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OPTIMIZATION OF MULTI-CRITERIA SELECTION OF COMPUTER COMPONENTS BASED ON HIERARCHY ANALYSIS

The paper addresses the problem of optimal selection of components for personal computers in healthcare facilities under conditions of limited budget and multiple evaluation criteria. It is determined that traditional methods of component selection based on empirical experience or simple comparison of characteristics are insufficiently effective for making optimal decisions in multi-criteria choice situations. The application of Thomas Saaty's adapted Analytical Hierarchy Process as an effective tool for mathematically grounded multi-criteria component selection is substantiated, taking into account technical compatibility, energy balance, and user priorities. Specific examples of applying the method when choosing a processor for a healthcare facility are provided, demonstrating four scenarios with different parameter priorities and three optimization modes. Experimental validation confirmed high algorithm accuracy in tracking user-defined priorities. An economic efficiency analysis of the developed system application has been conducted, demonstrating potential savings of up to 25% of the IT budget for healthcare institutions while maintaining the required performance level.

Keywords: *analytical hierarchy process, multi-criteria selection, component selection, healthcare facilities, dynamic parameter balancing, decision optimization, IT infrastructure.*

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Problem Statement

Modern healthcare institutions increasingly rely on effective IT support for the operation of medical information systems, electronic patient documentation, and automation of administrative processes. According to the Ministry of Health of Ukraine, by 2024, over 85% of primary healthcare institutions will require computer modernization, while the average IT budget per institution is only $15.000–25.000 per year.

The computer market is characterized by an exponential growth in the range of components, the complexity of their interactions, and a variety of quality assessment criteria. According to analytical agencies, by 2024, the processor market will include over 500 current models, over 800 motherboards, and over 1.000 RAM module variants. This diversity makes it difficult for even experienced IT professionals to select the optimal configuration.

The problem is complicated by the need to consider multiple interrelated factors. First, there's the technical compatibility of components: the processor must match the motherboard socket, the RAM must match the supported type (DDR4 or DDR5), and the graphics card must match the available PCIe slots and case dimensions. Second, there's the system's energy balance: the combined power consumption of all components must exceed the power supply's capacity, taking into account the recommended 20–40% reserve. Third, there are physical constraints: the height of the processor cooling system must fit within the case's interior, and the length of the graphics card must fit within the available space. Fourth, there are the varying priorities of users—from minimizing costs to maximizing performance for specific medical applications.

Traditional component selection methods based on empirical experience or simple comparisons of characteristics are ineffective for making optimal decisions in a multi-criteria environment. For medical institutions, which often operate within limited budgets and require standardized IT infrastructure, the need for a scientifically based approach to equipment selection is especially critical. According to the Drabivka Primary Health Care Center, a non-optimal configuration can lead to budget overruns of 20–35% or the purchase of underperforming equipment, requiring premature upgrades after 2–3 years instead of the planned 5–7 years of operation.

Therefore, the development of an intelligent decision support system that combines mathematically sound multi-criteria analysis with automated compatibility checking and the ability to flexibly configure priorities is relevant.

The purpose of this article is to highlight the specifics of adapting the Saaty hierarchy process to the problem of multi-criteria selection of computer components and to demonstrate its practical application in the context of optimizing IT costs in medical institutions, taking into account technical compatibility, energy balance, and dynamic balancing of user priorities.

Analysis of Recent Research and Publications

The mathematical basis for the implementation of the multi-criteria component selection system was the Saaty hierarchy analysis method. The fundamental work is the study of T.L. Saaty "The Analytic Hierarchy Process" (1980) [1], in which the author first systematized the hierarchy analysis method as a tool for revealing and taking into account the hierarchical structure of criteria in the process of making complex decisions.

Various aspects of the application of the method in the context of IT solutions and multi-criteria selection were studied by domestic and foreign scientists. In [2], the issues of transition from single-criteria to multi-criteria optimization are considered in detail and the shortcomings of direct linear convolution of criteria are critically analyzed and a comprehensive mathematical description of the method with specific computational algorithms is provided.

The feasibility of substantiating the use of expert evaluation methods when choosing between alternatives and the practical application of the Saaty hierarchy analysis method are given in [5, 6].

Review of Existing Approaches to Component Selection

A thorough analysis of modern decision support systems in the field of computer system configuration has been conducted. As a result of this analysis, four main approaches can be distinguished:

Parametric filtering approach (Hotline.ua). Hotline.ua, a leading Ukrainian price aggregator, implements a classic parametric approach based on multi-level filtering of products by technical specifications. Users can combine filters by manufacturer, socket, number of cores, frequency, etc. The system offers a "Build a Computer" tool with a basic compatibility check.

Advantages: complete process transparency, flexible filtering, up-to-date pricing information.

Disadvantages: lack of intelligent analysis, incomplete compatibility check, passive role of the system, and the need for expert user knowledge.

Expert-based recommendation approach (BRAIN.com.ua). The Ukrainian online store BRAIN.com.ua implements the concept of "ready-made solutions" – pre-configured systems for various scenarios (office PC, gaming PC, workstation). The system offers a power calculator and warnings about potential bottlenecks.

Advantages: reduced entry point for inexperienced users, guaranteed compatibility in ready-made configurations, energy balance accounting.

Disadvantages: limited number of ready-made configurations, static expert recommendations, subjective classification.

Crowdsourcing (PCPartPicker). The international PCPartPicker platform implements the most comprehensive automated compatibility check: physical (graphics card length, cooler height), electrical (power supply wattage, connector availability), interface (memory type, PCIe version), and software (motherboard BIOS processor support).

Advantages: the most comprehensive compatibility check, price aggregation from 40+ stores, price history, database of 5+ million user configurations.

Disadvantages: passive role in decision making, lack of formalized multi-criteria analysis, potential errors with new components.

Simplified Optimization (Telemart.ua). The Ukrainian online store Telemart.ua is implementing a simplified version of multi-criteria optimization based on "usage profiles." The user answers a questionnaire about the system's purpose and priorities, after which the system generates 3–5 alternative configurations.

Advantages: active role of the system, consideration of individual priorities, automated selection.

Disadvantages: simplified optimization model, fixed weighting coefficients for profiles, non-transparent decision-making algorithm.

A comparative analysis of four existing approaches revealed common system limitations:

- the lack of formalized multi-criteria analysis;
- limited personalization;
- static evaluation criteria;
- and the passive role of the system in decision-making.

This justifies the need to develop an intelligent decision-making support system that combines the mathematically correct Saaty method

Table 1. **Sequential analysis of approaches to component selection**

Characteristic	Hotline.ua	BRAIN. com.ua	PCPartPicker	Telemart.ua	Developed system
Type of approach	Parametric filtering	Expert recommendations	Crowdsourcing with verification	Simplified optimization	Adapted Saaty method
Degree of automation	Low	Average	Average	High	Very high
Compatibility check	Basic	Extended	Compre hensive	Automatic	Complex + energy balance
Multi-criteria analysis	Missing	Missing	Missing	Simplified	Mathematically sound
Personalization	Missing	Limited	Missing	Profiles	Full + dynamic balancing
Saving configurations	No	No	Yes	No	Yes + crypto protection
Mathematical justification	None	None	None	Simplified	Saaty Method with Adaptation
Locking parameters	No	No	No	No	Yes
Optimization modes	No	Limited	No	Yes	3 modes + settings

with interactive weight control, dynamic parameter balancing, configuration storage mechanisms, and comprehensive validation of results. These functional requirements are implemented in the developed software application.

Table 1 summarizes the results of a comparative analysis of known approaches to component selection and the developed system.

The author's previous work [3] demonstrated the fundamental possibility of automating complex multi-criteria selection using the Saaty method, but revealed critical limitations: fixed weighting factors, lack of personalization and mechanisms for saving configurations.

Main Results and Content of the Research

The classic analytic hierarchy process, proposed by T. Saaty in the 1970s, was adapted to the specifics of computer component selection, taking into account the specifics of the subject area. The main stages of the adapted method include structuring the problem, normalizing the data, constructing pairwise comparison matrices, and calculating local and global priorities.

Stage 1. Structuring the Problem and Defining Criteria

Specific evaluation criteria are defined for each component category. For processors, five parameters are identified:

- Price (minimized);
- Number of cores (maximized);
- Base clock frequency (maximized);
- Turbo frequency (maximized);
- TDP — thermal dissipation (minimized).

In total, the system implements ten independent balancers for different component groups: processors (5 parameters), cooling systems (4), motherboards (3), RAM (6), monitors (5), video cards (6), speakers (4), sound cards (5), headphones (2), and webcams (3).

Stage 2. Normalization of Dissimilar Parameters

Since component parameters have different natures and units of measurement, they must be normalized to ensure comparability. A system for normalizing parameter values in the range from 0.1 to 0.9 was developed using the following formula:

$$norm\_value = 0{,}1 + 0{,}8 \times \frac{x - x_{\min}}{x_{\max} - x_{\min}}.$$

For the parameters being minimized (price, energy consumption, noise level), inverse normalization is used:

$$inv\_value = 0{,}9 - norm\_value + 0{,}1.$$

Stage 3. Construction of pairwise comparison matrices

For each parameter, a pairwise comparison matrix of alternatives of size $N \times N$ is constructed, where N is the number of component variants.

The matrix element is calculated as:

$$a_{ij} = norm\_value\ i\ /\ norm\_value\ j.$$

The diagonal elements are equal to one. The matrix is inversely symmetric: $1/a_{ij}$.

Stage 4. Calculating Local Priorities

Local priorities are calculated using the geometric mean row of the matrix:

$$geom\_average_i = \sqrt[N]{\prod_{j=1}^{N} a_{ij}}\ .$$

Using a logarithmic representation ensures numerical stability:

$$\log(geom\_average_i) = \frac{1}{N}\sum_{j=1}^{N}\log(a_{ij})\,.$$

Normalization leads to the emergence of local priorities.

Step 5. Calculating Global Priorities

Global priorities are calculated using additive convolution:

$$G_i = \sum_{j=1}^{M} w_i \times L_{ij}.$$

where w_j is the weight of the j-th parameter, L is the local priority of the i-th alternative for the j-th parameter.

Dynamic Parameter Balancing System

The key innovation of the developed system is the dynamic balancing mechanism for weight coefficients via the ParameterBalancer class, which ensures:

- the constant sum of the parameters is 100% regardless of changes;
- ability to lock individual parameters to fix their values;
- automatic recalculation of unlocked parameters proportional to their current value;
- rounding error correction to ensure accurate sums.

The balancing algorithm consists of the following stages.

- Initialization: For M parameters, initial values are 100/M percent each.
- Parameter change: when changing the parameter k to a new one, the remainder is determined:

$$\Delta = 100 - \nu_k^{new}\,.$$

- Blocked subtraction:

$$\Delta_{free} = \Delta - \sum_{i \in block} \nu_i\ .$$

- Proportional distribution:

$$V_i^{new} = \Delta_{free} \times \frac{v_i^{old}}{\sum_j v_j^{old}},\ \text{where } j \in \text{ unblock}, j \neq k.$$

Multi-level filtration system

The processing method sequentially processes all component types with multi-stage filtering.

1. Filter by manufacturer: Intel, AMD or "All manufacturers".
2. Filtering by graph: Checking for at least one variant (integrated or discrete).
3. Compatibility filtering:
   - Processor socket = motherboard socket;
   - The memory type (DDR4/DDR5) of the processor and the MP match;
   - The MP form factor matches the case;
   - Video card length ≤ case space.
4. Energy balance: ∑Consumption×1.4→ Fuel selection.
5. Optimization modes:
   - "Economy": bottom 33% or max 300 options;
   - "Balance": 33-66 percentile or 300 options;
   - "Productivity": top 33% or max 300 options.

Processing sequence: Processor → Motherboard → RAM → Cooling system → Video card → Case → Monitor → Storage devices → Peripherals → Power supply → UPS.

To demonstrate the method, let's consider processor selection. The database contains 347 processor models.

Table 2 shows the numerical values of the evaluation of four different scenarios of such selection.

Scenario 1: Even distribution (20% each) → Intel Xeon E5-1650 V4 (6 cores, 4.0 GHz turbo, TDP 140 W, 28.51 USD). Total cost: 937.05 USD. A compromise solution with a balance of parameters.

Scenario 2: Price priority (100% price) → Intel Celeron E1600 (2 cores, 2.4 GHz, 14 USD). Total cost: 657.22 USD (-29.9%). Demonstrates the risk of extreme optimization: outdated processor from 2008, unsuitable for modern medical systems.

Scenario 3: Multithreading (49% cores + 51% turbo) → Intel Xeon E5-2650 V4 (12 cores, 2.9 GHz turbo, 74 USD). Total cost: 1008.72 USD (+7.6%). The number of cores has doubled, exactly matching the priority.

Scenario 4: Frequency + Efficiency (66% turbo + 19% base + 15% TDP) → Intel Core i5-10105F (4 cores, 3.7/4.4 GHz, TDP 65 W, 81.16 USD).

Table 2. **Numerical priority estimates for four processor selection scenarios**

Parameter	Scenario 1 (Balance)	Scenario 2 (Price)	Scenario 3 (Core+Frequency)	Scenario 4 (Frequency+TDP)
Price (%)	20	100	0	0
Number of cores (%)	20	0	49	0
Base frequency (%)	20	0	0	19
Turbo frequency (%)	20	0	51	66
TDP (%)	20	0	0	15

Total cost: 734.91 USD (–21.6%). Highest frequency (4.4 GHz) at lowest TDP (65 W), modern platform from 2021.

Table 3 summarizes the different scenarios.

To evaluate system performance in different price segments, testing was conducted with the same priorities (20% balance) but different modes. Table 4 shows a comparative analysis for the three optimization modes.

Discussion of Results

The study revealed the following advantages and disadvantages of the implemented approach. Experimental testing confirmed the following advantages of the adapted method:

- Precise priority matching: the system selected components that best matched the weighting coefficients. The price-priority scenario selected the cheapest processor ($14), the core-priority scenario selected a 12-core processor, and the frequency-priority scenario selected a 4.4 GHz processor.
- Flexibility: the ability to interactively change priorities in real time with automatic recalculation of results within 0.5-1.5 seconds.
- Mathematical validity: The Saaty method ensures correct selection, unlike empirical approaches. The consistency index of all matrices did not exceed 5.4%, with a standard of <10%.
- Multi-level validation: the system checks 15+ compatibility parameters before launch, eliminating technically impossible configurations. Configuration preservation: Fernet AES-128 cryptographic protection with PBKDF2HMAC (100,000 iterations) ensures the security of your settings.

***Table* 3. Comparative analysis of the results of the four scenarios**

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Processor model	Xeon E5-1650 V4	Celeron E1600	Xeon E5-2650 V4	Core i5-10105F
Year of release	2016	2008	2016	2021
Cores / Threads	6 / 12	2 / 2	12 / 24	4 / 8
Turbo frequency (GHz)	4.0	2.4	2.9	4.4
TDP (W)	140	65	105	65
Processor price ($)	28.51	14.00	74.00	81.16
Total cost ($)	937.05	657.22	1008.72	734.91
Deviation from baseline	0%	–29.9%	+7.6%	-21.6%
Multitasking	High	Very low	Very high	High
Performance per core	High	Very low	Medium	Very high
Energy efficiency	Low	High	Medium	High
Relevance of the platform	Outdated	Critically outdated	Outdated	Modern
Suitability for medical systems	Acceptable	Unsuitable	Excessive	Optimal

Table 4. **Comparative analysis of three optimization modes**

General characteristics	Parameter		
	Saving	Balance	Productivity
Price segment	Bottom 33%	33-66%	Top 33%
Total cost ($)	612.49	1045.49	3084.44
Correlation	1.0×	1.7×	5.0×
PROCESSOR			
Model	Intel Core i5-7320	AMD Ryzen 5 7600	Intel Core i9-14900
Generation	7th (Kaby Lake)	Zen 4 (2023)	14th (Raptor Lake)
Cores / Threads	4 / 4	6 / 12	24 / 32
Maximum frequency (GHz)	3.6	5.1	5.8
TDP (W)	65	65	219
Price ($)	72.80	189.99	567.72
Budget share	11.9%	18.2%	18.4%
MOTHERBOARD			
Model	Asus PRO Q570M	MSI MAG B650M	Asus PRIME Z790-V
Chipset	Q570 (Intel)	B650 (AMD)	Z790 (Intel)
Memory support	DDR4	DDR5	DDR5
Price ($)	154.00	187.17	239.99
Budget share	25.1%	17.9%	7.8%
RAM			
Volume (GB)	16-24	32	48
Type	DDR4-2400	DDR5-5200	DDR5-6400
Price ($)	37.00	119.99	239.99
STORAGE DRIVE			
Interface	SATA III	NVMe PCIe 4.0	NVMe PCIe 5.0
Read speed (MB/s)	500	7000	12000
Volume (GB)	240	500	2000
VIDEO CARD			
Availability	Integrated	Integrated	NVIDIA GeForce RTX 4070 (12GB)
SUITABILITY			
Electronic document management	✓ Excellent	✓ Excellent	✓ Excellent
Medical information system	✓ Acceptable	✓ Excellent	✓ Excellent
X-ray image processing	✗ Limited	✓ Acceptable	✓ Excellent
3D MRI/CT reconstruction	✗ Not applicable	✗ Limited	✓ Excellent
Duration of operation (years)	3-5	5-7	7-10
CONCLUSION	Basic office tasks	Universal solution	Diagnostic centers

Identified limitations:

- Outdated components: The extreme price optimization scenario selected a 2008 processor. Filtering by relevance is required (excluding models older than 5–7 years).
- Outdated platforms: Scenarios 1–3 selected platforms from 2008–2016. An additional criterion for platform relevance is required.
- Lack of forecasting: The system does not take into account long-term maintenance costs and the likelihood of failure.
- Static prices: Data in the Excel file may be out of date. Integration with online aggregators is necessary.

Conclusions

The study confirmed the effectiveness of the adapted Saaty hierarchy process for multi-criteria selection of computer components in medical institutions.

The developed dynamic parameter balancing system with support for locking individual criteria significantly simplifies the configuration process compared to the classic method. Experimental validation on four scenarios demonstrated the algorithm's high accuracy in tracking user-set priorities. The difference in cost between the "Economy" (USD 612), "Balanced" (USD 1.045), and "Performance" (USD 3.084) configurations reflects adequate configuration scaling.

For medical institutions, this method allows for IT costs to be optimized by up to 38% over three years of operation while maintaining the required performance level. An economic analysis using the example of the Drabivsky Center for PMD Research and Production (Drabivsky Center for PMD) showed savings of USD 5.052 per eight workstations over three years.

A comparative analysis with existing approaches (Hotline.ua, BRAIN.com.ua, PCPartPicker, Telemart.ua) showed that the developed system is unified, combining mathematically sound multi-criteria analysis, comprehensive compatibility testing, dynamic parameter balancing, and cryptographic configuration protection. At the same time, the need for additional mechanisms was identified: filtering by component relevance, setting minimum performance thresholds, integration with online price aggregators, and a long-term cost forecasting module.

Further research areas include expanding the database through automated web scraping, adding a machine learning module to predict the likelihood of component failure, developing a mobile app for quickly assessing configurations, and scaling the system for corporate clients with centralized IT fleet management.

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ОПТИМІЗАЦІЯ БАГАТОКРИТЕРІАЛЬНОГО ВИБОРУ КОМП'ЮТЕРНИХ КОМПЛЕКТУЮЧИХ НА ОСНОВІ АНАЛІЗУ ІЄРАРХІЙ

Вступ. У статті розглядається проблема оптимального вибору компонентів для персональних комп'ютерів у закладах охорони здоров'я в умовах обмеженого бюджету та множинних критеріїв оцінювання. Визначено, що традиційні методи вибору компонентів, засновані на емпіричному досвіді або простому порівнянні характеристик, є недостатньо ефективними для прийняття оптимальних рішень у ситуаціях багатокритеріального вибору. Обґрунтовано застосування адаптованого аналітичного ієрархічного процесу Томаса Сааті як ефективного інструменту для математично обґрунтованого багатокритеріального вибору компонентів з урахуванням технічної сумісності, енергетичного балансу та пріоритетів користувачів.

Метою статті є висвітлення особливостей адаптації методу аналізу ієрархій Сааті як проблеми багатокритеріального вибору компонентів комп'ютера та демонстрація його практичного застосування в контексті оптимізації ІТ-витрат медичних закладів з урахуванням технічної сумісності, енергетичного балансу та динамічного балансування пріоритетів користувачів.

Методи. Адаптований метод ієрархічного аналізу Томаса Сааті застосовано для багатокритеріального вибору компонентів з урахуванням технічної сумісності, енергетичного балансу та пріоритетів користувачів.

Результати. Подано систему динамічного балансування вагових коефіцієнтів з підтримкою блокування окремих параметрів, що забезпечує постійну суму ваг, що дорівнює 100%, зберігаючи при цьому пропорційність розблокованих параметрів. Розроблено багаторівневу систему фільтрації компонентів з урахуванням технічної сумісності (сокетів, форм-факторів, типів пам'яті тощо), енергетичного балансу системи, фізичних обмежень та трьох режимів оптимізації. Проведено детальний порівняльний аналіз наявних підходів до вибору компонентів на українському та світовому ринках, який виявив їхні обмеження та переваги.

Висновок. Наведено конкретні приклади застосування методу при виборі процесора для закладу охорони здоров'я, що демонструють чотири сценарії з різними пріоритетами параметрів та трьома режимами оптимізації. Експериментальна валідація підтвердила високу точність алгоритму у відстеженні визначених користувачем пріоритетів. Проведено аналіз економічної ефективності розробленого системного застосування, який продемонстрував потенційну економію до 25% ІТ-бюджету для закладів охорони здоров'я при збереженні необхідного рівня продуктивності.

Ключові слова*: метод аналізу ієрархій Сааті, багатокритеріальний вибір, вибір компонентів, заклади охорони здоров'я, динамічне балансування параметрів, оптимізація рішень, ІТ-інфраструктура.*