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MODEL FOR EVALUATING THE QUALITY OF INTERFACE PROTOTYPING

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This article is devoted to the development and substantiation of a comprehensive model for evaluating the quality of interface prototyping in software systems. The relevance of the study is determined by the increasing complexity of modern interfaces and the need to make well-founded design decisions prior to the software implementation stage. The paper addresses the problem of formalizing the evaluation of prototype quality while accounting for the multidimensional nature of evaluation criteria and the significant proportion of subjective qualitative characteristics.

The proposed approach is based on a systematic integration of structural analysis methods, hierarchical mathematical modeling, multicriteria optimization, and fuzzy logic techniques. At the first stage, factors determining the quality of interface prototyping are identified and classified based on a systematic analysis of scientific sources. The identified factors are grouped according to accessibility and usability criteria, which makes it possible to take into account both technical and cognitive characteristics of human-machine interaction. At the second stage, structural and hierarchical modeling is performed using graph theory, which ensures the identification of relationships between factors, the elimination of redundancy, and the determination of their local and global priorities. The third stage is devoted to multicriteria optimization of the model, the purpose of which is to calculate normalized weighting coefficients of quality factors. This enables the transition from relative expert priorities to quantitatively defined weights that reflect the actual contribution of each factor to the formation of overall prototype quality. At the fourth, predictive stage, fuzzy modeling is applied to process subjective expert assessments. A fuzzy rule base is formed, input data are fuzzified, fuzzy logical inference is performed, and the results are defuzzified. As a result, an integrated predictive indicator of interface prototyping quality is obtained. The approach also provides for the comparison of alternative prototyping options based on fuzzy preference relations.

The obtained results can be used as a methodological basis for the development of an information technology for evaluating the quality of interface prototyping and can be implemented in the practice of designing software systems of various purposes.

Keywords: *prototyping, interface, graph theory, hierarchical mathematical modeling, prioritization, factor, ranking, optimization, fuzzy logic, fuzzy set, alternative option, quality evaluation, information technology.*

Problem Statement. Modern software products are characterized by increasing interface complexity and high requirements for the quality of human–machine interaction. The early design stage is particularly critical, as key decisions regarding the structure, logic, and visual representation of the interface are established at this phase. Insufficiently substantiated prototyping may lead to reduced accessibility and usability, which subsequently has a negative impact on the effectiveness of software systems and user satisfaction.

The evaluation of interface prototyping quality is complicated by the multidimensional nature of the relevant criteria and a significant proportion of subjective characteristics. Traditional deterministic evaluation methods do not provide sufficient accuracy in accounting for these factors, thereby limiting the ability to make well-founded design decisions. In this regard, the development of a formalized approach to evaluating the quality of interface prototyping, which combines systematic structuring of factors, their prioritization, and quantitative integration of qualitative assessments in the form of a generalized quality indicator, remains a relevant research problem.

Analysis of Recent Research and Publications. In contemporary studies, the issue of evaluating the quality of interface prototyping has attracted increasing attention from researchers, particularly with regard to the application of fuzzy modeling and hierarchical approaches for processing subjective qualitative characteristics. In particular, study [1] presents a hierarchical model for evaluating the quality of web systems, which includes the identification of key quality factors and their prioritization based on pairwise comparisons. This makes it possible to rank criteria according to their significance in the context of the design and development of digital educational systems. In [2], a methodology for assessing the quality of multimedia publication design based on fuzzy logic is proposed. In this work, linguistic variables and membership functions are defined, and a multilevel fuzzy inference model is constructed to obtain an integrated quality indicator that accounts for fuzzy subjective assessments of various design characteristics. Study [3] demonstrates the application of the fuzzy analytic hierarchy process to determine local and global weights of usability factors and to rank academic websites according to these criteria. This emphasizes the importance of combining fuzzy approaches with structured prioritization of interface quality factors. In addition, in [4], the authors apply hierarchical fuzzy axiomatic design to form a usability index, which provides a systematic evaluation of human–object interaction. This approach is consistent with hierarchical modeling and fuzzy rule-based methods used in tasks related to the evaluation of interface prototype quality, especially when it is necessary to formalize fuzzy expert judgments.

Thus, modern research demonstrates a clear trend toward integrating fuzzy logic with hierarchical models and multicriteria evaluation methods to formalize qualitative characteristics of interfaces. However, insufficient attention has been paid to the direct evaluation of interface prototyping quality using a comprehensive model that combines factor structuring, prioritization, and the synthesis of a generalized predictive quality indicator.

Purpose of the Article. The purpose of this article is to develop and substantiate a model for evaluating the quality of interface prototyping that provides systematic hierarchical identification, prioritization, and integration of accessibility and usability factors, followed by the formation of a generalized predictive quality indicator for interface solutions.

Presentation of the Main Research Material. Ensuring a high level of human-machine interaction quality at the early stages of design requires the development of a comprehensive strategy for prototype evaluation. The proposed principles are based on a systems approach that integrates methods of structural analysis, decision-making theory, and fuzzy set theory. The evaluation logic proceeds from the decomposition of influencing factors to the synthesis of an integral predictive indicator of interface prototyping quality [5].

The first stage involves structuring the set of factors that determine the quality of the future software product. Since the concept of interface quality is multidimensional, it is reasonable to divide the overall set of criteria into two key subgroups: accessibility factors and usability factors. This approach enables a more detailed specification of prototype requirements, taking into account both the technical features of information perception and the cognitive principles of interaction [6, 7].

To identify dependencies among components within each group, graph theory is applied [8]. The construction of topological models in the form of graphs makes it possible to visualize the architecture of mutual influence by determining which factors are basic (input) and which are derivative. This allows the avoidance of criterion duplication and the identification of parameters whose improvement produces a systemic effect on the entire group. The next step after graph construction is the determination of factor priorities within each group. For this purpose, the analytic hierarchy process is employed. The essence of this method lies in decomposing the problem into simpler components and forming a matrix that quantitatively reflects the presence of relationships between them. By analyzing the hierarchical arrangement of vertices in the graph and the nature of their interconnections, the priority level of each factor within its group is determined. The outcome of this stage is a ranked list of factors, where each element has a defined degree of influence on the local objective (ensuring accessibility or usability) [9].

The subsequent step is the synthesis of a generalized model. From both groups, factors that have received the highest priority according to the results of the previous modeling are selected. On this basis, a generalized graph of interface prototyping quality factors is constructed, integrating the most significant accessibility and usability requirements into a unified system. For this combined structure, the hierarchical mathematical modeling method is reapplied, which makes it possible to recalculate priorities in a global context and to determine the final contribution of each key factor to the overall prototype quality [9, 10].

During hierarchical analysis, situations often arise in which several heterogeneous factors receive close or identical priority values. Such equivalence complicates the decision-making process, as it does not provide a clear indication of which parameter should be prioritized in resource allocation. Moreover, hierarchical modeling does not determine exact weighting coefficients. To address this issue, a stage of multicriteria optimization of the model is introduced. The purpose of this stage is to transition from relative priorities to precise weight values that account not only for the importance of a factor but also for its contribution to the overall system utility. A comparison is performed to assess the extent to which one criterion outweighs another in terms of achieving the local objective (maximizing accessibility or usability). The result of the multicriteria optimization is the formation of a final vector of weighting coefficients for the generalized factor model. The sum of these coefficients is normalized to unity, ensuring the mathematical correctness of subsequent calculations. Based on the obtained data, a model is constructed that reflects the dominance of the analyzed factors [11].

The specificity of the interface prototyping domain lies in the fact that most evaluation criteria are subjective and qualitative in nature (e.g., “convenient,” “understandable,” “aesthetic”). Classical deterministic methods are unable to adequately process such data, as they require clear binary assessments, whereas human perception is inherently fuzzy.

To overcome this limitation, fuzzy set theory is applied. It enables the formalization of uncertainty in expert judgments and brings computer modeling closer to the logic of human thinking by operating not only with numerical values but also with linguistic variables [12, 13]. The fuzzy modeling process begins with the fuzzification stage. Input numerical data are transformed into linguistic terms. For each quality factor, a term set is formed that describes its possible states, for example, “low,” “medium,” and “high.” The correspondence of a specific numerical value to a given term is determined through a membership function, which can be graphically represented as a triangular, trapezoidal, or bell-shaped curve [12, 14].

Membership functions for each factor are defined using triangular and trapezoidal forms, with parameters determined based on expert evaluations or statistical analysis of prior projects. The fuzzy rule base is constructed by generalizing expert knowledge and establishes a mapping between combinations of linguistic factor assessments and the integrated quality indicator.

The core of the predictive model is the fuzzy rule base. The rules are logical “if-then” constructs that link the states of individual factors to an integral quality assessment. At the aggregation (fuzzy inference) stage, all active rules are processed and a resulting fuzzy set is formed. This set represents a comprehensive quality evaluation. The final step of the algorithm is defuzzification, which converts the resulting fuzzy set into a crisp numerical value. The obtained value is a predictive indicator of interface prototyping quality.

It is interpreted as an integral index that enables a substantiated decision regarding the feasibility of proceeding to the software implementation stage or the need for further refinement of the prototype [2, 12].

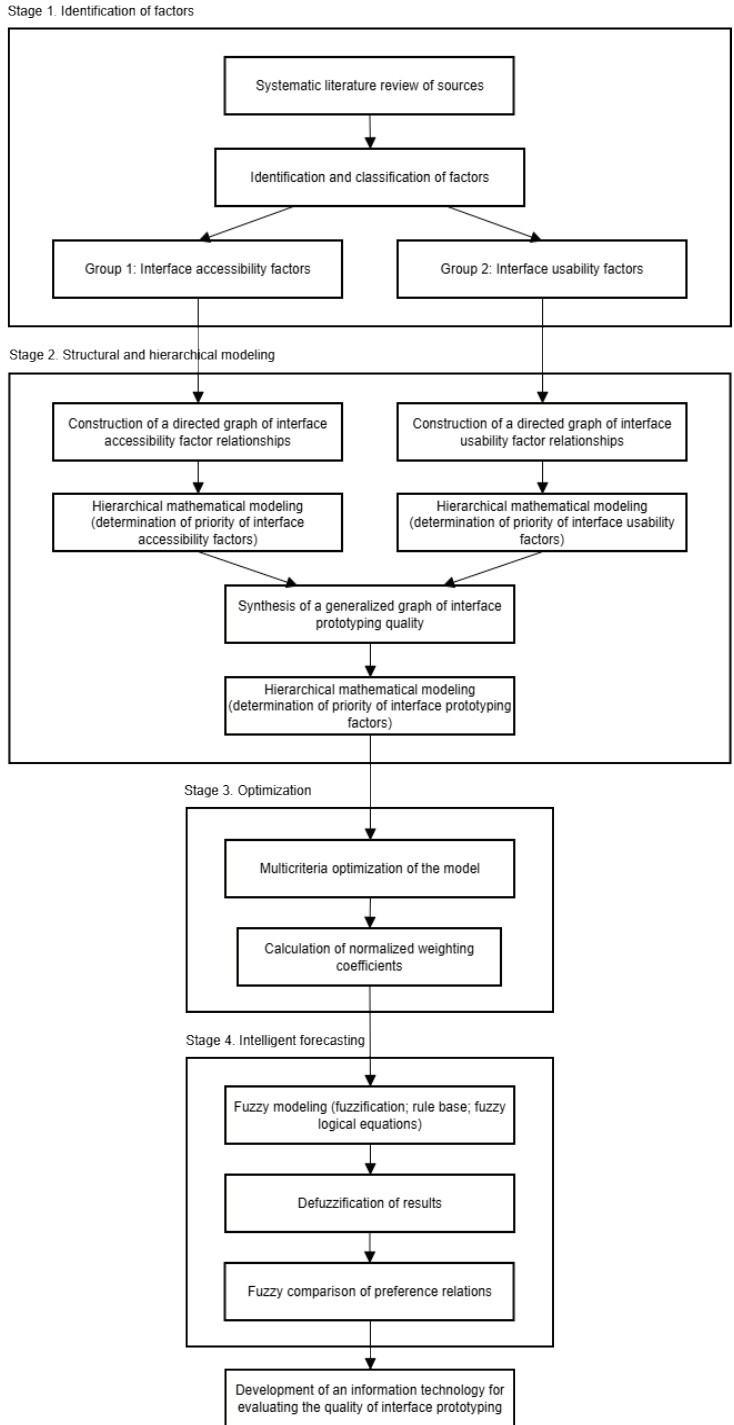


Figure 1. Structural model for evaluating the quality of interface prototyping

Figure 1 presents the developed structural model for evaluating the quality of interface prototyping. In subsequent research, it will serve as the basis for the development of an information technology for interface prototyping quality assessment.

In summary, the study begins with an information-analytical stage, during which the basic accessibility and usability factors are identified and classified through a systematic review. At the second stage, the obtained data undergo structural–hierarchical modeling using graph theory to determine influence priorities. This is followed by a parametric optimization stage aimed at calculating precise weighting coefficients. The process concludes with a predictive stage, in which an integral quality indicator is formed based on fuzzy logic methods, allowing the quantitative verification of the effectiveness of design decisions. The optimal interface prototyping option is selected based on fuzzy preference relations.

Based on the conducted research, an information technology for evaluating the quality of interface prototyping is developed.

Conclusions. A structural model for evaluating the quality of interface prototyping has been developed. The model formalizes the logic of transition from the identification and prioritization of factors to the synthesis of a generalized predictive quality indicator, ensuring the quantitative incorporation of subjective qualitative characteristics of interfaces.

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МОДЕЛЬ ОЦІНЮВАННЯ ЯКОСТІ ПРОТОТИПУВАННЯ ІНТЕРФЕЙСІВ

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Статтю присвячено розробленню та обґрунтуванню комплексної моделі оцінювання якості прототипування інтерфейсів програмних систем. Актуальність дослідження зумовлена зростаючою складністю сучасних інтерфейсів та необхідністю прийняття обґрунтованих проєктних рішень ще до етапу програмної реалізації. У роботі розглянуто проблему формалізації оцінювання якості прототипів з урахуванням багатомірності критеріїв і значної частки суб'єктивних якісних характеристик.

Запропонований підхід базується на системному поєднанні методів структурного аналізу, математичного моделювання ієрархій, багатокритеріальної оптимізації та апарату нечіткої логіки. На першому етапі здійснюється виокремлення та класифікація факторів, що визначають якість прототипування інтерфейсів, на основі систематичного аналізу наукових джерел. Визначені фактори згруповано за ознаками доступності та зручності користування. Це дозволяє врахувати як технічні, так і когнітивні характеристики людино-машинної взаємодії. На другому етапі виконується структурно-ієрархічне моделювання з використанням апарату теорії графів. Це забезпечує виявлення взаємозв'язків між факторами, усунення дублювання та визначення їх локальної і глобальної пріоритетності. Третій етап присвячено багатокритеріальній оптимізації моделі, метою якої є розрахунок нормованих вагових коефіцієнтів факторів якості. Це дозволяє перейти від відносних експертних пріоритетів до кількісно визначених ваг, що відображають реальний внесок кожного фактора у формування загальної якості прототипу. На четвертому, прогностичному етапі, застосовується нечітке моделювання для обробки суб'єктивних експертних оцінок. Формується база нечітких правил, здійснюється фазифікація вхідних

даних, нечітке логічне виведення та дефазифікація результатів. Унаслідок цього отримується інтегральний прогностичний показник якості прототипування інтерфейсу. Також передбачене здійснення порівняння альтернативних варіантів прототипування на основі нечітких відношень переваг. Отримані результати можуть бути використані як методологічна основа для розроблення інформаційної технології оцінювання якості прототипування інтерфейсів та впроваджені у практику проєктування програмних систем різного призначення.

Ключові слова: прототипування, інтерфейс, теорія графів, математичне моделювання ієрархій, пріоритетність, фактор, ранжування, оптимізація, нечітка логіка, нечітка множина, альтернативний варіант, оцінювання якості, інформаційна технологія.

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