUCTION

Human knowledge about complex problems can be successfully represented using the inaccurate terms of natural language. Thus, the inspiration for introducing fuzzy logic theory was the need to model real-world phenomena, which are inherently vague and ambiguous (CZABANSKI, JEZEWSKI E LESKI, 2017).

The basic idea in fuzzy control is modeling from an expert knowledge, rather than necessarily modeling the process with traditional models, performing a different approach to conventional methods of process control, where these are developed through mathematical modeling of processes in order to derive control actions as a function of the state of the process (MENDONÇA et al., 2015).

Fuzzy logic is divided into two main groups of interference. The first group brings together those that are based on fuzzy implication functions and composition operators for defining the fuzzy output of the controller (Mamdani model). In the second group, the definitions of implication functions for interference are dispensed with, and thus, the Takagi and Sugeno model fits into this category (SILVA, 2019).

In order to identify nonlinear systems, the applied model is takagi-sugeno, because they are universal approximators and have good interpolation and generalization characteristics. Therefore, the result of each rule is, then, a numerical value, assigning as weight the value of the pertinence that results from the processing of the rule antecedent (ANDRADE E PRUDÊNCIO JAQUES, 2008) and (BERRUEZO, 2016).

The Mamdani fuzzy inference system differs from Takagi-Sugeno's, basically, by the representation of the consequent of the rules. In this model the rules have antecedents composed of linguistic variables similar to Takagi-Sugeno's, but the consequent is also composed of linguistic terms and not by the composition of equations that relate the inputs to the outputs as in Takagi-Sugeno model (ANDRADE E PRUDÊNCIO JAQUES, 2008) and (CHAVES, NASCIMENTO and RIZOL, 2017). Because the Mamdani inference

model is more intuitive than the Takagi-Sugeno's, it has a higher applicability (SANTOS, 2015).

In the fuzzy controller, for every fuzzy input, the inference module produces a fuzzy output indicating the control to be adopted. If the entry is a real number, the corresponding output is also expected to be a real number. However, this generally does not occur on fuzzy controllers. Therefore, a method is indicated to defuzzify the output and obtain a real number that will indicate the control to be adopted (SOUZA, 2010).

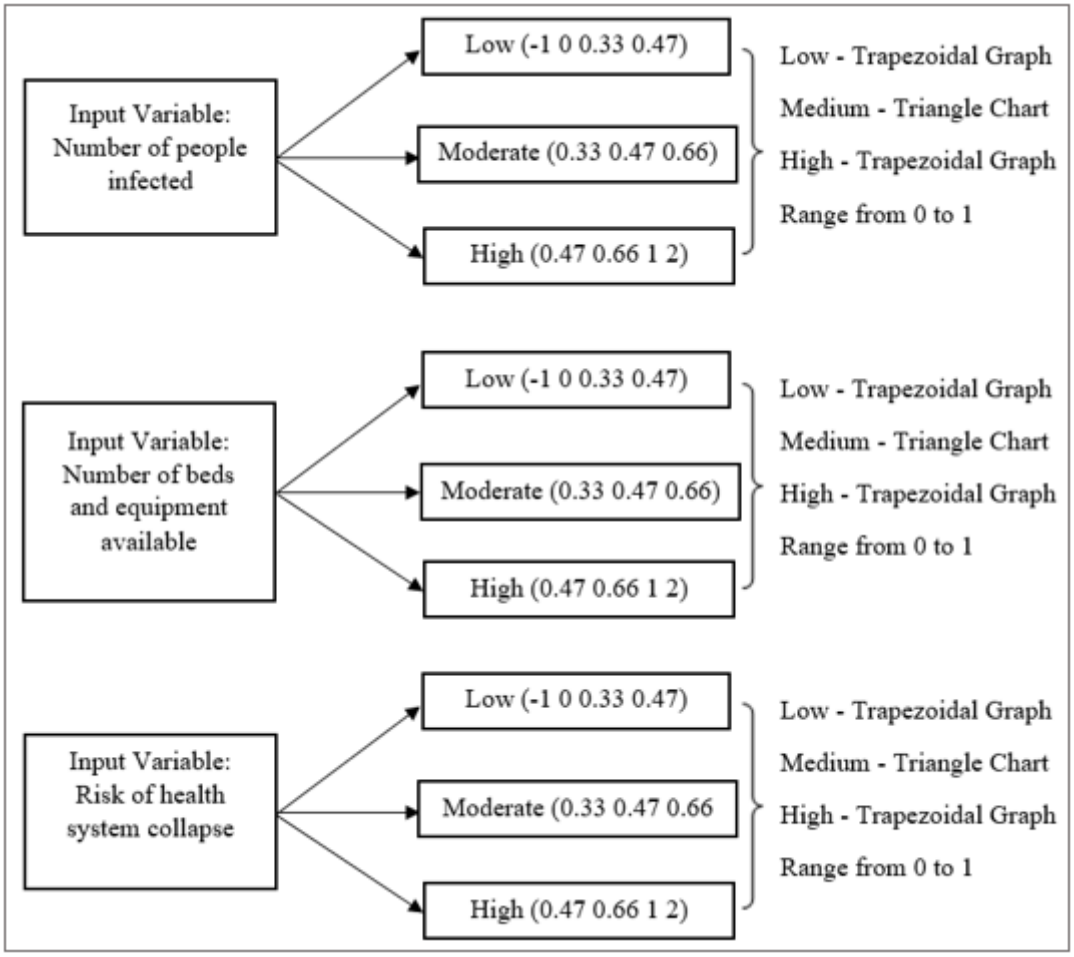
For the Mamdani model, the centroid defuzification method is the most applied, because it transforms the fuzzy output in a discrete output by finding the arithmetic mean between the centers of gravity of the fuzzy sets as the element belongs, weighted by the degree of pertinence. It has as a disadvantage becoming difficult to run with complex pertinence functions, this is because the centroid of the areas is not easily found (LIMA, 2016) and (SANTOS, 2017).

As fuzzy logic has the ability to model real-world phenomena, this study, by using this technique, graphically demonstrates the Risk of Collapse of the Health System, considering the availability of equipment and hospital beds versus the increase in the number of infected, from the SARS-CoV-2 pandemic.

2 METHODOLOGY

In order to model a fuzzy system, the behavior of the process must be described. To do so, the physical variables to be considered (input and output variables) are defined. Following, it was inserted a set of rules and pertinence functions with the graph type to be used. In the present study, modeling was performed with two variables at the entrance, each variable presenting three pertinence functions and one output variable that also has three pertinence functions. Each pertinence function is applied to a graph type (the chosen graph type was trapezoidal and triangular, because it characterizes simple functions when compared to the Gaussian function, for example) and it was performed in a mixed way. This modeling of the study is presented in Figure 1 and the graphs of pertinence generated by the program are in the Appendix. So that the results are reproduceable, the applied Range was inserted in Figure 1.

Figure 1: Variables with their respective Pertinence Functions and the chart type for Fuzzy.



Source: (THE AUTHORS, 2020)

In addition to the study variables, it is necessary to describe/generate the rules of the problem under study, which have the duty to describe the behavior of the process. In the present study, nine rules were used, maximum number/possible combinations of rules. In fuzzy logic it is not mandatory to make use of the maximum number of rules, in this study it was decided to do it due to it being a reasonable number of rules. Depending on the system making use of the maximum number of rules becomes unfeasible due to the high amount, in these cases the authors choose the most relevant ones. The rules created for the model are listed below in Table 1:

Table 1 - Rules created for the model.

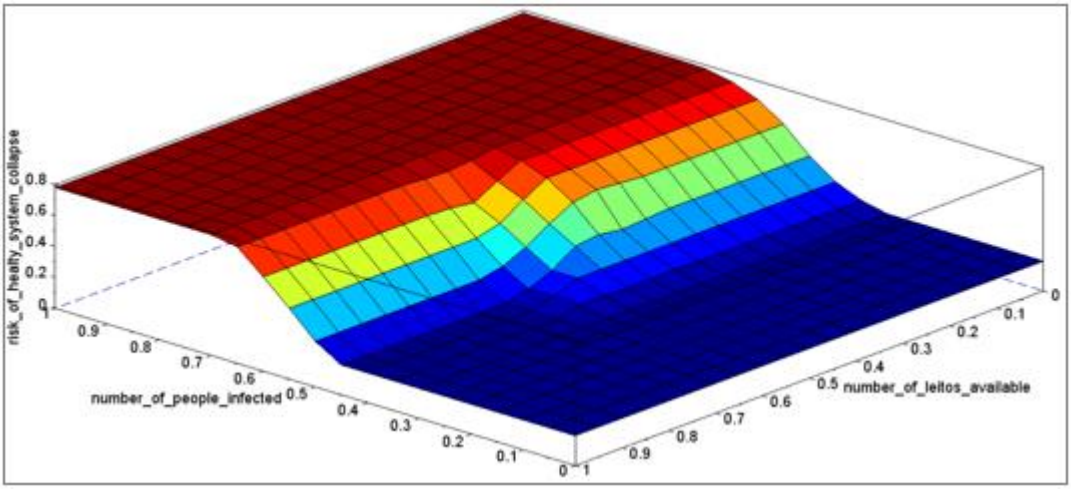
Inlet		Output
Nº of infected people	**Number of Available Beds and Equipment**	**Risk of Collapse of the Health System**
Low	Low	Low
Low	Moderate	Low
Low	High	Low
Moderate	Low	Moderate
Moderate	Moderate	Moderate
Moderate	High	Low
High	Low	High
High	Moderate	High
High	High	High

Source: (THE AUTHORS, 2020)

3 RESULTS

By modeling the study, it was observed that fuzzy logic graphically presented the risk of collapse of the country's health system, with the change in the number of infected and available beds/equipment. Figure 2 shows that if the number of infected people is high, consequently you will need a greater number of available beds/equipment. In these cases, the risk of the health system collapsing is high, as there may be a shortage of beds/equipment. This condition is shown in the graph by the warm colors (orange and red), while the cold colors (dark and light blue) are exactly the opposite, that is, if the amount of infected people is low, there will not be a shortage of beds/equipment, in this condition the risk of the health system collapsing is low. The central part of the graph, represented by the colors yellow and green, demonstrates when the ministries of health should be on alert, paying attention that the collapse of the health system can be achieved if an increase in available beds is not available and the number of infected is moderate. Even if it still has an availability of beds, but the pandemic continues to advance, the number of infected may become high, ending in the first situation.

Figure 2: Fuzzy Simulation of SARS-CoV-2, Centroid Defuzzyfication Method.



Source: (THE AUTHORS, 2020)

4 DISCUSSION

This fuzzy logic modeling along with the generated graph can be used to demonstrate a crisis in the healthcare of countries. Ideally, the number of infected people does not reach the high level. There is no way to precisely measure the high, moderate and low values, exactly why fuzzy logic is used, modelling a real, but difficult to measure, system, that is the pandemic, because for countries that have an advanced health system a number of infected can be considered low and not collapse the health system, whether the same number, however, can be considered high and cause collapse the system in another country, due to the assistance not being so good.

What every country should be avoid is letting the number of infected to reach the high level for their reality, because when this value becomes high, regardless of the number of beds/equipment available, the possibility of collapsing the health system is high and real, taking Brazil as an example, considering the number of cases reported by the Ministry of Health and the information on the number of beds, some Brazilian states have already declared to be on alert, because they have already used about 70 to 75% of their resources, that is, they are in the central sector of the graph, with moderate risk of collapsing of the health system, a growing number of infected and a diminishing on the number of beds/equipment available reducing. According to some newspapers and magazines in the country, some states have already had their first collapse of the health system, but the states that are not in critical conditions have supported and mitigated the situation (ADLER, 2020), (CERIONI, 2020), (MARIZ, 2020), (NUNES, 2020), (PADUAN, 2020), (MINISTÉRIO DA SAÚDE, 2020), (O ESTADO DE S.PAULO, 2020), (MARIZ and SOUZA, 2020).

The pandemic in Brazil, according to the ministry of health, has an incidence of 88.9 cases for every 100,000 inhabitants until May 14th, 2020. This demonstrates that if the country slightly reduce the isolation, several health systems might collapse and, consequently, the number of dead could increase (Ministério da Saúde, 2020).

This result demonstrates that the applied technique is an effective way of passing information, but for the fuzzy logic to be applied, it is necessary for the researcher to write and logically insert the rules, which are responsible for providing the reality of the situation.

5 CONCLUSIONS

The results were coherent and graphically demonstrate what would happen to the health system with changes in the number of infected and in the number of equipment/beds available. This technique increasingly gains space, because it allows the construction of several rules, which facilitate the modeling of problems, thus making them less complex. It is concluded that countries should avoid having the number of infected people becoming high, because when this situation happens, the risk of the collapse of the health system is high due to the unavailability of beds/equipment. Modeling of this type is a technique that allows many realistic predictions. To obtain good results in it, having the knowledge of what is expected will generate the necessary notion to make the appropriate choice of the software to be used and to enter the accurate information.

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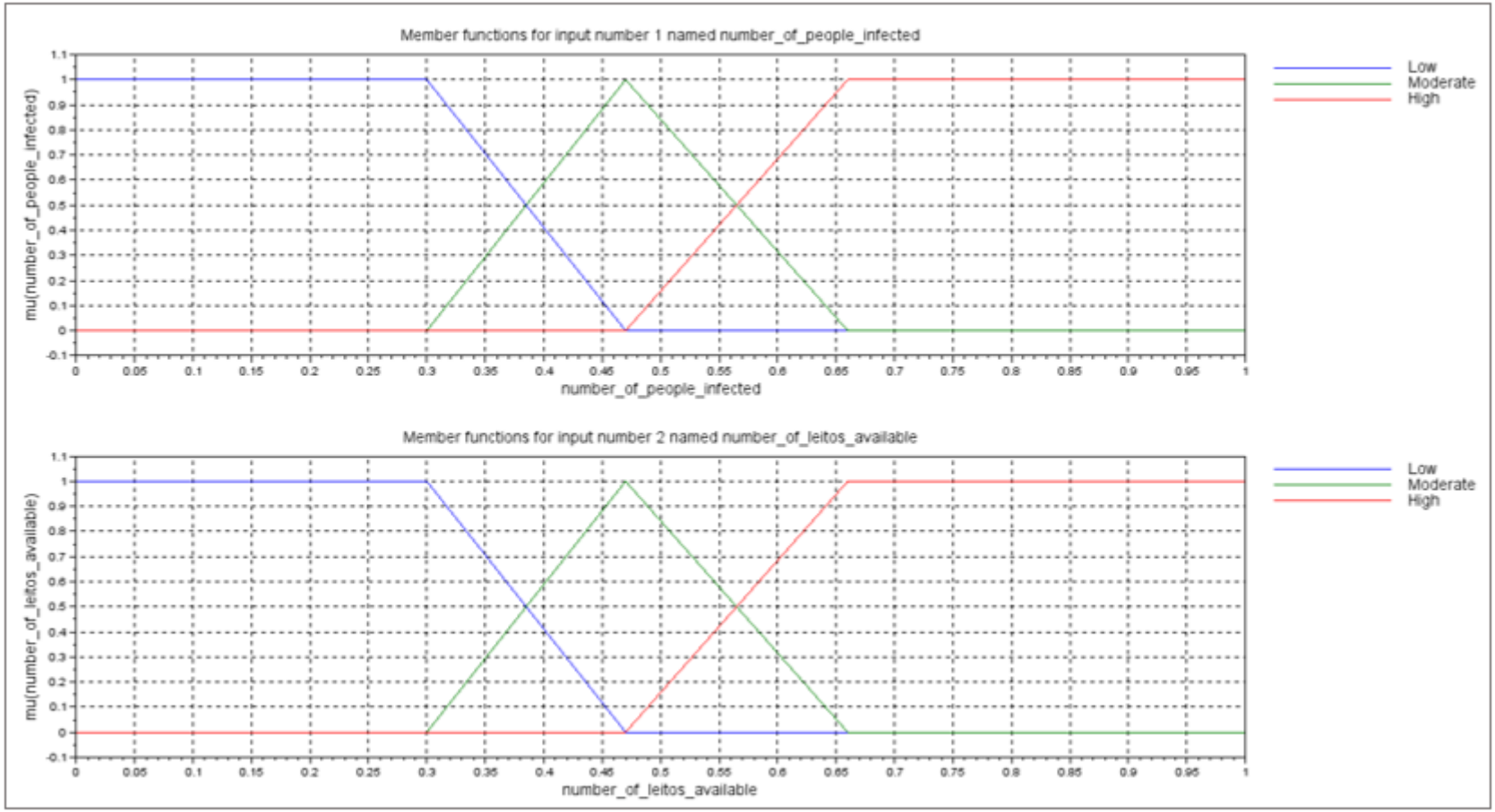
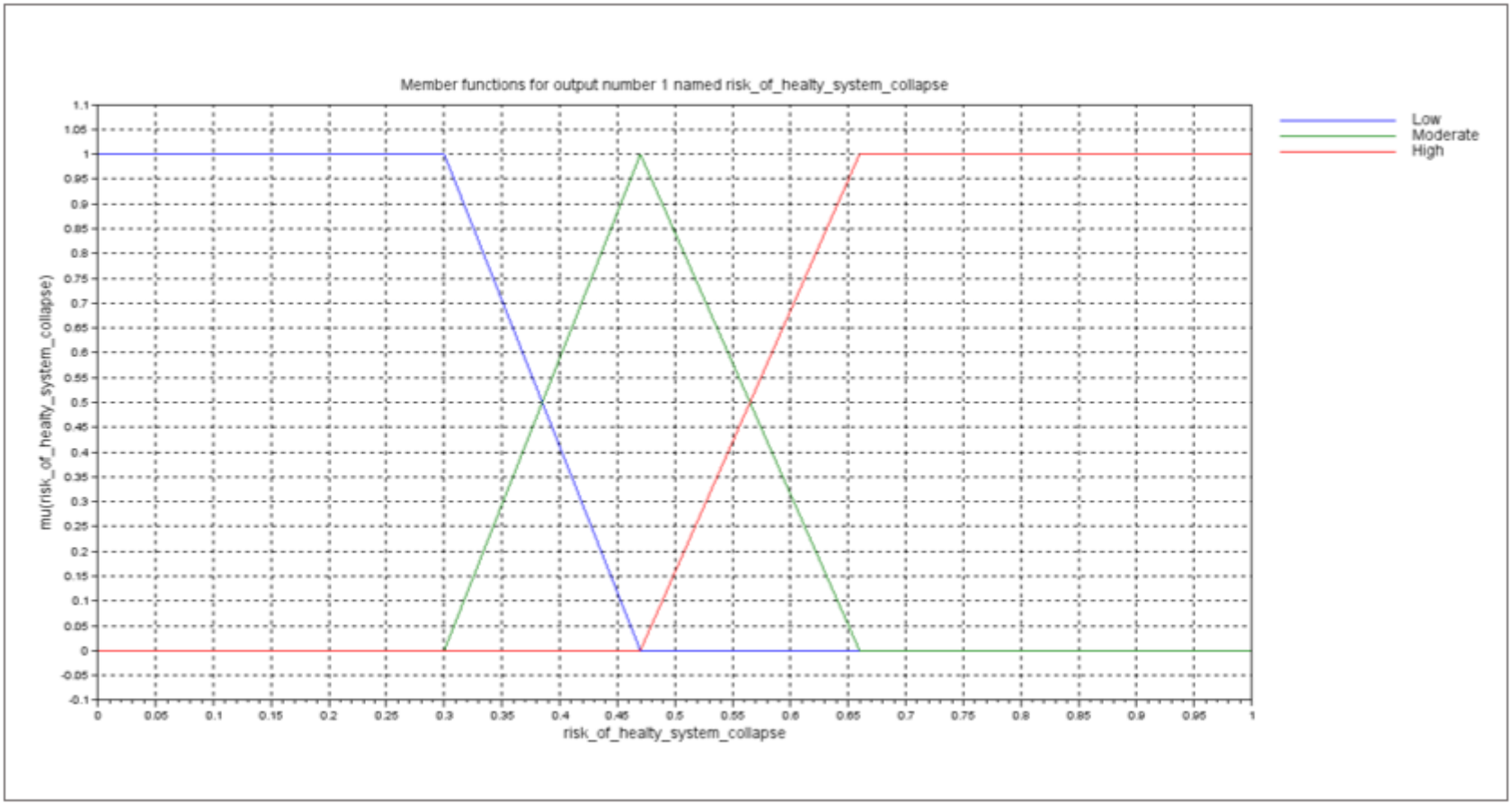
APPENDIX

Figure 3: Input pertinence graph, from Fuzzy logic.



Source: (THE AUTHORS, 2020)

Figure 4: Output pertinence graph, from Fuzzy logic.



Source: (THE AUTHORS, 2020)