Complex Analytical Method for Self-organizing Multiagent Systems

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Abstract. *The complex analytical method (cro. kompleksna analitička metoda - KAM), a method for organizational design is put into a new perspective of designing multi-agent communities. The KAM method uses a numerical algorithm to deal with organizational exertion and provides a decision criteria for optimizing the overall organization of a business system. The main aim of the paper is to adapt KAM to multi-agent system (MAS) organizations. It is shown that when KAM is applied to MAS communities a number of drawbacks (namely human factor faults) can be eliminated. In the end possible solutions to a decentralized application of KAM in MAS is discussed.*

Keywords. KAM; complex analytical method; multi-agent systems; community design; organizational design

1 Introduction

The complex analytical method (KAM) is an organizational design and business process modeling method introduced by Dešić in [2] and later extended in [3, 4]. What makes it interesting and visionary for the time of publishing is that it takes into account that an organization is an open non-linear cybernetic system of business processes [4, p. 17]. KAM is used both for auditing the state of the current as well as the design of a new organization [1, p. 145]. The method has been well studied on a particularly large number of case studies in ex-Yugoslav companies [4, p. 38], and is still in use today [1, pp. 145-153.].

The application of organization theory research to multi-agent systems (MAS) is not a new idea. There have been a number of studies which deal with various aspects of using organizational structures in MAS. For example [7] propose a number of organizational architectures for MAS from organization theory and strategic alliance literature. They model the organizational styles using the i^* framework [10] which has basic concepts like actors, goals, and actor dependencies. In [5] the drawbacks of agent centered MAS are analyzed and a minimal model of organization centered MAS based on three categories: agents, groups and roles is proposed. Later on [6] introduced a multi-modal logic formalism for modeling organizational structure in MAS and argued that organizational structures exhibit at least three relevant dimensions: power, delegation and control.

Neither of these studies however, deal with organizational methods that can cope with organizational changes and provide an optimal organization for a current situation. KAM on the other hand provides just this, a method that allows analysis of the current organization and proposes a new and optimized organizational model. Thus the main aim of this study will be to adapt KAM to MAS organizations.

The rest of this article is organized as follows: in section 2 an outline of the KAM method is given. In section 3 we establish our critique on KAM in order to modernize the approach and give guidelines for further development of the method. Afterwards we adapt the approach to MAS in section 4. Section 5 discusses the possibility to apply KAM in a distributed environment. In the ending section 6 we draw our conclusions.

2 KAM

KAM as its name states is a complex method which is why only a short outline of it will be presented here. For a profound study of the method please refer to [2, 3, 4]. KAM uses a number of steps to transform the existing organization into an optimized form by eliminating organizational exertion. Organizational exertion is a numerical value obtained by a number of computations based on an initial matrix of organizational elements (mostly business activities), their mutual correspondence across organizational units, and a number of factors and weights. The steps according to [1, p. 145] are:

1. Calculation of indisposable organizational potentials and their weights

2. Determination of organizational unit engagement using a functional and/or phase criteria

3. Analysis the activity structure of organizational units
4. Plotting the information network that ensures efficiency of the business processes
5. Examination of organizational exertions using various criteria
6. Creating a new organizational diagram (organigram)

Most of this steps can be modeled using well founded mathematical algorithms, except for the audit step which includes grading of various organizational factors and determining their weight by an (as much as possible) objective professional [4, p. 69]. This part is probably the most important drawback of the method since it is vulnerable to human error. The audit step, however can be eliminated in a MAS environment, since even if it can provide valuable insights into the functioning of a business organization, it is irrelevant for the optimization of the overall organizational structure. Herein we will concentrate on steps 1, 3, 5 and 6 since they are directly applicable to a MAS organization.

Table 1 gives a short outline of the first part of step 1 which is constructing the organizational elements frequency table.

Each row lists an organizational element, which are mostly various activities executed by a particular organization unit, but can also refer to other factors like the quality of some activity. Herein we will observe organizational elements as activities of an organizational unit. Organizational elements are sorted by organizational unit to which they belong (for example elements 1, 2 and 3 belong to O_1, 4, 5 ... belong to O_2, ..., 160 belongs to O_{11}). Then for each organizational element we determine if it interacts with the appropriate organizational unit. If so, we add a + sign in the adequate cell, if not a – (for example, element 1 interacts with organizational units 1, 5, 8, 10 and 11. The last column F is the frequency which is the row sum of + signs.

After the table has been constructed the following factors and wights are introduced:

Q - quantity of production (expressed in products or services annually)

C - business costs (expressed in money annually)

$k_q = Q_{opt}/Q_c$ - critical factor of organizational exertion needed to achieve optimal revenue (optimal quantity through critical quantity)

$k_c = Q_{min}/Q_c$ - critical factor or organizational exertion needed to achieve minimal revenue (minimal quantity through critical quantity)

k_s - critical factor describing the complexity of an organizational element

Thus organizational exertion is defined as the needed efforts of an organization (or organizational unit) to achieve a given quantity of goods or services.

To calculate the indisposable organizational potentials and their weights a table similar to table 2 in which we assume that:

$$\begin{aligned} k_q &= 1.65 \\ k_c &= 1.08 \\ k_s &= \text{between } 1.00 \text{ and } 1.15 \end{aligned}$$

The first column of the table lists the individual organizational elements. Column F list the individual frequency of each organizational element. Column $Q-C$ determines if the organizational element under consideration has a considerable impact on production quantity and/or business costs. For example element 1. has impact on both Q and C, whilst element 5. has only impact on C. This column also determines the value in columns k_q and k_c - when an element hasn't impact on Q or C than the appropriate critical factor is set to 1.00. Column k_s lists the critical factor of complexity of each individual element. The weight column is the product $W = F \times k_q \times k_c \times k_s$ and represents the actual weight of the element under consideration. The last column is the sum of all elements in the organizational unit, e.g. $W_{O_i} = \sum_j^{n_i} W_j$, where by O_i is the organizational unit under consideration and n_i is the number of elements in the unit.

The narrower indisposable organizational potentials of a given organizational unit (tasks or activities the organizational unit provides for it self) are calculated as the sum of products of frequencies and weights of the given element, e.g. $NIOP_{O_i} = \sum_j^{n_i} F_j \times W_j$ (each interaction of a given element takes an equal part of the weight). For example the indisposable organizational potentials for organizational unit O_1 would be $NIOP_{O_1} = 5 \times 10.25 + 5 \times 9.49 + 3 \times 3.45 = 109.05$. This is the indisposable organizational potential needed to ensure effective functioning of organizational unit O_1. The broader indisposable organizational potentials of an organizational unit (tasks or activities provided for other units) equals the vertical sum of all weights for the given unit minus the weights of its own organizational elements, e.g. $OIOP_{O_i} = \sum_k^a W_k$ whereby a is the total number of organizational elements.

In this way we can calculate the indisposable organizational potentials for each organizational unit which results in a table similar to table 2.

Our next step is analyzing the engagement of each organizational unit's indisposable potentials in the overall organization of the system. This is done using a table similar to table 2.

Table 1: Frequency of organizational elements (adapted partially from [4, p. 59]

Elem. #	Organizational units											
	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	O_{11}	F
1.	+	–	–	–	+	–	–	+	–	+	+	5
2.	+	–	+	–	+	–	–	+	–	–	+	5
3.	+	–	–	–	–	–	–	+	–	–	+	3
4.	+	+	+	+	+	+	+	+	+	+	+	11
5.	–	+	–	–	–	–	–	+	–	–	+	3
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
160.	+	+	+	+	+	+	+	+	+	+	+	11

Table 2: Indisposable organizational potentials' weights

Elem. #	F	$Q-C$	k_q	k_c	k_s	Weight	
1.	5	$Q-C$	1.65	1.08	1.15	10.25	
2.	5	$Q--$	1.65	1.00	1.15	9.49	
3.	3	$---$	1.00	1.00	1.15	3.45	23.18
4.	11	$Q-C$	1.65	1.08	1.10	21.56	
5.	3	$--C$	1.00	1.08	1.05	3.40	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
160.	11	$Q-C$	1.65	1.08	1.15	22.54	127.81
							624.68

Table 4: Analysis of the indisposable organizational potentials' structure

Elem. #	Organizational units											
	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	O_{11}	IOP
1.	*10.25*	–	–	–	10.25	–	–	10.25	–	10.25	10.25	51.25
2.	*9.49*	–	9.49	–	9.49	–	–	9.49	–	–	9.49	47.45
3.	*3.45*	–	–	–	–	–	–	3.45	–	–	3.45	10.35
Σ	23.19	0.00	9.49	0.00	19.74	0.00	0.00	23.19	0.00	10.25	23.19	109.05
4.	21.56	*21.56*	21.56	21.56	21.56	21.56	21.56	21.56	21.56	21.56	21.56	237.16
5.	–	*3.40*	–	–	–	–	–	3.40	–	–	3.40	10.20
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
160.	22.54	22.54	22.54	22.54	22.54	22.54	22.54	22.54	22.54	22.54	*22.54*	247.94
Σ	102.45	56.60	96.59	123.48	79.51	82.09	65.94	93.38	149.32	110.74	75.89	1035.99

Table 3: Narrower indisposable organizational potentials for each organizational unit

Units	O_1	...	O_{11}	$\sum$
$NIOP$	109.05	...	1035.99	6486.98

Each row of the table shows the distribution of IOP for a given organizational element over the other organizational units. The last column shows the $NIOP$ for a given element, whilst the intermediate sums show the $OIOP$ for each organizational unit. This table is the foundation for plotting an information network between organizational units whereby each IOP value represents the intensity of communication of a given organizational element with the particular organizational unit, whilst each $BIOP$ value represents the intensity of communication between the two analyzed organizational units.

For optimizing the organizational structure we can summarize table 2 in the following organigram (figure 1).

Each element represents an organizational unit. The position of the organizational units is arbitrary but it is usual to put the management organizational unit on top of the organigram. Each organizational unit has its $BIOP$ (top), $NIOP$ (left) and $BIOP - NIOP$ inscribed. This organigram together with the previous tables can be used to analyze the organizational exertion using seven criteria [4, pp. 107–112]:

1. Internal exertion of organizational units (represented by $NIOP$) which constitutes the exertion along a professional criteria.

2. Internal exertion of activities which enable the ef-

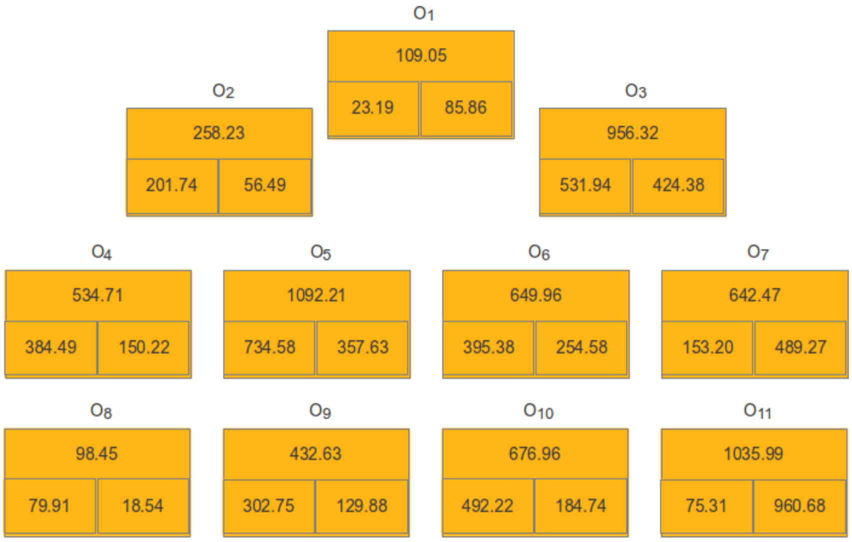

Figure 1: Original organigram of the analyzed organization

ficient functioning of other organizational units ($OIOP$).

3. Total organizational exertion of an organizational unit ($BIOP$).

4. Total exertion of the organization along a functional criteria (structure of IOP in specialized activities).

5. Mutual exertion between organizational units depending on the number of information exchanged.

6. Mutual exertion between organizational units depending on the weight of information exchanged.

7. Degree of mutual dependency of organizational units (ratio between numbers and weights of information provided and needed).

The organizational units are ordered upon each criteria in descending order whereby the first few organizational units are denoted as possible bottlenecks if the difference is significant enough. There is no reference in [4] to what significant exactly means, however. The possible bottlenecks of the organization are identified using a table similar to table 5.[1]

From this table one can easily deduce that organizational units O_{11}, O_3, O_5 and possibly O_7 represent the bottlenecks of the organization. These bottlenecks should be analyzed and adequate measures should be taken to avoid them, but Dešić gives us only a vague reference on the interpretation of this bottlenecks [4, pp. 111–112], and only the third criteria is analyzed in detail an measures are given to optimize the structure [4, pp. 112–120].

[1] In this table we always took the first three organizational units regardless of significance which is not a good solution. It would be better to define a criteria based on a statistical measure of significance. Our approach also disables the informational value of the last column which gives valuable insights about the overall organization (e.g. which criteria found the most bottlenecks).

In order to optimize the structure of the organization the exertions have to be adjusted and arranged equally among the organizational units. To do so, Dešić explains [4, pp. 115–120] the individual exertions of each organizational unit have to be allocated equally among its organizational subunits. From our perspective organizational units can be whole organizations, divisions, departments, groups or individual employees as it is explained in [9, p. 121, pp. 151–154] which would makes this approach applicable to any level of organization except for the lowest (individual) level. Suppose that our organizational units are divided into subunits as follows:

O_1 - SU_1

O_2 - SU_2, SU_3

O_3 - SU_4, SU_5, SU_6

O_4 - SU_7, SU_8

O_5 - $SU_9, SU_{10}, SU_{11}, SU_{12}$

O_6 - $SU_{13}, SU_{14}, SU_{15}$

O_7 - $SU_{16}, SU_{17}, SU_{18}$

O_8 - SU_{19}

O_9 - $SU_{20}, SU_{21}, SU_{22}$

O_{10} - $SU_{23}, SU_{24}, SU_{25}$

O_{11} - $SU_{26}, SU_{27}, SU_{28}, SU_{29}$

Under the presumption that the indisposable organizational potentials of each organizational unit is

Table 5: Organizational bottlenecks

Criteria	Organizational units											
	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	O_{11}	Σ
1.	−	−	+	−	+	−	−	−	−	+	−	3
2.	−	−	+	−	−	−	+	−	−	−	+	3
3.	−	−	+	−	+	−	−	−	−	−	+	3
4.	−	−	+	−	−	−	−	−	−	+	+	3
5.	−	−	−	−	−	+	+	−	−	−	+	3
6.	−	−	−	−	+	−	+	−	−	−	+	3
7.	+	−	−	−	+	−	−	+	−	−	−	3
Σ	1	0	4	0	4	1	3	1	0	2	5	

Table 6: Organizational exertions among subunits of particular organizational units

O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	O_{11}
109.05	129.12	318.77	267.36	273.05	216.65	214.16	98.45	144.21	225.65	259.00

equally divided among its subunits,[2] the total exertions of the subunits of each organizational units would be as summarized in table 6.

The significant differences between the particular exertions have to be balanced, the ideal being that all organizational subunits have the same exertion. In principle, there are two ways of doing that: (1) by splitting an organizational unit into two or more units, and (2) by merging organizational units. Again, Dešić doesn't provide us with a sound criterion on how to do this, but escapes with using descriptive and heuristic approaches like "it is usual that such organizational unit is divided into such and such organizational units".[3] According to his approach some organizational units are merged or split and then the organizational exertions are recalculated for further analysis. For every iteration a new organigram is constructed until no further optimizations are possible. The last organigram is the final organizational structure of the organization.

3 A Critique on KAM

Besides the aforementioned notes about KAM, it is obvious that KAM is constrained on individual (more or less) specialized, functionally organized, hierarchical organizations. This observation is important since modern organizations, and likewise MAS organizations, do not have to be such. In order to generalize the approach we have to move from the traditional (functional, hierarchical) view towards a modern (hybrid, divisional, subject-oriented and/or heterarchical view).[4] We didn't name the various organizational units in our example on purpose, to abstract away the burden of the specific (organizational and ontological) situation. The important part of the method, that we want to point out here is that an organization is viewed as a network of processes which are interconnected by information.

The obscure definition of organizational elements has to be replaced by organizational activities or tasks which are the building blocks of organizational processes. This makes the definition of interaction as the exchange of information much more plausible and allows us to manipulate which such sound categories.

Most of KAM (as outlined herein) is well established and easy to implement (programmatically), except for the last (and appropriately most important) step which deals with the actual reorganization of structure. It is our opinion that the identified bottlenecks have to play a much more important role in this step.

Firstly we propose that the ways of reorganizing can be threefold: (1) merging, (2) splitting, (3) combined merge/split using subunits. The third way allows for rearranging one or more organizational subunits from one organizational unit to another.

Secondly we propose that the organizational exertions are not equally divided among the organizational units, but calculated by using the actual organizational elements each subunit is responsible for. This can be easily established by dividing the initial tables not only by organizational units, but subunits as well (with appropriate sum calculations where needed). This makes the calculation of organizational exertion more precise and allows for better reallocation of subunits.

Thirdly, we propose that the criteria for merging, splitting and reallocation the actual information network between the organizational units (exertion criteriae 5, 6, and 7). If two organizational units have a lot of mutually exchanged information they will be more likely to be merged. If two or more organizational subunits of some organizational unit have a relatively

[2] Which is a bold assumption made by Dešić [4, p. 118]

[3] Dešić uses real examples for each organizational unit including management, production, human resource etc., not generic ones as we do herein.

[4] This means dropping some steps of KAM including criteria 4 for calculating bottlenecks.

amount of information interchange they should be split into smaller, more cohesive organizational units. If one or more organizational subunits have a lot of information interchange with another organizational unit and at the same time only a small amount of interchange within its organizational unit, it should be reallocated to the other organizational unit.

4 Adapting KAM to MAS

The mapping of KAM concepts to MAS organizations is mostly obvious. Business organizations become MAS organizations, organizational units become groups of interacting agents (or groups of groups of interacting agents etc. according to the fractal principle outlined in [9, p. 153]), organizational elements become the individual activities performed by organizational units of agents, interactions between organizational elements become exchanged messages.

The fractal principle is best understood in the following definition of organizational units [8]:

An organizational unit is defined as follows:

- Any agent is an organizational unit.
- If $O = \{o_1, o_2, ..., o_3\}$ is a set of organizational units which collaborate with a common objective, then O is an organizational unit.

This definition allows us to manipulate organizational units regardless of their origin. The various rearrangements of organizational units can now be modeled explicitely using active graph grammars as shown in [8].

Q (and likewise Q_{min}, Q_{opt} and Q_c) and C do not have to be expressed annually but in an appropriate time-frame. Additionally, C does not have to be expressed in money, but in an appropriate cost measure like time, processor resources or specific resources handled by the MAS. k_s can be an internal measure of each agent dealing with the complexity of the service or activity to execute.

5 Towards a Distributed Application of KAM

An important feature of MAS is that they operate in a distributed environment and have to be adjusted to decentralized decision making. KAM is in business organizations performed by an individual in most cases an external consultant who can approach the organization as much as possible in an objective manner and build the "big picture" of the organization.

In order to apply KAM in a distributed environment every agent has to be aware of the current Q and C values in order to be able to calculate their particular indisposable organizational exertions. In order to avoid a management agent which deals with these values, this can be solved by a decentralized P2P network approach. The C (cost) values can be propagated by each agent to all of its peers. Each peer reviews the C value, adds its cost if any non-calculated cost, and forwards the value to all of its peers. Agents wouldn't have the most recent cost values, but a (still valuable) approximation of it that can be used for calculating their exertion. The Q values are much more easy to propagate since they depend on the initially established values and eventually the C value.

Additionally, each agent has to be aware of the organizational unit he belongs to, as well as of all other agents which are part of this unit in order to differentiate between activities he provides for co-workers and activities for agents from other organizational units. Based on its internal information counter, each agent can decide if it is time to "switch" to another organizational unit. This also presumes that each exchanged message has an organizational unit tag.

In order to account for splits and mergers of organizational units of agents, a protocol has to be established that will allow agents to collectively decide when it is time for change. This can be a very simple protocol in which, for example, each agent can query its coworkers for their exertion and sends a broadcast message if it detected that it is time for a split or merger.

6 Conclusion & Future Work

This initial study shows that by adding a few improvements to the original method, KAM can almost directly be applied as a method of self-organization in MAS. By defining a set of protocols KAM can be decentralized which could allow MAS organizations to optimize their structure by eliminating organizational exertion. In order to evaluate the approach KAM has to be implemented in a number of MAS scenarios. The exact definition of the protocols as well as the evaluation are subject to future research.

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