Mathematical model and coordination algorithms for ensuring complex security of an organization

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Abstract. The mathematical model of coordination when ensuring complex security of the organization is considered. On the basis of use of a method of casual search three types of algorithms of effective coordination adequate to mismatch level concerning security are developed: a coordination algorithm at domination of instructions of the coordinator; a coordination algorithm at domination of decisions of performers; a coordination algorithm at parity of interests of the coordinator and performers. Assessment of convergence of the algorithms considered above it was made by carrying out a computing experiment. The described algorithms of coordination have property of convergence in the sense stated above. And, the following regularity is revealed: than more simply in the structural relation the algorithm, for the smaller number of iterations is provided to those its convergence.

1. Introduction
Security of the organization represents the complex category including at least the following local components: providing mode and protection, fire security, information security, health and security of people. Need of coordination arises owing to the fact that the persons making private decisions on ensuring separate aspects of security are allocated with a certain independence. Not only the exception, but infringement of this independence reduces security as is followed by removal of responsibility from subordinates when performing of the functional duties by them. At the same time, the independence leads to the conflict of interests "private-part" and "private-general" which permission requires adoption of the complex coordinated decision considering both local interests, and interests at the level of all system in general [1-15].

2. Formulation of a problem
Let $S_{1234}^{r,t} \in \mathbb{R} \{\bar{r}, (\bar{q}_1, \bar{q}_2, \bar{q}_3, \bar{q}_4)\} \times \mathbb{R} \{\bar{r}'\}$, $t$ – the tetravalent tensor describing security status of penal correction system institution; $\mathbb{R} \{\bar{r}\}$ – space of indicators of complex security $(\bar{r})=(\bar{q}_1, \bar{q}_2, \bar{q}_3, \bar{q}_4)$; $\mathbb{R} \{\bar{q}_i\} \times \mathbb{R} \{\bar{r}'\}$, $t$ – the tensor standard setting the required levels of complex security $(\bar{r}')$. Then the problem of ensuring complex security in her mathematical
representation will consist in the decision relatively $C_{\tau_1,\ldots,\tau_4}^{R',\ldots,\ldots}$ and $C_{q_i}^{q_i'}(i=1,4)$ systems of the equations [1]:

$$
\begin{align*}
S_{1234}^{1234} & \left[ R(r), (Q_1(q_i), Q_2(q_i'), Q_3(q_i'), Q_4(q_i')), t \right] M(q_1,\ldots,q_4) C_{\tau_1,\ldots,\tau_4}^{R',\ldots,\ldots} = S_{1234}^{1234} \left[ R(r), t \right]; \\
& s^i(q_i,t)K(q_i,\ldots,q_i')C_{q_i}^{q_i'} = s^i(q_i',t); \\
& \ldots \\
& s^4(q_i,t)K(q_1,\ldots,q_4)C_{q_4}^{q_4'} = s^4(q_4',t)
\end{align*}
$$

(1)

where $C_{\tau_1,\ldots,\tau_4}^{R',\ldots,\ldots}$ and $C_{q_i}^{q_i'}(i=1,4)$ – the transformation tensors putting in compliance the flowing and demanded security levels; $\|\alpha\|$ – matrix of mismatch of the private aspects of security defined in coordinates $q_1,\ldots,q_4$, spaces $Q_1, Q_2, Q_3, Q_4$, respectively; $K(q_1,\ldots,q_4)$ – the coordination matrix set in spaces $q_1,\ldots,q_4$; $s^i(q_i',t);i=1,4$ – the tensors describing conditions of private aspects of security; $s^i(q_i',t);i=1,4$ – the tensors standards setting the required levels of separate aspects of security $(q_1',\ldots,q_4')$.

The obvious shortcoming (1) is that she has no constructive decisions as in neyaspekta of management and coordination are set implicitly. Directly to mark out the specified aspects we detail and we concretize (1). For this purpose, we will consider the control system of complex security of the organization represented on the scheme figure 1.

![Figure 1. Control system of complex security of the organization.](image)

On this scheme are designated by symbols: $C_0$ - the coordinator who is responsible for all system of security of the organization in general and coordinating work of performers; $C_1$, $C_2$, $C_3$, $C_4$ – performers, the exercising direct control of processes of ensuring local of the organization; $P_1$, $P_2$, $P_3$, $P_4$. 

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$P_4$ – the processes of providing the mode and protection (1), fire security (2), information security (3), health and security (4) making the general process of providing complex complex security of $P$; $\tilde{y}_i (i = 1, 4)$ – vectors of the coordinating influences; $\tilde{m}_i (i = 1, 4)$ – vectors of the operating influences; $\tilde{u}_i (i = 1, 4)$ – vectors of information on a condition of private processes $P_1$, $P_2$, $P_3$, $P_4$; $A = \|a_{ij}\|; i, j = 1, 4; a_{ii} = 0$ – matrix of mismatch of processes $P_1$, $P_2$, $P_3$, $P_4$; $\xi$ – matrix of mismatch of processes.

Functioning of such system is represented as follows. Coordinator $C_0$, obtaining information $\|a_\alpha\|$ about the current mismatch of private processes of ensuring local security $P_1$, $P_2$, $P_3$, $P_4$ seeks to minimize a deviation of all process $P$ from the required (reference) state that in an assumption of one-dimensionality of space $\mathbb{R}(\vec{r})$, that is when $\langle \vec{r} \rangle = r$, formally is expressed as the following criterion function:

$$r = \left[ \int_0^T \sqrt{\frac{1}{4} \sum_{i=1}^4 \mu_i \left(1 - Q_i(t)\right)^2} dt \right] \rightarrow \min_{\tilde{y}_i} \quad (2)$$

where $\mu_i = \frac{1}{1}$ – the expert coefficients reflecting the relative importance of private components of complex assessment of security; $T$ – the considered time interval; $Q_i (\tilde{m}_i, \tilde{u}_i, \tilde{y}_i, t) = \sqrt{\frac{1}{5} \sum_{k=1}^5 \mu_{ik} (1 - q_{ik} (\tilde{m}_k, \tilde{u}_k, \tilde{y}_k, t))^2}$; $Q_k (\tilde{m}_k, \tilde{u}_k, \tilde{y}_k, t) = \sqrt{\frac{1}{7} \sum_{k=1}^7 \mu_{ik} (1 - q_{ik} (\tilde{m}_k, \tilde{u}_k, \tilde{y}_k, t))^2}$;$Q_4 (\tilde{m}_4, \tilde{u}_4, \tilde{y}_4, t) = \sqrt{\frac{1}{5} \sum_{k=1}^5 \mu_{ik} (1 - q_{ik} (\tilde{m}_k, \tilde{u}_k, \tilde{y}_k, t))^2}$; $\mu_{ik} = \mu_{ik}^*$ – the rated expert coefficients reflecting the importance of indicators $q_1, ..., q_4$ in the general structure of security of an object which contents reveals in table 1.

Performers of $C_1$, $C_2$, $C_3$, $C_4$, receiving from the coordinator of the instruction in a look $y_i (i = 1, 4)$, aspire within these instructions to minimize deviations of the processes of $P_1$, $P_2$, $P_3$, $P_4$ from the required (reference) states that it is formally possible to express as the following system of criterion functions:

$$Q_1 = \int_0^T Q_1 (\tilde{m}_1, \tilde{u}_1, \tilde{y}_1, t) dt \rightarrow \min_{\tilde{m}_1 \in M_1}$$

$$Q_2 = \int_0^T Q_2 (\tilde{m}_2, \tilde{u}_2, \tilde{y}_2, t) dt \rightarrow \min_{\tilde{m}_2 \in M_2}$$

$$Q_3 = \int_0^T Q_3 (\tilde{m}_3, \tilde{u}_3, \tilde{y}_3, t) dt \rightarrow \min_{\tilde{m}_3 \in M_3}$$

$$Q_4 = \int_0^T Q_4 (\tilde{m}_4, \tilde{u}_4, \tilde{y}_4, t) dt \rightarrow \min_{\tilde{m}_4 \in M_4}$$

(3)

Considering that indicators $q_1, ..., q_4$ can be measured in different scales and have polar orientation, it is necessary before the decision (3) to carry out their normalization: $\hat{q}_{ij} = (q_{ij} \max - q_{ij} \min) / (q_{ij} \max - q_{ij} \min)$. 


for the indicators focused on a maximum, that is the more the better and 
\( \tilde{q}_{ij} = 1 - \left( q_{ij} - q_{ij}^{\text{min}} \right) / \left( q_{ij}^{\text{max}} - q_{ij}^{\text{min}} \right) \) – for the indicators focused on a minimum that is the it is less, the better where \( q_{ij}^{\text{max}} \), \( q_{ij}^{\text{min}} \) – minimum and maximum possible values of an indicator; \( \tilde{q}_{ij} \) – rated value of an indicator \( q_{ij} \). Such normalization allows to reduce all indicators to the range of change from 0 to 1 and to identical orientation to a maximum. It gives the chance to construct a vector \( \tilde{q}_1, \ldots, \tilde{q}_4 \) for a reference condition of \( P_1, P_2, P_3, P_4 \) which components are in on a formula \( q_{ij} = \max_i q_{ij} \). Therefore, all components of a reference vector \( \tilde{q}_1, \ldots, \tilde{q}_4 \), will be equal 1: \( \tilde{q}_1 = (1,1,1,1,1,1) \); \( \tilde{q}_2 = (1,1,1,1,1,1) \); \( \tilde{q}_3 = (1,1,1,1,1,1) \); \( \tilde{q}_4 = (1,1,1,1,1,1) \).

### Table 1. Types and contents of indicators of private aspects of institution security.

| Type | Maintenance of an indicator |
|------|-----------------------------|
| Indicators of the mode and protection \( (\tilde{q}_1) \) | \( q_{11} \) – security level when holding various actions; \( q_{12} \) – level of protection of buildings, rooms, equipment, production and technical means of ensuring production and other activity; \( q_{13} \) – level of personal security of the management and employees; \( q_{14} \) – timeliness of identification and elimination of the critical situations connected with actions of malefactors and terrorists; \( q_{15} \) – level of control of the mode of privacy and admission; \( q_{16} \) – level of completeness and quality of implementation of requirements of Fire security regulations and also other normative documents; \( q_{17} \) – level of security with fire extinguishing means and notifications; |
| Indicators of fire security \( (\tilde{q}_2) \) | \( q_{21} \) – level of proficiency of staff to Fire security regulations and actions on a fire case; \( q_{22} \) – level of a fire-prevention condition of jobs and territories; \( q_{23} \) – level of the organization and ensuring fire security; \( q_{24} \) – level of potential danger of ignition of objects; \( q_{25} \) – timeliness of identification and elimination of the critical situations connected with the fires; \( q_{26} \) – reliability of providing information; \( q_{27} \) – completeness of output information; \( q_{28} \) – timeliness of providing information; \( q_{29} \) – reliability of output information; \( q_{30} \) – maintaining confidentiality of information; |
| Information security indicators \( (\tilde{q}_3) \) | \( q_{31} \) – security level from unauthorized access and dangerous program and technical influences; \( q_{32} \) – timeliness of identification and elimination of the critical situations connected with information security; \( q_{33} \) – levels of undesirable impacts on different person of streams of energy (mechanical, electromagnetic, ionizing); \( q_{34} \) – the doses received by the person during action on him the negative technogenic factors (ionizing, electromagnetic, etc.); \( q_{35} \) – concentration of the undesirable to the person toxic and polluting chemicals; \( q_{36} \) – volumes of emissions in the atmosphere and dumpings into the hydrosphere undesirable to the person toxic and (or) pollutants; \( q_{37} \) – timeliness of identification and elimination of the critical situations connected with danger of activity. |
| Health and security indicators \( (\tilde{q}_4) \) | \( q_{41} \) – levels of undesirable impacts on different person of streams of energy (mechanical, electromagnetic, ionizing); |
Follows from told that criterion functions (2) and (3) can be interpreted as follows: complex assessment of security is distance in 5, 7, 7 and 5 measured spaces \( Q_i(i=1,4) \) from a point with coordinates \( \{1,1,1,1,1\}, \{1,1,1,1,1,1\}, \{1,1,1,1,1,1,1\}, \{1,1,1,1,1,1,1,1\} \), corresponding to their current state.

Thus, the substantial party of mathematical model of coordination at adoption of the complex decision on security of the organization to be in that the coordinator on the basis of information on the level of mismatch of private decisions \( [\alpha_{ij}] \) it developed and has brought such coordinating influences to subordinates \( \vec{y}_i(i=1,4) \), which will help them to develop the managements of the security measures providing the greatest possible integrated effect at the level of the organization, but in too time keeping "optimality" of management of own processes from the point of view of local interests.

3. Assessment of mismatch of private processes of security of the organization
The theoretical base of such assessment is made by the typology of interference of private processes of ensuring local security of \( P_1, P_2, P_3, P_4 \) presented in table 2 [1, 5].

**Table 2.** Types of paired interaction between the private security processes of the institution and the corresponding level of inconsistency assessment.

| Type interferences | Version                      | Interference manifestation form                                      | Mismatch assessment \( (\alpha_{ij}) \) |
|--------------------|------------------------------|-----------------------------------------------------------------------|------------------------------------------|
| Negative           | Negative only                | Achievement of the goal of one process excludes achievement of the goal of another | Arkh high \( (\alpha_{ij} = -1.0) \)    |
|                    | Strictly negative            | The greatest efficiency of one process is reached at the smallest efficiency of another | Very high \( (\alpha_{ij} = 0.8) \)     |
|                    | Not strictly negative        | Processes, exert negative impact at each other, but their purposes are achievable, though not fully | High \( (\alpha_{ij} = 0.5) \)          |
|                    | Unilaterally negative        | One process exerts negative impact on another which doesn't exert any impact on the first | Not really high \( (\alpha_{ij} = 0.1) \) |
|                    | Exclusively positive         | The purposes of processes merge in one common goal                   | Zero \( (\alpha_{ij} = 1.0) \)          |
| Positive           | Strictly positive            | Processes are united by unity of the purpose, but the contribution to her achievement at each of them is various | Very low \( (\alpha_{ij} = 0.8) \)     |
|                    | Not strictly positive        | The purposes of processes are various, but are various on minor questions | Low \( (\alpha_{ij} = 0.5) \)           |
|                    | Unilaterally positive        | One process exerts positive impact on another which doesn't exert any impact on the first | Not really high \( (\alpha_{ij} = 0.1) \) |
| Positive and negative | Normal                      | Despite counteraction, the purposes of processes are achievable       | Very low \( (\alpha_{ij} = 0.8) \)     |
|                    | Abnormal                     | Despite assistance, the purposes of processes are unattainable        | Very high \( (\alpha_{ij} = 0.8) \)    |
|                    | Neutral                      | Processes don't exert impact at each other                            | Zero \( (\alpha_{ij} = 1.0) \)          |
Using data table 2, we leave a symmetric matrix \( \alpha_{ij} = 0; i, j = 1, ..., 4 \) by which we determine average degree of mismatch of private processes of security in the organization:

\[
\alpha \approx 0.11 \left[ \sum_{i=1}^{4} \left( \sum_{j=1}^{4} \alpha_{ji} \right) \right].
\]

Size \( \alpha \) defines type and the maintenance of an algorithm of coordination [3,4]. If \( -1 < \alpha \leq 0.33 \), then in system essential mismatches take place, and it is necessary for effective coordination that instructions of the coordinator dominated over decisions of performers. At \( 0.33 < \alpha \leq 1 \) in system there are practically no mismatches concerning security, and effective coordination can be reached if the solution of problems is given not "payoff" to performers. If \( -0.33 < \alpha \leq 0.33 \), then in system insignificant mismatches on minor questions which can be eliminated on the basis of parity of interests of the coordinator and performers [5, 16-17] take place.

4. Coordination algorithm at domination of instructions of the coordinator

In this case the criterion of efficiency of coordination has to be based on comparison of sizes \( r \) and \( r' \), reflecting the flowing and demanded levels of security of all system in general. Taking into account it the algorithm of coordination comes down to the step-by-step iterative procedure of the following look.

\textit{Step 1.} Using a program method of generation of random numbers, we set a starting vector of the coordinating influences \( \bar{y}_i^{(0)} \in Y; (i = 1,4) \). Random numbers have to get out of an interval from 0 to 1, at the same time their sequence has to submit to the uniform law of distribution.

\textit{Step 2.} By method of calculus of variations, we solve problems (3). Also, we remember \( Q_i^{(0)}(i = 1,4) \) the received values \( m_i^{(0)} \).

\textit{Step 3.} For the received values \( Q_i^{(0)}(i = 1,4) \) we solve a problem (2) and we remember values \( \bar{y}_i^{(0)}(i = 1,4) \) and \( r^{(0)} \).

\textit{Step 4.} We compare \( r^{(0)} \) to the required level of complex security \( (r') \). If \( r^{(0)} \geq r' \) – the task is solved, the coordinating influences \( \bar{y}_i^{(0)}(i = 1,4) \) are recognized as optimum. As \( r^{(0)} < r' \) we continue the solution of a task.

\textit{Step 5.} We choose a new casual vector \( \bar{y}_i^{(0)} \in Y; (i = 1,4) \).

\textit{Step 6.} We solve problems (3), the received values \( m_i^{(1)}(i = 1,4) \) and \( Q_i^{(1)}(i = 1,4) \) remember.

\textit{Step 7.} For the received values \( Q_i^{(1)}(i = 1,4) \) we solve a problem (2) and we will remember values \( \bar{y}_i^{(1)}(i = 1,4) \) and \( r^{(1)} \).

\textit{Step 8.} We compare \( r^{(1)} \) to the required level of complex security \( (r') \). If \( r^{(1)} \geq r' \) – the task is solved, the coordinating influences \( \bar{y}_i^{(1)}(i = 1,4) \) are recognized as optimum. As \( r^{(0)} < r' \) we continue the solution of a task.

\textit{Step 9.} We compare \( r^{(1)} \) and \( r^{(0)} \). If, \( r^{(1)} < r^{(0)} \) that is the procedure repeats from a step 5. Otherwise \( (r^{(1)} \geq r^{(0)}) \) the attempt is considered unsuccessful. Search stops after \( \mu \) of unsuccessful steps is made: the problem of ensuring the required level of security of an object at the available basic data is considered impracticable.
5. Coordination algorithm at parity of interests of the coordinator and performers

Unlike two previous cases, the criterion of efficiency of coordination has to be based as on comparison of sizes \( r \) and \( r' \), reflecting the flowing and demanded levels of security of all system in general, and on comparison of sizes \( Q_i (i = 1, 4) \) and \( Q'_i \), reflecting the flowing and demanded levels of separate aspects of security. Taking into account it the coordination algorithm at parity of interests of the parties comes down to the step-by-step iterative procedure of the following look.

**Step 1.** Using a program method of generation of random numbers, we set a starting vector of the coordinating influences \( y^{(0)}_i (i = 1, 4) \in Y; y^{(0)}_i \).

**Step 2.** One of methods of calculus of variations we solve problems (3). The received values \( y^{(0)}_i (i = 1, 4) \) and \( r^{(0)} \) remember.

**Step 3.** For the received values \( Q^{(0)}_i (i = 1, 4) \) we solve a problem (2) and we remember values \( y^{(0)}_i (i = 1, 4) \) and \( r^{(0)} \).

**Step 4.** Compare \( r^{(0)} \) с \( r' \) and \( Q^{(0)}_i (i = 1, 4) \) с \( Q'_i \). If \( (r^{(0)} \geq r') \) and \( \forall i \in i_{1, 4} \left(Q^{(0)}_i \geq Q'_i \right) \) — the task is solved, the coordinating influences \( y^{(0)}_i (i = 1, 4) \) are recognized as effective. If at least one their specified conditions aren't satisfied, then we continue the solution of a task.

**Step 5.** We choose a new casual vector \( y^{(1)}_i (i = 1, 4) \in Y; y^{(1)}_i \).

**Step 6.** We solve problems (3), the received values \( y^{(1)}_i (i = 1, 4) \) and \( Q^{(1)}_i (i = 1, 4) \) remember.

**Step 7.** For the received values \( Q^{(1)}_i (i = 1, 4) \) we solve a problem (2) and we remember values \( y^{(1)}_i (i = 1, 4) \) and \( r^{(1)} \).

**Step 8.** Compare \( r^{(1)} \) с \( r' \) and \( Q^{(1)}_i (i = 1, 4) \) с \( Q'_i \). If \( (r^{(1)} \geq r') \) и \( \forall i \in i_{1, 4} \left(Q^{(1)}_i \geq Q'_i \right) \) — the task is solved, the coordinating influences \( y^{(1)}_i (i = 1, 4) \) are recognized as effective. In a case \( (r^{(1)} \geq r^{(0)} \) the attempt \( \mu \) is considered unsuccessful. Search stops after unsuccessful steps.

6. Conclusion

Assessment of convergence of the algorithms considered above it was made by carrying out a computing experiment. At the same time, it was necessary that the algorithm meets if for the number of iterative cycles (about 150-200) accepted for practice, it allows to receive established results, that is results having no more than 10% a deviation from average value at tenfold repetition of cycles. Results of a computing experiment are presented in table 3.

| Table 3. The results of the computational experiment on the analysis of convergence of coordination algorithms. |
|---------------------------------------------------------------|
| Kind of an algorithm | Minimum of iterations for ensuring convergence | Deviation from an average at tenfold repetition of cycles |
| Coordination algorithm at domination of instructions of the coordinator | 95-100 | 10-15% |
| Coordination algorithm at domination of decisions of performers | 80-90 | 10-15% |
| Coordination algorithm at parity of interests of the coordinator and performers | 120-160 | 10-15% |
From the analysis of the obtained data it is visible that the described algorithms of coordination have property of convergence in the sense stated above. And, the following regularity is revealed: than more simply in the structural relation the algorithm, for the smaller number of iterations is provided to those its convergence. So, for example, for the simplest algorithm of coordination at domination of interests of performers the convergence is reached approximately for 80-90 cycles, in case of the most difficult a coordination algorithm at parity of interests of the coordinator and performers – for 120-160 cycles.

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