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Environmental Monitoring and Population Protection from Environmental Factors

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Abstract. The paper deals with the problem of providing users with information on optimal environmental protection means that guarantees safe stay in a given region. Problem statement of choosing optimal environmental protection means is given. A method to receive safety recommendations for general public based on information regarding available protection means, known thresholds of harmful emissions and hazardous substances impact on humans and environmental situation in a given region is considered.

Keywords: Environmental factors, Environmental protection equipment, Genetic algorithm, Branch and Bound algorithm, Dynamic programming.

1 Introduction

Ukraine is painted black on the UN map due to its environmental deterioration. It is the color of a country where the population is dying out. Ukraine ranks first in the world by death to birth rate [1]. According to Ptoukha Institute for Demography and Social Studies of the National Academy of Sciences of Ukraine the South and the East of Ukraine – the so-called “Black Belt” – is dying out at a record pace. Environmental problems contribute in no small part to this shocking statistics.

According to the Ministry of Health of Ukraine and the Ministry of Ecology and Natural Resources of Ukraine there are more than 3 million people living in more than 2000 settlements on radionuclide-contaminated territories only. Due to environmental deterioration, over the last 10 years medical incidence rate has increased by 25% on average. According to World Health Organization data, 80% of environmentally induced deceases are severe and practically incurable illnesses. Information on environmental conditions such as air pollution, water contamination, epidemiological situation, radiological hazards level etc. has become vital.

However where and how to get such information promptly? Can the received information be trusted? These are the questions that the authors attempt to answer with their EcoSpotter project.

One of important functions of the EcoSpotter project is providing its users recommendations on protection from environmental factors. The relevant task is to develop means for a person to receive safety recommendations based on information regarding current environmental situation, known thresholds of harmful emissions and hazardous substances impact on humans and environmental situation in a given region and available protection means. Every person has right to be aware of all changes in ecological situation that take place both locally and country-wide, to know everything about the food consumed, quality of water drunk and to understand existing dangers and to act accordingly [2].

2 Analysis of existing web resources and services regarding environmental situation

Analysis of accessible to public information resources and services that provide data on current environmental situation shows that obtaining reliable and up-to-date information is not an easy task. Following is an overview of some information resources that provide environmental monitoring data.

Environmental Interactive Maps [3] offers a list of interactive environmental maps of Europe. Water and soil pollution are represented best. Indisputable advantage of this resource is the variety of information. However, user-specified search for environmental data is complicated due to necessity to separate different forms of data representation.

Wireless Environmental Monitoring Systems (EMS) [4] provides data on the most reliable, consistent and accurate wireless environmental monitoring and control solutions by Hanwell Solutions Ltd. The Hanwell EMS software takes environmental monitoring data display to another level. The top-level displays a general overview of site sensor activity, with subsequent levels enabling customizable data groups for individual user requirements. Full data collection with interactive graphs, tables and plan views enable users to slice historical environmental data in multiple ways for more advanced analysis.

The Baltic Sea Region GIS, Maps and Statistical Database [5] is a result of the Baltic Drainage Basin Project, a multi-disciplinary research project under the EU. The datasets and maps have been combined into one interactive on-line map service. Database has become the most popular and pertinent environmental information resource about the transboundary Baltic Sea Region.

Lakes Environmental Company [6] offers a wide range of environmental software products. The Company provides a wide variety of services in the areas of air dispersion modeling, human health and ecological risk assessment, emissions inventory, compliance, as well as emergency release.

Climate Interactive Company [7] creates simulation models, interactive tools and programs for environmental and sustainability planning and education in such areas as climate change, energy, sustainability, environment, and disaster risk reduction.

Environmental Performance Index (EPI) [8] scores 180 countries on 24 performance indicators across ten issue categories covering environmental health and ecosystem vitality. The overall EPI rankings indicate which countries are doing best against the array of environmental pressures that every nation faces. Ukraine is on the 109th place (out of 180) in the 2018 EPI Country Rank.

Main Center of the Special Monitoring website [9] manages data of seismic, radio-nuclide, electromagnetic, infrasound monitoring, monitoring of nuclear tests and space weather, on both global and local scale, providing the state central government structures, which are responsible for the national security and defense, as well as other interested ministries and departments with all the required information.

Analysis of existing information resources that provide data on environmental situation and parameters leads to the following conclusions:

- Existing information services do not possess adequate degree of interactivity: the data is provide either as static maps or interactive maps with complicated and not user-friendly interface and limited functionality;
- Existing information services do not possess ecological monitoring data search tools;
- Information services software requires lengthy and complicated installation and configuration process;
- Information resources are narrowly focused on certain territories and/or provided data type;
- Information resources provide no recommendations on lessening or negating environmental hazards impact on human health and ways to improve environmental security.

3 Problem statement

Within the context of environmental problems which society faces, development of ecological monitoring systems to provide timely, complete and reliable information on environmental state and civil protection from environmental hazards activities is a pressing challenge.

The goal of this work is to build mathematical model of choosing environmental protection means and to analyze performance of algorithms solving this task.

4 Mathematical model of choosing environmental protection means

Suppose in a given region a person is influenced by a set of environmental hazards (radioactivity, water contamination with heavy metals salts, electromagnetic fields, hazardous air emissions from moving sources, hazardous chemical substances etc.). We consider that harmful emissions and hazardous substances exposure not exceeding government-approved thresholds causes no harm to human health. Suppose there is a set of protective equipment available with each item lessening negative impact of certain

factors by a certain degree. The goal is to define the most affordable set of protective items that provides for person's safety.

A person is influenced by a set of hazardous environmental factors F . Every i -th environmental factor is characterized by its degree of influence upon a person's health f_i . $F = \{f_i, i = \overline{1, m}\}$.

Let boundary values of environmental factors lie within a_i to b_i in accordance with government-approved norms. This gives us boundary system (1):

$$\begin{cases} a_1 \leq f_1 \leq b_1 \\ a_2 \leq f_2 \leq b_2 \\ \dots \\ a_m \leq f_m \leq b_m \end{cases} \quad (1)$$

A person has a set of protective means $D = \{d_{ij}, i = \overline{1, m}, j = \overline{1, n}\}$ available. For each j -th protective mean its cost $c_j, j = \overline{1, n}$, and degree of lessening negative impact $d_{ij}, i = \overline{1, m}$ of i -th environmental factor with j -th protective mean are known. Then the negative impact of i -th environmental factor upon a person can be defined as $f_i - \sum_{j=1}^n d_{ij}x_j$, where components of $X = \{x_1, x_2, \dots, x_n\}$ vector acquire discrete values from $[0, 1]$ range according to (2):

$$x_j = \begin{cases} 1, & \text{if a person uses protective means.} \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

To define most the most affordable environmental hazards protection items objective function (3) is set:

$$\sum_{j=1}^n c_j x_j \rightarrow \min \quad (3)$$

Function (3) minimization is performed on a set of constraints (4):

$$\begin{aligned} a_i &\leq f_i - \sum_{j=1}^n d_{ij}x_j \leq b_i, i = \overline{1, m} \\ x_j &\in \{0, 1\}, j = \overline{1, n} \end{aligned} \quad (4)$$

Let's reduce problem to the canonical form. To do it we apply to each i -th $i = \overline{1, m}$ system (4) constraint elementary operations, which gives us (5):

$$a_i - f_i \leq -\sum_{j=1}^n d_{ij}x_j \leq b_i - f_i, \quad i = \overline{1, m} \quad (5)$$

Let's represent each of constraints (5) with two, introduce free variables $s_i, i = \overline{1, m}$ convert inequalities into equalities and come to a canonical form (6):

$$\begin{cases} \sum_{j=1}^n d_{ij}x_j + s_i = f_i - a_i \\ \sum_{j=1}^n d_{ij}x_j + s_i = f_i - b_i \end{cases} \quad x_j \in \{0, 1\}, \quad j = \overline{1, n}; \quad i = \overline{1, m}. \quad (6)$$

The problem (2), (3), (6) is a Boolean programming problem. The solution lies in determining vector $X = \{x_j \mid x_j \in [0, 1], j = \overline{1, n}\}$ minimizing (3) on constraints set (6). Problem can be solved using exact or heuristic algorithms.

Model flexibility

Problem model (3), (6) is built accounting for certain range of environmental factors levels in accordance with government sanitary norms. It is known that government authorities periodically implement changes and additions to such norms to ensure adequacy of civil protection measures. In some instances, there is only upper boundary of environmental factor level. For instance, radiation level is considered safe up to 30 $\mu\text{R/h}$. To account for changes in model parameters and their range the second constraint (6) is made infinitely small (if it is a lower boundary) $-\infty \leq f_i \leq b_i, i \in I, I \subset N, N = \{1, \dots, n\}$ or infinitely big (in case of an upper boundary) $a_i \leq f_i \leq \infty, i \in I', I' \subset N, N = \{1, \dots, n\}$. For example, in case of radiation level restriction we have $-\infty \leq f_1 \leq 30$. If some of protective devices are unavailable their cost has to be set infinite, for example $c_j = \infty, j \in J, J \subset M, M = \{1, \dots, m\}$. This way flexibility of the model is implemented.

5 Solution algorithm for the problem of choosing optimal environmental protection means

In this paper use of genetic algorithm (GA), branch and bound algorithm and dynamic programming to solve the problem (2) (3) (6) were analyzed. Time complexity assessment was performed and problem solving results were compared.

GA is intended to solve problems of combinatorial optimization, that is optimization of structures determined by vectors, components of which acquire discrete values.

Since genetic algorithm uses some encoding of set of parameters instead parameters itself during search, it can be effectively used to solve discrete optimization problems.

If solutions of the problem of choosing optimal environmental protection means are to be presented as a decision tree, where on each level branching of sets of solutions is performed and estimation of approximation to the optimal solution is given, feasibility of branch and bound method is obvious.

Choosing optimal environmental protection means can be interpreted as a step-by-step process. On each step a category or set of items is chosen and eventually a certain item is chosen. This is the way problems are solved with dynamic programming.

Thus, to compare accuracy of calculations exact methods of solving discrete programming integer problem, such as branches and boundaries and dynamic programming.

5.1 Implementation of genetic algorithm for the problem of choosing optimal environmental protection means

To implement genetic algorithm the problem should be given in such form that its solution was presented as an array, contents of which are similar to a chromosome [10].

In our case set of individual environmental protection equipment is given as a vector with dimension n , where n is a quantity of individual environmental protection equipment. Vector elements are bits. Bit 1 corresponds to a chosen protective item that is a part of the solution, bit 0 means that the item was not chosen.

Several starting elements are designated in the array randomly, that is starting population is determined. Elements of this population are estimated using adaptation function, and as a result, each element gets certain adaptation value, that determines possibility of its survival. After that, selection of elements for the crossover is performed based on these values. Genetic operators are used on the element: crossover and mutation, thus creating next generation of elements. Genetic operators are used on the next generation again. This way, evolution process is simulated that goes on for several iterations (generation lifecycles), until stop criterion of the algorithm is met:

- A global or close to optimal solution is found;
- Number of generations designated for evolution is exhausted;
- Time given for evolution is over.
- Generalized structure of genetic algorithm can be presented as such [6]:
- Step 1. Starting population P_0 numbering n is initialized. In order to do that:
- Set current population number $t = 0$;
- Generate random chromosome set of n string encodings with fixed length L , where Hamming distance between any pair of encodings does not equal zero;
- Estimate each string of the chromosome set with adaptation function.

Step 2. Producing offspring with inherited parental genetic properties. In order to do that:

- Randomly choose from current population P_t two parents that make “wedding couple”, according to encoding crossover scheme;
- Generate for the chosen “wedding couple” with probability P_c one or several offspring encodings that inherit parental genetic properties with the crossover operation;
- Assess each offspring encoding with adaptation function;
- Repeat all step two operations until predetermined number N_c of “wedding couples” is processed.

Step 3. Creation of mutants with genetic properties different from parental. In order to do that:

- Randomly choose encoding that inherits genetic properties from one or both parents from set of parents and offspring;
- Generate with probability P_m mutant code with the mutation operation for chosen encoding, ensuring variability of parental genetic properties;
- Assess mutant encoding with adaptation function;
- Repeat all step three operations until predetermined number of mutants N_m is generated.

Step 4. Change current population P_t with new population P_{t+1} . In order to do that:

- Choose population P_{t+1} creation strategy;
- Build reproductive set of encodings that differ from each other by Hamming distance out of parents and offspring;
- Copy encodings that carry out population P_{t+1} creation strategy out of reproductive set with selection operation.

Step 5. Checking for condition of iterative cycle termination. Change the number of current generation $t = t + 1$ and repeat all operations of step 2 if genetic search ending condition is not met (for example evolution of population P_t is considered complete if it has exhausted its lifecycle, that is $t > T$).

5.2 Implementation of branch and bound method for the problem of choosing optimal environmental protection means

Branch and bound is based on the idea of successive partitioning of current possible solutions set into branching subsets [12]. On each step, these subsets are checked for optimal solution presence. To do that, target function value assessment is performed on a given subset and the result is compared with the current record. Record is the target function value for the best current solution. If target function value assessment on the

solutions subset is not less (or more) than the record this subset can be eliminated. Solution subset that is being checked can also be eliminated if at some point a solution was found that is better than target function assessment on this subset. If the target function value for the solution found is less than the previous record, the record value is changed to the found value of target function. When at some step all solution subsets can be eliminated, the record is the optimal solution of the problem. Otherwise, the most promising of the remaining subsets is chosen and undergoes partitioning. New subsets are checked again. Upon the completion of algorithm calculation, current record is optimal target function value and corresponding solution is the optimal problem solution [13].

Let's review branch and bound scheme that is used to solve the problem of choosing optimal environmental protection means [11].

Branching

The problem is partitioned into two sub problems on each algorithm step. Let there be a rule β , that matches any set $\bar{X} \subset X$ with finite number of subsets $X_j, j \in J$ such that $X_j \cap X_i = \bar{X}, \forall i, \forall j; X_j \cap X_i \neq \emptyset$. Partitioning of set \bar{X} is designated $\beta(\bar{X}) = \{X_j\}$. Let's designate $|\bar{X}|$ the cardinality of \bar{X} . Let rules $\beta(\bar{X})$ of set \bar{X} partitioning meet (7) and (8):

$$|\bar{X}| > |X_j|, \text{ if } |\bar{X}| > 1, \forall j \in J \quad (7)$$

$$\beta(\bar{X}) = \emptyset, \text{ if } |\bar{X}| = 1 \quad (8)$$

Subsets X_j , that are found during \bar{X} branching can be normalized by branching and this connection can be shown as a tree (V, U) of solution subsets, where V – set of vertices, U – set of edges. The root of the tree corresponds to the set X , and leaves are singleton sets. Condition (7) guarantees that any route from the root to a leaf contains no more than $|X|$ edges. Condition (8) attests that it is impossible to partition singleton sets.

For each specific problem, there are many ways to branch set of its solutions into a tree (V, U) . Considering the fact that all variables in problem (3), (6) of choosing optimal environmental protection means are Boolean, it is practical to use binary partitioning. For the problem under study, the partitioning means that for each j -th protective mean all possible solutions containing this mean are included in one set and possible solutions without this mean are included in another set.

Assessment procedure

For each of subsets X_j of possible solution set of the given problem an assessment $\gamma(X_j)$ of target function $f(x)$ that corresponds to (9) – (11) is given:

$$\gamma(X_j) \leq f(x), \forall x \in X_j, \text{ as a minimum target} \quad (9)$$

$$\gamma(X_j) = f(\tilde{x}), \text{ if } |X_j| = 1, X_j = \{\tilde{x}\} \quad (10)$$

$$\gamma(X_j) = +\infty, \text{ if } X_j = \emptyset, \text{ as a maximum target} \quad (11)$$

To calculate assessment $\gamma(X_j)$ of the target function $f(x)$ of the given problem another simple optimization problem can be solved that we shall call evaluative problem. Let there be problem (12):

$$f(x) \rightarrow \min, x \in X_j, \forall j \in J \quad (12)$$

For the problem (12) evaluative problem (13) is considered:

$$\varphi(x) \rightarrow \min, x \in \tilde{X}_j \supset X_j, \forall j \in J \quad (13)$$

Evaluative problem (13) has to meet the following conditions:

- If evaluative problem (13) has no possible solutions than the problem (12) has no possible solutions also;
- Target function value for the problem (12) solutions is not worse the target function value for the problem (13) solution.

For the given problem, target function (3) assessment is defined according to (14) and (15) [13]:

$$\gamma(X_j) = \gamma(\bar{X}) + c_j \quad (14)$$

$$\gamma(X_j) = \gamma(\bar{X}) \quad (15)$$

Expression (14) attests that assessment $\gamma(X_j)$ of subsets X_j of possible solutions that contains j -th environmental protection item is equal to assessment $\gamma(\bar{X})$ of branched set of solutions, increased by the cost of this item. Assessment value of the solutions set that does not contain the j -th protective item equals to assessment value of branched set (15).

Testing procedure

In the process of successive partitioning of solutions set those subsets, which do not contain possible solutions better than the record, are eliminated. Elimination is performed with a test that is based on calculating assessment values and comparing them with the record. Let the current record value be f^* . Let's make a test: if for some set X_j the expression $\gamma(X_j) \geq f^*$ is true then set X_j is eliminated.

The record

For the problem under study the following record notion is used: the best problem target function value that is achieved on the set of found possible solutions.

5.3 Implementation of dynamic programming for the problem of choosing optimal environmental protection means

Dynamic programming is based on Bellman's principle of optimality, according to which at any given step out of several possible solutions the one where gain at this step plus optimal total gain on all subsequent steps is maximal [14] [15].

This method is used for problems that fulfill following requirements:

- Optimization problem is interpreted as an n -stepped process of decision making;
- Target function of the problem equals the sum of each step's target functions;
- Choice of solution on the k -th step depend on the system state at current step and does not influence previous steps (no feedback);
- State S_k after k -th decision making step depends only on the previous state S_{k-1} and solutions x_k (no after-action);
- At each decision making step x_k depends on finite number of control variables and state S_k – on finite number of parameters.

In accordance with provisions of the given problem let's split protective items into sets, each of which contains mutually exclusive items. For example several protective suits or gas masks cannot be used simultaneously. Given task can be interpreted as a multistage decision making if protective items from each set are chosen (or not chosen) sequentially one by one.

Let the system state to be defined by $\langle j, y_j \rangle$, where j – index of the protective items set currently being processed, $y_j = (y_{1j}, y_{2j}, \dots, y_{mj})^T, j = \overline{1, n}$ is the vector, components of which define lessening of negative impact of i -th environmental factor $i = \overline{1, m}$ due to use of j -th protective item.

Given task can be made into a task of finding the shortest path in a directed acyclic network, where each layer represents choice of certain protective items set and each vertice is a choice (or its absence) of a certain protective item from this set. Recursive nature of defining optimality principle brings recurrent ratios. Let's review creation of recurrent ratio for our problem.

Let there be protective items chosen from a set $k = \overline{1, j}$, that lessen harmful factors impact by $y_j = (y_{1j}, y_{2j}, \dots, y_{ik}, \dots, y_{mj})^T, j = \overline{1, n}$, where y_{ik} defines lessening of harmful effects of i -th environmental factor $i = \overline{1, m}$ due to use of k -th protective item. The

problem requires choosing such protective items that guarantee human vital functions that is harmful factors impact has to be lessened by at least (16):

$$P = (f_1 - b_1, f_2 - b_2, \dots, f_m - b_m)^T \quad (16)$$

Then y_j can be defined as $0 \leq y_j \leq P$.

Let's denote $f_i(y_j)$ as the minimal cost of protective items from the set $k = \overline{1, j}$, that lessens impact of the i -th environmental factor by at least y_j . Let's consider that choice of protective item x_j from the j -th set is possible if uncompensated impact of harmful factors after this item's use can be lessened with protective items from the remaining sets. The condition of environmental factors impact compensation is (17):

$$y_{ij} - p_{ij}(x_j) \leq \sum_{k=1}^{j-1} \max(p_{ik}(x_k)), i = \overline{1, m}, \forall j \in J \quad (17)$$

where $p_{ij}(x_j)$ – degree of protection from i -th environmental factor impact that is provided with the choice of x_j -th protection item from the j -th set.

If x_j -th protective item is chosen from the j -th set, it lessens environmental factors impact by $p_j(x_j)$, then items from the remaining sets have to lessen environmental factors impact by $y_j - p_j(x_j)$. Then the minimal costs of protective items from sets $k = \overline{1, j}$, that lessen environmental factors impact by y_j , on condition that from the j -th set item x_j was chosen is defined (18):

$$c_j(x_j) + f_{j-1}(y_j - p_j(x_j)) = f_j(y_j) \quad (18)$$

Protection provided by choice of items from sets $k = \overline{1, j-1}$ by definition of $f_i(y_j)$ function is performed optimally thus, the sum (18) is conditionally minimal cost.

Let's minimize expression (3) with possible values of x_j , which we denote as x_j^v . According to (4) we get expressions (19) and (20):

$$x_j^v = x_j / \left(y_j - p_j(x_j) \leq \sum_{k=1}^{j-1} \max(p_{ik}(\cdot)), i = \overline{1, M} \right) \quad (19)$$

$$f_j(y_j) = \min_{x_j^v} \left\{ c_j(x_j) + f_{j-1}(y_j - p_j(x_j)) \right\} \quad (20)$$

Expression (20) is true with $j=1$, if $f_0(\cdot)=0$. The result is the value of $f_n(P)$, where P corresponds to (16).

6 Testing results

In this paper, the problem statement of choosing optimal environmental protection means was solved using genetic algorithm (GA), branches and boundaries method and dynamic programming.

The settings for GA were chosen as follows: maximum number of iterations – 5 lifecycles; probability of crossover 0.5; probability of mutation 0.2; population size 100 individuals; stop criterion – achieving maximum number of iterations (5 lifecycles); parental choice scheme – the best with random selection; mutation based on random change of one bit in the genotype (one protective item is added or removed); the crossover is standard. Runtime results are shown in Figure 1.

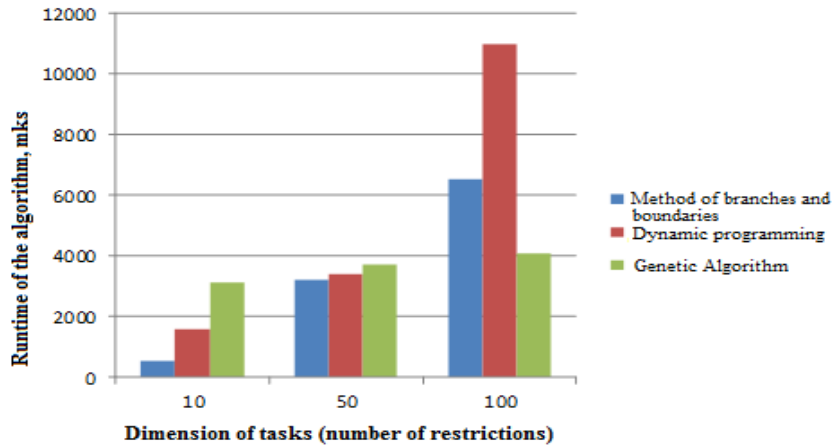


Fig. 1. Runtime results

Comparison of the algorithms runtime results showed that exact algorithms perform well in small-dimensional problems (10 constraints). Thus, the task execution time using the branch and bound method is 520 μ s, the dynamic programming method is 1580 μ s, and the genetic algorithm is 3120 μ s. In medium-sized problems (50 constraints), the algorithms show almost the same results in terms of speed: the task execution time by the branch and bound method is 3200 μ s, by dynamic programming 3400 μ s, and the genetic algorithm 3700 μ s. In large-scale problems, the 4100 μ s genetic algorithm performs well, while the branch and bound method requires 6540 μ s, and dynamic programming 11000 μ s. So, it is advisable to use the branch and bound method, as well as the dynamic programming method, for problems with the number of constraints up to 50, and the genetic algorithm in large-dimensional problems (> 50 constraints).

7 Conclusion

Authors have analyzed current state of population environmental awareness and protection from hazardous environmental factors impact, formalized the problem of choosing optimal personal environmental protection means. The problem was described in terms of Boolean programming. Methods of solving given task were reviewed and testing performed on tasks with low and high dimensionality. Further research prospects lie in inclusion of fuzzy logic elements due to imprecision of data regarding pollution parameters and protective gear availability or small data samples. The reviewed elements of algorithmic tools and software were implemented in one of real estate agencies in Kiev (Ukraine).

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