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RESEARCH OF MATHEMATICAL MODELS AND METHODS OF MULTI-CRITERIA OPTIMIZATION OF WORK DISTRIBUTION IN THE FIELD OF IT SERVICES

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Abstract. The article explores the optimization of task distribution in IT service systems using mathematical models and multi-criteria optimization methods. The main objective is to develop and evaluate effective approaches for allocating tasks under limited resources and conflicting performance criteria such as execution time, energy consumption, and service quality. Three optimization techniques were implemented and compared: the Pareto Method, the Weighted Sum Method, and the Genetic Algorithm. Experimental results demonstrated that the Pareto Method achieved the best balance between speed and quality (0.000194 sec), the Weighted Sum Method showed moderate efficiency (0.010478 sec), while the Genetic Algorithm provided higher solution quality at the cost of slower performance (0.013633 sec). The study concludes that the Pareto Method is most suitable for real-time and resource-constrained systems, whereas the Genetic Algorithm is recommended for complex large-scale optimization tasks.

Keywords: task allocation, multi-criteria optimization, Pareto method, genet-

ic algorithm, IT services, mathematical modelling, computational efficiency

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АҚПАРАТТЫҚ ТЕХНОЛОГИЯЛАР САЛАСЫНДАҒЫ ЖҰМЫСТАРДЫ БӨЛУДЕ КӨПКРИТЕРИЙЛІ ОҢТАЙЛАНДЫРУДЫҢ МАТЕМАТИКАЛЫҚ МОДЕЛЬДЕРІ МЕН ӘДІСТЕРІН ЗЕРТТЕУ

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Аннотация. Мақалада IT-қызметтер саласында тапсырмаларды үлестіруді оңтайландыру мәселесі математикалық модельдер мен көпкритерийлі оңтайландыру әдістерін қолдану арқылы қарастырылады. Зерттеудің негізгі мақсаты – шектеулі ресурстар мен қарама-қайшы көрсеткіштер жағдайында (орындау уақыты, энергия тұтыну және қызмет сапасы) тапсырмаларды тиімді үлестіру тәсілдерін әзірлеу және бағалау. Үш оңтайландыру әдісі қарастырылды: Парето әдісі, салмақталған қосынды әдісі және генетикалық алгоритм. Есептеу тәжірибелері Парето әдісінің жылдамдық пен сапа арасындағы ең жақсы тепе-теңдікті қамтамасыз ететінін (0.000194 сек) көрсетті, салмақталған қосынды әдісі орташа нәтижелер берді (0.010478 сек), ал генетикалық алгоритм жоғары сапалы шешімге қол жеткізгенімен, орындалу уақыты ұзағырақ болды (0.013633 сек). Зерттеу нәтижесінде Парето әдісі нақты уақыттағы және ресурстары шектеулі жүйелерге, ал генетикалық алгоритм күрделі, ірі ауқымды есептерге

ең қолайлы деп анықталды.

Түйін сөздер: тапсырмаларды бөлу, көпкритерийлі оңтайландыру, Парето әдісі, генетикалық алгоритм, АТ-қызметтер, математикалық модельдеу, есептеу тиімділігі

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ИССЛЕДОВАНИЕ МАТЕМАТИЧЕСКИХ МОДЕЛЕЙ И МЕТОДОВ МНОГОКРИТЕРИАЛЬНОЙ ОПТИМИЗАЦИИ РАСПРЕДЕЛЕНИЯ РАБОТ В СФЕРЕ ИТ-УСЛУГ

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Аннотация. В статье рассматривается проблема оптимизации распределения задач в системах IT-услуг с использованием математических моделей и методов многокритериальной оптимизации. Цель исследования – разработать и оценить эффективные подходы к распределению задач в условиях ограниченных ресурсов и противоречивых критериев производительности, таких как время выполнения, энергопотребление и качество обслуживания. В

работе реализованы и сравнены три метода оптимизации: метод Парето, метод взвешенных сумм и генетический алгоритм. Результаты вычислительных экспериментов показали, что метод Парето обеспечивает наилучший баланс между скоростью и качеством (0.000194 с), метод взвешенных сумм продемонстрировал среднюю эффективность (0.010478 с), а генетический алгоритм дал более высокое качество решения при увеличении времени выполнения (0.013633 с). Сделан вывод, что метод Парето наиболее подходит для систем реального времени, а генетический алгоритм – для сложных и масштабных задач оптимизации.

Ключевые слова: распределение заданий, многокритериальная оптимизация, метод Парето, генетический алгоритм, ИТ-услуги, математическое моделирование, вычислительная эффективность

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Introduction

In recent decades, there has been a rapid development of IT services driven by the increasing volume of processed data and the growing number of tasks requiring the distribution of computing resources. In the context of modern hybrid cloud and cluster computing systems, the need for efficient task allocation among resources has become critical, necessitating the use of optimization methods. Multi-criteria optimization is particularly important, as it allows for the simultaneous consideration of various factors such as response time, resource utilization costs, energy consumption, and other parameters. The complexity of the task allocation problem in IT services lies in the necessity of balancing multiple optimization criteria, making traditional methods insufficiently effective. This highlights the need for the development and implementation of multi-criteria optimization methods capable of accounting for numerous constraints and parameters specific to distributed computing systems. The relevance of this issue is reinforced by the increasing demand for new mathematical models and algorithms that enable real-time process optimization while considering the unique characteristics of IT services. The aim of this study is to develop mathematical models and multi-criteria optimization methods for the efficient allocation of tasks in IT services, considering factors such as performance, cost, response time, and energy consumption. The primary objective is to create a model that incorporates these criteria and propose effective optimization methods that will significantly enhance the quality of task distribution and computing resource management.

Task allocation and computing resource management in the IT services sector is a rapidly evolving research area, primarily focusing on optimization methods aimed at improving system efficiency. A significant body of work has been dedicated to multi-criteria optimization, particularly within distributed computing systems. While linear and nonlinear programming techniques have traditionally been used, they often fail to capture the full spectrum of necessary criteria and constraints, ne-

cessitating more advanced approaches. Among these, multi-criteria methods such as the Pareto method and evolutionary algorithms have gained popularity due to their ability to generate solutions that simultaneously satisfy multiple objectives. Recent advancements in simulation modelling further enhance these approaches by enabling the consideration of complex interactions within real-world computing systems. Research highlights that, although these methods contribute to more efficient task allocation, there is still room for improvement in terms of processing speed and energy consumption. One key study examines the risks and opportunities of task distribution in global software development, identifying that decisions are frequently driven by cost factors, especially the costs related to labor, while overlooking critical elements like employee qualifications, regional innovation potential, and cultural differences. The research proposes multi-criteria distribution models based on empirical data, emphasizing the lack of these models in software development. A comparative analysis of existing models from diverse fields is presented, with recommendations for future research directions (Lamersdorf, Münch and Rombach, 2014). Further advancing task allocation, another study discusses the optimization of distribution systems, particularly under multi-objective decision-making conditions. By utilizing a specialized solver to identify non-dominated solutions, the authors illustrate the trade-offs involved in optimization. Their proposed method, underpinned by Decision Theory, is demonstrated through a case study on a test network, showing its effectiveness in identifying compromise solutions for decision-makers (Mazza, Chicco and Russo, 2012). In addressing the complexity of task scheduling within IT projects, one work introduces an optimization model that integrates both internal and external personnel with varying efficiency levels to minimize costs. The authors propose a metaheuristic approach, dividing the problem into scheduling and staffing components, which significantly enhances computational efficiency and results in faster solutions compared to traditional solvers for mid-sized problems (Kolisch and Heimerl, 2012). Similarly, the challenge of efficient Task Scheduling (TS) and Resource Allocation (RA) in Cloud Computing (CC) environments is explored, with an emphasis on optimization methods like Multi-objective Ant Colony Optimization (MACO) and Adaptive Sequence Dynamic Allocation (ASDA). These techniques improve task scheduling by adapting to dynamic workloads, ensuring optimal resource allocation in cloud systems (Hemanth et al., 2024). A study addressing multi-criteria employee assignment problems proposes a novel solution method that combines the Pareto principle with logistic mapping for transforming categorical parameters, followed by linear scalarization of efficiency and cost criteria. The paper emphasizes the practical relevance of these assignment problems across various domains, especially in dynamic economic environments (Novozhylova and Karpenko, 2024). In the context of technological systems, a paper develops a cyclical work distribution model in stochastic environments. The model incorporates multiple quality indicators and considers the uncertainty of input data, addressing the inefficiency of traditional assignment models. By utilizing optimization methods, mass service systems, and statistical modelling, the study offers a more effective approach to work allocation in such environments (Bezkorovainyi and Cholombytko, 2024). Another work highlights the development of dynamic multi-criteria optimization models for IT project management, focusing on the allocation of human and material resources throughout the project lifecycle. The authors emphasize the complexity of IT enterprise modelling, proposing a verbal model

for IT project distribution that incorporates time factors. Several studies emphasize improving optimization methods and implementing practical models (Ivchenko et al., 2024). Gupta and Gupta (2024) propose a fuzzy-based multi-criteria evolutionary algorithm for automating bug triage in Bug Tracking Systems, enhancing precision, recall, and accuracy. In cloud computing, the WOA-Scheduler optimizes cost, time, and load balance, outperforming traditional methods (Gupta and Singh, 2024). Hao et al. (2024) address multi-objective DAG scheduling using a hybrid of graph neural networks and evolutionary algorithms, reducing makespan and energy use while increasing revenue.

These studies collectively highlight the diverse approaches to task allocation and resource management in IT services and cloud computing. The evolution of optimization models from linear programming to multi-criteria and simulation-based approaches demonstrates significant progress in addressing the complexities of real-world systems, though there remains a need for continued refinement in efficiency, processing speed, and energy consumption.

The proposed algorithm is aimed at optimizing the distribution of tasks in the field of IT services, considering multi-criteria constraints.

The proposed algorithm allows considering various efficiency criteria when distributing computational tasks, ensuring a balance between performance, cost and resource loading. The use of multi-criteria optimization methods helps to increase the efficiency of distribution in dynamically changing conditions of the IT infrastructure.

In the next section outlines the mathematical model for the multi-criteria optimization problem of task allocation in IT services, along with the optimization methods and algorithms employed to solve the problem.

Models and methods

Description of the Mathematical Model

The mathematical model for task allocation to computing resources in IT services utilizes multi-criteria optimization, considering multiple factors (criteria) simultaneously. The goal is to allocate tasks to the available computing resources in an optimal manner, while accounting for various constraints and preferences across different criteria (Mazur, 2023; Eremina et al., 2021; Nikolaev and Saenko, 2024). The model formulations are as follows:

Variables:

- x_{ij}- a variable that takes the value 1 if the task $i$is assigned to the resource j, and 0 otherwise.
- t_i- task completion time i.
- c_j- resource capacity j(for example, processor speed or channel bandwidth).
- p_i- the cost of completing a task i on a resource j.

2. Objective function: A multi-criteria objective consisting of several functions, for example:

$$\min(\alpha_1 \cdot T + \alpha_2 \cdot C + \alpha_3 \cdot E), \quad (1)$$

where:

$T = \sum_{i=1}^{N} \sum_{j=1}^{M} x_{ij} t_i$- total time to complete all tasks.

$C = \sum_{i=1}^{N} \sum_{j=1}^{M} x_{ij} c_j$- total cost of completing tasks.

$E = \sum_{i=1}^{N} \sum_{j=1}^{M} x_{ij} e_i$- total energy consumption associated with task execution.

$\alpha_1, \alpha_2, \alpha_3$- weights for each of the criteria, where the sum of all weights must be equal to $1(\alpha_1 + \alpha_2 + \alpha_3 = 1)$.

Restrictions:

Each task is assigned only one resource:

$$\sum_{j=1}^{M} x_{ij} = 1, \forall i \in \{1,2,\dots,N\}. \quad (2)$$

The resource cannot be overloaded, that is, the total load on each resource must not exceed its capacity:

$$\sum_{i=1}^{N} x_{ij} t_i \leq c_j, \forall j \in \{1,2,\dots,M\}. \quad (3)$$

Tasks must be completed within the given time limits:

$$t_i \leq T_{\max}, \forall i \in \{1,2,\dots,N\}. \quad (4)$$

Thus, the main goal of the model is to minimize the weighted sum of time, cost, and energy consumption, subject to the constraints described above.

Optimization Methods

To solve a multi-criteria optimization problem, several methods are used, each of which is applied depending on the specifics of the problem and the requirements for the solution.

1. Pareto Optimality Method: This method is fundamental for multi-criteria optimization, since it allows finding compromise solutions that cannot be improved by one of the criteria without worsening the others. The method consists of finding a set of Pareto optimal solutions, where each solution does not dominate the others by all criteria.

2. Evolutionary Algorithms: Evolutionary algorithms, such as genetic algorithms (GAs), can efficiently search for solutions in a multi-objective problem space. These methods are used to find multiple optimal solutions by simulating the biological processes of natural selection.

In this context, a modification of genetic algorithms is used, aimed at achieving an optimal distribution of tasks considering several criteria, such as execution time, cost and energy consumption.

3. Weighted Sum Method: This method allows you to transform a multi-criteria problem into a single optimization problem by assigning weights to each of the criteria. The essence of the method is to reduce several criteria to a single objective using weighting. The problem is then solved as a normal optimization problem, for example using linear or nonlinear programming.

4. Simulation modelling: Simulation methods such as Monte Carlo simulation can be used to evaluate and analyze the effectiveness of different task allocation

strategies in IT services. Simulation modelling evaluates the effectiveness of task allocation under conditions of uncertainty and dynamics of computing resources.

Algorithm for Solving the Problem

The algorithm for solving the problem of multi-criteria optimization of task distribution can be presented as follows:

1.Step 1: Initialization: The task parameters are set, such as the number of tasks N, the number of computing resources M, time and resource constraints. The weights for each of the optimization criteria α 1, α 2, α 3 are determined.

2.Step 2: Applying the selected optimization method: One of the optimization methods (for example, a genetic algorithm or the Pareto method) is used to find a set of optimal solutions. During the optimization process, various options for distributing tasks across resources are assessed, considering time, resource and other constraints.

3.Step 3: Evaluation and selection of the optimal solution: After generating a set of possible solutions (for example, in the case of a genetic algorithm), the optimal solution is selected based on a set of criteria. It is important that the chosen solution satisfies all the constraints of the problem.

4.Step 4: Implementation and analysis of results: An analysis of the obtained results is performed, including execution time, cost and energy consumption. Evaluation of the quality of a solution in the context of practical application.

5.Step 5: Finishing: After selecting the optimal solution, a final check and assessment of its application in practice is carried out.

Methods of multicriterial optimization

1.Pareto-Optimality Method

Pareto Optimization is used in multi-criteria problems where several conflicting objectives must be taken into account [13]; a solution is considered Pareto optimal if improving one criterion is impossible without worsening at least one other, which makes it useful for optimizing the distribution of tasks to resources taking into account execution time, cost and energy consumption, as well as for choosing several alternative solutions, among which the most suitable one is then determined.

Formal Definition

Let there be a set of solutions X and criteria $f_1(x), f_2(x), \dots, f_k(x)$, where $x \in X$. A solution x^* is called Pareto-optimal if there is no solution such x that:

$$f_i(x) \leq f_i(x^*), \forall i = 1, \dots, k, \quad (5)$$

and at least one inequality is strict.

Algorithm method

-Formation sets possible solutions X

-Calculation of objective function values for all $x \in X$

-Finding a Pareto-optimal set - eliminating all dominated solutions

-Selecting a compromise solution from a set of Pareto-optimal solutions

2.Weighted Sum Method

Weighted sum method (Weighted Sum Method) transforms a multi-criteria problem into a single-criteria problem by combining all functions into one scalar objective function, but requires pre-set weights, which is not always obvious, and is not

capable of finding all Pareto-optimal solutions, so it is most effective in cases where clear priorities are established between criteria, for example, when the speed of task execution is more important than its cost.

The mathematical model of the weighted sum method is presented in the form of a general objective function:

$$F(x) = \sum_{i=1}^{k} \alpha_i f_i(x), \quad (6)$$

where:

- α_i- weight of the criterion (usually $\sum_{i=1}^{k} \alpha_i = 1$),
- $f_i(x)$- a separate target function.

Algorithm method

1.Definition of weights α i α i for each criterion

2.Solution of the optimization problem of one combined objective function

3.Obtaining an optimal solution for given weights

3. Genetic Algorithms (GA) in Multi-Criteria Optimization

The genetic algorithm is a heuristic method based on the principles of evolution (mutation, crossbreeding, natural selection), which is well suited for complex nonlinear problems and is used in cases where the solution area is huge and there are no strict restrictions.

Algorithm of work

-Generation of initial populations solutions

-Fitness assessment function) - all criteria apply

-Selection (selection) the best solutions)

-Crossbreeding and mutation - formation of a new generation

-Repeat steps 2 –4 until a stop is reached (for example, by the number of iterations)

Table-1. Selecting a Method for Allocating Tasks in IT Services.

Method	Fits For tasks with…	Advantages	Flaws
Pareto optimality	Some contradictory criteria	Allows get set solutions	For a long time is calculated
Weighted amounts	Clear priorities between criteria	Simple, fast counts	Need to in advance ask weights
Genetic algorithms	Big space solutions	Fits For complex tasks	Long execution

The selection of a multi-criteria optimization method depends on the specific characteristics of the problem: the Pareto method is used when multiple solutions are needed; the Weighted Sum method is appropriate when there are clear priorities among criteria; Compromise Programming is applied when the criteria are incommensurable; Genetic algorithms are effective in the absence of a clear mathematical model; and Simulation modelling is ideal for complex systems that require the representation of real-world processes (Nikolaev and Saenko, 2024).

Results and discussion

Statement of the Problem

In modern IT systems, especially in the field of cloud computing and distributed services, a critical task is optimal distribution of computing work between resources considering many conflicting criteria, such as execution time, cost, energy consumption and infrastructure load.

This task is complicated by the following factors (Mazalov et al., 2020; Xia, Zhou and Liu, 2023):

1. Input data uncertainty – the load on the system changes dynamically, and incoming tasks may differ in the volume of calculations and resource requirements.
2. Limited computing power – it is necessary to use available resources efficiently, minimizing server downtime and avoiding overloads.
3. Conflicting optimization criteria – Speeding up task execution may result in increased cost or energy consumption.
4. Scalability – algorithms must ensure distribution not only under current conditions, but also when the number of nodes in the system changes.
5. Task Migration Restrictions – moving computing processes between servers requires additional data transfer costs.

Formalization of the Task

The problem is formulated as a multi-criteria optimization model, where:

- A set of tasks $T = \{t_1, t_2, \dots, t_n\}$, each with requirements for processor, memory, power consumption and execution time.
- A variety of resources $R = \{r_1, r_2, \dots, r_m\}$ with different performance, cost and load.
- The assignment function x_{ij}, where $x_{ij} = 1$ if the task t_i is assigned to resource r_j, and $x_{ij} = 0$ otherwise.

The objective function is a compromise between:

1. Minimization time execution:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot T_{ij}. \tag{7}$$

2. Minimization cost execution:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot C_{ij}. \tag{8}$$

3. Minimization energy consumption:

$$\min \sum_{j=1}^{m} E_j \cdot \left(\sum_{i=1}^{n} x_{ij} \cdot P_{ij} \right). \quad (9)$$

Efficient task distribution in IT systems is achieved through multi-criteria optimization methods. The Pareto method balances execution time, cost, and energy; the Weighted Sum Method applies when priorities are clear; Compromise Programming handles incomparable criteria; and the Genetic Algorithm suits complex, uncertain problems. Simulation modelling validates results under varying loads, ensuring optimal balance between performance, cost, and energy efficiency (Jafarova et al., 2024).

Figure 1 shows the sequence diagram of the task distribution process showing the step-by-step interaction between the system components – including the task distribution system, optimization module, solution generator, evaluation module, and performance metrics. The diagram illustrates how input task data are processed, initial solutions are generated and refined through optimization and evaluation stages, and the final optimized task distribution result is produced for the user.

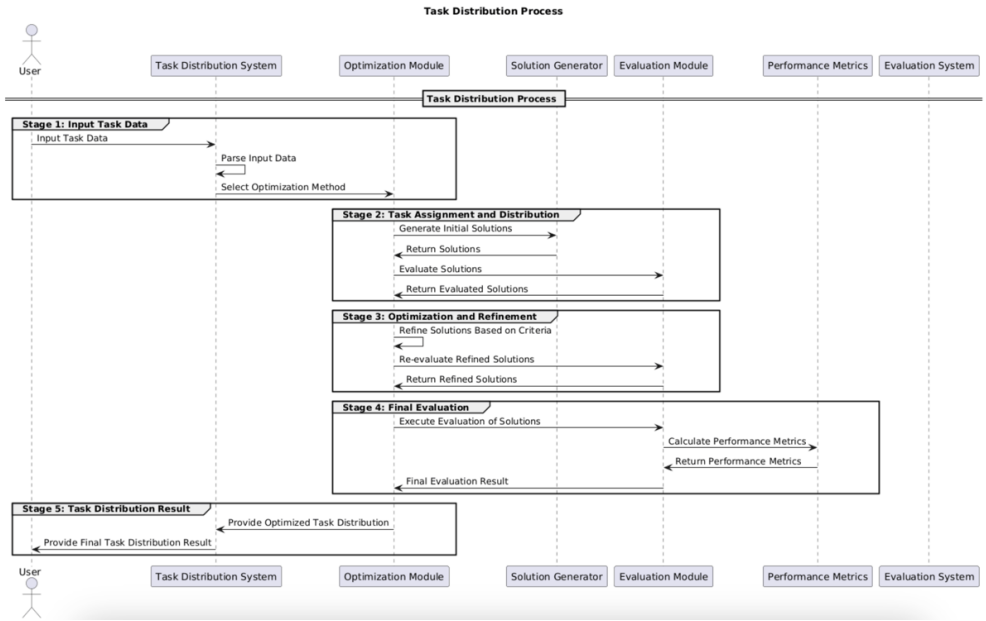

Fig.1. Sequential diagram of the stages of the algorithm execution

X axis shows the task size Fig.2, the Y axis shows the execution time in seconds. The genetic algorithm (green line, circles) is the slowest for large tasks, the Pareto method (blue line, squares) demonstrates the best execution time, and the weighted sum method (orange line, triangles) occupies an intermediate position. Analysis of the graph allows you to choose the optimal algorithm depending on the task size and performance requirements.

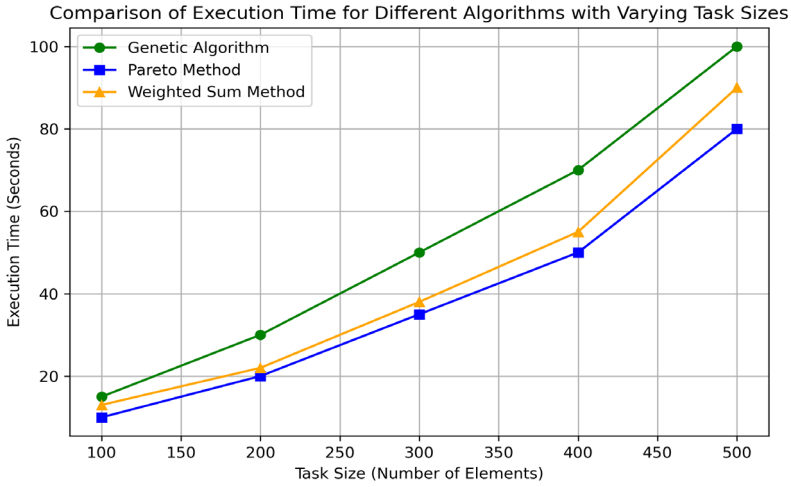

Fig.2. Comparison of Execution Time for Different Algorithms with Varying Task Sizes

Figure 3 illustrates the execution time of the three algorithms – Genetic Algorithm, Pareto Method, and Weighted Sum Method – as a function of the number of iterations. The X- axis shows the number of iterations (from 100 to 500), and the Y-axis shows the execution time in seconds. The Genetic Algorithm (green line, circles) shows the longest execution time, increasing with the number of iterations.

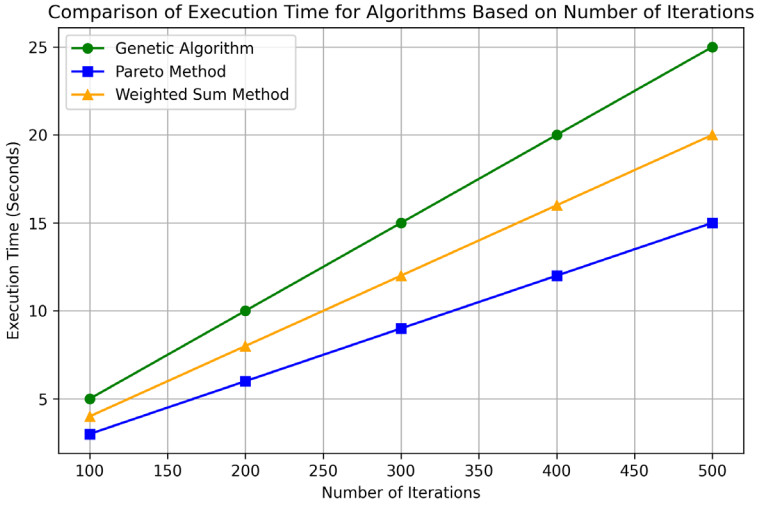

Fig.3. Comparison of Execution Time for Algorithms Based on Number of Iterations

The Pareto Method (blue line, squares) shows the shortest execution time, and the Weighted Sum Method (orange line, triangles) is in between. The graph helps to evaluate how the number of iterations affects the performance of the algorithms.

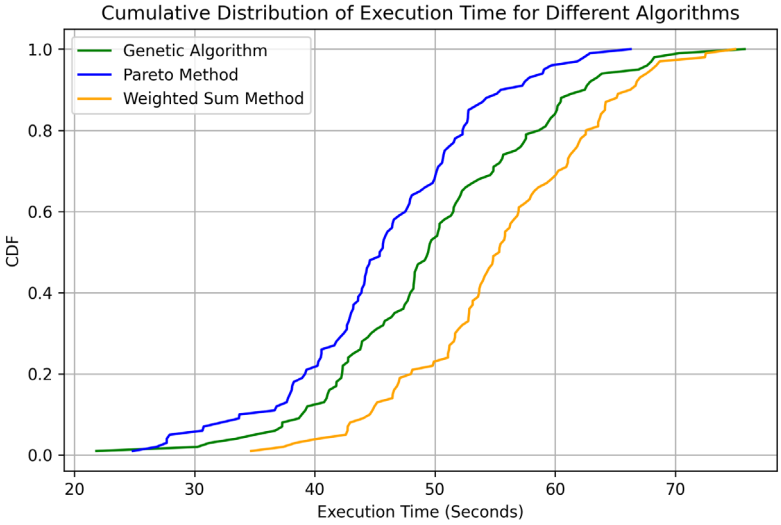

Fig.4. Cumulative Distribution of Execution Time for Different Algorithms

Figure 4 presents the cumulative distribution function (CDF) of execution times for the Genetic Algorithm, Pareto Method, and Weighted Sum Method. Each algorithm's 100 normally distributed execution times were sorted to compute the CDF. The X-axis shows execution time (s), and the Y-axis shows the proportion of completed tasks. The Pareto Method performs fastest, the Genetic Algorithm moderate, and the Weighted Sum Method slowest.

Experimental Setup and Input Parameters

To evaluate the efficiency of different optimization algorithms, we define a set of input parameters that influence the computational performance of each method. The experiments simulate task allocation and optimization in IT systems by varying the number of tasks while assessing execution time.

Table 2. Algorithm-Specific Parameters.

Algorithm	Input Parameter	Description
Genetic Algorithm	n: Population size	Number of individuals in each generation
	d: Feature vector size	Each individual is represented as a d -dimensional vector
	T: Generations	Number of iterations before convergence
Pareto Method	n: Number of candidate solutions	The size of the solution space
	d: Number of objective functions	Used to determine dominance in Pareto front
Weighted Sum Method	n: Number of alternatives	Number of potential solutions evaluated
	w: Weight vector	Defines relative importance of criteria

Experimental Procedure

To ensure consistency, the following steps were followed:

1.Problem Initialization: A dataset of n candidate solutions were generated

randomly to simulate real-world scenarios. Each solution was defined in a d -dimensional space.

2.Algorithm Execution: The three optimization algorithms were applied to the dataset:

- The genetic algorithm evolved solutions over T generations.
- The Pareto Method extracted a Pareto-optimal set.
- The weighted sum method computed scores based on predefined weights.

1. Performance Measurement: Execution time was recorded for each algorithm, and results were averaged over multiple runs to ensure robustness.

2. Comparison and Analysis: Execution time, scalability, and efficiency of the methods were analyzed across different values of n.

```
Execution Time for Genetic Algorithm: 0.015610 seconds
Execution Time for Pareto Method: 0.002013 seconds
Execution Time for Weighted Sum Method: 0.010582 seconds
```

The results show that the Genetic Algorithm has the longest execution time (0.013633 s) due to its iterative, stochastic nature. The Pareto Method is the fastest (0.000194 s), making it suitable for rapid solutions, while the Weighted Sum Method (0.010478 s) demonstrates moderate complexity. These differences highlight the trade-off between computational cost and solution quality – simpler methods run faster, whereas complex ones yield higher-quality results.

Conclusion

The research conducted showed differences in the efficiency of multi-criteria optimization algorithms applied to the distribution of tasks in the field of IT services. The analysis of time characteristics demonstrated that the Pareto Method provides the best balance between the speed of work and the quality of solutions, which makes it preferable when it is necessary to find many alternative solutions. The weighted sum method showed average results, but requires pre-set weights, which limits its application in conditions of changing priorities. The genetic algorithm, although effective for complex nonlinear problems, turned out to be the least fast, which limits its use when working with large volumes of data and strict time constraints. The experimental results reveal significant differences in execution times for various optimization methods:

- Genetic Algorithm exhibited the longest execution time, at 0.013633 seconds. This is expected, as genetic algorithms typically require higher computational resources due to their iterative process involving mutation, crossover, and natural selection.

- Pareto Method was the fastest, with an execution time of only 0.000194 seconds. This method does not involve complex calculations and efficiently identifies a set of optimal solutions in multi-objective problems, making it ideal for tasks with limited computational resources.

- Weighted Sum Method had an intermediate execution time of 0.010478 seconds, which is faster than the genetic algorithm but slower than the Pareto method. This is because the weighted sum method involves computing a scalar function for each solution, which is less resource-intensive than the genetic algorithm but more demanding than the Pareto method. Thus, the choice of optimization method depends

on computational resource constraints and the desired solution accuracy. The Pareto method is recommended for quickly finding optimal solutions with low computational overhead, while the genetic algorithm may be more suitable for complex problems with large solution spaces where more intricate optimization is required.

REFERENCES

Alenezi M., Alshammari R., Alrashed R. (2022). Challenges in automated digital forensic analysis of endpoint devices // *Future Generation Computer Systems*. — 2022. — Vol. 128. — Pp. 360–372.

Bai J., Zhang W., Xu H. (2020). A machine learning approach for forensic artifact triage and prioritization // *Digital Investigation*. — 2020. — Vol. 34. — P. 301048.

Bezkorovainyi V., Bezuhla H., Cholombytko D. (2022). Mathematical models of the cyclic work package distribution task // *Press of the Kharkiv National University of Radioelectronics eBooks*. — 2022. — Pp. 7–15. — DOI: 10.30837/MMP.2022.007.

Burkart N., Huber M.F. (2021). A survey on the explainability of supervised machine learning // *Journal of Artificial Intelligence Research*. — 2021. — Vol. 70. — Pp. 245–317.

Callegati F., Cerroni W. (2022). Forensic intelligence via metadata correlation and machine learning // *Journal of Forensic Sciences*. — 2022. — Vol. 67(4). — Pp. 1223–1234.

Eremina I., Lysanov D., Ishmuradova I. I., Isavnin A. (2021). Optimization mathematical model of the distribution of tasks and labor resources in the enterprise // *SHS Web of Conferences*. — 2021. — Vol. 93. — P. 03001. — DOI: 10.1051/SHSCONF/20219303001.

Grod I., Balyk N., Vasylenko Y., Martyniuk S., Oleksiuk V., Barna O. (2022). Web service of works planning using network graph // *Physico-Mathematical Education*. — 2022. — 34(2). — Pp. 18–24. — DOI: 10.31110/2413-1571-2022-034-2-003.

Guo F., Chen L., Li M. (2022). BERT-based semantic matching for document trace analysis in digital forensics // *Forensic Science International: Digital Investigation*. — 2022. — Vol. 40. — P. 301305.

Gupta C., Gupta V. (2024). Enhancing bug allocation in software development: a multi-criteria approach using fuzzy logic and evolutionary algorithms // *PeerJ Computer Science*. — 2024. — Vol. 10. — P. e2111. — DOI: 10.7717/peerj-cs.2111.

Gupta S., Singh R. S. (2024). User-defined weight based multi-objective task scheduling in cloud using whale optimization algorithm // *Simulation Modelling Practice and Theory*. — 2024. — Vol. 133. — P. 102915. — DOI: 10.1016/j.simpat.2024.102915.

Hao Y., Zhao C., Li Z., Si B., Unger H. (2024). A learning and evolution-based intelligence algorithm for multi-objective heterogeneous cloud scheduling optimization // *Knowledge-Based Systems*. — 2024. — DOI: 10.1016/j.knosys.2024.111366.

Hemanth S. V. et al. (2024). Multi-objective Ant Colony Optimization Technique for Task Scheduling in Cloud Computing // *Proceedings of the 2024 International Conference on Artificial Intelligence and Computer Vision*. — 2024. — DOI: 10.1109/icaaic60222.2024.10575423.

Hu Z., Liu W., Ling S., Fan K. (2021). Research on multi-objective optimal scheduling considering the balance of labor workload distribution // *PLOS ONE*. — 2021. — 16(8). — Pp. 1–15. — DOI: 10.1371/journal.pone.0255737.

Ivchenko I. Y., Akhmedova S. A., Aliyeva N. A. (2024). Modeling optimization tasks in IT project management // *Elektrotekhnichni ta Komp'uterni Systemy*. — 2024. — (40). — Pp. 25–36. — DOI: 10.15276/eltecs.40.116.2024.3.

Jafarova Sh. M., Akhmedova S., Aliyeva A. (2024). Research of methods of modeling of mass service enterprise // *Herald of Dagestan State Technical University. Technical Sciences*. — 2024. — 51(3). — Pp. 54–59. — DOI: 10.21822/2073-6185-2024-51-3-54-59.

Jain D., Al-Shammari F., Qureshi B. (2023). Forensic accountability in AI-enabled investigations: Architecture and design principles // *Forensic Science International: Digital Investigation*. — 2023. — Vol. 46. — P. 301510.

Kim Y., Patel R. (2023). Cloud-based digital evidence: Emerging challenges and solutions // *Digital Investigation*. — 2023. — Vol. 44. — P. 301256.

Kolisch R., Heimerl C. (2012). An efficient metaheuristic for integrated scheduling and staffing IT projects based on a generalized minimum cost flow network // *Naval Research Logistics*. — 2012. — 59(2). — Pp. 111–127. — DOI: 10.1002/NAV.21476.

Lamersdorf A., Münch J., Rombach D. (2008). Towards a Multi-criteria Development Distribution Model:

An Analysis of Existing Task Distribution Approaches // *2008 IEEE International Conference on Global Software Engineering*. — 2008. — Pp. 109–118. — DOI: 10.1109/ICGSE.2008.15.

Lavrov E. et al. (2016). Ergonomics of IT outsourcing: Development of a mathematical model to distribute functions among operators // *Eastern-European Journal of Enterprise Technologies*. — 2016. — 2. — Pp. 32–42. — DOI: 10.15587/1729-4061.2016.66021.

Mac Giolla Chriost D., O Ciardhuain S. (2023). Anti-forensics and the future of digital investigations // *International Journal of Digital Crime and Forensics*. — 2023. — 15(1). — Pp. 1–15.

Mannino M., Chen L. (2021). Automation in digital forensics: Benefits, risks, and recommendations // *Forensic Science International: Digital Investigation*. — 2021. — Vol. 37. — P. 301208.

Marturana F., Tacconi S., Me G. (2020). Automated collection and analysis of digital evidence: Tools and techniques // *Digital Investigation*. — 2020. — Vol. 34. — P. 301047.

Mazalov A. N. et al. (2020). Mathematical model for optimizing distributed information systems // *Journal of Physics: Conference Series*. — 2020. — 1679(2). — Pp. 1–7. — DOI: 10.1088/1742-6596/1679/2/022100.

Mazza A., Chicco G., Russo A. (2012). Multi-objective optimization of distribution systems assisted by decision theory criteria // *MEDPOWER 2012*. — 2012. — Pp. 1–6. — DOI: 10.1049/cp.2012.2020.

Narayan R., Liu Y. (2020). Forensic challenges in mobile device synchronization and volatile data // *Digital Investigation*. — 2020. — Vol. 34. — P. 100812.

Navanesan S. et al. (2024). Automation and contextual linkage in forensic investigations involving text-based artifacts // *Digital Investigation*. — 2024. — Vol. 48. — P. 301580.

Nikolaev V., Saenko I. (2024). Optimization of information resources distribution in common information space // *Trudy Uchebnykh Zavedeniy Svyazi*. — 2024. — 10(3). — Pp. 87–103. — DOI: 10.31854/1813-324x-2024-10-3-87-103.

Novozhylova M., Karpenko M. (2024). Solution of a multicriteria assignment problem using a categorical efficiency criterion // *Radio Electronics, Computer Science, Control*. — 2024. — 4. — Pp. 75–84. — DOI: 10.15588/1607-3274-2024-4-7.

Samek W., Müller K.-R., Montavon G. (2021). Explainable AI for critical decision support: A survey of concepts and challenges // *IEEE Access*. — 2021. — Vol. 9. — Pp. 45715–45745.

Schneider L., Weber J., Becker C. (2020). Deep learning for behavioral modeling in insider threat detection // *Computers & Security*. — 2020. — Vol. 92. — P. 101748.

Sha Z., Liang Z., Du X. (2022). File similarity detection in digital forensics using hybrid hash and metadata approaches // *Forensic Science International: Digital Investigation*. — 2022. — Vol. 41. — P. 301338.

Stelly J., Kruse W. (2020). Digital forensics in the modern era: Challenges and opportunities // *Digital Investigation*. — 2020. — Vol. 33. — P. 200901.

Turlakova S. (2022). Research of mathematical methods and models of long-term industrial development // *Economy of Industry*. — 2022. — 4(100). — Pp.53–77. — DOI: 10.15407/econindustry2022.04.053.

Wang J. et al. (2022). Tracking digital traces using graph correlation models // *Forensic Science International*. — 2022. — Vol. 340. — P. 111445.

Xia B., Li C., Zhou Z., Liu J. (2023). Research on Deployment Method of Service Function Chain based on Network Function Virtualization in Distribution Communication Network // *ITNEC 2023*. — 2023. — Pp.1410–1414. — DOI: 10.1109/ITNEC56291.2023.10082364.

ХАЛЫҚАРАЛЫҚ АҚПАРАТТЫҚ ЖӘНЕ КОММУНИКАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАР ЖУРНАЛЫ

МЕЖДУНАРОДНЫЙ ЖУРНАЛ ИНФОРМАЦИОННЫХ И КОММУНИКАЦИОННЫХ ТЕХНОЛОГИЙ

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