Development of the quality assessment information system for infection control in penitentiary institutions

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Abstract. The article describes the quality assessment system for infection control in penitentiary institutions that was developed using a mathematical model based on analytic hierarchy process (AHP). The following parameters were chosen as indicators of infection control quality level: HIV, tuberculosis, incidence of other infectious diseases, compliance with sanitary regulations and the water quality. The reliability and adequacy of the research has been proved. Quality assessment of infection control is an important criterion for the successful development of effective measures aimed at the improvement of the epidemiological situation in penitentiary institutions.

1. Introduction
In the modern world, the development of information systems and technologies, mathematical models for the healthcare is an important area of medical science. At the same time researchers pay great attention to socially significant diseases [1]. The infection control level is an indicator of the anti-epidemic measures quality. Assessment of infection control in institutions of the penitentiary system (IPS) is carried out using a special index developed on the basis of the logical-mathematical method of hierarchy analysis developed by T.A. Saati [2].

To calculate the proposed "infection control index" in IPS healthcare institutions, an automated software package has been developed. The program is created for automatic control over the implementation of all the measures stipulated by the Integrated program for infection control, prevention of nosocomial HIV transmission in IPS, approved by Order of the Federal Penitentiary Service of Russia dated 10.10.2017 No. 256-r (hereinafter referred to as the Integrated Program).

The program allows to collect, analyze, store and visualize statistical data on the level of Integrated Program measures implementation in each region. The program algorithm includes a mathematical model for evaluating the Integrated Program measures implementation according to 5 criteria and 19 indicators. Visualization of the program monitoring results is implemented in the form of a classic window interface with elements of a geographic information system (charts, graphs, maps).
2. Research methods
As is well known, methods of machine learning and data analysis are used in various fields today. Medical science is no exception [3-5]. AHP method was proposed as the basis for developing a model (according to which the program was developed further). AHP allows to structure a complex decision-making problem in the form of a hierarchy, as well as to compare and quantify alternative solutions.

AHP is used all around the world for decision-making in a wide variety of situations: from management at the interstate level to solving industry and private problems in business, healthcare and education.

With the help of AHP the following tasks can be solved:

- The problem of multi-criteria choice. The choice of one alternative from a set of alternatives based on certain criteria.
- Ranking. Multicriteria ordering of a given set of alternatives.
- Prioritization of alternatives and criteria in multi-criteria selection tasks.
- Resource allocation. The distribution of resources between alternatives from a given set.
- Comparative analysis. Development of recommendations for optimizing the organization internal processes based on the successful experience of competitors.
- Quality control. Analysis of various aspects of quality and ways to improve quality.

There are many examples of successful use of AHP in solving complex problems, in particular:

- Developing a strategy to reduce the negative impact of global climate change (Fondazione Eni Enrico Mattei).
- Calculation of the indicator of the system total quality, for example, software systems (Microsoft Corporation).
- The choice of specialization at university studies (Bloomsburg University of Pennsylvania).
- Deciding on the location of offshore companies (University of Cambridge).
- Assessment of risks associated with the functioning of oil pipelines running in the country (American Society of Civil Engineers).
- Developing the most effective US watershed management strategy (U.S. Department of Agriculture).

Analysis of the decision-making problem in AHP begins with the creation of a hierarchical structure, which includes the goal, criteria, alternatives and other factors considered affecting choice. This structure reflects the understanding of the problem by the decision maker (figure 1).

![Figure 1. Hierarchical structure](image)

Hierarchy can be complex (figure 2).
The first stage of AHP involves the problem structuring in the form of a hierarchy or network. In the most elementary form, the hierarchy is built from the top (goal), through intermediate levels-criteria to the lowest level [6]. A hierarchical structure is a graphical representation of a problem in the form of an inverted tree, where each element, with the exception of the uppermost one, depends on one or more elements located above. AHP implementing can solve a lot of problems, when hierarchy structure is used as a tool for processing and perceiving large amounts of information. As this structure is designed, the researcher develops increasingly complete understanding of the problem. Each level consists of nodes. Elements emanating from a node are usually called descendants (children elements). Elements from which the node originates are called parents [2]. Groups of elements having the same parent element are called comparison groups. Priorities are numbers that are associated with hierarchy nodes. They represent the relative weights of the elements in each group. Like probabilities, priorities are dimensionless quantities that can take values from zero to one. The higher the priority value, the more significant is the corresponding element. The sum of the priorities of the elements subordinate to one element of the higher hierarchy level equal to one. In order to formalize expert assessments, a special rating scale is introduced in the AHP that is a scale of relative importance. In this research, the experts were the leading specialist of the Healthcare department and the Main Center of State Sanitary and Epidemiological Surveillance of the Federal Penitentiary Service of Russia (FPSR).

The system of pairwise comparisons leads to a result that can be represented as an inverse symmetric matrix. The element of the matrix \( a_{i,j} \) is the intensity of the hierarchy element hierarchy \( i \) relative to the element of the hierarchy \( j \), evaluated on an intensity scale from 1 to 9, that was proposed by the author of the method. The effectiveness of such a gradation has been proven empirically. If, when comparing one factor \( i \) with another \( j \), the result is a \( a_{i,j} = b \), then when comparing the second factor with the first, the result will be \( a_{j,i} = 1/b \).

3. Results
To assess the infection control level, a mathematical model has been developed, the model structuring the problem, where the infection control level in penitentiary institutions is located at the top, at the second level there are 5 criteria (“The human immunodeficiency viruses”, “Incidence of other infectious diseases” “Tuberculosis”, “Water quality”, “Compliance with sanitary regulations”), at the third level there are 19 indicators characterizing the criteria.

The selected indicators were assigned the following conventions (Xn):

1. The human immunodeficiency viruses (HIV). The following indicators were selected for this parameter [7]:
   - The level of awareness of FPSR employees and inmates about risk factors of HIV and other infectious diseases (X1).
   - Proportion of people infected with HIV receiving antiretroviral therapy from the total number of people infected with HIV under clinical supervision (X2).
   - HIV test coverage (X3).

2. Incidence of other infectious diseases (IOID). The following indicators were selected.
• The indicator of the general infectious morbidity of inmates in penitentiary institutions (X4).
• Vaccination coverage of inmates in penitentiary institutions (X5).
• Influenza Vaccination Coverage of inmates in penitentiary institutions (X6).
• Influenza Vaccination Coverage of FPSR employees (X7).
• The incidence rate of acute infections of the upper respiratory tract of multiple or unspecified localization in penitentiary institutions (X8).
• Proportion of persons who underwent preventive medical examinations (PME) from all persons subjected to PME (X9).

3. Tuberculosis (TB). The following indicators were selected for this parameter [8]
• Tuberculosis prevalence rate among inmates in in penitentiary institutions (X10).
• Primary Tuberculosis Rate among inmates in in penitentiary institutions (X11).
• Quality control of ongoing and final disinfection in foci of tuberculosis (X12).

4. Water quality (WQ)
• The proportion of water samples according to microbiological indicators from the total number of samples studied (X13).
• The proportion of water samples according to sanitary-chemical indicators from the total number of samples studied (X14).

5. Compliance with sanitary regulations (CSR)
• Implementation of the plan of production and laboratory control over sanitary rules compliance at food facilities (X15).
• Implementation of the plan of production and laboratory control over sanitary rules compliance at healthcare facilities (X16).
• The proportion of medical facilities that do not meet sanitary requirements (X17).
• The proportion of food facilities that do not meet sanitary requirements (X18).
• Implementation of the measures included in the Integrated program for infection control, prevention of nosocomial transmission of HIV and nosocomial transmission of HIV in penitentiary institutions (X19).
• Below there are presented Pairwise Comparison Matrices, assessment of expert opinion consistency and priority (weight) calculation (P) of the researched factor (tables 1-6).

Table 1. Pairwise Comparison Matrix for the indicator “Infection control”.

| Criteria | HIV   | IOID  | TB    | WQ    | CSR   | $\omega_i$ | $P$   |
|----------|-------|-------|-------|-------|-------|------------|-------|
| HIV      | 1.000 | 0.500 | 0.143 | 0.333 | 0.333 | 0.380      | 0.055 |
| IOID     | 2.000 | 1.000 | 0.333 | 3.000 | 3.000 | 1.431      | 0.206 |
| TB       | 7.000 | 3.000 | 1.000 | 7.000 | 5.000 | 3.743      | 0.538 |
| WQ       | 3.000 | 0.333 | 0.143 | 1.000 | 1.000 | 0.678      | 0.097 |
| CSR      | 3.000 | 0.333 | 0.200 | 1.000 | 1.000 | 0.725      | 0.104 |
| Sum      | 16.000| 5.167 | 1.819 | 12.333| 10.333| 6.957      | 1.000 |

Table 2. Pairwise Comparison Matrix for the indicator “HIV”.

| Criteria | X1   | X2   | X3   | $\omega_i$ | $P$   |
|----------|------|------|------|------------|-------|
| X1       | 1.000| 0.125| 0.333| 0.347      | 0.086 |
| X2       | 8.000| 1.000| 2.000| 2.519      | 0.628 |
| X3       | 3.000| 0.500| 1.000| 1.145      | 0.285 |
| Sum      | 12.000| 1.625| 3.330| 4.011      | 1.000 |
According to the developed model, it can be noted that the factors of the "tuberculosis" criterion are of incidence and prevalence of tuberculosis. The data obtained are reflected in modern medical scientific literature. In the modern world, it is possible to develop the infection control level index that includes an assessment of 5 criteria and 19 parameters. The quality assessment system for infection control in penitentiary institutions gives a possibility to assess the quality in penitentiary institutions: HIV = 0.206; TB = 0.538; WQ = 0.097; CSR = 0.104. Indicator Priority Values are for the criterion «HIV»: X₁ = 0.005; X₂ = 0.0343; X₃ = 0.016, for the criterion «IOID»: X₄ = 0.079; X₅ = 0.028; X₆ = 0.020; X₇ = 0.013; X₈ = 0.056; X₉ = 0.009, for the criterion «TB»: X₁₀ = 0.315; X₁₁ = 0.190; X₁₂ = 0.033, for the criterion «WQ»: X₁₃ = 0.083; X₁₄ = 0.014, for the criterion «CSR»: X₁₅ = 0.012; X₁₀ = 0.008; X₁₁ = 0.033; X₁₂ = 0.038; X₁₃ = 0.012.

4. Findings
The quality assessment system for infection control in penitentiary institutions gives a possibility to develop the infection control level index that includes an assessment of 5 criteria and 19 parameters. The data obtained are reflected in modern medical scientific literature. In the modern world, the incidence and prevalence of tuberculosis is a kind of indicator of well-being and quality of life [9]. According to the developed model, it can be noted that the factors of the "tuberculosis" criterion are of leading importance in determining the infection control level, since they have the highest priority (0.538).

### Table 3. Pairwise Comparison Matrix for the indicator “IOD”.

| Criteria | X4 | X5 | X6 | X7 | X8 | X9 | ω₄ | P  |
|----------|----|----|----|----|----|----|----|----|
| X4       | 1.00 | 3.00 | 3.00 | 7.00 | 2.00 | 6.00 | 3.018 | 0.383 |
| X5       | 0.333 | 1.00 | 3.00 | 3.00 | 0.250 | 2.00 | 1.069 | 0.136 |
| X6       | 0.333 | 0.333 | 1.00 | 2.00 | 0.333 | 3.00 | 0.778 | 0.099 |
| X7       | 0.143 | 0.333 | 0.500 | 1.00 | 0.250 | 3.00 | 0.511 | 0.065 |
| X8       | 0.500 | 4.000 | 3.000 | 4.000 | 1.000 | 4.000 | 2.139 | 0.271 |
| X9       | 0.167 | 0.500 | 0.333 | 0.333 | 0.250 | 1.000 | 0.364 | 0.046 |
| Sum      | 10.583 | 8.867 | 18.333 | 27.000 | 7.283 | 1.968 | 7.881 | 1.000 |

### Table 4. Pairwise Comparison Matrix for the indicator “TB”.

| Criteria | X10 | X11 | X12 | ω₁ | P  |
|----------|-----|-----|-----|----|----|
| X10      | 1.00 | 2.00 | 8.000 | 2.519 | 0.586 |
| X11      | 0.500 | 1.000 | 7.000 | 1.518 | 0.353 |
| X12      | 0.125 | 0.143 | 1.000 | 0.261 | 0.061 |
| Sum      | 1.625 | 3.143 | 16.000 | 4.299 | 1.000 |

### Table 5. Pairwise Comparison Matrix for the indicator “WQ”.

| Criteria | X13 | X14 | ω₂ | P  |
|----------|-----|-----|----|----|
| X13      | 1.000 | 6.000 | 2.449 | 0.857 |
| X14      | 0.167 | 1.000 | 0.408 | 0.143 |
| Sum      | 1.167 | 7.000 | 2.858 | 1.000 |

### Table 6. Pairwise Comparison Matrix for the indicator «CSR».

| Criteria | X15 | X16 | X17 | X18 | X19 | ω₃ | P  |
|----------|-----|-----|-----|-----|-----|----|----|
| X15      | 1.000 | 1.000 | 0.333 | 0.250 | 2.000 | 0.699 | 0.117 |
| X16      | 1.000 | 1.000 | 0.333 | 0.250 | 0.333 | 0.488 | 0.081 |
| X17      | 3.000 | 3.000 | 1.000 | 1.000 | 3.000 | 1.933 | 0.323 |
| X18      | 4.000 | 4.000 | 1.000 | 1.000 | 3.000 | 2.169 | 0.362 |
| X19      | 0.500 | 3.000 | 0.333 | 0.333 | 1.000 | 0.699 | 0.117 |
| Sum      | 9.500 | 12.000 | 3.000 | 2.833 | 9.333 | 5.988 | 1.000 |

Thus, the following values were obtained for the weight coefficients of the studied criteria describing the infection control level quality in penitentiary institutions: HIV = 0.055; IOID = 0.206; TB = 0.538; WQ = 0.097; CSR = 0.104. Indicator Priority Values are for the criterion «HIV»: X₁ = 0.005; X₂ = 0.0343; X₃ = 0.016, for the criterion «IOID»: X₄ = 0.079; X₅ = 0.028; X₆ = 0.020; X₇ = 0.013; X₈ = 0.056; X₉ = 0.009, for the criterion «TB»: X₁₀ = 0.315; X₁₁ = 0.190; X₁₂ = 0.033, for the criterion «WQ»: X₁₃ = 0.083; X₁₄ = 0.014, for the criterion «CSR»: X₁₅ = 0.012; X₁₀ = 0.008; X₁₁ = 0.033; X₁₂ = 0.038; X₁₃ = 0.012.
Since, inmates have a direct impact on the epidemic situation in public health institutions, the possibility to ensure a high level of anti-epidemic measures in penitentiary institutions becomes of the highest importance for protecting the health of the entire population of the Russian Federation.

Implementation in practical work of the effective model for assessing the infection control level gives a possibility to identify the most vulnerable penitentiary institutions, as well as problematic issues that are not given due attention, additional organizational measures or the new approaches development, which will improve the sanitary-epidemiological well-being of the population.

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