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Mathematical Modeling and Simulation of Systems

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Method for Searching of an Optimal Scenario of Impact in Cognitive Maps During Information Operations Recognition

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Abstract. In this paper, we consider cognitive maps as an additional tool for building a knowledge base of the DSS. Here we present the problem of choosing the optimal scenario of the impact between nodes in the cognitive maps based on of the introduced criteria for the optimality of the impact. Two criteria for the optimality of the impact, which are called the force of impact and the speed of implementation of the scenario, are considered. To obtain a unique solution of the problem, a multi-criterial assessment of the received scenarios using the Pareto principle was applied. Based on the criteria of a force of impact and the speed of implementation of the scenario, the choice of the optimal scenario of impact was justified. The results and advantages of the proposed approach in comparison with the Kosko model are presented. Also we calculate rank distribution of nodes according to the degree of their impact on each other to reveal key and the most influential components of the cognitive map that corresponds some subject domain.

Keywords: Cognitive map · Optimal scenario of impact · Pareto principle · Algorithm of accumulative impact · Force of impact · Rank distribution · Information operation recognition

1 Introduction

In today’s world, it is difficult to overestimate the impact of information on people. Recently, the number of information sources has increased significantly and, accordingly, their influence is also increased. Information operations [1] may be one of the negative manifestations of this effect.

During the recognition of information operations [1], decision support systems (DSS) are used to make recommendations. When building knowledge bases of DSSs it often encounters the problem of lack of knowledge for describing a subject domain, which is corresponded to an object of an informational operation. In this case, a cognitive map, which is built automatically based on the textual data that corresponding to the object of the information operation, can be an additional tool for

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building a knowledge base of the DSS. Such a cognitive map is a network of key terms that influence each other. Rank distribution of nodes according to the degree of their impact on each other makes it possible to reveal the key and the most influential components of the subject domain.

Rank distribution is one of the methods of ordering objects either physical or informational. In the case of certain numerical value can be assigned to each object from the collection, the ranking problems become formally trivial, since objects can be ranked by the value [2]. For example, the introduction of weight coefficients, characterizing the power of impact, turned out to be the main direction of development of the cognitive approach for analyzing a situation [3].

A cognitive map is a directed graph in which the edges (and sometimes the nodes) are characterized by weighted factors. A cognitive map, like any graph, is defined by the adjacency matrix W [4], comprised of elements w_{ij} – representing weight values of the edges connecting the corresponding nodes $u_1, u_2, \ldots, u_n$. The nodes of the cognitive map correspond to certain concepts, and edges are the casual (causal-consequential) connections between the corresponding concepts. Weight values are also used to analyze well-structured situations, where the value of the impact in different paths between the two nodes is summed up. However, the difficulty is that, firstly, it is not always clear how to determine such a numerical value, and secondly, such numerical values may be many and not always clear criterion for choosing one of them. In other words, the most complex, poorly formalized part of the problem of ranking is the choice of criterion for which the object is attributed to numerical values (formalization of objects).

In this paper, the value of impact is calculated as follows:

1. In order to calculate the force of impact of one node on another (the impact of u_i on u_j), it is necessary to find all the simple paths that exist between these two nodes. To find all the simple paths between a pair of nodes (u_i, u_j), the algorithm presented in work [5] is used. Each simple path represents a certain scenario of impact $(u_i, u_j)_k$.
2. Having introduced the criteria, the scenario of impact can be considered optimal for: the force and speed of the implementation of the scenario.

The purpose of this paper is to justify a choice the optimal scenario of impact according to the introduced criteria.

2 Methods and Models for Nodes Ranking

In this section a short survey of other methods that can be used for cognitive maps for ranking of nodes according to the degree of their impact on each other makes is presented.

In the impulse method [6], each node in a cognitive map is assigned a value $v_i(t)$ at each moment of discrete time $t = 0, 1, 2, \ldots$. The weight of an edge is positive $(w_{ij} > 0)$ if an increase in the weight of node u_i causes an increase in the weight of node u_j. Conversely, the weight of an edge has a negative value $(w_{ij} < 0)$ if decreasing the weight of node u_i results in a decrease in the weight of node u_j. The weight $w_{ij} = 0$ if nodes u_i and u_j are not related.

The problem is to define the final value of node $v_i(t \to \infty)$, or in some cases the rate of change over time. To define $v_i(t)$ it is necessary to define how the node's value changes depending on its initial value, values of neighboring nodes, and weights of relations.

The basic procedure of cognitive mapping analysis is determined by the rule of the impulse process changing which is described in detail in [6]. According to this rule, the value of each concept $v_i(t)$ changes at the moment of discrete time t (t = 0, 1, 2,….) by the following equation:

$$v_i(t+1) = v_i(t) + \sum_{j=1}^{n} w_{ij} p_j(t), t = 0, 1, 2, \ldots. \tag{1}$$

where n is the number of nodes in the graph.

An impulse is defined by the following equation:

$$p_j(t) = v_j(t) - v_j(t-1), t > 0. \tag{2}$$

While investigating cognitive maps, values $v_i(0)$, which correspond to the concepts of the directed graph, and the pulse values $p_i(0)$ are defined at the initial moment of time t = 0.

In the Kosko model [7, 8] an influence value is calculated as follows: the indirect influence (i.e., the indirect effect) of action I_p of vertex i on vertex j through path P that connects vertex i to vertex j is defined as $I_p = \min_{(k,l) \in E(P)} w_{kl}$, where $E(P)$ is a set of edges along path P and w_{kl} is the weight of edge (k, l) of path P, the value of which is defined in terms of the linguistic variables.

The general influence $Inf_{km}(i,j)$ of vertex i on vertex j is defined as follows: $Inf_{km}(i,j) = \max_{p(i,j)} I_p$, where max is the maximum value along all possible paths from vertex i to vertex j. Thus, I_p defines the weakest link in path P, and $Inf_{km}(i,j)$ defines the strongest influence among the indirect influences I_p.

3 Criteria of Optimality of Impact

Considering each possible simple path from node u_i to the node u_j of cognitive map as a certain scenario of impact $(u_i, u_j)_k$, it is necessity to determine criteria for choosing one of them.

The paper presents two criteria for optimality of impact C_1 and C_2, which are called the force of impact and speed of implementation of the scenario respectively.

The force of impact of node u_i on node u_j is calculated for every path while considering the weights of the edges. The impulse from node u_i is distributed along the path in the direction from u_i to u_j according to rules (a)–(d) [5]:

(a) $u_i \xrightarrow{+} u_k \xrightarrow{-} u_j$

If node u_i has a positive impact on node u_k and node u_k has a negative impact on node u_j, then node u_i is said to increase the negative impact of u_k on u_j. As a result, node u_i is said to have a negative impact on u_j.

(b) $u_i \xrightarrow{-} u_k \xrightarrow{-} u_j$

If node u_i decreases the negative impact of node u_k on u_j, then node u_i is said to have a positive impact on u_j.

(c) $u_i \xrightarrow{+} u_k \xrightarrow{+} u_j$

In this case, u_i has a positive impact on u_j, which increases the positive impact of node u_k on u_j.

(d) $u_i \xrightarrow{-} u_k \xrightarrow{+} u_j$

In this case, node u_i has a negative impact on node u_k and u_k has a positive impact on u_j. In other words, node u_i decreases the positive impact of u_k on u_j. Thus, node u_i has a negative impact on u_j.

The full impact z_{ij} on the node u_j, which is accumulated from the node u_i, is the sum of the partial impacts calculated as subtract between $z_{ij}^k - \tilde{z}_{ij}^k$ in all simple paths from node u_i to node u_j (following to the algorithm for calculating of a mutual impact between nodes in weighted graphs – the algorithm of an accumulative impact, which is presented in [5]) where

$$z_{ij}^k(t+1) = \left(1 + \operatorname{sign}\left(z_{ij}^k(t)\right) * \alpha\left(\left|\frac{z_{ij}^k(t)}{\mu}\right|\right)\right) * w\left(q_t^k, q_{t+1}^k\right) \tag{3}$$

$$\tilde{z}_{ij}^k(r+1) = \left(1 + \operatorname{sign}\left(\tilde{z}_{ij}^k(r)\right) * \alpha\left(\left|\frac{\tilde{z}_{ij}^k(r)}{\mu}\right|\right)\right) * w\left(q_r^k, q_{r+1}^k\right) \tag{4}$$

where sign is a signum function;

q_t^k – the sequence of nodes included in the k-th path ($q_0 = u_i$, $q_{m-1} = u_j$);

$t = 0, 1,\ldots,m-2$, a $r = 1,\ldots,m-2$, (m is the number of nodes included to the k-th path).

Here, the initial conditions are: $z_{ij}^k(0) = 0, \tilde{z}_{ij}^k(1) = 0$.

$$\mu = \max\left|w_{ij}\right|, \tag{5}$$

where $i = 0, 1, \ldots, n$, $j = 0, 1, \ldots, n$ (n is the dimension of the cognitive map).

The impact of a node u_j on a node u_j is called "the strongest", if the partial impact on the final node is characterized by the greatest of absolute magnitude of an impact among all of the partial impacts on all other simple paths between two nodes u_j and u_j.

The impact of the node u_j on node u_j is considered to be "the fastest in realization", if it is carried out in the shortest path. The speed of the implementation of the k-th scenario is determined by the number of edges ($m-1$) connecting the nodes u_j and u_j in k-th path (where m is the number of nodes included in the k-th path).

The introduced criteria of C_1 and C_2 are almost equivalent in terms of priority, thereby if one get several different optimal scenarios $(u_i, u_j)_k$ of the impact of the node, one cannot just select neither of them. Therefore, the fundamental complexity of choice in multi-criteria problems consists in impossibility of determining the optimal scenario a priori. So, there is a need to compare alternatives to all criteria.

Let us consider X as a set of possible scenarios (alternatives) $(u_i, u_j)_k$ of the impact of the node u_i on u_j. The minimum number of elements included in the set X is two (to be able to make a choice). There is no limit on the number of possible scenarios: the number of elements of the set can be both finite and infinite. It is worth noting that sometimes a choice of not one, but an entire set of decisions is made, which is a subset of a set of possible solutions X. In this paper, it is necessary to justify the choice of the optimal scenario of impact according to the introduced criteria C_1 and C_2. Then $C(X)$ is a set of selected scenario. It is a solution of the problem of choice and it can be any subset of the set of possible scenarios X. Thus, solving the problem of choice means to find a subset of $C(X)$, $C(X) \subset X$.

In the case where a plurality of selected scenarios does not contain any element, the choice does not occur, due to the fact that no solution has been selected. That is, in order to make the choice, it is necessary that the set $C(X)$ contains at least one element.

There are various methods for solving multi-criteria problem [9]. In order to obtain a unified solution to the problem posed in this paper, a multi-criteria assessment of the scenarios obtained according to the Pareto principle [10–12] is used.

Pareto's approach is as follows: the alternative is "the best" than the alternative for Pareto $(x \succ y)$, if alternative x alternatives are rated "no worse" than alternatives y, and at least one alternative x is "the best" than alternatives y:

$$\forall_i \, C_i(x) \geq C_i(y) \text{ and } \exists_j : C_j(x) > C_j(y) \tag{6}$$

where $C(X)$ is a function of choice ($C(X) \subset X$).

The resulting set of solutions is called pareto-optimal.

4 Method for Searching of an Optimal Scenario of Impact

Let us set of possible vectors X consist of a finite number of elements N and has the form $X = \{x^{(1)}, x^{(2)}, \ldots, x^{(N)}\}$.

In order to construct it on the basis of the definition of the Pareto set, it is necessary to compare each vector $x^{(i)} \in X$ with any other vector $x^{(j)} \in X$. Thereby, a step-by-step comparison of scenarios (corresponding columns of the table) based on the principle of "no less" ("no more") according to all criteria is performed. Namely: if the i-th scenario is larger (at minimization) or smaller (at maximization) of j-th scenario by at least one criterion, then this scenario is no longer taken into account. But if at least one i-th scenario criterion is less (at minimization) or larger (at maximization) for j-th scenario, with one or more other criteria, it is greater (at minimization) or smaller (at maximization), then both scenarios are taken into account.

It must be pointed out that it is convenient to use a table whose rows are criteria C_1 and C_2 (a force of impact and ease of implementation of the scenario, respectively), and the columns are the number of a scenario $(u_i, u_j)_k$ (the numbers of simple paths connecting the nodes u_i and u_j) for comparison alternatives.

Thus, columns of a table form a set of possible vectors (possible scenarios), which consist of two elements - the values of the criteria. The result of a staged comparison is the set $C(X)$ of such non-extracted vectors forms the Pareto set. But often this is the case, and as already mentioned above, the Pareto set may contain more than one element. These are scenarios that cannot be compared according to the Pareto principle. In the general case, when the Pareto set contains more than one element, in order to determine the optimal scenario of impact in this paper, the following algorithm is proposed:

(a) Firstly, the least common multiple (LCM) of the criterion C_2 for all values of the Pareto set is determined. Considering C_2 as time the corresponding scenario is implemented for, then the LCM of all values is the least time for which the integer number of each of the scenarios included in the Pareto set is realized. Thereby, at the same time $LCM(c_2^{(1)}, \ldots, c_2^{(d)})$, the number of realizations of the various scenarios included in the Pareto set are different accordingly $\{a^{(1)}, a^{(2)}, \ldots, a^{(d)}\}$:

$$a^{(k)} = \frac{LCM(c_2^{(1)}, \ldots, c_2^{(d)})}{c_2^{(k)}} \tag{7}$$

where $c_2^{(k)}$ – value of the criterion C_2 for k-th scenario;
d – the number of elements included in the Pareto set.

(b) Next, for each of the scenarios included in the Pareto set, the values of their assessments by the criterion C_1 $\left\{c_1^{(1)}, c_1^{(2)}, \ldots, c_1^{(d)}\right\}$ are multiplied by the corresponding value $\{a^{(1)}, a^{(2)}, \ldots, a^{(d)}\}$. That is, it determines what will be the overall impact of the node u_i on node u_j the time $LCM(c_2^{(1)}, \ldots, c_2^{(d)})$ of the k-th scenario.

(c) In order to determine the optimal scenario of impact, it is necessary to find the highest value of the multiplication $\mathrm{c}_1^{(\mathrm{k})} \cdot \mathrm{a}^{(\mathrm{k})}$ defined in step (b):

$$\max_k = c_1^{(k)} \cdot a^{(k)} \tag{8}$$

where $k = 1, .., d$.

That is, the number k to which the largest multiplication $c_1^{(k)} \cdot a^{(k)}$ corresponds is the number of the optimal scenarios of impact. As a result of the justification of the choice of the optimal criteria C_1 and C_2 the impact scenario for each pair of nodes (u_i, u_j) of a weighted graph, we can construct a matrix Z which consists of elements z_{ij} and a matrix T which consists of elements t_{ij}.

Definition 1: The full impact z_{ij} is the partial impact of the node u_i on the node u_j, which is accumulated in accordance with the optimal scenario of impact (i.e., the value of the criterion C_1 of the optimal scenario of impact). If u_j is unavailable from node u_i, then $z_{ij} = 0$.

Definition 2: The full time t_{ij} is the time it takes to implement the optimal scenario of impact node u_i on node u_j (i.e., the value of the criterion C_2 of the optimal scenario of impact). If u_j is unreachable from the node u_i, then $t_{ij} = 0$.

In order to determine what the impact of each of the nodes at $t \to \infty$, must be fulfilled as follows. Firstly z_{ij}^1 needed to be defined z_{ij}^1 - the impact of each node at $t = 1$. Taking into account the time required to implement each of the scenarios for the impact matrix Z by dividing each of its non-zero elements z_{ij} $\left(z_{ij} \neq 0\right)$ into the corresponding element t_{ij} of the matrix T, a matrix Z_1 is obtained, the elements of which are:

$$z_{ij}^1 = \begin{cases} \frac{z_{ij}}{t_{ij}}, \; z_{ij} \neq 0 \\ 0, \; z_{ij} = 0 \end{cases}. \tag{9}$$

Next, the impact of each node in time t is calculated as $z_{ij}^{t+1} = z_{ij}^t + z_{ij}^1$.
At each step of $t = 2, 3, 4\ldots$, the process of normalization is carried out:

$$z_{ij}^t = \frac{z_{ij}^t}{\sum\limits_{k=1}^{n} \sum\limits_{l=1}^{n} z_{kl}^t}. \tag{10}$$

5 Example

The work [12] considered the weighted directed graph shown in Fig. 1.

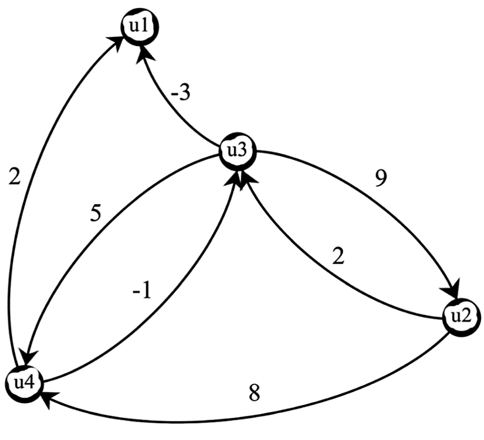

Fig. 1. Weighted directed graph.

The weighted directed graph, presented in Fig. 1, corresponded to cognitive map is defined by the adjacency matrix:

$$W = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 8 \\ -3 & 9 & 0 & 5 \\ 2 & 0 & -1 & 0 \end{pmatrix} \tag{11}$$

Table 1 demonstrates an example of assessment of impact scenario of nodes u_3 on nodes u_4 by criteria C_1 and C_2:

Table 1. Example of assessment of impact scenario of nodes

$(u_3, u_4)_k$	Simple path from u_1 to u_4	C_1	C_2
1	$u_3 \xrightarrow{5} u_4$	6.92	2
2	$u_3 \xrightarrow{9} u_2 \xrightarrow{8} u_4$	5	1

Table 2 shows the Pareto table to find the optimal criteria C_1 and C_2 scenario of the node u_3 impact on node u_4 for the cognitive map, which is shown in Fig. 1.

Table 2. Pareto table to find the optimal criteria

$(u_3, u_4)_k$	1	2
C_1	6.92	5
C_2	2	1

In this case, the Pareto set consists of two non-comparable vectors (two scenarios 1 and 2), among which it is impossible to determine uniquely optimal by criteria C_1 and C_2 (scenario 1 is the optimal by criterion C_1, and scenario 2 is by C_2 one). Therefore, for the final solution of the problem of choosing the optimal scenario of impact, it is necessary to determine the alternative to the optimal solution for a particular practical problem.

According to the method for searching of an optimal scenario of impact, which is proposed in this paper, when the Pareto set contains more than one element, it is first necessary to find *LCM* of values of the criterion C_2 values for all elements of the Pareto set. For the Pareto set constructed from the set of alternatives presented in Table 2, the least time for which the integer number of each of the scenarios included in this Pareto set is equal:

$$LCM(2, 1) = 2.$$

The number of implementations of the first and second scenarios will be equal respectively

$$a^{(1)} = \frac{LCM(2,1)}{2} = \frac{2}{2} = 1,$$

$$a^{(2)} = \frac{LCM(2,1)}{1} = 2.$$

Over time equal to $LCM(2,1) = 2$, the overall impact of the node u_3 on node u_4 the 1st scenario $(u_3, u_4)_1$ is:

$$c_1^{(1)} \cdot a^{(1)} = 6.92 \cdot 1 = 6.92$$

In the 2nd scenario

$$c_1^{(2)} \cdot a^{(2)} = 5 \cdot 2 = 10.$$

$$\max(\mathrm{c}_1^{(1)} \cdot \mathrm{a}^{(1)}, \mathrm{c}_1^{(2)} \cdot \mathrm{a}^{(2)}) = \max(6.92, 10) = 10$$

Therefore, for this example (Table 2), scenario number 2 $(u_3, u_4)_2$, in accordance with the proposed method, is optimal.

The Pareto table for other pairs of nodes (u_i, u_j) $(i, j = 1, 2, 3, 4)$ with more than one scenario of impact is given in Table 3.

Table 3. Pareto table for other pairs of nodes

$(u_2, u_1)_k$	1	2	3	4
C_1	-1.08	0.41	1.66	0.22
C_2	2	3	2	3
$(u_2, u_3)_k$	1	2		
C_1	2	-0.83		
C_2	1	2		
$(u_2, u_4)_k$	1	2		
C_1	8	1.79		
C_2	1	2		
$(u_3, u_1)_k$	1	2	3	
C_1	-3	0.27	1.34	
C_2	1	3	2	
$(u_4, u_1)_k$	1	2		
C_1	0.59	2		
C_2	2	1		

For all possible scenarios presented in Table 3 for pairs (u_2, u_1), the Pareto set will consist of one element $(u_2, u_1)_3$ - from scenario 3. For a pair (u_2, u_3), the Pareto set consists of the element $(u_2, u_3)_1$ - scenario 1. For -(u_2, u_4) – $(u_2, u_4)_1$, for (u_3, u_1) – $(u_3, u_1)_1$- and for the pair - (u_4, u_1) – $(u_4, u_1)_2$.

After choosing the best scenario of impact by the introduced criteria C_1 and C_2 for each pair of nodes (u_i, u_j) $(i, j = 1, 2, 3, 4)$ of the weighted directed graph represented in Fig. 1, we can construct an influence matrix Z which consists of elements z_{ij} (see *Definition 1*) and a matrix T which consists of elements (see *Definition 2*):

$$Z = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 1.66 & 0 & 2 & 8 \\ -3 & 9 & 0 & 5 \\ 2 & -1.79 & -1 & 0 \end{pmatrix}$$

$$T = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 2 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 2 & 1 & 0 \end{pmatrix}$$

Taking into account the process of normalization at each step with $t \to \infty$, the impact of each of the nodes to other for the influence matrix Z is represented in the form of the influence matrix:

$$Z_t = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0.038 & 0 & 0.091 & 0.365 \\ -0.137 & 0.41 & 0 & 0.228 \\ 0.091 & -0.04 & -0.046 & 0 \end{pmatrix} \quad (12)$$

The full impact Inf_{pm} of each node for the influence matrix Z_t is determined by the rule:

$$Inf_{pm}^i = \sum_{j=1}^{n} \left| z_{ij}^t \right| \quad (13)$$

where n is the number of nodes of a cognitive map; pm is a short for “the Pareto method”.

The full impact Inf_{pm} of each node and its rank distribution for the influence matrix (12), according to (13), are presented in Table 4.

Comparing the results of using the method for searching of an optimal scenario of impact with the results provided by the Kosko model for the adjacency matrix (11), it can be notice (Table 5) that the rank distribution of nodes by degree of impact, as a result of applying of each method, is remained the same.

In Table 5 km is a short for “the Kosko model”.

Table 4. Rank distribution of nodes

Node (№)	Inf_{pm}
3	0.775
2	0.494
4	0.178
1	0

Table 5. Rank distribution of nodes according to Kosko model and proposed method

Node (#)	Inf_{km}	Node (#)	Inf_{pm}
3	20	3	0.775
2	12	2	0.494
4	4	4	0.178
1	0	1	0

6 Conclusions

Consequently, the multi-criteria choice problem was considered in the paper. Based on the criteria of a force of impact and speed of the implementation of the scenario, the choice of the optimal scenario of impact was justified. As the result, scenario of impact of node 3 on node 4, which has the number 2, in accordance with the proposed method, is optimal for the considered example. Also the choice of the optimal scenario of impact was justified for other pairs of nodes in the presented cognitive map. A comparison of the results of applying the method for searching of an optimal scenario of impact according to the introduced criteria, with the results which are obtained with applying the Kosko model was fulfilled. It was established that the rank distribution of nodes by degree of impact, as a result of applying of each method, is remained the same.

Using the results of these calculation, decision makers can develop strategic and tactical steps to counter-act the information operation, evaluate the operation's efficiency.

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