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METHOD OF SELECTION OF ERP SYSTEMS USING MULTI-CRITERIAL OPTIMIZATION MODELS

Purpose. To develop theoretical and practical recommendations for a scientifically based selection of Enterprise Resource Planning (ERP) systems and their composition with the use of economic and mathematical modeling for businesses in Ukraine.

Methodology. The theoretical and methodological basis of the study is fundamental principles of modern economic theory, the scientific work of scientists. During the research, the following methods were used: mathematical modeling (to solve the problem of multicriterial optimization consisting in finding optimal variants of the introduction of automated information systems for the management of industrial enterprises); graphic (for visual presentation of research results); analytical and structural (by optimizing the choice of ERP by analytical hierarchical approach).

Findings. A complex approach with the use of modeling is proposed to find such an ERP that meets and harmonizes the requirements of the company under conditions of uncertainty. A system of methodological guidelines adapted and suitable for use in practice is developed.

Originality. A optimal multi-criteria selection method of the ERP system under conditions of uncertainty is developed, which allows the company to select ERP systems according to their own optimality criteria.

Practical value. The results of the study will allow companies to reduce the costs of implementing ERP systems, the proposed method and algorithm can be implemented in applications for computers and mobile devices to automate the process of choosing an ERP system and its composition.

Keywords: *method, model, optimization, criterion, ERP, expert analysis, SAP*

Introduction. Extensive and continuous improvement of information technology, the presence of many ERP systems on the market as well as the absence of skilled experts, technical knowledge and experience for the optimal choice of ERP software, make the development of methods and tools for choice among many ERP analogues necessary. The choice of ERP to implement is a complex decision that has important economic consequences. The task of choice requires a compromise between technical characteristics, functional capabilities and financial problems, and can be formulated as a multi-criteria decision-making problem. Therefore, it is necessary to develop mathematical methods and algorithms that will allow finding a scientifically proven optimal variant of the implementation of ERP in the company.

Analysis of the recent research and publications. Many scientists such as Moutaz Haddara [1], Jun-Der Leu [2], P. K. Dey [3], Kanchana V. [4], C. López [5], solved the problems of choosing ERP systems with the help of mathematical modeling methods. In the works of these authors the feasibility of using economic and mathematical modeling to find the optimal choice is proved. It is proposed that the decision criteria should be chosen according to the needs of the enterprise and considering its economic and technical situation.

Unsolved aspects of the problem. The current methodology for making heuristic decisions on the multicriteria choice of ERP systems under conditions of uncertainty is quite complicated, and only allows finding a rational version instead of the optimal version of the implementation of the system.

Objectives of the article. The study of theoretical and practical problems in the management of the implementation, or the modernization of the ERP, determines the following objectives:

- to develop an economic and mathematical approach that allows us to find the optimal version of the ERP implementation, considering many criteria that are formulated by all parties involved in the implementation of the ERP;
- to develop a decision-making algorithm that can be implemented in an application software.

Presentation of the main research. Modern companies in Ukraine implement or update the ERP systems software, so they face the problem of choosing a system that best fits the requirements of the company. The management of the company faces conditions of uncer-

tainty and complex choices between many criteria of implementation of the system in the company, their coordination and their implementation in practical production activities. There are many ERP systems and their configurations. It is necessary to refine the range of systems that can be analyzed in depth.

The choice of a system is a multi-criteria problem with such criteria.

Completeness. The software must integrate all aspects of the production activity, from the purchase of materials and the hiring of the workforce to the sales of finished product.

Convenience and ease of work: the implemented system must be up to date. Communication with the system should be intuitive for employees. This will facilitate implementation and staff training.

Adjustment. The system should allow the creation of new input and output documents and system settings without the participation of the developer.

Flexibility. The software must be adapted to the conditions of the company. ERP should not require a change in the structure or the business operation.

Integrity. Changes made at any given time in the system should automatically update all system modules.

Cost. Development and maintenance systems must meet the budget of the company.

System Requirements. It is important to choose an ERP, which is independent of hardware, operating system and database system.

The reputation and the manufacturer's capabilities: market share of sellers, customer feedback, availability of consultants, examples of implemented systems, infrastructure support and system support.

ERP after-sales support and training. The ERP provider must provide training for users, as well as software support after implementation in the enterprise.

System Backup. Database backup is performed to ensure the security and reliability of ERP systems.

Reporting and Analysis Features. The team must be able to develop their own tools of reporting and analysis and implement them in the system for future use.

Integration with other applications. ERP modules must be integrated and provide a continuous exchange of data with all other manufacturers systems or modules.

Online Integration. The software should support e-business, e-commerce, and electronic transaction exchange.

Real-time operation. ERP modules must operate in real time, handle batch information processing and provide uninterrupted 24-hour service of the production process.

Financing options. Investment calculation options, software license, technical support, cloud data space subscriptions.

It is necessary to consider all the possible criteria, when choosing the ERP system and the structure and configuration of the modules implemented.

Criteria defining the qualitative characteristics of the system should be presented as quantitative indicators for applying optimization algorithms and expert estimation methods [6].

The experience of operating the systems indicates that for companies implementing an ERP system, the most important criterion is the cost of the system [7]. The importance of other criteria varies according to the needs of certain companies. The place in the hierarchy of the criteria can vary from one company to another. Structure of the importance of system selection criteria and its configuration may vary within an enterprise depending on the considerations and estimates of business units. In addition, the hierarchy of criteria varies over time [8]. Therefore, to draw scientifically and economically reasoned conclusions about the choice of the system, it is necessary to evaluate the different variants of ERP implementation and choose optimal ones among them. Generally, in companies, such a choice is made manually and includes a significant proportion of subjective evaluations that ultimately result in no optimal but rational solution, which may seem attractive but not optimal [9]. Therefore, it is necessary to develop formal mathematical procedures that could be programmed and implemented in the software to allow the accounting of optimal estimates for the management of the enterprise in the complex tasks of investing in a new ERP or to modernize the existing system.

At present, the Ukrainian market is represented by a wide range of ERP-class systems: SAP, SAP Business One, ORACLE, IT Enterprise, Parus, 1C: Enterprise, ERP-Infor Baan, GrossBee, Galaxy.

Consider the economic-mathematical model of multicriteria optimization.

The task of multicriteria optimization includes a set of n solutions, a set of objective functions f_i $i = 1, ..., k$, and a set of m constraints. Objective functions and constraints are functions of variable solutions. The objective of optimization is to find the maximum

$$\overline{y} = f(x) = (f_1(x), f_2(x), \ldots, f_k(x),$$

with constraints

$$e(x) = (e_1(x), e_2(x), \ldots, e_m(x)) < \Omega;$$

$$\overline{x} = (x_1, x_2, \ldots, x_n\} \in X;$$

$$\overline{y} = (y_1, y_2, \ldots, e_k) \in Y,$$

where $\overline{x}$ is the vector of solutions; $\overline{y}$ is the vector of objective functions; X is admissible solutions space; Y is the space of objective functions. Constraints $e(x) < \Omega$, determine the set of possible solutions. The set of feasible solutions X_f is defined as a set of vectors of solutions x satisfying constraints

$$X_f = \{x \in X | e(x) \le \Omega\}.$$

The area of the admissibility in the space of the objective functions has the form

$$Y_f = f(X_f) = \bigcup_{x \in X_f} \{f(x)\}.$$

The optimal value of the multicriteria task $f(x)$ corresponds to the largest value of the area created by the three criteria of Fig. 1.

In the case of multi-criterion optimization, the set X_f is partially determined. The solution represented by point B (Fig. 2) is better than the solution for point C. In

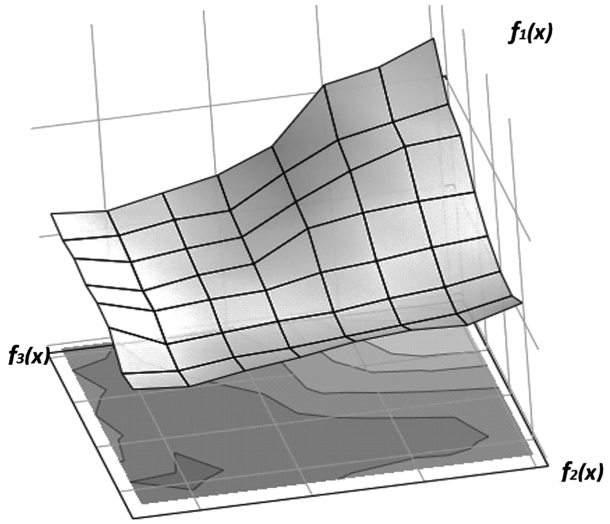

Fig. 1. Interconnection of the criteria

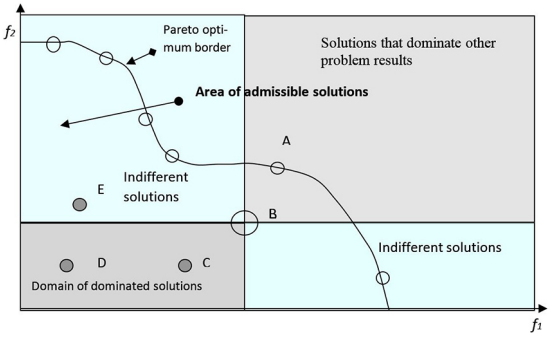

Fig. 2. The optimality of Pareto in the space of the objective functions and the relationship between the solutions

the same way, *C* is better than *D* for equal values. Then if *u* and *v* are two vectors of the objective functions then

$$u = v \Leftrightarrow \forall i \in \{1,2,...,k\} : u_i = v_i;$$
$$u \geq v \Leftrightarrow \forall i \in \{1,2,...,k\} : u_i \geq v_i;$$
$$u > v \Leftrightarrow u \geq v \wedge u \neq v.$$

It turns out that $B > C$, $C > D$ and therefore $B > D$. Comparing *B* and *E*, we find that these solutions do not exceed each other, that is, $B\neg > E$ and $E\neg > B$. In this case, domination takes place.

$$a \succ b \,(a \text{ dominates } b) \Leftrightarrow f(a) > f(b);$$
$$a \succeq b \,(a \text{ weakly dominates } b\} \Leftrightarrow f(a) \geq f(b);$$
$$a \sim b \,(a \text{ indifferent towards } b) \Leftrightarrow$$
$$\Leftrightarrow (f(a)\neg \geq f(b)) \wedge (f(b)\neg \geq f(a).$$

Fig. 2 shows the dominant areas, the dominated areas and areas indifferent from the point B. In Fig. 2 there is one point *A*, among *B, C, D, E* for which the vector of solutions is not dominated by any vector of solutions. This means that *A* is the optimum Pareto. In Fig. 2, white circles indicate optimal solutions that are indifferent to each other. These solutions form the optimal set of Pareto, and the vector of objective functions forms the Pareto optimal limit.

Therefore, in multi-criteria problems, there is no single optimal solution, and there is a set of optimal solutions. None of these solutions can be determined as better without further definition of its advantage.

Therefore, the multi-criteria optimization algorithm must satisfy the following conditions:

- the distance between the non-dominant limit and the optimal Pareto limit should be minimized;
- in the optimization process, not all criteria should be used, but only a subset of criteria located on or in the immediate vicinity of the Pareto optimality;
- it is advisable to determine the concessions, for certain criteria of a certain subset of criteria, to find optimal solutions for the objective functions.

Consider the algorithm for finding the optimal ERP system which we determine using a variety of criteria.

We have several criteria $f_1(x), f_2(x), ..., f_k(x)$. Among them we find the dominant criterion which is Pareto optimal. Let us get the dominant criterion, which lies on the Pareto optimality limit. Restrictions in the task will be $X_f = \{x \in X | e(x) \leq \Omega\}$. The restrictions include other criteria fulfilling the expressions $f_i(x) \neq f_i(x)$, $j = \overline{1,k};\ i = \overline{1,k}.$ The criteria included in the multicriteria optimization problem have optimum at different points of the space of admissible solutions. It is impossible to be in all these points at the same time, it is necessary to optimize one of these criteria, and other criteria should be constrained. We will assume distinct information systems chosen to implement as variables x_i $(x_i = \overline{0,1})$, then accomplish the optimization and find ERP system to agree to the optimal value of this criterion. Since the ERP system is chosen according to many competing criteria, the next step is the selection of another objective function (criterion) and the calculation of the optimal solution of this problem by these criteria. At the same time, the criterion $f_i(x)$, under which the previous optimization was performed, becomes one of the constraints. The criterion $f_i(x)$ is weakened by 1–5 % of its optimal value. The solution of this optimization problem will give another ERP system for implementation.

We carry out *k* iterative steps, each of which performs the optimization in turn according to all the criteria of a subset, which are on the optimal limit of Pareto or in the immediate vicinity of this one. As a result, we obtain several solutions (Fig. 3) for the criteria that determine the set of possible options for implementing ERP systems at the enterprise. Criteria indicated in Fig. 3 are competing, so to determine the best option, each of the criteria is supplemented by a subset of indicators that characterize the effectiveness of the system.

In general, indicators have different impacts on the effectiveness of a specific ERP. Therefore, for each of the system indicators, priority is given using the expert estimation method [10]. The indicators vary from 0 to 1, the sum of the priorities for a criterion is equal to one. In turn, the business-customer has its own preferences and an estimate of the benefits of the systems implemented [11]. As a result, ERP systems have different perspectives and implementation priorities [12, 13]. Therefore, it is advisable to determine the priorities φ_i of the implemented ERP

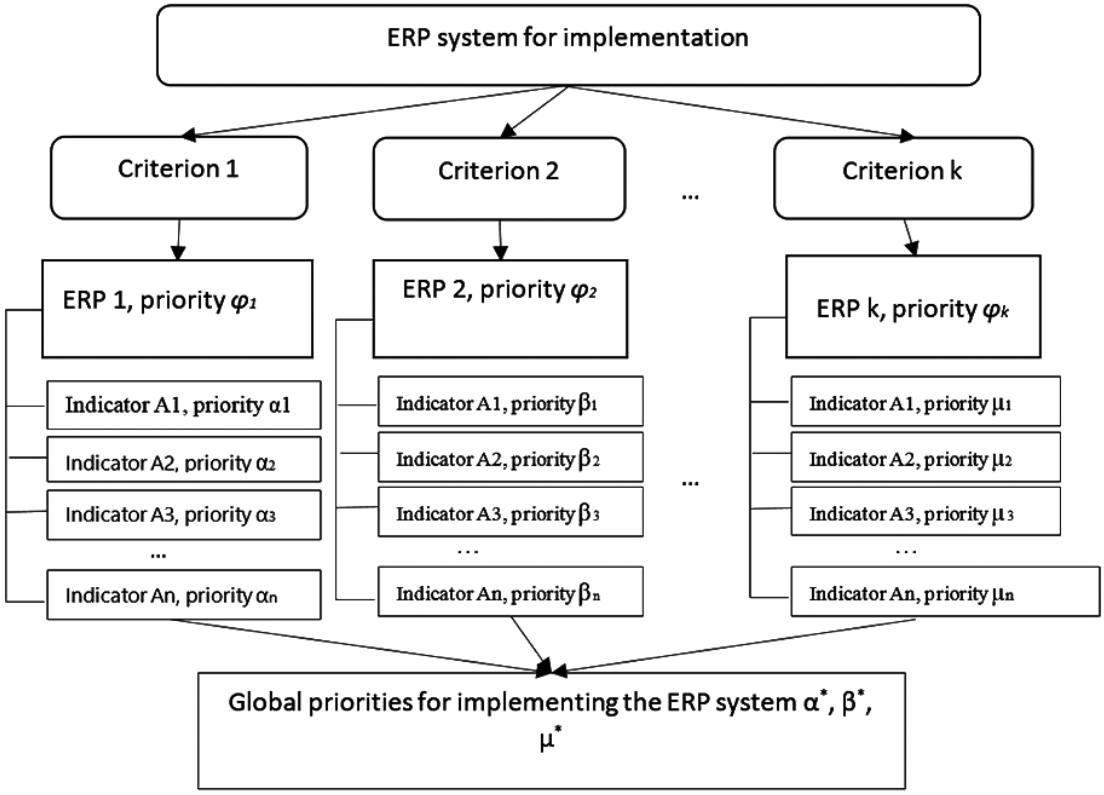

Fig. 3. ERP system selection algorithm

Table

Comparative analysis of ERP systems

Indicator	IT-Enterprise	1C: Enterprise	Parus	ERP SAP SAPBusiness One	Oracle E-Business Suite
Manufacturer	IT-Enterprise	LLC "1C Kyiv, Ukraine"	Parus, Kyiv, Ukraine	SAP AG, Germany	Oracle, USA
Enterprise scale	Small, medium, large	Small, medium, large	Small, medium, large	Small, medium, large	Medium, large
Deadlines of implementation	6 months– 1.5 years or more	3 months – 1 year or more	4 months – 1 year or more	1–5 years or more	1–5 years or more
Estimated cost of implementation	Cost of one work place – from $100 and above	License for one workplace is $150–600. The cost of implementing one workplace is $200–1000	The cost of a license for one workplace is $1–2 thousand. Cost of implementation is 100–200 % of the price of the solution	About $ 390000 USD for 50 users (includes license fee and implementation costs)	Cost of a solution for one workplace is about $5 thousand. The final cost is comparable to SAP
Pricing policy	It is necessary to negotiate with IT-Enterprise or intermediary	Fixed price for a license	Fixed price for a license	Complex and opaque	Complicated. It is necessary to negotiate through the intermediary of the PARUS corporation
The cost of maintenance	In one year, about 10–20 % of the cost of the system	Support is provided by the developer, not 1C. Up to 30 % of software costs	30 % per year from software costs	In one year about 18 % of the cost of the system	In one year about 15–20 % of the cost of the system
Availability of professionals and developers firms	Huge range of availability	Quite a big range of availability	Moderate range of availability	Not enough	Not enough
Scalability of ERP	perfect	good	good	good	good
Operating System	Windows	Windows	Windows	Windows, Unix, Linux	Windows, Unix, Linux

systems by an expertise. The sum of all the priorities φi is equal to one. In the last step, we calculate global priorities. For each criterion, an indicator of the global priority is calculated, respectively α *, β *, ..., μ *. The priority indicators indicate the portion of weight, or the advantages of some ERP systems to others, considering all the criteria and limits retained in the specific multicriteria task of the optimal choice of the ERP system. Calculations are made according to the following formulas

$$\begin{cases} \alpha^* = \sum_{i=1}^{n} \alpha_i * \varphi_1 \\ \beta^* = \sum_{i=1}^{n} \beta_i * \varphi_2 \\ \dots \\ \mu^* = \sum_{i=1}^{n} \mu_i * \varphi_k \end{cases};$$

$$\alpha^* + \beta^* + \dots + \mu^* = 1.$$

The ERP system that will be recommended for implementation has a global priority that meets the formula

$$F_{\max} = \max(\alpha^*, \beta^*, \dots, \mu^*).$$

The research conducted for machine building companies has allowed comparative analysis of ERP systems commonly used in Ukraine. The data presented in Table should be considered when formulating the criteria and constraints when selecting an ERP system for a given company.

Conclusions.

1. The method of multicriteria comparative estimation for the selection of the best ERP systems is proposed.

2. A two-stage algorithm for optimal determination of the best systems by many criteria and an optimal choice among them using expert estimates and analytical hierarchical analysis is proposed.

3. Based on the research carried out for machine-building enterprises, a comparative analysis of the common ERP systems in Ukraine was made. It is advisable to consider the analysis when formulating the criteria and constraints for choosing an ERP system for an enterprise.

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Метод вибору ERP системи із використанням багатокритеріальних оптимізаційних моделей

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Мета. Розробка теоретичних і практичних рекомендацій щодо науково-обґрунтованого вибору систем ERP (Enterprise Resource Planning) та їх складу для підприємств України із застосуванням економіко-математичного моделювання.

Методика. Теоретичною й методологічною основою дослідження є фундаментальні положення сучасної економічної теорії, наукові праці вче-

них. У процесі дослідження використовувалися такі методи: економіко-математичного моделювання (для розв'язання багатокритеріальної оптимізаційної задачі пошуку оптимальних варіантів упровадження автоматизованих інформаційних систем для управління промисловими підприємствами); графічний (для наочного представлення результатів дослідження); аналітичний і структурно-логічний (при оптимізації вибору ERP за аналітично-ієрархічним підходом).

Результати. Запропоновано комплексний підхід для знаходження в умовах невизначеності з використанням моделювання, такого складу ERP, що задовольняє та узгоджує вимоги до системи як окремих підрозділів служб, так і всього підприємства в цілому. Розроблена чітка система методичних положень, придатних і зручних для використання на практиці.

Наукова новизна. Розроблено метод оптимального багатокритеріального вибору ERP системи в умовах невизначеності, що дає змогу підприємству здійснювати вибір ERP систем за власними критеріями оптимальності.

Практична значимість. Отримані результати дослідження дозволять підприємствам знизити видатки на впровадження ERP систем, запропонований метод і алгоритм можуть бути реалізовані в додатках для комп'ютерів і мобільних пристроїв для автоматизації процесу вибору системи ERP та її складу.

Ключові слова: *метод, модель, оптимізація, критерій, ERP, експертний аналіз, SAP*

Метод выбора ERP системы с использованием многокритериальных оптимизационных моделей

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Цель. Разработка теоретических и практических рекомендаций для научно-обоснованного выбора систем ERP (Enterprise Resource Planning) и их состава для предприятий Украины с использованием экономико-математического моделирования.

Методика. Теоретической и методологической основой исследования являются фундаментальные положения современной экономической теории, научные труды ученых. В процессе исследования использовались следующие методы: экономико-математического моделирования (для решения многокритериальной оптимизационной задачи поиска оптимальных вариантов внедрения автоматизированных информационных систем для управления промышленными предприятиями), графический (для наглядного представления результатов исследования); аналитический и структурно-логический (при оптимизации выбора ERP по аналитически-иерархическому подходу).

Результаты. Предложен комплексный подход для нахождения в условиях неопределенности с использованием моделирования, такого состава ERP, который удовлетворяет и согласовывает требования к системе как отдельных подразделений и служб, так и всего предприятия в целом. Разработана четкая система методических положений, пригодных и удобных для использования на практике.

Научная новизна. Разработан метод оптимального многокритериального выбора ERP системы в условиях неопределенности, что позволяет предприятию осуществлять выбор ERP систем по собственным критериям оптимальности.

Практическая значимость. Полученные результаты исследования позволят предприятиям снизить расходы на внедрение ERP систем, предложенный метод и алгоритм могут быть реализованы в приложениях для компьютеров и мобильных устройств для автоматизации процесса выбора системы ERP и ее состава.

Ключевые слова: *метод, модель, оптимизация, критерий, ERP, экспертный анализ, SAP*

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