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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ. МАТЕМАТИКА

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CHOICE OF SOFTWARE DEVELOPMENT TECHNOLOGIES BASED ON PARETO-OPTIMAL SOLUTIONS

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Summary. *The choice of the software development technology based on the methods of multicriteria selection is considered in the paper. Technologies of software life cycle are analyzed. Alternatives and evaluation criteria for software development technologies are formed. The methodology of forming Pareto set with the subsequent Pareto-optimal choice on it is proposed. The considered procedure for identifying the relative importance of the criteria makes it possible to narrow down Pareto set and, reelatively, to reduce the number of possible solutions. The numerical example of the proposed methodology for applying Pareto set construction is given. As a result, the procedure for identifying the relative importance of the criteria made it possible to narrow down Pareto set and hence reduce the number of possible solutions up to two alternatives.*
Key words*: software development technologies, Pareto set, pareto-optimal choice, alternative.*

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Statement of the problem. The correct choice of software development technologies (software) plays an important role in the successful implementation of software projects. First of all, this choice depends on the specific subject area and the content of the stated tasks. For example, software for oil and gas transportation management can be developed by one technology, and the personnel subsystem of the enterprise information management system by another, etc. This can be explained by the fact that at present there are a number of technologies for the software life cycle implementation [1–3]: waterfall, waterfall with intermediate control, V-model, iterative, incremental, spiral, etc. In addition, in the process of mobile devices development (smartphones, tablets and other gadgets), a new class of mobile application development technologies was developed on the platforms iOS, Android, Windows Phone, etc. [4].

Therefore, the task of finding and selecting of software development tools set should be performed on the basis of a number of criteria, which are not always uniquely defined, as they have different priorities for the decision maker (DM). In general, such problem can be considered as poorly structured, and it is reasonable to use multicriteria selection methods for its solution.

Analysis of the available publications and research results. Numerous publications deal with the analysis and selection of software development technologies [1–7, 10–12, etc.]. For example, such technologies in terms of their advantages and disadvantages are described

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in papers [1–3]. The comparative analysis of the current state of mobile application development on iOS, Android, and Windows Phone platforms is given in paper [4]. Approaches to selecting software development tools using expert evaluation, fuzzy sets, criteria ranking, and others are presented in papers [5–8]. However, the basic approaches of Edgeworth-Pareto principle according to which the best solution should be chosen among the Pareto-optimal solutions is not presented or applied in the described approaches.

The objective of the paper is to solve the problem of multicriteria selection of software development technologies by forming Pareto set and subsequent Pareto-optimal selection on such a set.

Statement of the problem and presentation of the basic material. The set containing alternatives that are not worse than others at least according to one criterion is called Pareto set, or non-dominant alternatives set [9]. In order to construct such set, we can use the algorithm described in paper [10], the implementation of which is determined by the following three conditions:

1. Availability of possible (permissible) alternative solutions set $A=\{a_1,a_2,...,a_i,...,a_n\}$.
2. Availability of vector criterion $K=(K_1,K_2,...,K_m), m\geq 2$, defined on the set of possible solutions *A*.
3. Availability of advantage relation $\underset{A}{>}$, given on the set of possible solutions *A* (for example $a_1 \underset{A}{>} a_2$).

The first step of the algorithm is to compare sequentially the first solution a_1 with all others $a_2,...,a_n$. The purpose of this comparison is to check the correctness of the relations $a_1 \underset{A}{>} a_i$ and $a_i \underset{A}{>} a_1$ at each $i=2,...,n$. In the case of truth for some *i* of the first relation $a_1 \underset{A}{>} a_i$, the dominant solution a_i is removed from the set *A*. In the second relation $a_i \underset{A}{>} a_1$, the solution a_1 is to be removed. If none of the above mentioned relations $a_1 \underset{A}{>} a_i$ and $a_i \underset{A}{>} a_1$ is true, then nothing should be removed. In case when comparisons of solutions a_1 are performed with all other solutions $a_2,...,a_n$ and for none $i=2,...,n$ the relation $a_i \underset{A}{>} a_1$ is fulfilled, the first solution should be remembered as non-dominant and removed from *A*. If after the first step no solutions are left in the set *A* (that is, all are removed), then the algorithm stops its operation. In this case only one non-dominant solution *a* is stored in memory. In other case (that is, when not all the solutions are removed), it is necessary to turn to the second step of the algorithm, which is similar to the first one. At first, the elements of the newly obtained set should be numbered, and then the first solution of the given set should be sequentially compared with all its other elements. Thus, at each step of the algorithm it is necessary to record the non-dominant solutions, which in the final step make Pareto set.

However, very often such a set is rather wide and the specific choice within its limits is quite challenging. In such a case, within the compensation strategy, the approach of identifying information about the relative importance of the criteria through direct DM survey is used for Pareto set narrowing. This survey reveals the relation of DM, for example, to the situation where, in order to increase the value of the more important criterion K_i by w_i units, DM is ready to neglect the losses of w_j units according to the criterion K_j provided that values are kept according to all other criteria.

In this case the coefficient of relative importance θ_{ij} expressing the proportion of the relative amount of loss and gain K_i compared with K_j is calculated [10]:

$$\theta_{ij} = \frac{w_i}{w_i + w_j}, 0 < \theta_{ij} < 1 \tag{1}$$

Regarding this indicator, the values of the selected criteria are calculated by the following formulas:

$$\begin{aligned} K_i^* &= \theta_{ij} * K_i + (1 - \theta_{ij}) * K_j; \\ K_j^* &= \theta_{ij} * K_j + (1 - \theta_{ij}) * K_i. \end{aligned} \tag{2}$$

Obtained in such a way K_i^* and K_j^* are used Pareto set narrowing procedure.

Let us consider the example of Pareto set construction by means of the algorithm described for the problem of software development technologies selection. In order to do this, we use the above mentioned software life cycle models as alternatives (*a*):

a_1 is waterfall model;
a_2 is waterfall model with intermediate control;
a_3 is V-model (as an extension of the waterfall model);
a_4 is iterative model;
a_5 is incremental model;
a_6 is spiral model.

As the criteria for evaluation of software development technologies, we use those proposed in paper [7]:

K_1 is the possibility of modular programs implementation;
K_2 is correctness control of operation with data types;
K_3 is operation with complex structure data;
K_4 is software module interface control;
K_5 is programs readability;
K_6 is programmer error protection with the ability to detect and correct software errors;
K_7 is technology flexibility, ability to generate new data types;
K_8 is completeness of software functionality implementation.

Thus, $n=6$ versions (alternatives) of the selected software development technologies and $m=8$ criteria for evaluating alternatives are involved in the Pareto set construction. In order to evaluate alternatives for each criterion, we use five-point scale and represent the results in Table 1.

Table 1

Evaluation of software development technologies according to each criterion

Alternatives	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8
a_1	4	3	4	3	1	4	3	5
a_2	5	3	3	3	2	3	4	4
a_3	2	4	2	4	4	2	3	5
a_4	5	3	2	3	2	1	4	3
a_5	3	4	3	4	5	2	4	2
a_6	4	3	5	4	4	4	3	5

According to the considered algorithm the following pairwise comparisons are carried out:

1. Let us pairwise compare a_1 and a_2; a_1 and a_3; a_1 and a_4; a_1 and a_5; a_1 and a_6 according to each of K_1-K_8 criteria.

We get:

$$a_1 \underset{K_1}{<} a_2; a_1 \underset{K_2}{=} a_2; a_1 \underset{K_3}{>} a_2; a_1 \underset{K_4}{=} a_2; a_1 \underset{K_5}{<} a_2; a_1 \underset{K_6}{>} a_2; a_1 \underset{K_7}{<} a_2; a_1 \underset{K_8}{>} a_2;$$

$$a_1 \underset{K_1}{>} a_3; a_1 \underset{K_2}{<} a_3; a_1 \underset{K_3}{>} a_3; a_1 \underset{K_4}{<} a_3; a_1 \underset{K_5}{<} a_3; a_1 \underset{K_6}{>} a_3; a_1 \underset{K_7}{=} a_3; a_1 \underset{K_8}{=} a_3;$$

$$a_1 \underset{K_1}{<} a_4; a_1 \underset{K_2}{=} a_4; a_1 \underset{K_3}{>} a_4; a_1 \underset{K_4}{=} a_4; a_1 \underset{K_5}{<} a_4; a_1 \underset{K_6}{>} a_4; a_1 \underset{K_7}{<} a_4; a_1 \underset{K_8}{>} a_4;$$

$$a_1 \underset{K_1}{>} a_5; a_1 \underset{K_2}{<} a_5; a_1 \underset{K_3}{>} a_5; a_1 \underset{K_4}{<} a_5; a_1 \underset{K_5}{<} a_5; a_1 \underset{K_6}{>} a_5; a_1 \underset{K_7}{<} a_5; a_1 \underset{K_8}{>} a_5;$$

$$a_1 \underset{K_1}{=} a_6; a_1 \underset{K_2}{=} a_6; a_1 \underset{K_3}{<} a_6; a_1 \underset{K_4}{<} a_6; a_1 \underset{K_5}{<} a_6; a_1 \underset{K_6}{=} a_6; a_1 \underset{K_7}{=} a_6; a_1 \underset{K_8}{=} a_6.$$

Here while comparing a_1 and a_6 the relation $a_6 \geq a_1$ is fulfilled, relatively a_1 is dominant and removed from consideration.

2. Let us pairwise compare a_2 and a_3; a_2 and a_4; a_2 and a_5; a_2 and a_6.

We get:

$$a_2 \underset{K_1}{>} a_3; a_2 \underset{K_2}{<} a_3; a_2 \underset{K_3}{>} a_3; a_2 \underset{K_4}{<} a_3; a_2 \underset{K_5}{<} a_3; a_2 \underset{K_6}{>} a_3; a_2 \underset{K_7}{>} a_3; a_2 \underset{K_8}{<} a_3;$$

$$a_2 \underset{K_1}{=} a_4; a_2 \underset{K_2}{=} a_4; a_2 \underset{K_3}{>} a_4; a_2 \underset{K_4}{=} a_4; a_2 \underset{K_5}{=} a_4; a_2 \underset{K_6}{>} a_4; a_2 \underset{K_7}{=} a_4; a_2 \underset{K_8}{>} a_4;$$

$$a_2 \underset{K_1}{>} a_5; a_2 \underset{K_2}{<} a_5; a_2 \underset{K_3}{=} a_5; a_2 \underset{K_4}{<} a_5; a_2 \underset{K_5}{<} a_5; a_2 \underset{K_6}{>} a_5; a_2 \underset{K_7}{=} a_5; a_2 \underset{K_8}{>} a_5;$$

$$a_2 \underset{K_1}{>} a_6; a_2 \underset{K_2}{=} a_6; a_2 \underset{K_3}{<} a_6; a_2 \underset{K_4}{<} a_6; a_2 \underset{K_5}{<} a_6; a_2 \underset{K_6}{<} a_6; a_2 \underset{K_7}{>} a_6; a_2 \underset{K_8}{<} a_6.$$

Here the relation $a_2 \geq a_4$ is fulfilled, so a_4 is dominant and is not considered further.

3. Let us compare a_3 and a_5; a_3 and a_6.

We get:

$$a_3 \underset{K_1}{<} a_5; a_3 \underset{K_2}{=} a_5; a_3 \underset{K_3}{<} a_5; a_3 \underset{K_4}{=} a_5; a_3 \underset{K_5}{<} a_5; a_3 \underset{K_6}{=} a_5; a_3 \underset{K_7}{<} a_5; a_3 \underset{K_8}{>} a_5;$$

$$a_3 \underset{K_1}{<} a_6; a_3 \underset{K_2}{>} a_6; a_3 \underset{K_3}{<} a_6; a_3 \underset{K_4}{=} a_6; a_3 \underset{K_5}{=} a_6; a_3 \underset{K_6}{<} a_6; a_3 \underset{K_7}{=} a_6; a_3 \underset{K_8}{<} a_6.$$

In this case the pairs a_3, a_5 and a_3, a_6 are not comparable relatively to $\geq$. Accordingly, a_3 is non-dominant alternative and therefore is not included in Pareto set $P = \{a_3\}$.

4. Let us compare a_5 and a_6.

We get:

$$a_5 \underset{K_1}{<} a_6; a_5 \underset{K_2}{>} a_6; a_5 \underset{K_3}{<} a_6; a_5 \underset{K_4}{=} a_6; a_5 \underset{K_5}{>} a_6; a_5 \underset{K_6}{<} a_6; a_5 \underset{K_7}{>} a_6; a_5 \underset{K_8}{<} a_6.$$

Here a_5 and a_6 are incomparable as well, thus both are included in Pareto set $P = \{a_5, a_6\}$.

Hence, the resulting Pareto set has the form $P = \{a_3, a_5, a_6\}$, therefore, the final choice of software development technology should be made from these alternatives (Table 2).

Table 2

Pareto set

Alternatives	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8
a_3	2	4	2	4	4 (3)	2 (3)	3	5
a_5	3	4	3	4	5 (3,5)	2 (3,5)	4	2
a_6	4	3	5	4	4	4	3	5

However, for this, it is necessary to have information about DM advantages benefits relatively to the chosen criteria $K_1 \div K_8$. For example, let DM, in order to increase K_6 criterion (programmer error protection), be ready to neglect K_5 criterion (program readability) by the value $K_6^* = K_5^* = 0,5$ points. Then the coefficient of relative importance is $\theta = \frac{K_6^*}{K_6^* + K_5^*} = \frac{0,5}{1} = 0,5$. Taking this into account, the new values of K_6 and K_5 criteria evaluation for each of alternatives a_3, a_5 and a_6 are as follows:

$$a_3 : K_6 = 0,5*2 + (1-0,5)*4 = 3; K_5 = 0,5*4 + (1-0,5)*2 = 3;$$

$$a_5 : K_6 = 0,5*2 + (1-0,5)*5 = 3,5; K_5 = 0,5*5 + (1-0,5)*2 = 3,5;$$

$$a_6 : K_6 = 0,5*4 + (1-0,5)*4 = 4; K_5 = 0,5*4 + (1-0,5)*4 = 4.$$

The obtained values of the criteria in brackets are presented in Table 2. The values of K_5 and K_6 criteria for alternative a_6 remained unchanged since they were the same in their advantages from the very beginning.

Further, in the same way as it is done before, we compare pairwise alternatives a_3, a_5 and a_6, taking into account the new values of K_5 and K_6 criteria.

1. Let us compare a_3 and a_5; a_3 and a_6:

$$a_3 \underset{K_1}{<} a_5; a_3 \underset{K_2}{=} a_5; a_3 \underset{K_3}{<} a_5; a_3 \underset{K_4}{=} a_5; a_3 \underset{K_5}{<} a_5; a_3 \underset{K_6}{<} a_5; a_3 \underset{K_7}{<} a_5; a_3 \underset{K_8}{<} a_5;$$

$$a_3 \underset{K_1}{<} a_6; a_3 \underset{K_2}{>} a_6; a_3 \underset{K_3}{<} a_6; a_3 \underset{K_4}{=} a_6; a_3 \underset{K_5}{<} a_6; a_3 \underset{K_6}{<} a_6; a_3 \underset{K_7}{=} a_6; a_3 \underset{K_8}{=} a_6.$$

Here alternative a_3, which is removed from the obtained Pareto set $P=\{a_3, a_5, a_6\} \Rightarrow P=\{a_5, a_6\}$ is dominant.

2. Let us compare a_5 and a_6:

$$a_5 \underset{K_1}{<} a_6; a_5 \underset{K_2}{>} a_6; a_5 \underset{K_3}{<} a_6; a_5 \underset{K_4}{=} a_6; a_5 \underset{K_5}{<} a_6; a_5 \underset{K_6}{<} a_6; a_5 \underset{K_7}{>} a_6; a_5 \underset{K_8}{<} a_6.$$

In this case, alternatives a_5 and a_6 do not dominate each other, so they remain in the set P.

Thus, the considered procedure for identifying the relative importance of the criteria makes it possible to narrow down Pareto set and, hence, to reduce the number of possible solutions. In this example, there are two of them: a_5 is incremental model and a_6 is spiral model. In order to come to the single solution, that is, to obtain one-element Pareto set, it is possible to repeat the procedure of revealing the relative importance of the criteria or to involve the additional criterion into analysis.

Conclusions. The variety of subject areas, the problems of their analysis and the availability of the sufficiently wide range of software development technologies require the efficient choice of these technologies.

Such a problem can be formulated as the multicriteria choice on solutions set (alternatives). Its solution using Pareto-optimal approach ensures the optimal choice of the best alternatives under conditions of their expected uncertainty.

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ТЕХНОЛОГІЯ РОЗРОБЛЕННЯ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ НА ОСНОВІ ПАРЕТО-ОПТИМАЛЬНИХ РІШЕНЬ

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Резюме. *Розглянуто визначення технологій розроблення програмного забезпечення на основі методів багатокритеріального вибору, базуючись на цілому ряді критеріїв, які не завжди можуть бути визначені однозначно, оскільки можуть мати різні пріоритети для особи, що приймає рішення. Проаналізовано технології реалізації життєвого циклу програмного забезпечення. Сформовано альтернативи та критерії оцінювання технологій розроблення програмного забезпечення. Запропоновано методологію формування множини Парето зі здійсненням подальшого парето-оптимального вибору на ній. Розглянута процедура виявлення відносної важливості критеріїв дозволяє звузити множину Парето та, відповідно, зменшити кількість можливих рішень. У випадку, коли множина досить широка й конкретний вибір є досить проблематичним, у межах стратегії компенсації для звуження множини Парето використано підхід виявлення інформації про відносну важливість критеріїв за допомогою прямого опитування особи, що приймає рішення. Наведено формули для вирахування коефіцієнта відносної важливості, який виражає частку відносної суми втрати й прибавки одного критерію в порівнянні з іншим. Запропонований підхід дозволяє отримати більш формалізовану процедуру для отримання єдиного оптимального рішення (одноелементного набору Парето). Якщо ж в кінцевому варіанті єдиного рішення не отримано, то можна повторити процедуру виявлення відносної важливості критеріїв або залучити до аналізу додатковий критерій. Наведено чисельний приклад запропонованої методології застосування побудови множини Парето з використанням описаного алгоритму для задачі вибору технологій розроблення програмного забезпечення. В якості альтернатив використано моделі життєвого циклу, а в якості критеріїв – критерії оцінювання технологій розроблення програмного забезпечення. В результаті процедура виявлення відносної важливості критеріїв дозволила звузити множину Парето й зменшити кількість можливих рішень до двох альтернатив.*

Ключові слова: *технології розроблення програмного забезпечення, множина Парето, парето-оптимальний вибір, альтернатива.*

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