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FUZZY MODEL FOR ESTIMATING THE RISK OF INFECTION BY COVID-19

MEHKI MODEL NAPOVEDI OGROŽENOSTI Z BOLEZNIJO COVID-19

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Keywords: Covid-19, fuzzy variable, fuzzy inference, risk of infections

Abstract

The present paper presents a fuzzy model for predicting the risk of a community (country) to being infected by the coronavirus Covid-19. The research is not the medical field, where favourable news about vaccines against this disease is just emerging from the research community. Instead, it presents a relatively simple mathematical model based on the use of fuzzy logic. The model is created as a fuzzy system, in which the basic postulates of fuzzy logic and fuzzy inference are used. The presented model is, of course, only one possibility for describing and predicting the threat to the population due to the Covid-19 disease.

Povzetek

V članku je predstavljen mehki model napovedi ogroženosti prebivalcev neke skupnosti (države) z boleznijo Covid-19. Raziskava se ne spušča na medicinski področje, kjer se v svetovni raziskovalni skupnosti ravnokar pojavljajo ugodne vesti o cepivu proti tej bolezni. Raziskava predstavlja relativno preprost matematični model, ki temelji na uporabi mehke logike. Model je kreiran kot mehki sistem, kjer uporabljamo osnovne postulate mehkega sklepanja. Predstavljeni model je seveda le ena od možnosti opisovanja in predvidevanja ogroženosti prebivalcev zaradi bolezni Covid-19.

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1 INTRODUCTION

The end of the first and the beginning of the second quarter of 2020 was marked by a global outbreak of the Covid-19 disease, which results from infection with a new and hitherto unknown virus. The threat of infection and death was declared worldwide, and the World Health Organization (WHO) declared a pandemic in the first half of March 2020. Individual countries took the same or at least similar rigorous measures to curb the epidemic, because the situation was serious. As of June 8, 2020, WHO data were as follows, *[5]*: 6,881,352 infected, 399,895 dead in 216 countries. All affected countries have taken (more or less) drastic measures to curb the pandemic. Countries reacted differently to the pandemic, from extremely strict measures (e.g., Italy, Spain, also Slovenia) to extremely lenient ones (e.g., Sweden, Belarus). The results were different, but no variant was explicitly confirmed to be correct and thus successful. Health services cannot confirm or deny any possibility.

A huge number of tests have been performed worldwide; as a rule, these tests are not completely credible, but they are certainly a significant indicator of the spread of the virus.

After the end of the epidemic, countries greatly relaxed their measures, social life and the economy were revived, and restrictions on tourism were greatly relaxed. Slovenia was quite successful in this first wave, declaring the coronavirus epidemic over, as of June 1 2020, thus relieving a series of preventive measures taken at the beginning of the outbreak. Many other countries have done the same. The main reason for this was, of course, of an economic nature, as during the quarantine period prescribed by the states to contain the disease, many economic activities around the world declined markedly, or ceased entirely. The global pandemic was thus (at least theoretically) over, the economic recovery was beginning, which is a condition *sine qua non* mainly for the functioning of the labour market, which has experienced a marked decline in all countries.

In Slovenia, a national survey, *[4]*, was conducted in the first wave, which was supposed to answer the question about the infection of the population with coronavirus. The projected random sample of 3,000 respondents is certainly large, significant, and robust. Unfortunately, these characteristics were lost due to the unresponsiveness of the respondents, as the response was less than half. Thus, the results of the research are questionable, *[8]*. These possibly correct results show that the population of Slovenia is slightly infected, which is not exactly an encouraging result.

States have revoked strict measures at the time of the worst outbreak. In the summer months, tourism also revived to a large extent, having experienced the worst shock of all economic activities. Unfortunately, the abolition of the strict measures turned out to be premature, as too much relaxation led to a second wave of infections, which was significantly more severe than the first. Thus, on February 19 2020, the following data can be found, *[6]*: 55,927,327 confirmed cases and 1,344,003 dead. In less than 24 weeks, the number of infections increased by more than eight times (813%), and the increase in the number of deaths was fortunately much smaller (336%). The number of deaths is less rapid than the number of infected, which is probably due to better knowledge of the disease in hospitals and thus more effective treatment. The World Health Organization conducts a comprehensive overview of the spread of the disease to all its members. On the same website, *[6]*, we also find data for Europe on 19.11.2020: 15,999,670 confirmed cases and 459,195 deaths.

Up-to-date data for Slovenia are available on the website of the government, *[4].*

The purpose of our research, the result of which is a fuzzy model for assessing the risk of Covid-19 disease, is to sketch a fuzzy system with which, based on fuzzy reasoning, we can roughly predict the risk of coronavirus infection in the population of each country or the threat in general.

The results are interesting, but not necessarily correct, as any disease cannot be predicted with certainty.

2 FUZZY SYSTEM

The virus's behaviour has not yet been fully elucidated, in medicine or in other sciences. In the final phase of testing, several different vaccines would successfully curb COVID-19 and thus end the global socially unnatural behaviour humanity has been forced to undergo. However, this current failure gives various mathematical models that attempt to explain the dynamic behaviour of the virus, the status of vagueness, and roughly speaking, perhaps even speculation. Several mathematical models have emerged on the virus's prevalence and behaviour and the (un)successful handling of the virus, but so far no prediction has been sufficiently stable/robust and thus entirely credible. Several studies and articles have appeared online (e.g. *[2]*, *[7]*, *[9]*) that attempt to explain and predict the course and threat of population infection with coronavirus using classical mathematical methods, such as statistics, probability calculus, and differential equations. All these models, which are dynamic, are only more or less successful guesses about the disease, and the results are more or less successful approximations of actual events.

In contrast to these principles of straightforward approaches, we have developed a fuzzy mathematical model based on a relatively simple and sensible perception of the aggressiveness of the virus and thus the threat to the inhabitants of an individual community (country). This model (or its results) is only a guess at the actual situation and threat of the coronavirus. The preference for a model is (at least) not possible so far, but above all, it is not sensible and thus rational. For this reason, we can not claim that the model presented below is worse or better than other assumptions.

The fuzzy model is presented in the form of a fuzzy system. In this manner, we proceeded from some rudimentary and meaningful assumptions. The basic idea of the model is that we cannot predict the level of infection or even mortality (this is the work of medical science), but we can (more or less successfully) predict the level of risk of infection of the population in a community (country).

If we want to create a fuzzy system, we need to know the rules and operation of fuzzy logic. We will not list these basics in this article, but we can refer readers to sources [10]–[14], where the idea of fuzzy logic, fuzzy reasoning, and the creation of a fuzzy system with all theoretical postulates and applied approach is described in detail.

The construction of a fuzzy system generally takes several steps: the selection of decision variables and their fuzzification, establishing the goal and construction of algorithm (base of rules of fuzzy reasoning), inference and defuzzification of results of fuzzy inference. A presentation of a fuzzy system is given in Figure 1.

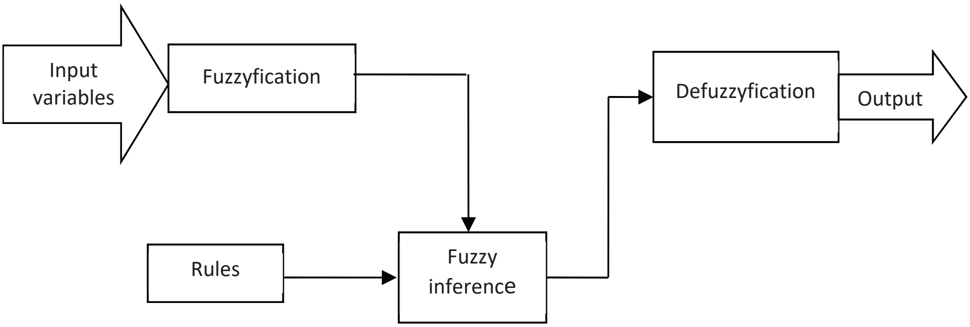

Figure 1: *Elements of a fuzzy system*

The entire system demonstrates the course of inference from input variables against output, and it is built on base "if-then" fuzzy rules. In the frame of fuzzy inference, we have tasks with three phases *[10]*, *[14]*:

1. Fuzzification
2. Fuzzy inference
3. Defuzzification

In the defuzzification phase, fuzzy sets for all fuzzy variables (input and output) must be defined, as well as their membership functions. Every fuzzy variable is presented by more terms/fuzzy sets.

It occurs very rarely that the input values in a system are already fuzzy. For fuzzy inference, it is necessary to transform sharp input values to fuzzy ones, which is done in fuzzification. To the input and output parameters within this phase, we assign membership functions. The choice of fuzzy sets and linguistic variables has a huge influence on the sensitivity of the controlled system, but there is no exact procedure for this, *[10].* Most commonly, a procedure of trial and error is used, which will also be used in our model. For each linguistic expression, we must determine the relevant fuzzy set.

Fuzzy inference is a process in which a certain conclusion is derived from a set of fuzzy statements. In addition to linguistic variables, there are basic widgets of a fuzzy logic system and sets of rules that define the behaviour of a system. A single fuzzy rule (implication) assumes the form: if x is A, then y is B, where A and B are linguistic values defined by fuzzy sets on the universes of discourse X and Y, respectively. Variables x and y are defined by the sets X and Y.

With the assembly of a base of rules, the question always appears of how to obtain the rules. Usually, this is written down as a base of knowledge within the framework of "if-then" rules by an expert for a definite system based on his knowledge and experiences. An expert must also define entry and exit fuzzy functions, as well as their shape and position. However, it often occurs that the expert's knowledge is not sufficient, and he cannot define an adequate number of rules.

The result of the evaluation of fuzzy rules is fuzzy. Defuzzification is the conversion of a given fuzzy quantity to a precise and crisp quantity. In the procedure of defuzzification, fuzzy output variables are changed into crisp numerical values. There are many procedures for defuzzification, which give different results. The most frequent method used in praxis is CoM-defuzzification (the Centre of Maximum). As more than one output term can be accepted as valid, the defuzzification method should be a compromise between different results. The CoM method does this by computing the crisp output as a weighted average of the term membership maxima, weighted by the inference results, [10]. In our example, our model is created using FuzzyTech 5.55i software, and we use the Centre of Maximum (CoM) defuzzification method.

2.1 Creating a COVID-19 fuzzy model

The model presented below is a two-phase model, which means that some of the second phase's input variables are the output variables of the first phase. We have a total of 14 fuzzy variables and four blocks of rules in the whole model (Figure 2).

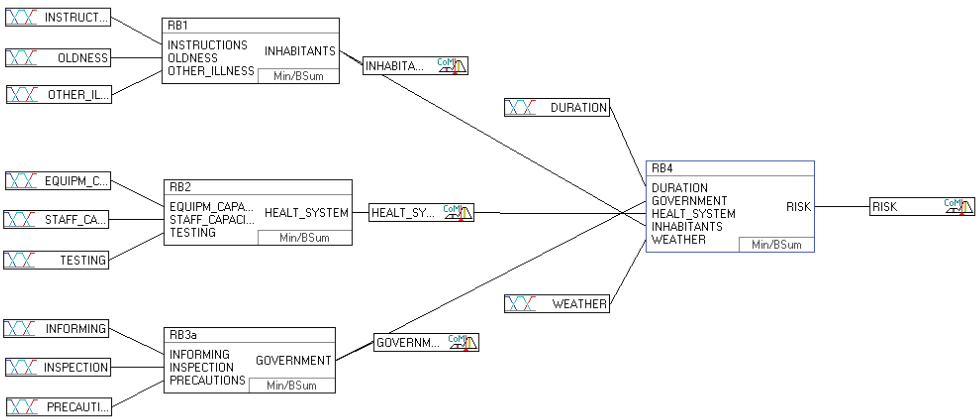

Figure 2: *The fuzzy model*

In model development, we start from facts that are known and encountered for several months. The model's final outcome is the level of risk (threat) of humans to the virus infection.

These outcomes are influenced by several factors: PEOPLE (INHABITANTS), HEALTH SYSTEM, GOVERNMENT, DURATION, WEATHER. These are the second phase's input variables and enter Block 4, where the output is RISK.

The fuzzy variables PEOPLE (INHABITANTS), HEALTH SYSTEM, GOVERNMENT are the outputs of fuzzy reasoning in the first phase (rule blocks 1, 2 and 3).

Every fuzzy variable has to be defined by its linguistic terms (fuzzy sets) and presented by membership functions.

Rule Block 1 represents a fuzzy reasoning process with three input and one output variable.

- The input variable INSTRUCTIONS represents responsible compliance with the rules (masks, disinfection, hand washing, etc.). It is given with three fuzzy sets/terms: POOR IMPLEMENTATION, MEDIUM IMPLEMENTATION, STRICT IMPLEMENTATION.
- The input variable OLDNESS = {YOUNG, MIDDLE, OLD} represents the age of the population.
- Input variable OTHER_ILLNESS = {NONE, FEW, MANY} represents other diseases of the population.

- The output variable INHABITANTS = {LOW_RESPONSIVE, MEDIUM_RESPONSIVE, VERY_RESPONSIVE} indicates the susceptibility of the population to the coronavirus.

Rule Block 2 means a fuzzy reasoning process with three input and one output variable.

- The input variable STAFF_CAPACITY = {FEW, MEDIUM, ENOUGH} represents the medical staff's capacity.
- Input variable EQUIPMENT_CAPACITY = {BAD, MEDIUM. ENOUGH} represents the capacity of hospital equipment.
- The input variable TESTING = {NOT_ENOUGH, MEDIUM, MANY} represents the number of population tests.
- The output variable HEALTH_SYSTEM = {DEFICIENT, GOOD, VERY_GOOD} means the robustness and sustainability of the health system.

Rule Block 3 means a fuzzy reasoning process with three input and one output variable.

- The input variable INFORMING = {BAD, MEDIUM, GOOD} represents the level of success of information on the course and state of the disease, on the measures taken, on the vaccine, and similar.
- The input variable PRECAUTIONS = {BAD_TOO_LATE, MEDIUM, GOOD} represents the level of security measures taken by the government, such as mandatory wearing of masks, self-isolation, quarantine, purchase of equipment and timely preparation of hospitals, curfew, and similar.
- The input variable INSPECTION = {DEFICIENT, MEDIUM, GOOD} represents the activity of government departments in checking compliance with the measures taken.
- The output variable GOVERNMENT = {UNSUCCESSFUL, SUCCESSFUL, VERY_SUCCESSFUL} indicates the government’s performance in fighting the virus.

Rule Block 4 represents the second phase of the fuzzy model and represents a process of fuzzy reasoning with five inputs and one output.

- We already know the input variables INHABITANTS, HEALTH_SYSTEM, GOVERNMENT, as these are the outputs of the first phase of our model.
- The input variable DURATION = {SHORT, LONG} represents the time component of the epidemic.
- The input variable WEATHER = {BAD, GOOD} represents the effect of weather on the intensity of the virus’s spread.
- The output variable RISK = {VERY_LOW, LOW, MEDIUM, HIGH, DRAMATIC} is also the final output of the fuzzy system and indicates the level of susceptibility of the population and thus the possibility of infection.

All fuzzy variables are given in the range of 0 to 100 and show the incidence rate. All fuzzy sets are described and represented by membership functions. For the fuzzy variables INHABITANTS, HEALT_SYSTEM, GOVERNMENT and RISK, the membership functions are shown in Figures 3 - 6.

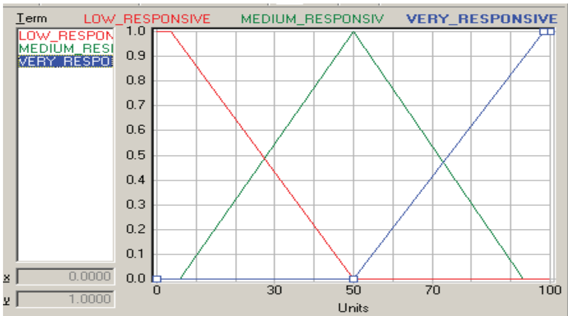

Figure 3: *Membership functions of INHABITANTS*

Figure 4: *Membership functions of HEALTH_SYSTEM*

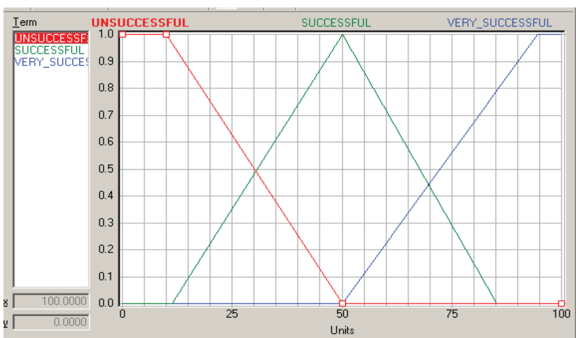

Figure 5: *Membership functions of GOVERNMENT*

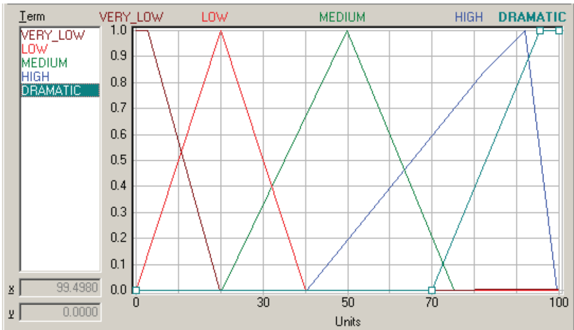

***Figure 6:** Membership functions of RISK*

2.2 Fuzzy inference

The rule blocks contain the control strategy of a fuzzy logic system. Each rule block confines all rules for the same context. A context is defined by the same input and output variables of the rules.

The rules of fuzzy reasoning (inference) of our model are contained in rule blocks RB1, RB2, RB3a and RB4. The rules consist of two parts: a condition and a consequence; it is, therefore, a reasoning in the form of IF-THEN statements, which describe the laws of an individual fuzzy (sub)system.

With fuzzy inference, we must put all values and facts in a definite order and connect them to the procedure of inference execution, so that will be feasible do with a computer. This order is given as a list or system of rules. In our work, we applied FuzzyTech software, *[3].* In accordance with this software tool, 27 rules in RB1, 27 rules in RB2, 27 rules in RB3a and 108 rules in RB4 were automatically created. Some of them are represented in Tables 1, 2, 3 and 4.

***Table 1:** Some rules of the Rule Block "RB1"*

IF			THEN
INSTRUCTIONS	**OLDNESS**	**OTHER_ILLNESS**	**INHABITANTS**
POOR_IMPL	JUNG	NONE	MEDIUM_RESPONSIV
MEDIUM_IMPL	MIDDLE	NONE	MEDIUM_RESPONSIV
MEDIUM_IMPL	OLD	MANY	VERY_RESPONSIVE
STRICT_IMPL	JUNG	NONE	LOW_RESPONSIVE
STRICT_IMPL	MIDDLE	MANY	MEDIUM_RESPONSIV
STRICT_IMPL	OLD	MANY	MEDIUM_RESPONSIV

***Table 2:** Some rules of the Rule Block "RB2"*

IF			THEN
EQUIPM_CAPAC	**STAFF_CAPACITY**	**TESTING**	**HEALT_SYSTEM**
BAD	FEW	NOT_ENOUGH	DEFICIENT
BAD	FEW	MEDIUM	DEFICIENT
MEDIUM	MEDIUM	MANY	GOOD
MEDIUM	ENOUGH	MANY	VERY_GOOD
ENOUGH	MEDIUM	MEDIUM	GOOD
ENOUGH	ENOUGH	MANY	VERY_GOOD

***Table3:** Some rules of the Rule Block "RB3a"*

IF			THEN
INFORMING	**INSPECTION**	**PRECAUTIONS**	**GOVERNMENT**
BAD	DEFICIENT	BAD_TOO_LATE	UNSUCCESSFUL
BAD	GOOD	MEDIUM	SUCCESSFUL
MEDIUM	DEFICIENT	BAD_TOO_LATE	UNSUCCESSFUL
MEDIUM	GOOD	GOOD	VERY_SUCCESSFUL
GOOD	DEFICIENT	BAD_TOO_LATE	UNSUCCESSFUL
GOOD	GOOD	GOOD	VERY_SUCCESSFUL

***Table 4:** Some rules of the Rule Block "RB4"*

IF					THEN
DURATION	**GOVERNMENT**	**HEALT_SYSTEM**	**INHABITANTS**	**WEAT HER**	**RISK**
SHORT	UNSUCCESSFUL	DEFICIENT	MEDIUM_RESPONSIV	BAD	HIGH
SHORT	UNSUCCESSFUL	GOOD	MEDIUM_RESPONSIV	GOOD	MEDIUM
SHORT	UNSUCCESSFUL	VERY_GOOD	LOW_RESPONSIVE	GOOD	LOW
SHORT	UNSUCCESSFUL	VERY_GOOD	MEDIUM_RESPONSIV	BAD	MEDIUM
LONG	UNSUCCESSFUL	DEFICIENT	LOW_RESPONSIVE	BAD	HIGH
LONG	UNSUCCESSFUL	VERY_GOOD	LOW_RESPONSIVE	BAD	MEDIUM
LONG	SUCCESSFUL	GOOD	LOW_RESPONSIVE	GOOD	LOW
LONG	VERY_SUCCESSFUL	VERY_GOOD	VERY_RESPONSIVE	GOOD	MEDIUM

3 RESULTS

The FuzzyTech software enables interactive work so that by changing the input data, we can obtain the output values in the outputs of the first phase and the final output RISK.

The model shows that changing the entry conditions (population behaviour, health system, government measures, control, weather, and duration of the epidemic) naturally changes the threat to the population or disease risk.

In the case of extremely poor measures at all levels, this risk is extremely high, and in extremely favourable conditions it is, of course, small. Intermediate options are associated with the more or less successful implementation of all measures. In the model, we also take into account that the final result is also influenced by the weather and the duration of the epidemic or the state of readiness. We proceeded from the recommendations that good weather (sun, high temperature, low humidity) has a positive effect on low infection, and bad on the contrary. We also took into account the fact that the time duration strongly influences the possibility of infection; the longer the state of risk of infection, the greater the chance that people will become sick and vice versa.

Tables 5 to 8 show some of the results obtained in individual subsystems and in the whole system as the final output of the fuzzy model.

3.1 Subsystem INHABITANTS

This is a subsystem (Fig. 7) that uses the rules of Block 1 to check the behaviour and responsibility of the inhabitants of a community (state).

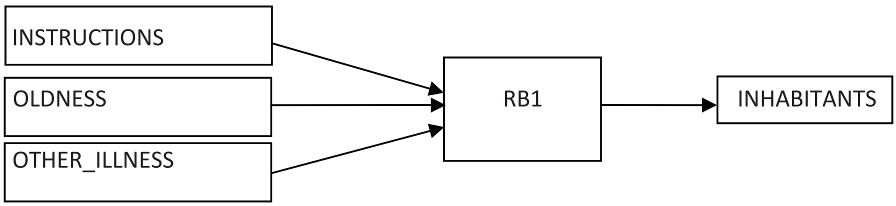

Figure 7: *Rule block 1*

Some results of the simulation of different data are given in Table 5.

Table 5: *Some results of subsystem INHABITANTS*

INSTRUCTIONS	OLDNESS	OTHER_ILLNESS	INHABITANTS
100	10	10	1.8
30	10	10	29.5
30	80	80	99.0
100	80	80	50.0
90	60	10	24.8
25	90	90	99.1

3.2 Subsystem HEALTH_SYSTEM

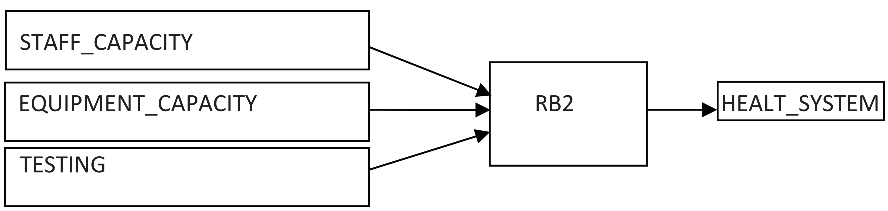

Figure 8: *Rule block 2*

Some results of the simulation of different data are given in Table 6.

Table 6: *Some results of subsystem HEALTH_SYSTEM*

STAFF_CAPACITY	EQUIP_CAPACITY	TESTING	HEALTH_SYSTEM
60	80	60	73.7
50	100	50	51.0
80	80	60	84.3
100	80	80	97.5
90	100	50	97.3
80	90	40	84.4

3.3 Subsystem GOVERNMENT

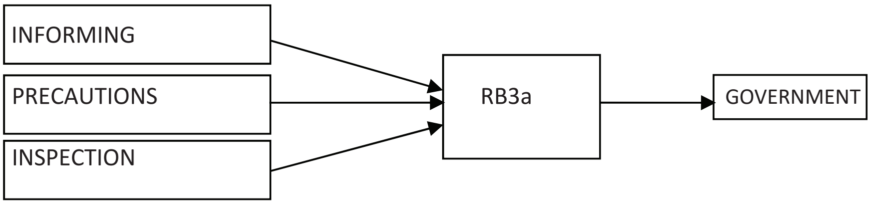

Figure 9: *Rule block 3a*

Table 7: *Some results of subsystem GOVERNMENT*

PRECAUITIONS	INSPECTION	INFORMING	GOVERNMENT
50	40	30	41.3
80	20	50	58.6
80	100	80	96.7
90	30	70	72.3
90	100	80	97.5
50	30	60	50.2

3.4 Subsystem RISK

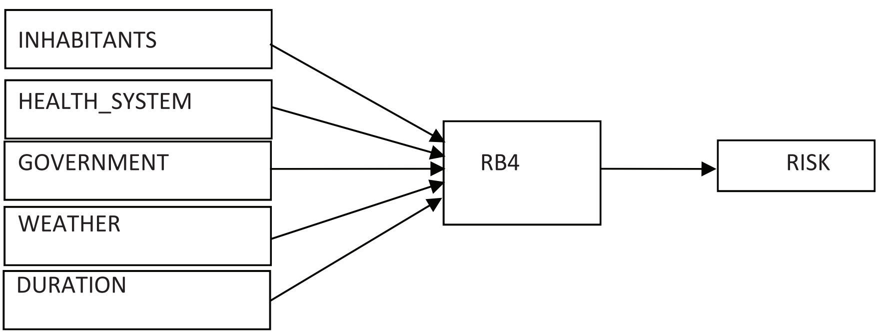

Figure 10: *Rule block 4*

The subsystem RISK (set of rules in RB4) represents the second phase of the fuzzy model. The output of this subsystem is the output of the whole system and, thus, the response of the model to all input data.

The simulation allows for many possible scenarios, from which we attempt to choose the most favourable one. The simulation provides the possibility to determine what needs to be done or what needs to be emphasised with changes in the input data.

Some simulation results are in Table 8.

Table 8: *Some results of subsystem RISK*

INHABIT.	HEALTH_S	GOVERN.	WEATHER	DURATION	RISK
1,8	74,1	41,3	10	90	34.8
29,5	51,0	58,6	30	70	35.0
99,0	84,3	96,7	50	80	47.0
50,0	97,5	72,3	70	30	34.1
24,8	97,3	97,5	90	10	11.6
99,1	84,4	50,2	30	50	65.9

3.5 Analysis

The fuzzy reasoning rules in all four blocks follow the hitherto known knowledge about the coronavirus's behaviour. The virus is more aggressive in bad weather, is hardy, and has a long-lasting effect. To date, the only protection is the responsible behaviour of the population. The health care system's sustainability is extremely important, and maintaining it an essential task for the current government. Government action is paramount in such a situation. Any delay in this leads to unnecessary additional infections of the population. In addition to measures (wearing masks, prohibited gathering of several people, self-isolation, quarantine, closed shops, in extreme cases even curfew), control over the implementation of these measures is necessary.

The model clearly shows that any change in input data (instructions and their observance, implementation of measures, control, the stability of the health system by providing human and technical resources, timely and objective information, etc.) affects the final result, meaning the threat (risk) to the population.

Without a doubt, every government's task is to work for the good of its citizens and, to this end, to do everything in its power to achieve this goal. The task of the population (citizens) is to behave responsibly and protect themselves and everyone else.

In the simulation process in the described model, it is seen that any change in behaviour affects the result. In particular, we would like to draw attention to the well-known fact that in the process of the epidemic, a functioning health system is successful in treating people with Covid-19 disease.

The simulation shows that a change for the worse in each input means a deterioration of the situation and an increased threat to the population. When the virus is largely disabled, control actions are relaxed, and people behave less responsibly. This, in turn, provides a good basis for a new wave, which is what has happened in Europe. After a relatively successful battle with the virus in the spring, life returned to normal too quickly. There was a resurgence of tourism and mass crossings of people across national borders to tourist destinations, where they held uncontrolled mass gatherings and group parties. States (governments) did not act in time, and there was a second wave as early as September 2020, which is not over at the time of writing. It seems that the virus will not go away on its own; mass vaccination will be needed.

4 CONCLUSION

Our fuzzy model, of course, does not solve the problem of Covid-19. Nor is it solved by any other mathematical model that uses different methods, such as the SIR (Susceptible Infected Recovered Model) used in many scientific articles (e.g., in *[1]*).

The proposed model only describes the coronavirus problem and attempts to point to a causal link between individual phenomena affecting Covid-19. As elsewhere, in this model, the result is only a more or less accurate guess about the consequences of individual communities' more or less responsible behaviour. Each fuzzy model is largely subjectively coloured and requires special expertise to create the rules of fuzzy reasoning. Input and output variables can be changed, subtracted, and added according to individual expert experience and knowledge. For each point of the definition area, we check whether the system is giving the desired result and if this result is logical. If we are not satisfied with the results, we can change any membership functions or fuzzy inference rules. For optimisation, we have some different methods, such as trial and errors, or using graphic tools, which can visually demonstrate system activity. Such a graphic demonstration shows us the response to a change of data or change in the definition of the system elements in FuzzyTech, *[8].* One of the most efficient methods is using neural nets during neuro-fuzzy training to obtain good and regular results. Unfortunately, this cannot be done in the case of the Corona-19 disease, as there is no explicit data for neural network formation.

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