U.Porto Journal of Engineering, 10:1 (2024) 59-68
ISSN 2183-6493
DOI: 10.24840/2183-6493_0010-001_002344

Received: 06 September, 2023
Accepted: 06 April, 2024
Published: 11 April, 2024

Can a mathematical model describe the main problems of the modern world?

Ioannis Rizos
Department of Mathematics, Univesity of Thessaly, Lamia 35100, Greece (ioarizos@uth.gr) ORCID 0000-0002-4092-1715

Nikolaos Gkrekas
Department of Mathematics, Univesity of Thessaly, Lamia 35100, Greece (ngkrekas@uth.gr) ORCID 0000-0001-9665-4559

Author Keywords

Mathematical Modeling, Empirical Models, Global Crises, Quantification.

Type: Research Article

Open Access
Peer Reviewed

Abstract

This article focuses on the transformation of current global problems into mathematical data and the drawing of conclusions from the results. After a theoretical introduction that clarifies the philosophy of the above approach and provides an innovative description of the mathematical model concept, a method for describing and analyzing crises is presented, with the goal of measuring its influence on the observable system, whether at the EU, global, or other levels. Converting social issues into quantitative data provides a systematic assessment of the severity of crises and allows for comparisons across different crises and systems. The main conclusion of the article is that a mathematical model, such as the one introduced here, could, to some extent, describe, as a first approach, global problems and their interrelationship, and thus be useful to policy makers.

1. Introduction

In early May 2023, the head of the World Health Organization declared the end of the Covid-19 pandemic as a global health emergency. A pandemic that cost humanity around 7 million lives and deeply affected billions of people causing intense stress and dramatic changes in their way of life and work. A few days later, however, the World Health Organization urged all the countries of the world to prepare for the next pandemic (UN 2023).

More recently, on December 2023, the United Nations Climate Change Conference (COP28) successfully concluded with an agreement that paves the way for a move away from fossil fuels. After difficult negotiations, the groundwork was laid for the transition to "green energy", limiting CO_2 emissions and maintaining the global temperature limit of 1.5 °C. This historic agreement is an important step at the diplomatic level, at the level of international consensus on an objective, as it involves conflicting positions (e.g. the EU countries, which want to phase out the use of fossil fuels, on the one hand, and the oil-producing countries, which want to continue with the status quo, on the other).

The above recent, very typical examples remind us in a very emphatic way of the constant need to carry out studies in the field of public health, climate change and beyond, which could contribute to the management of such crisis situations. As a technique and a field, mathematical modelling is one of these study areas (Atoyev and Knopov 2023, Çakan 2020).

Mathematical modeling can be broadly defined as a process that uses mathematics (functions, systems of equations, algorithms, etc.) in order to simulate, analyze or predict real phenomena (Barwell 2013). Those phenomena can be social, political, economic, health, environmental, educational and more (Barwell 2018). The model considering in this study focused on combining these types of phenomena, without depending on parametric or non-parametric tests, but only on the use of pre-existent statistical data. The idea of this type of mathematical modeling is to take data from various fields, seemingly unrelated to mathematics, and converts them into numerical solutions, thus making them comparable and allowing conclusions to be drawn (Tian and Xie, 2022).

For us, a mathematical model is essentially a mathematical representation of an already existed mediated representation of a part of the world, in the sense that it does not represent reality itself but describes in a mathematical way our perceptions about it. In other words, mathematical models emerge from a process of reflection on already experienced problem situations, a process which implicitly presupposes an interpretation of reality according to some ideological/epistemological beliefs by which certain elements are arbitrarily selected in order to become objects of study. Thus, mathematical models are in some sense technological but also political or sociological tools, which are based on reality but, at the same time, can give a distorted picture of it (cf. Lopes 2022, Merck et al. 2021).

In world history, such mathematical models have really helped us understand and describe complex situations in social, economic and psychological systems through the ages. Such examples of models are the Malthusian population growth model (first appeared in 1798), the Weber-Fechner law considering psychology and reaction to stimuli (first appeared in 1860) and the Adam Smith economic theory (first appeared in 18th century) (Fiaschi and Signorino 2003).

Understanding the underlying processes and forecasting their consequences in the face of global crises such as climate change, food insecurity, economic recessions, geopolitical conflicts, and pandemics, is crucial for effective decision-making and policy creation. The concept of the importance of decision-making has been also studied in the field of Mathematics Education by conducting classroom experiments (see Patronis et al. 1999), such as the importance of using models with the help of technology in order to construct conjectures or finding the best solution (see Rizos and Gkrekas 2022, Rizos and Gkrekas 2023). Empirical modeling provides a useful framework for investigating complex social systems, enabling researchers to capture complicated linkages, identify significant drivers, and make informed predictions (Robinson et al. 2007).

Traditional analytical methodologies (behavioral models, pattern of traffic, decision-making etc.) face major obstacles due to the intrinsic complexity of social crises, such as models describing a health crises (see Harjule et al. 2022), an economic crisis (see Ivanyuk 2021) and even problems in distribution of basic resources (see Bello at al. 2019). Empirical modeling, on the other hand, offers an alternate method that embraces the complexities of these occurrences by utilizing real-world data and statistical tools (Zenil 2020). Researchers may construct models that represent the multidimensional dynamics of social crises by examining empirical data obtained from many sources, such as surveys, accurate websites, official records, and other relevant data repositories (Helbing and Balietti 2011).

The fundamental goal of this study is to propose an empirical model that describes a wide range of the condition of modern civilization utilizing a variety of criteria. These models are useful tools for policy makers, social scientists, and academics attempting to understand the basic causes of crises and the impact on society. Furthermore, this research will focus on the effectiveness of an empirical model in expressing global crises. While empirical modeling can provide a data-driven method that approximates the precise real-world dynamics, it also has restrictions in terms of data availability, model validation, and result interpretation. The modern world problems we concentrate on are able to be expressed with mathematics, such as energy crisis, health crisis, economic instability, geopolitical issues, climate change and the relation with mathematics. For example, multiple players' geopolitical conflicts can be modeled using game theory and thus many complex events can be explained (Zagare 2019). This research concentrates mainly on the EU (27 countries) section.

2. The mathematical elaboration

The present model is not probability based nor on a pre-existent model. Its purpose is to describe the current situation/period when the data inputted are collected.

The data that were received are taken by the online portal Statista, the scientific online publication Our World in Data as well as the statistical office of the European Union Eurostat, and are not completely real-life accurate. The data are indicative in order to apply this model – but are as close to reality as there is access to.

The data are expressed in tables, for each subject and after the integration of the model. More specifically, the model is used each year in the time period 2015-2019 and it has two steps: a) applying an equation (product) for each one of the following tables and b) use a second equation with fixed parameters (sum) that way reducing the data from five tables to one. This process is being done separately for each year.

In Table 1 (Energy crisis) the variables are explained as such: "jobs in wind energy in thousands" means the open positions in renewable energy sources on windmills. "Fossil Fuel consumption in European Union" means the amount of TWh that are produced in EU from fossil fuels. "Green energy of total production in EU" means the percentage of the energy produced in EU that is from green sources (renewable energy sources) and "Biofuel Production in EU" means the amount produced in biofuel translated in TWh of energy.

In Table 2 (Economic instability) the variables are explained as such: "GDP EU" is the mean value of the Gross Domestic Product of the 27 countries in the European Union and is counted in millions of dollars. "Inflation EU" is the percentage of inflation at the end of each year (the mean value of the 27 nations in EU). "Euro Stoxx index" is an economic index considering the European stock market and is counted in stock points, similar to Dow Jones index, and "Employment EU Q4" is the mean value of the employment rate (percentage) in the 27 EU countries in the fourth quartile of each year.

In Table 3 (Health crisis) the variables are explained as such: "EU hospital beds" is the number of available hospital beds in the 27 EU countries per thousand citizens. "Life expectancy in EU" is the mean value of the life expectancy age in the EU countries. "Mental problems rate" is the percentage of people that suffer from a variety of mental problems, and "Deaths in EU" is the amount of deaths in the 27 countries in EU for each year.

In Table 4 (Geopolitical issues) the variables are explained as such: "Deaths in conflicts worldwide" is the number of deaths worldwide in wars and conflicts. "Military expenses in Europe" is the amount of expenses in weapons and warfare in Europe counted in billions of dollars. "Illegal crossings EU borders" is the amount of illegal crossings (refugees etc.) in the EU countries counted in thousands, and "Terrorist attacks EU" is the amount of failed or successful terrorist attacks (with victims or not) in the 27 countries in EU.

In Table 5 (Climate change) the variables are explained as such: "Water pollution deaths worldwide" is the amount of deaths caused by non-healthy waters in the world per 100,000 citizens. "Loss of Rainforest area worldwide" is the area of lost rainforest in square kilometres in the world. "Earthquakes EU" is the number of earthquakes in the European Union each year and "EU Temperature in Celsius anomalies" is the rise of temperature in the EU in degrees Celsius, as it is referred at COP28 UN argument.

Energy crisis

Year	Jobs in wind energy (1000s)	Fossil Fuel consump-tion EU (TWh)	Green energy of total production (%) EU	Biofuel Production (TWh) EU
2015	1,081	6,217	14.85	156
2016	1,155	6,336	14.86	148
2017	1,148	6,445	14.78	166
2018	1,160	6,458	15.77	177
2019	1,165	6,443	16.52	182

Table 1: The collected data for the factors concerning energy
(Source: Statista, Our-world-in-data, Eurostat)

Economic instability

Year	GDP EU (in millions)	Inflation EU December (%)	Euro Stoxx index	Employment EU Q4
2015	12,214,623.9	0.2	3,267.52	64.9
2016	12,552,500.0	1.1	3,290.52	65.9
2017	13,076,045.9	1.6	3,503.96	67.1
2018	13,531,477.0	1.6	3,001.42	67.9
2019	14,017,090.6	1.6	3,745.15	68.6

Table 2: The collected data for the factors concerning the economic situation
(Source: Statista, Our-world-in-data, Eurostat)

Health crisis

Year	EU hospital beds (per 1.000 inhabitants)	Life expectancy EU (years)	Mental problems rate (%)	Deaths EU (1000s)
2015	5.49	78.0	5.70	8,178
2016	5.45	78.4	5.74	8,009
2017	5.41	78.7	5.78	8,076
2018	4.59	78.8	5.76	8,112
2019	4.59	79.1	5.74	8,020

Table 3: The collected data for the factors concerning the health situation
(Source: Statista, Our-world-in-data, Eurostat)

Geopolitical issues

Year	Deaths in conflicts worldwide	Military expenses (bil. $) Europe	Illegal crossings EU borders (1000s)	Terrorist attacks (failed or not) EU
2015	126,213	332.819	1,822.18	104
2016	109,212	346.007	511.05	140
2017	99,071	336.975	204.72	199
2018	86,007	342.980	150.10	127
2019	77,256	360.540	141.85	110

Table 4: The collected data for the factors concerning the geopolitical situation
(Source: Statista, Our-world-in-data, Eurostat)

Climate change

Year	Water pollution deaths per 100,000 worldwide	Loss of Rainforest area worldwide	Earthquakes EU	EU Temperature (in Celsius anomalies)
2015	19.87	2,932.04	1,565	1.89
2016	19.00	6,128.12	1,696	1.87
2017	18.59	5,001.64	1,566	1.74
2018	17.64	3,648.02	1,808	2.12
2019	16.81	3,751.05	1,637	2.02

Table 5: The collected data for the factors concerning climate change
(Source: Statista, Our-world-in-data, Eurostat)

The basic idea behind the model we use is expressed by the following equation:

$$x = \prod_{i,j\in I} a_i {b_j}^{-1} \quad (1)$$

Where a_i are the factors with positive impact and b_j are the factors with negative impact to the system, knowing that $1 \leq i,j \leq 4$, where $i,j \in I$. The capital I is used as a general set of indices. After applying the above model to our data in each table we get five more tables.

More specifically the model of the five tables are the following, where $n = 1,2,3,4,5$ is the number of the tables.

For Table 1:

$$x_1 = a_1 a_3 a_4 {b_2}^{-1} \quad (2)$$

Where a_1 is "jobs in wind energy", a_3 is "Green energy total production", a_4 is "Bio fuel production" and b_2 is "Fossil fuel consumption in EU".

For Table 2:

$$x_2 = a_1 a_3 a_4 b_2^{-1} \quad (3)$$

Where a_1 is "GDP in EU (in millions)", a_3 is "Euro Stoxx index", a_4 is "Employment rate in EU during Q4" and b_2 is "Inflation in EU counted on December (in %)".

For Table 3:

$$x_3 = a_1 a_2 b_3^{-1} b_4^{-1} \quad (4)$$

Where a_1 is "Hospital beds in EU per 1000 inhabitants", a_2 is "Life expectancy in EU", b_3 is "Mental problems rate (in %)" and b_4 is "Deaths in EU (in thousands)".

For Table 4:

$$x_4 = b_1^{-1} b_2^{-1} b_3^{-1} b_4^{-1} \quad (5)$$

Where b_1 is "Death in conflicts in the world", b_2 is "Military expenses (in millions of Euros)", b_3 is "Illegal crossings in EU borders (in thousands)"and b_4 is "Terrorist attacks in EU (failed or not)".

For Table 5:

$$x_5 = b_1^{-1} b_2^{-1} b_3^{-1} b_4^{-1} \quad (6)$$

Where b_1 is "Deaths by water pollution in the world (per 100.000 citizens)", b_2 is "Loss of rainforest area (in km^2)", b_3 is "Earthquakes in EU" and b_4 is "EU Temperature in (Celsius degree anomalies)".

The mathematical elaboration behind our model and approximations

Year	Total table1	Total table 2	Total table 3	Total table 4	Total table 5	Total
2015	0.402805	1.295129	0.918639	0.125621	0.580304	3.322500
2016	0.400910	0.247450	0.929442	0.369873	0.270801	2.218478
2017	0.437020	0.192148	0.912111	0.735262	0.394700	2.671243
2018	0.501377	0.172354	0.774084	1.778332	0.405424	3.631573
2019	0.543649	0.225077	0.788683	2.300871	0.479600	4.337882

Table 6: The final table after approximations

After that, we use the second part of our model for the results we got. The following equation is:

$$y = \sum_{n=1}^{5} k_n x_n \tag{7}$$

The term y represents the final results for each table that was input in Table 6 in the "Total" column. The terms x_n are the total results of each table, after applying the first part of the model. Additionally, k_n are constants used for approximations in order to obtain comparable results for the effectiveness of the model. These constants were not obtained by any operations, but they were chosen not only for the value of the final results but also for elimination of the complex units. More specifically, the constants k_n are:

$$(k_1, k_2, k_3, k_4, k_5) = (10^{-3}, 10^{-13}, 10^{2}, 10^{15}, 10^{8}). \tag{8}$$

The model is applied separately for each year during the period 2015-2019. In Figure 1 the whole process is presented including our starting variables (types of crises, Table 1, Table2, Table 3, Table 4, Table 5, and Table 6), model applications and final results after approximations. In the figure, the one-way arrows mean the order of the process, how and when was the data fed or when a transformation was applied. The two-way arrows mean the interrelation/ interaction and the dynamics between two or more entities.

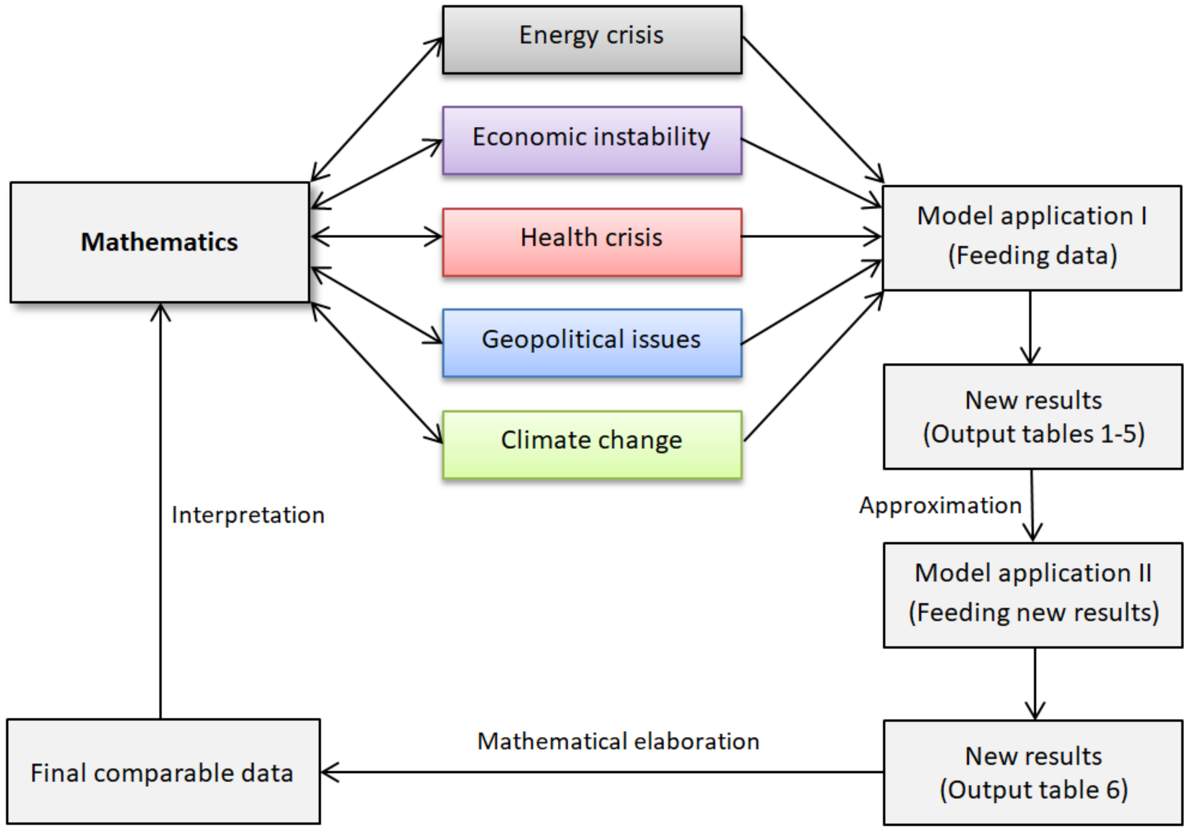

Figure 1: Visual representation of the nonlinear model and all steps of the process (Source: Authors)

3. Discussion

After the approximations with the factors from equation (8), we obtain the values in Table 6. One of the main reasons we need so many decimals in the results is because of the influence of each variable in every table. The outcome of the process is also important as an index for comparing socio-economic stability of the EU each year and even work backwards, meaning comparing the results for the "most stable" year and then looking at the factors that may cause the value increase. When applying this model and taking the final results it could be very useful to create a curve and maybe predict approximately the rate of change about stability throughout the years.

The numbers as results of Table 6 maybe do not give enough information on their own. Besides, the novelty of this article, apart from the definition of mathematical modeling, is the introduction of an original method that, as far as we know, combines for the first time so many seemingly non related variables. But if, this model is enriched with more variables and data (i.e. different countries, different economic blocks, geopolitical entities, military alliances etc.), for a greater time period, then it may give a curve that could maybe approximately predict the rate of change of the stability factor throughout the years. The idea for the model, as long as the data are available, could be applied in different systems with different variables and factors.

The modern world is very erratic – especially the political and economic situation in Europe after the Covid-19 pandemic, the outbreak of war in Ukraine, and the high levels of tension in Middle East. It is important to have appropriate tools in order to manage crises and make optimal decisions. A case study could be the Eastern Mediterranean region, which can offer very positive prospects for stable geopolitical and regional cooperation, but at the same time it is an extremely thermally vulnerable area, which is expected to be affected by frequent and severe heat waves in the coming period. Recent remarkable studies propose realistic scenarios and weather models in order to shed light on these very important parameters and the interconnection between them (Karakasis 2023, Koutroumanou-Kontosi et al. 2023). A mathematical model such as the one suggested in this paper could contribute in this direction.

4. Conclusion

The research delved into the transformation of modern problems into mathematical data. By approaching societal issues from a quantitative perspective, we aimed to gain insights and draw objective conclusions. This approach allowed for a systematic analysis of crisis situations, providing a structured framework for understanding their complexities.

The method, designed to describe and analyze crises, enables the quantification of their impact. By applying mathematical techniques, numerical representations that capture the essence of a crisis within the observed system (European Union of 27 countries) can be obtained. This enables a more objective evaluation of the crisis' severity, facilitating comparisons between different crises and systems. The methodology employed in this study facilitates the measurement of the impact a crisis has on societal stability. The index derived from the model's outcomes provides a multi-dimensional perspective on stability within the portion of society from which the data are collected. By considering various factors and dimensions, the index offers a more comprehensive understanding of the stability dynamics influenced by the crisis. This holistic approach helps policymakers and stakeholders assess the potential ramifications of a crisis and develop informed strategies to mitigate its effects.

Finally, this research established a methodology for transforming current issues into mathematical data, as well as a systematic framework for analysis and quantification. By using this technique one can gain insights into the impact of crises and draw useful conclusions. The resulting model allows us to characterize, assess, and quantify the impact of various crises on the observable system (in this case the European Union). The obtained index shows the multidimensional stability dynamics of the observed population. Such mathematical evaluations and results help to inform evidence-based decision-making and aid in the development of successful crisis-response tactics.

In future research, if the model is applied in a greater time period, there might be a pattern of the results of the model through the years. In this research, the application of the model has been done in the interval of five years and no pattern seems to emerge, but if the same is conducted in the future in the interval of decades, there might be a certain convergence, divergence or rate of change that could be calculable.

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