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Optimization Models and Strategy Approaches Dealing with Economic Crises, Natural Disasters, and Pandemics – An Overview

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Abstract**:** *The occurrence of large-scale crises is a great challenge for people. In such cases, many levels of public life are affected and recovery takes time and considerable resources. Therefore, approaches and tools for predicting and preventing crises, as well as models and methods for crisis management and crisis overcoming, are necessary. In this review, we present approaches, models, and methods that support decision-making in relation to the prevention and resolution of large-scale crises. We divide crises into three types: natural disasters, pandemics, and economic crises. For each type of crisis situation, the types of applied tasks that are solved and the corresponding models and methods that are used to support decision-makers in overcoming the crises are discussed. Conclusions are drawn on the state of the art in this area and some directions for future work are outlined.*

Keywords**:** *Optimization models and methods, Economic crises, Natural disasters, pandemics, Sustainable development.*

1. Introduction

According to statistics, natural disasters have been steadily increasing over the last century [22, 70]. At the same time, our civilization is evolving technologically and the world is globalizing. With the technological progress, many organizations and companies widely use information technology and various mathematical approaches and models in their management.

The crises are a part of everyday life. Many examples can be listed: climate variations, earthquakes, volcano eruptions, hurricanes, floods, drought, wildfires, etc. Every natural process has also a certain cycle. In some cases, this can be connected with the periodic rise of natural disasters. Since facing crises is inevitable, crisis prediction and crisis management are necessary. Crises can be purely economic, but they can also arise due to natural disasters and wars, as well as pandemics. Given the complexity of the phenomena, crisis management involves the processing of large amounts of data in real-time and the use of mathematical models to reduce losses from these events and to overcome their effects. The main idea is to support the organization of human activity in these cases through decision support, making optimal decisions and optimizing the effect of efforts with minimal time and resource-costs.

The purpose of this article is to review the optimization approaches and models used in economic crises, natural disasters, wars, and pandemics. In addition, an attempt is made to identify gaps in the consideration of one type of event (non-use of applicable models formulated for another type of event), as well as to note previously unexplored possibilities for formulating models and optimization tasks. For example, earthquake or tsunami evacuation models could also be used successfully in wars and other natural disasters such as hurricanes, forest wildfires, and more.

In [16] is studied how sustainable development is incorporated at the company's level. There are three pillars of sustainability (according to [33] and **www.thwink.org**): social, environmental, and economic pillar.

2. Environmental aspects of economic sustainability

2.1. The key formula of life

Human activity and industrialization in recent centuries have led to increasing pollution of the atmosphere, water, and soil. The release of CO_2 and other harmful emissions into the atmosphere causes the effect of global climate warming. As a precautionary measure, carbon trading is introduced. According to it, the companies have to "monitor and report their emissions annually" and are highly motivated to reduce their harmful emissions. The Emissions Trading Scheme (ETS) is the European Union's flagship policy on combating climate change. It was introduced in 2005. In order to ensure the successful operation of ETS, mathematical models and approaches for their measurement, planning, and reporting must be created. In this respect, there are two possible "green solutions": 1) Active planting (increasing the number of trees), and 2) Green transformation of the cities using modern technologies like Internet of Things (IoT), Internet of Everything (IoE) and Artificial Intelligence (AI) to improve the efficiency in resources and energy-consumption in an environment-friendly manner, as well to use renewable energy sources. The author of [81] introduces the key formula of life, where the value of the Balance function ($\mathbf{F}_{\mathbf{Balance}}$) must be higher than the critical value $\mathbf{F}_{\mathbf{critical}}$. The Balance function itself represents the ratio of the number of trees and the number of people on the Earth (see Figs 1 and 2).

If the above condition for sustainability is violated, nature is out of balance and disasters will follow until reaching of a new state of resilience (sustainability). In this connection should be noted that the number of natural and man-caused disasters has increased exponentially over the last 70 years according to many statistical sources [22, 70]. According to this trend, many scientific papers on this topic have been published as shown in Fig. 3. (The data have been taken from Google Scholar).

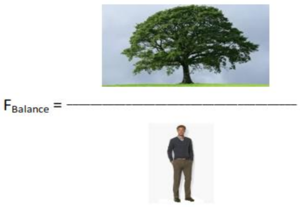

Fig. 1. The Balance function in the (key) formula of life

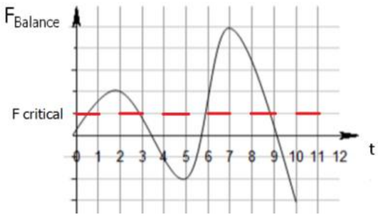

Fig. 2. The condition for sustainability

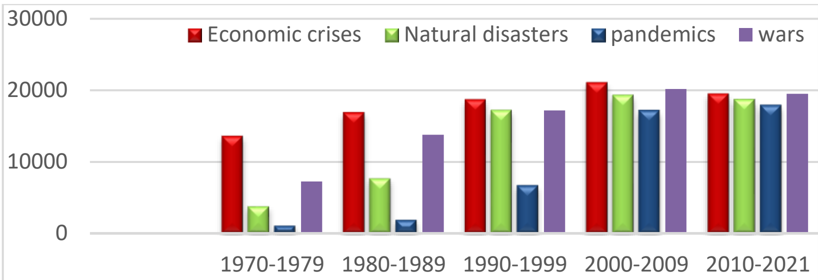

Fig. 3. Number of articles on models or optimization methods for economic crises, natural disasters, pandemics, and wars; (Number of publications per period)

2.2. Policies and measures to reach the environmental balance

The environmental pillar of sustainability is very important. It has been discussed by many authors and many institutions, both national and international all over the world. The program Global Environment Outlook (GEO) is a part of UN Environment program (1972-2022). One direction of the GEO-5 for Business is “Adapt to Survive: Business transformation in a time of uncertainty” (2021). The basic conclusions made are that the global economic system is locked into a pattern of environmental damage and the future is into moving “towards a nature positive economy”.

The Special Report on Global Energy Perspectives “Energy and Climate Change” by OECD/IEA [60, 62], as well as the reports of the International Energy Agency [41] and [58], set the goal of achieving a low-carbon economy and mitigating climate change.

The World Commission on Environment and Development (WCED) [83] considers “sustainability” as determined by the factors – needs and limitations. Business Sustainability (BS) is defined in [6] as the ability of companies “to meet their short-term financial needs”, without diminishing their “ability to meet the future requirements” to them. The classical theory of Business Sustainability (BS) is based on closed integration between Corporate Financial Performance (CFP), social cooperation (Corporate Social Commitment or CSC), and Corporate Environmental Commitment (CEC) [33]. The organization’s ability to anticipate and respond to changes in the environment in a timely and effective manner determines its resilience as discussed in [14, 52, 77]. The authors of [70] have noted that the interactions of the processes are caused by turbulence in the environment, where resilience can evolve over time. When an organization is in a period of turbulence, there are specific threats, and on the other hand, it is forced to seek and find new opportunities for survival and development. In the course of these changes, the resilience of the organization improves. The emergence of natural disasters and pandemics (Environmental Turbulence (ET)) requires the development of sustainability concepts for organizations. For example, the concepts of dynamics and sustainability of the global supply chain [85] concerning the variability of products and services, technologies, and the demand for new products and services on the market need to be further developed by addressing the global health crisis.

3. Social stability as a part of sustainable economic development

The social aspect of the economy is very important and it is interesting to see the role of the National Government and of the larger organizations (European Union, etc.) in promoting and supporting social stability in the context of sustainable economic development. The practice of Social Innovation Fund (SIF) – Scotland is studied in [79]. The conclusion is that in the short-term the results of activities of SIF are very promising. However, the open question is how the long-term activities reflect on the organizations' behavior.

The role of social construction in sustainability transitions is explored in [31, 48] with the aim to understand better the economic crisis.in connection with chronic problems such as environmental degradation, unemployment, and social inequality. This is a good cause for concern and undertaking measures. In [48] there are summarized various alternative points of view, leading to the conclusion that a more fundamental systemic change is needed. Social innovation and transition are linked to self-government and self-organization [19, 29, 55] and re-localization [5]. Research is necessary, to see how different governance and management approaches affect social innovation and the dynamics of economic transformation.

In [25] is stated that theoretical models for studying the links between socio-economic mechanisms and sustainability are still in their initial development stage and need further development.

Authors of [67] have considered the national security and risks for it in connection with sustainable development.

The conclusion is that deeper theoretical analysis and more simulations are necessary to formulate better models of economic dynamics, social risks, and social innovation effects in order to achieve social stability and basic conditions for sustainable economic development.

4. Optimization models developed to deal with economic crises, natural disasters, and pandemics to reach economic sustainability

4.1. Optimization models and approaches to overcome economic crises

A cybernetic theoretical model of the brain has been developed in [7, 8], and applied on a real example with a company that produces steel rods. The main question of this research is: "How are systems viable?", i.e., How are systems "capable of independent existence"? Later, the Viable System Model (VSM) was developed, which considers the separate organization as a complete system, existing in balance with its rapidly changing (market) environment. Based on the fundamentals of cybernetics, B e e r [10] develops a cybernetic model of the viability of any organization that is capable of maintaining its identity. In [10] it is noted that the theoretical model is “difficult to understand by people”, which has led to the creation of a simplified version of the model in the book “Brain of the Firm” [9]. The simplified version uses neurophysiological terminology instead of mathematics. A new version of the VSM called the “The Heart of Enterprise” has been developed [11]. Finally, based on the theory of the viable system and its “laws” in management cybernetics, a third book entitled “Diagnosing the System for Organizations” was published [12]. In the VSM model, five subsystems have been developed, each with its own role, but working in close interaction with each other. The first three systems relate to the current activities of the organization, and the first subsystem consists of such elements that the organization produces. The fourth system focuses on the future effects of external changes and requirements affecting the organization. The fifth system maintains a balance between both current activities and future external changes and ensures the viability of the organization. All systems interact with each other and are in connection with dynamically changing markets.

With the help of this model the viability of an organization can be determined, i.e., it can be evaluated whether an organization has a chance to survive or not. In addition, with this model, it is possible to examine the internal and external balance of the organization and to make the necessary improvements to ensure its survival, which represents in essence a management tool. Other important works on this topic are [30] and [56].

The business intelligence approach by means of decision-making is considered in [20, 21].

If a theory is developed on how a company can overcome an economic crisis, then integrating its results for all companies in one economic system, (better) sustainability of the economy can be achieved. In this regard, two main approaches have been developed to predict bankruptcy or optimize the investment policy of an enterprise/company in order to improve its viability:

I. The first approach is based on Discriminant analysis techniques (see, for example, W a r m a c k and G o n z a l e z [82], and R u b i n [72], and S o l t y s i k and Y a r n o l d [76]. This approach usually uses statistics for certain indicators (parameters) of two groups of companies: survivors and losers/disappearing companies (representative sample of data). Then a dividing surface (in the simplest case a plane) is built to separate the two groups. The positioning of the dividing surface is optimized so that the number of incorrectly classified companies is minimal. Using the optimal parameters of the dividing surface, one can make predictions with a certain accuracy to which group of companies a new company that is not included in the sample belongs, as well as give advice on which parameters the company needs to improve in order to fall into the survivors’ group. The main work in this connection is that by A l t m a n [4]. This study examines manufacturing corporations in the context of bankruptcy forecasting. The initial sample includes statistical data for sixty-six companies. A function is optimized that distinguishes companies into two mutually exclusive groups: bankrupt and non-bankrupt companies.

II. The second approach is the direct approach. It is based on optimizing one or more criteria (objective functions) and improves the values of the factors (parameters) that are crucial for the better viability of companies. For example, this approach has been applied in the field of Electronic Design Automation (EDA) companies [53]. It is noted there, that the first available data for this type of company are from 1961. The existence of EDA companies is very dynamic and depends largely on many factors related to technological development. A major factor influencing the viability of EDA companies is the emergence of technological events (innovations). There are other important factors, such as those affecting the market. Factors influencing the market for electronic design automation software are analyzed in [34]. The disappearance of EDA companies is analyzed in [54] and the key factors determining their viability is formalized, namely the response time / allowable delay Dmax for the implementation of innovation/technological improvement by the companies, as well as the reduction or increase of the company's profits. It was found that the reaction to the innovation event and Dmax are a result of the sensing and learning processes in the EDA companies, which are related to attracting and using talented people in the company. In [53] authors conclude that when the delay in response to an innovation event increases, the profit of the respective EDA company decreases. Two mathematical models are suggested in [37] to improve (extend) the EDA companies' viability. The first one is aimed at optimizing the investments of EDA companies maximizing their profit, and the second one − is to minimize the reaction delay of the companies to an innovation event.

The design and implementation of a new tool for Sharing Economy Business Models (SEBM) is proposed in [26]. It represents a morphological box created by means of morphological analysis. The authors consider the SEBM from three dimensions: value facilitation, value delivery, and value capture. In [78] authors have used value creation instead value facilitation. In [26] is concluded that the proposed tool can be used also for improved sustainability performances, i.e., it can be used for resolving crises.

In periods of economic crises, natural disasters, and pandemics the focus of organizations' efforts is on short-term survival and no special attention is paid to long-term development. In a rapidly changing environment and negative business conditions, the survival of the company (organization) requires optimal management of its capabilities (resources and actions). This is the only way to improve the economic sustainability of an organization as stated in [51, 63]. A conceptual framework of dynamic capabilities and organizational sustainability is proposed in [39] Fig. 4.

A key factor in overcoming a crisis situation is the innovation. In [32] the authors discuss innovation and in particular the role of Information Technology (IT) for service innovation in sharing economy organizations. The service innovation is presented by service ecosystem, service platform(s), and value co-creation in [51] and [79]. IT role and product/service innovation for sustainability improvement are considered in [57]. On the basis of cross-case analysis, the IT role is summarized in four archetypes: Broad facilitator, Service operation facilitator, Value creation differentiator, and Broad differentiator.

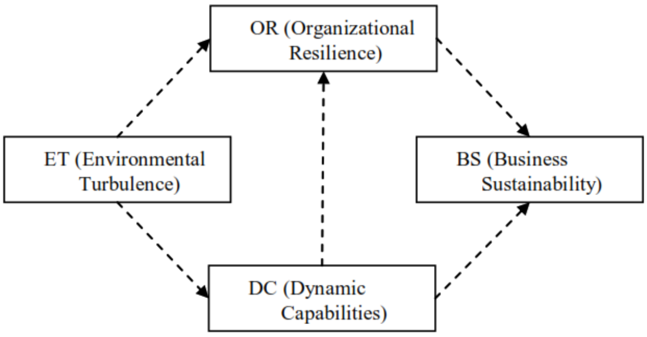

Fig. 4. Organizational Resilience and Business Sustainability – a conceptual framework

More generally, we can talk about innovations in terms of business modeling. The role of business model innovation is considered in [13] as a solution against crisis. Following the model proposed in [42], several recommendations are made:

- to pay attention to new technologies;
- to change the business model in time;
- compliance with traditional patterns;
- look for innovative solutions;
- better consideration of customer requirements;
- accept crisis as a natural phenomenon.

The most popular approaches and models for optimization problems in connection with overcoming economic crises are presented in Table 1.

An empirical study between High Sustainability and Low Sustainability companies is provided in [28], with the focus on integrating social and environmental issues into the company strategy and business model through the corporate policies, and how it is related to the performance and the organizational structure. As High Sustainability companies, the authors consider the companies that have applied policies that impact society and the environment. On the other hand, the Low Sustainability companies correspond to the traditional model of corporate profit maximization in which social and environmental issues are predominantly regarded as externalities. They suggest that High Sustainability companies have benefited relatively more in Business-to-Customer (B2C) sectors and in sectors where companies compete based on brands and human capital [28].

Bondarenko et al. [17] have proposed a Strategic Management System, which is used to forecast results of enterprise activities, to form strategies for activities management and control, as well as to improve the efficiency of organization activities under conditions of economic instability.

In conclusion, the better viability of the companies in cases of crises, natural disasters, wars, and pandemics would lead to higher economic sustainability. The Discriminant analysis allows calculating the tolerances of key parameters essential for the survival of the companies but with not very high precision. By means of the

Direct approach, better results can be achieved, but the model formulation is very difficult and requires deep data analytics. New models based on the Direct approach should be formulated and further research is necessary to develop a fundamental theory on how the companies have to improve their behavior in order to overcome different crisis situations.

Table 1. Problem, models, and approaches in connection with economic crises

Source	Problem	Model, Approach	Method, Optimization technique applied
[7, 8, 9, 10, 11, 12, 30, 56]	Improving the Organization's viability	Viable System Model (VSM)	Cybernetic model
[20, 21]	Support of decision-making in the publishing sector	Business intelligence approach	Group decision making
[4, 72, 76, 82]	Prediction of bankruptcy or optimizing the investment policy of a company	A function is optimized that divides companies into two groups: bankrupt and non-bankrupt companies	Discriminant analysis
[34, 37, 53, 54]	Improving (extending) the EDA companies' viability	Direct approach, Model 1. Optimizing the investments of EDA companies maximizing their profit, Model 2. Minimizing the reaction delay of the companies to an innovation event	Nonlinear optimization methods for constraint optimization problems
[26, 78]	Improving economic sustainability in crisis situations	Sharing Economy Business Models (SEBM)	Mixed methods for study of marketplaces
[39, 51, 63]	Improving the economic sustainability of an organization	Optimal management of capabilities (resources and actions) of the organization	Nonlinear optimization methods for constraint optimization problems
[32, 51, 57, 79]	Improving economic sustainability by means of service innovation, presented by service ecosystem, service platform(s) and value co-creation	Cross-case analysis	New dominant logic for marketing
[13, 42]	Business model innovation as a solution against crisis	Reinventing the business model	Business modelling
[17, 28]	Improving the company strategy and business model	1. Models that impact the society and the environment 2. Traditional model of corporate profit maximization 3. Forecasting results of enterprise activities	Nonlinear optimization methods for constraint optimization problems

4.2. Optimization models and approaches connected with events of wars and natural disasters

Some crisis warning models and indicators are considered in this section. In addition, optimal localization of humanitarian aid points, models for supply optimization and evacuation in such events as war, earthquake, tsunami, hurricane, wildfire, flood, drought, or other disasters, as well as logistics models and strategic management systems designed to manage such events, are discussed.

Usually, the signaling thresholds on crisis probabilities have to be optimized in the early-warning models. The drawbacks connected with threshold optimization are unstable thresholds in recursive estimations. In [74] are proposed two alternatives for threshold setting: 1) including preferences in the estimation itself, and 2) setting thresholds in advance only according to preferences. The authors provide real-world and simulated evidence that this simplification leads to stable thresholds and improves the performance out-of-sample. Their solution can be directly transferred to the signaling approach and to probabilistic models for early warning.

Financial crises usually happen suddenly and unexpectedly, and the interconnectedness of digital development, global investment, and trade increases the risk level of another crisis. The Organization for Economic Co-operation and Development (OECD) [61] states that the probability of a crisis occurring is increasing over time, because of the global economic linkages. During the crisis economic activity decreases, welfare is reduced, and income inequality is increasing [15].

The knowledge of the economic indicators of crises is very important and can help policymakers develop policies mitigating the economic crises. Crisis early-warning indicators and optimal policies for the management of economic crises are discussed in [1]. Based on a meta-analysis of 72 studies, the authors have found that the exchange rate is the most used indicator for crisis detection and monetary and fiscal policies are the optimal mitigation policies in crisis. The second dominant indicator of crises in developed countries is the interest rate. In these countries, currency, international reserves, and the current account are the other dominant indicators. For developing countries, policies aimed at representing the external sector have been shown to be preferable for crisis mitigation.

The fast response to emergencies and disasters, and optimization of supply models are very important for the effective management of such situations (better resilience) and the mitigation of possible consequences. Akwafuo, Mikler and Irany [2] have considered the existing computational models and algorithms for routing of deliveries and logistics during emergencies in public health. They overview the latest developments in optimization models and contributions. The application of corresponding algorithms in situations of insecurity, which usually occur in countries with low resources (Low and Middle-Income Countries – LMICs), is considered. Specific recent improvements in genetic algorithms, intelligent algorithms, biologically inspired algorithms, and artificial immune system techniques are discussed. Some gaps in research have been identified and guidelines for future research have been proposed. For example, route optimization of deliveris and Emergency Car System programs especially in LMICs could reduce the morbidity and mortality rate during and after disasters. In this case, data collection and actualization are necessary to formulate qualitative route minimization models.

Several exact methods and heuristic algorithms on vehicle routing and scheduling problems, as well as on supply chain management problems in cases of crises are considered and compared in [43].

The work [38] presents an overview of different optimization methods in the organization of humanitarian aid, especially in the areas of disaster management and humanitarian logistics. This is a review of the current literature on the application of multicriteria optimization in cases of natural disasters, epidemics, and the like. The authors consider some multicriteria approaches to decision-making, as well as various optimization criteria. MCDM methods are an important component of the well planning humanitarian operations, especially in the field of humanitarian logistics. In [38] is noted that methods in the MultiAttribute Utility Theory (MAUT) are not used in solving optimization problems connected with disasters. The explanation of this fact is that the preference elicitation connected with pairwise comparisons seems unpractical in the cases of disaster response, but in some situations or “phases in the disaster life cycle”, this may not be true. The authors have also found that ELECTRE and PROMETHEE methods, which are often used for environmental MCDM problems are still “widely unexplored in the field of humanitarian aid”. It could be expected also increasing the researchers’ interest in this direction in the near future.

A decision support system called HADS (Humanitarian Aid Distribution System) has been created in [64]. It is developed in an accessible way via a web platform and is designed for humanitarian logistics operations. The authors have validated the system through a comparison of the solutions generated by their system and the results of a real operation in connection with a food crisis in Niger.

A two-stage stochastic programming model for hurricane preparedness has been suggested in [24]. The model is tested on real-world examples concerning the United States infrastructure. The proposed approach is currently in use at Los Alamos National Laboratory for rising hurricanes of the category at least 3 in the United States.

Zamanifar and Hartmann [86] have analyzed optimization models for decision-making on the problem of planning transport networks in the event of disaster recovery. The four phases of the decision-making modeling process through optimization are considered: “problem definition, problem formulation, problem-solving, and model validation”. The research methodology in each of these phases is analyzed. The authors identify and discuss four areas for further research: 1) developing conceptual or systematic decision support for choosing decision attributes; 2) integrating recovery issues with traffic management models; 3) avoiding uncertainty due to the type of solvers’ algorithms; 4) reduction of subjectivity in the process of validation of disaster recovery models.

A three-step MILP deterministic robust relief chain model consisting of suppliers, relief distribution centers, and affected areas has been proposed in [88]. It contributes to humanitarian logistics under uncertainty. The model minimizes the total costs of the relief chain and implicitly maximizes the level of satisfaction of people in the affected areas by applying a sanction for shortages of aid goods. Uncertain parameters in the model are the cost parameters, the demand, and supply. The degree of conservatism of the model is determined by the uncertainty budget corresponding to these parameters.

A new multi-objective mathematical model in the case of natural disaster response is proposed for relief distribution location [73]. The model includes three objectives: 1) the costs of constructing new distribution centers and the costs of the supply’s transportation; 2) the cost of relief supplies shortages; and 3) the response time to access to people affected by the corresponding disaster is considered. The authors apply the Epsilon Constraints (EC) method and NSGA II algorithm to solve the formulated problem.

Ghasemi et al. [35] propose a stochastic multi-objective mixed-integer mathematical model for the problem of logistic distribution and evacuation planning during an earthquake. Pre- and post-disaster phases are considered. Three objective functions on humanitarian and cost issues have been introduced. Several sets of constraints are also considered in order to achieve a better fit of the model to real problems. Stochastic demands are assumed to be for blood, water, food, blankets, and tents. After that, the model is transformed into a deterministic equivalent model by means of a chance constraint programming approach. The transformed problem is solved using the epsilon-constraint approach and the Non-dominated Sorting Genetic Algorithm (NSGA-II). The test experiments have been performed on a real-world example of a Tehran earthquake. The obtained results show that the proposed model and the approach used are effective.

Optimized strategies to mitigate or reduce various losses and improve the effectiveness of disaster response are developed in [22]. An integrated framework has been developed, including several elements such as emergency organization, environment, decision-making agents, and their relationships. A new multi-purpose 0-1 integer programming model has been formulated to minimize total weighted completion time, total carbon emissions, and total emergency costs. A real example of the Wenchuan earthquake is considered in order to illustrate the proposed model and solution strategies. The results of the calculations demonstrate significant potential advantages in the allocation of the emergency organization in terms of the target functions, the preferences of the decision-making agents, and the size of the problem.

Optimizing the location of emergency facilities is the preferred approach to dealing with urgent humanitarian logistical problems. Boonmee, Arimura and Asada [18] combine an exact algorithm and a heuristic algorithm to solve problems about the location of facilities related to emergency humanitarian logistics. Four main problems are considered: deterministic problems with the location of the facilities, problems with the dynamic location of the facilities, stochastic problems with the location of the facilities, and stable problems with the location of the facilities. For each problem, an assessment is made of the type of facility location, data modeling type, disaster type, solutions, objectives, constraints, and solution methods.

The number of civilian victims reducing based on monthly data for a period from 1991 to 2008 in armed conflicts in Africa is analyzed in [40]. The analyses show that the increase in the number of United Nations personnel with several thousand troops and several hundred police in peacekeeping operations leads to dramatically fewer civilian deaths.

Quttineh [68] considers models and methods in military decision support systems. He solves problems for military mission planning optimizing allocation and deployment of military resources, as well as logistics problems. The author suggests an effect-oriented planning approach to an advanced weapon-target allocation problem, where the expected outcome of a coordinated attack has to be maximized. A mathematical model is proposed. In addition, a military aircraft mission planning problem is considered, minimizing the overall mission time during an attack of an aircraft fleet against a set of targets, and maximizing the mission success.

The models for people's evacuation after an earthquake or after a tsunami can be adapted or transformed suitably if necessary and can be used successfully in cases of wars and other natural disasters.

The optimization methods and models considered in this subsection are focused on crisis (early) warnings and warning indicators, as well as on logistic distribution, evacuation planning, and using qualified personnel to reduce the number of human casualties and victims in cases of natural disasters and wars. This is very important for overcoming the corresponding negative consequences and is connected with the improvement of economic sustainability.

The most important models and approaches for optimization problems in connection with overcoming wars and natural disasters are presented in Table 2.

Table 2. Problem, models, and approaches in connection with wars and natural disasters

Source	Problem	Model, Approach	Method, Optimization technique applied
[2]	Routing of deliveries and logistics during emergencies in public health	Specific recent improvements in genetic algorithms, intelligent algorithms, biologically inspired algorithms, and artificial immune system techniques	Survey paper
[43]	Supply chain management problem in cases of crises	Vehicle routing and scheduling problems	Linear and binary linear models, exact methods and heuristic algorithms
[38]	Organization of humanitarian aid, especially in the areas of disaster management and humanitarian logistics	Different MCDM models excluding MAUT	Multicriteria optimization methods
[64]	Humanitarian logistics operations	Web-based decision support system called HADS (Humanitarian Aid Distribution System)	Decision making
[24]	Hurricane preparedness	Two-stage stochastic programming model	Stochastic programming
[86]	Planning transport networks in the event of disaster recovery	Optimization models for decision-making	Decision making
[88]	Humanitarian logistics under uncertainty	Three-step MILP deterministic robust relief chain model	MILP
[73]	Natural disaster response	Multi-objective model	Epsilon Constraints (EC) method and NSGA II algorithm
[35]	Logistic distribution and evacuation planning during an earthquake	Stochastic multi-objective mixed-integer model for the problem of pre-, and post-disaster phases	NSGA-II
[22]	Optimization strategies to mitigate or reduce various losses and improve the effectiveness of disaster response	An integrated framework including several elements, such as emergency organization, environment, decision-making agents, and their relationships	0-1 integer programming
[18]	Location of facilities related to emergency humanitarian logistics	Deterministic, dynamic, and stochastic models	Exact and a heuristic optimization
[40]	Civilian victims in armed conflicts in Africa from 1991 to 2008	Statistical analysis	Statistics
[68]	Military mission planning optimizing allocation and deployment of military resources, as well as logistics problems	Military decision support systems	Decision making

4.3. Optimization models and approaches to deal with pandemics such as Covid-19

Humankind has gone through a number of mass and global epidemics in its history. More famous among them are the plague epidemics, dating back more than 5,000 years, with documented such epidemics in 431 Before the Christ (BC) in Greece and in 1347-1351 from the New Age in Europe. The death toll from the plague is estimated at more than 100 million. Nowadays, AIDS is a pandemic. This disease originated around 1979 and is caused by the Human Immunodeficiency Virus (HIV). In 2007, the number of patients worldwide was estimated at 33.2 million, and the number of victims of the disease at 2.1 million per year, including 330,000 children. More than three-quarters of the dead are in sub-Saharan Africa. In 2012, there were approximately 35.3 million people living with HIV in the world. Other known modern pandemics are SARS in 2003, Avian Influenza in 2004, H1N1 (swine flu) in 2009, Ebola in West Africa in 2014 and Congo in 2019, and the latest – COVID-19 from early 2020 which requires the restructuring of organizations and societies as noted in [77]. It is estimated that about 410 million people worldwide have been infected with COVID-19 to the mid-February 2022 (**https://www.trt.net.tr/bulgarian/covid19**), about 6 million have died and about 328 million have recovered. The necessary effective measures to overcome this pandemic are commented in [45]. An accurate risk assessment is also very important [46, 75].

Essential is that natural disasters and catastrophes, as well as pandemics, have a shocking effect on stopping/reducing all kinds of social and economic activities, and on shrinking market volume. In pandemics, lockdowns limit the interaction between businesses and consumers. The large number of sick people is an internal obstacle for the manufacturers. Therefore, the survival of companies is associated with the rapid overcoming of many external and internal negative influences.

- **Models.** How sustainable development is related to and affected in crisis times, such as during the COVID-19 pandemic, is described in [3] taking China as a model. The authors conclude that if sustainable development is to be really achieved within countries, it will enable them to confront and overcome crises.

Zhou et al. [87] have used the Wells-Riley model and the Quanta concept to define a "specific exposure time" for a low cross-infection rate. In addition, an agent-based simulation model is used to simulate the reasonable efficacy of hospital screening for a given exposure time at different stages of the COVID-19 pandemic in different screening processes. The results determine the allocation of health care centers with insufficient screening capacity in the area under consideration and facilitate targeted policy-making and planning to reduce cross-infection with COVID-19.

Epidemics require dynamic response strategies including a multitude of policy alternatives and balancing health, economic and social aspects. A simulation–optimization framework is proposed in [36] to aid policymakers in selection of closure, protection and travel policies to minimize the total number of infections under a limited budget. The proposed framework combines a modified, age-stratified Susceptible-Exposed-Infectious-Removed (SEIR) compartmental model to evaluate the health impact of response strategies and a Genetic Algorithm to effectively search for better strategies. This model is used to study a real case in Nova Scotia to obtain optimal strategies considering different budget scenarios and to find out a trade-off between health and economic requirements. The results show that Closure policies are the most sensitive to policy restrictions, followed by travel policies. Authors suggest practicing social distancing and wearing masks whenever their economic impacts are not too strong. The framework is generic and can use different epidemiological models and optimization methods.

- **Approaches.** A simple and robust data-driven approach based on the concept of information entropy under conditions of non-sufficient statistics and uncertainty is used in [65] to analyze the dynamics of COVID-19 epidemic waves on the example of Bulgaria.

Overcoming the COVID-19 pandemic requires timely workforce education, including rapid readiness for simulation, evaluation and training in all health sectors. It is shown in [27] that simulation is essential for the training of healthcare providers and for the integration of systems with a view to testing and integrating new processes and rapid changes in practice in Canada. The healthcare system needs unprecedented in volume and speed individual, team and systemic trainings, which are most often generated with the help of proactive simulation training. D u b e et al. [27] share the unique characteristics and advantages of using a centralized provincial team for simulation and readiness, using training methods and system integration. They have assessed the highest risk and presented the results of an analysis of mass volume simulation of COVID-19 data in the largest health authority in Canada.

The evolution of the semiconductor market since 1990, with a focus on the recent developments in connection with the COVID-19 pandemics and the economic crisis of 2020-21 is explored in [66]. The traditional Information Theory concept for entropy and a novel concept for hierarchy are applied to explore the specifics of competition interactions among the largest suppliers of semiconductor components and the dynamics of market concentration.

Covid-19 pandemic has affected sectors as public service, transport, food retail, industry, healthcare, education and tourism. The study in [84] highlights that information technology can play a pivotal role in the companies' sustainability and growth and that the governments should support small and medium enterprises.

O b r e n o v i c et al. [59] have analyzed key factors that affect enterprises operational sustainability and their ability to overcome adversity taking in consideration the pandemic situations, such as Covid-19. The authors have conceptualized a new framework for enterprises to sustain business operations and ensure survival during a pandemic and other crisis. In their methodology, they have considered economic theory as Theory of crisis management teams, the Stakeholder theory and Distributed cognition theory to detect the essential organizational strategies and processes to be taken into account during the crisis together with contemporary case studies and best practices.

Another work related with the effects of Covid-19 in the social and economic sustainability structure of the countries is presented in [69]. This analysis is based on an empiric study via a structured questionnaire distributed in different companies in India. Three aspects of organizational resilience as: i) crisis anticipation;

ii) organizational robustness; and iii) recoverability; are considered for assessing the impact on social and economic sustainability. The authors conclude that all three of them have a positive impact on social and economic sustainability. They also provide and study a combined approach of organizational resilience and social-economic sustainability, where the combination of low resilience and high sustainability is more relevant to a large-scale crisis scenario. Resilience and sustainability complement each other and the organizations have to build up organization resilience in order to stabilize their sustainability structure. Different sustainability-resilience combinations can lead to "Failure", "Risk", "Sustained Build-up" or "Quick recovery" (Fig. 5).

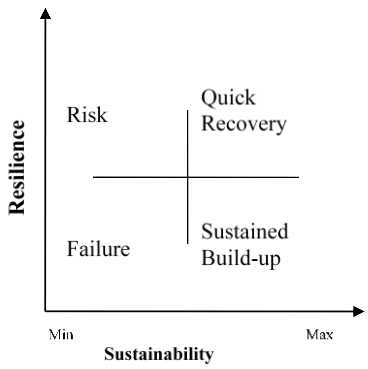

Fig. 5. Results of different sustainability-resilience combinations

The conclusion in [69] is that Sustainable recovery from the pandemic crisis can be achieved by considering the evolution of the pandemic, public policy response, and social and economic vulnerability.

The post-crisis economy discussing the current COVID-19 pandemic crisis is considered in [50]. One of the ideas discussed here is that business transformation has to be done not only by single firms, organizations, etc., but "for simultaneous and joint changes in various domains: tax laws and labor regulations, cultural institutions, higher education, etc.," The same authors have discussed also the sustainable business model innovation [49]. In this case, the benefits are not only for companies and organizations themselves but for the community too.

Post-pandemic recovery in Latin America and the Caribbean (LAC) is studied in Cárdenas and Ayala [23]. According to the authors, the main question for LAC countries for resolving that task seems to be unemployment, indebtedness, and the recession. A set of recovery measures are proposed taking into account multiple objectives and prerequisites. The final goal is to meet the requirements of the three pillars of sustainability: social, environmental, and economic.

The COVID-19 crisis in Germany in the context of innovative startups is studied in [44]. On the base of interviews with entrepreneurs at different positions, the authors summarize the challenges arising to startups such as reducing sales, and questions about long-term development.

Table 3. Problems, models, and approaches in connection with pandemics

Source	Problem	Model	Approach / Method, Algorithm
[3]	Sustainable development	Sustainable develop-ment model for China	
[87]	“Specific exposure time” for a low cross-infection rate	Wells-Riley model and the Quanta concept	“Specific exposure time” approach
	Reasonable efficacy of hospital screening for a given exposure time at different stages of the COVID-19 pandemic in different screening processes	Agent-based simulation model	Agent-based approach
[36]	Simulation–optimization framework to aid policy-makers in selec-tion of closure, protect-tion, and travel policies to minimize the total number of infections under a limited budget	Modified, age-stratified Susceptible-Exposed-Infectious-Removed (SEIR) compartmental model	Genetic Algorithm
[65]	Analysis of the dynamics of COVID-19 epidemic waves in Bulgaria	Information entropy model	A robust data-driven approach based on the concept of information entropy under conditions of non-sufficient statistics and uncertainty
[27]	Training of healthcare providers, analysis of mass volume simulation of COVID-19 data in the largest health authority in Canada		Proactive simulation training
[66]	Evaluation of competition interactions among the largest suppliers of semi-conductor components and the dynamics of market concentration in connection with the COVID-19 pandemic and the economic crisis of 2020-2021		Traditional information theory concept for entropy and a novel concept for hierarchy
[84]	Evaluation of companies’ sustainability and growth		Information technology concept
[59]	Analysis of Key factors and detection of essential organizational strategies that affect enterprises’ operational sustainability and their ability to overcome adversity taking into consideration the pandemic situations, such as COVID-19		Application of economic theory as Theory of crisis management teams, the Stakeholder theory, and Distributed cognition theory
[69]	Analysis of the effects of COVID-19 on the social and economic sustainability of different companies in India		The combined approach of analysis of scenarios for organizational resilience and social-economic sustainability
[47]	Analysis of the sustainable recovery from the pandemic crisis		Evaluation of the evolution of the pandemic, public policy response, social and economic vulnerability
[49, 50]	Analysis of the post-crisis economy in connection with the current Covid-19 pandemic crisis	Business transformation model	Sustainable business model innovation
[23]	Analysis of the post-pandemic recovery measures in Latin America and the Caribbean		Approach to achieve social, environmental, and economy sustainability
[44]	Analysis of the Covid-19 crisis in Germany in the context of innovative startups		Long-term development approach

In this subsection, different organizational strategies are considered. Key factors that affect enterprises’ operational sustainability and their ability to overcome pandemics are defined and analyzed. Also, different sustainability-resilience combinations are considered with the aim of achieving “Quick recovery”. The above-considered approaches should be further investigated and compared. The considered models are connected with the allocation of healthcare centers in order to minimize cross-infection and the number of sick people. Optimal strategies under different budget scenarios have been also analyzed. Dynamic and very fast decision-making is necessary for balancing health, economic, and social aspects during pandemics. In this connection, data should be collected daily, and real-world problems should be quickly formulated and solved in real-time every day.

The models and approaches for optimization problems in connection with pandemics are presented in Table 3

5. Conclusion

Approaches, models, and methods that support decision-making in resolving large-scale crisis situations are considered in this overview. Large-scale crises are those in which large groups of people are affected. We divide the crises into three types: natural disasters, pandemics, and economic crises.

Industrialization with all its positive aspects also brought quite a few side effects. It caused huge damage to the environment. The predatory consumer attitude towards nature and its constant damage should stop. Sustainable economic development is only possible by means of a "friendly and nature-positive economy". Therefore, the current and future strategies of world organizations, governments, and companies to overcome the main causes of natural disasters and global climate warming should be aimed at reducing harmful gases and carbon dioxide emitted into the atmosphere, improving energy efficiency, economical use of natural resources and protection of the ecosystem – called *Green economy* (*Green transformation*). All these ideas cannot be realized suddenly and everywhere at the same time, and are inevitably accompanied by significant adjustments of social and economic life.

Thus, the dilemma for the realization of the new goals must be carefully considered at all levels:

- organizations must implement and implement social policies and activities;
- more work by intergovernmental institutions and other stakeholders needs to be done;
- the role of world organizations in the implementation of such global goals is increasing.

All this explains and promotes the use of structured approaches and methods of crisis management.

To manage economic crises, the following tasks are mainly solved: improvement/optimization of various organizational activities, supporting decision-making at various levels; bankruptcy prediction, and/or investment policy optimization. For this purpose, a wide range of optimization and decision-making approaches such as linear and nonlinear models, integer and mixed models, and corresponding solution methods are used.

To overcome the consequences of natural disasters, types of tasks such as logistics (humanitarian aid, distribution, evacuation), supply chain management, planning, location, etc., are considered. The corresponding models and methods cover a wide spectrum such as decision-making, linear and integer programming, exact and heuristic methods, and statistics.

Models are least used in pandemic surveillance/management. Although statistical approaches have long been applied, mainly to monitor various specific parameters. A powerful stimulus in this regard was the COVID-19 pandemic. It must be said that a number of models to predict the appearance and development of pandemics exist. How accurate such models are is an open question for science. The Wells-Riley model and the Quanta concept can be mentioned for defining "specific exposure time". Various aspects of society during a pandemic – economic, social, health, and psychological, are the subject of scientific and practical research.

Thus, it can be said that there is a sufficient range of crisis management models and approaches available to science. Another question is how effectively they are used in practice. It can be said that most models and approaches are used in two main cases: to predict crises (more or less successfully) and to manage and overcome the crisis when it arises.

What can we expect in the near future? As a main trend, it can be stated that the development and application of crisis-management models and approaches will expand. Mass digitization and the development of IT technologies will contribute to a large extent to enable real-time crisis management.

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