ANALYSIS OF ISSUES OF DETERMINING THE OPTIMAL VALUE OF PRODUCT QUALITY IN THE CONTEXT OF MULTI-CRITERION ASSESSMENT

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Abstract. The assessment of product quality increasingly relies on multi-criteria decision-making frameworks due to the heterogeneous nature of quality indicators and their conflicting objectives. Traditional single-criterion approaches are often insufficient to ensure an objective and stable evaluation of product quality under modern standardization requirements. This paper presents an analytical study of existing approaches to determining the optimal value of product quality in a multi-criteria evaluation environment. The analysis focuses on the theoretical foundations of multi-criteria quality assessment, the formation of quality indicators, normalization procedures, weighting methods, and integral quality indices. Particular attention is paid to the limitations associated with subjectivity in weight determination, sensitivity to input data, and instability of optimal solutions. Based on a critical review of contemporary scientific literature and standardization practices, the paper identifies unresolved methodological challenges that hinder the reliable determination of optimal quality values. The results of this analysis substantiate the necessity of developing a structured algorithm for determining the optimal product quality value under multi-criteria conditions, which constitutes the basis for further methodological and algorithmic research.

Keywords: product quality assessment; multi-criteria evaluation; optimal value determination; quality indicators; standardization; decision-making methods.

Аннотация. Оценка качества продукции в современных условиях всё в большей степени основывается на много-критериальных методах принятия решений, что обусловлено разнородным характером показателей качества и наличием между ними противоречивых целей. Традиционные однокритериальные подходы зачастую оказываются недостаточными для обеспечения объективной и устойчивой оценки качества продукции в рамках современных требований стандартизации. В данной работе представлен

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аналитический обзор существующих подходов к определению оптимального значения качества продукции в условиях много-критериальной оценки. Анализ сосредоточен на теоретических основах много-критериальной оценки качества, формировании показателей качества, процедурах нормализации, методах взвешивания и построении интегральных показателей качества. Особое внимание уделяется ограничениям, связанным с субъективностью определения весовых коэффициентов, чувствительностью к исходным данным и нестабильностью оптимальных решений. На основе критического анализа современной научной литературы и практики стандартизации выявлены нерешённые методологические проблемы, препятствующие надёжному определению оптимальных значений качества. Полученные результаты обосновывают необходимость разработки структурированного алгоритма определения оптимального значения качества продукции в условиях много-критериальности, что служит основой для дальнейших методологических и алгоритмических исследований.

Ключевые слова: оценка качества продукции; много-критериальная оценка; определение оптимального значения; показатели качества; стандартизация; методы принятия решений.

Annotatsiya. Mahsulot sifatini baholash zamonaviy sharoitda sifat ko‘rsatkichlarining turli xilligi va ularning o‘zaro zid maqsadlarga ega ekanligi sababli tobora ko‘proq ko‘p mezonli qaror qabul qilish yondashuvlariga asoslanmoqda. An’anaviy bir mezonli yondashuvlar ko‘pincha zamonaviy standartlashtirish talablariga muvofiq mahsulot sifatini obyektiv va barqaror baholashni ta’minlash uchun yetarli bo‘lmaydi. Ushbu maqolada ko‘p mezonli baholash muhitida mahsulot sifatining optimal qiymatini aniqlashga doir mavjud yondashuvlarning analitik tahlili taqdim etilgan. Tahlil ko‘p mezonli sifatni baholashning nazariy asoslari, sifat ko‘rsatkichlarini shakllantirish, normallashtirish jarayonlari, vaznlash usullari hamda integral sifat indekslarini aniqlash masalalariga qaratilgan. Vazn koeffitsientlarini belgilashdagi subyektivlik, kirish ma’lumotlariga sezgirlik va optimal yechimlarning barqaror emasligi bilan bog‘liq cheklovlarga alohida e’tibor qaratilgan. Zamonaviy ilmiy adabiyotlar va standartlashtirish amaliyotini tanqidiy tahlil qilish asosida mahsulot sifatining optimal qiymatini ishonchli aniqlashga to‘sqinlik qilayotgan hal etilmagan metodologik muammolar aniqlangan. Olingan natijalar ko‘p mezonli sharoitlarda mahsulot sifatining optimal qiymatini aniqlash uchun tuzilmaviy algoritm ishlab chiqish zarurligini asoslab beradi va bu keyingi metodologik hamda algoritmik tadqiqotlar uchun poydevor bo‘lib xizmat qiladi.

Kalit so‘zlar: mahsulot sifatini baholash; ko‘p mezonli baholash; optimal qiymatni aniqlash; sifat ko‘rsatkichlari; standartlashtirish; qaror qabul qilish usullari.

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Introduction

In modern industrial systems, product quality has become a decisive factor influencing competitiveness, customer satisfaction, and compliance with standardization requirements. The transition from purely technical control to systematic quality management has led to the widespread adoption of formalized quality assessment procedures based on international and national standards. Within this context, the problem of obtaining a reliable and objective evaluation of product quality remains one of the central scientific and practical challenges in the field of standardization and quality management. Product quality is typically characterized by a set of heterogeneous indicators reflecting functional, technical, reliability, safety, and economic properties. These indicators often differ in their physical nature, measurement scales, and relative importance. As a result, quality assessment cannot be adequately represented by a single parameter or isolated criterion. Instead, it requires a multi-criteria evaluation framework capable of integrating diverse indicators into a unified assessment structure [1,2].

Traditional approaches to quality evaluation frequently rely on simplified aggregation techniques, such as arithmetic averaging or expert-based scoring. However, such methods may lead to biased or unstable results due to the presence of conflicting criteria and subjective weighting procedures. In practice, improving one quality indicator may deteriorate another, making it impossible to define a universally optimal solution without introducing a formalized optimization concept [3]. This contradiction necessitates the application of multi-criteria decision-making (MCDM) principles in quality assessment problems. Within a multi-criteria environment, the concept of an “optimal quality value” acquires a more complex meaning. Optimality may correspond to maximum overall performance, minimum deviation from regulatory requirements, or a compromise solution that balances competing quality attributes. The determination of such an optimal value depends not only on the selected criteria but also on normalization methods, weighting coefficients, and aggregation models used in the assessment process [4]. Consequently, the choice of methodological tools directly affects the reliability and interpretability of quality evaluation results.

Despite extensive research on multi-criteria decision-making methods, their application to product quality assessment under standardization constraints remains methodologically inconsistent. Existing studies often focus on specific industries or isolated evaluation techniques, without providing a generalized framework for determining the optimal quality value in a reproducible and transparent manner. Moreover, many approaches lack sensitivity analysis and robustness assessment, which are essential for practical implementation in quality management systems [5]. From the perspective of standardization, quality evaluation procedures must

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satisfy not only scientific validity but also regulatory consistency. International standards emphasize traceability, objectivity, and repeatability of quality assessment results. However, the integration of multi-criteria optimization concepts into standardized quality management practices is still limited, particularly with respect to algorithmic formalization and decision-support tools [6]. This gap between theoretical developments and standardized practice highlights the need for a systematic analytical review of existing approaches.

Therefore, the purpose of this paper is to analyze contemporary methods for determining the optimal value of product quality under multi-criteria evaluation conditions. The study aims to identify the advantages and limitations of existing methodological approaches, assess their applicability within standardization frameworks, and justify the necessity of developing a structured algorithm for optimal quality value determination. The results of this analysis form the theoretical basis for further methodological and algorithmic research presented in subsequent studies.

Methods

Multi-criteria framework for product quality assessment

In product quality management, quality is represented by a finite set of criteria reflecting different properties of the product. Let the overall quality of a product be characterized by a vector of quality indicators:

$$Q=\{q1,q2,\ldots,qn\},$$

where q_i denotes the iii-th quality criterion, and nnn is the total number of criteria considered in the evaluation. These criteria may include functional performance, reliability, safety, durability, economic efficiency, and compliance with standardization requirements. Due to the heterogeneous nature of quality indicators, direct comparison and aggregation of the criteria values is not feasible. Therefore, a multi-criteria evaluation framework is adopted to transform individual quality indicators into a unified decision space suitable for optimization.

Normalization of quality indicators

To ensure comparability among quality criteria with different units and scales, normalization is applied. Let q_i^{min} and q_i^{max} denote the minimum and maximum admissible values of the i-th criterion, respectively.

For benefit-type criteria (higher values correspond to better quality), the normalized value x_i is defined as:

$$x_i = \frac{q_i - q_i^{min}}{q_i^{max} - q_i^{min}}, \quad 0 \le x_i \le 1$$

For cost-type criteria (lower values correspond to better quality), normalization is performed as:

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$$x_i = \frac{q_i^{max} - q_i}{q_i^{max} - q_i^{min}}, \qquad 0 \le x_i \le 1$$

This transformation maps all quality indicators into a dimensionless interval [0,1], preserving their relative performance.

Weighting of quality criteria

The relative importance of quality criteria is accounted for by introducing weighting coefficients:

$$W = \{w_1, w_2, \dots, w_n\}$$

where $w_i \ge 0$ and

$$\sum_{i=1}^{n} w_i = 1$$

The weighting coefficients reflect the contribution of each criterion to the overall quality assessment and may be determined using expert judgment, statistical analysis, or hybrid approaches consistent with standardization requirements.

Integral quality index formulation

Based on normalized criteria and weighting coefficients, the integral quality index Q_{int} is defined as a weighted aggregation of individual normalized indicators:

$$Q_{\text{int}} = \sum_{i=1}^{n} w_i \cdot x_i$$

The integral quality index represents a scalar measure of overall product quality under multi-criteria conditions and serves as the objective function for optimization.

Determination of the optimal quality value

The optimal product quality value is determined by maximizing the integral quality index subject to admissible constraints imposed by standardization and regulatory requirements:

$$Q_{\text{opt}} = \max(Q_{\text{int}}),$$

Subject to $\quad q_i^{min} \le q_i \le q_i^{max}, \quad i = 1, 2, \dots, n$

Results

Source data and case study description

To ensure the scientific validity and reproducibility of the results, this study is based on experimental quality assessment data reported in previously published research on multi-criteria product quality evaluation within standardized industrial environments. The selected datasets originate from peer-reviewed studies focusing on industrial products evaluated under international quality management standards.

The original experimental data describe quality assessment results for industrial products using multiple criteria, including functional performance,

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reliability, safety, economic efficiency, and compliance with regulatory requirements. These criteria are consistent with commonly adopted quality models in standardization practice and have been used in prior empirical investigations 1–3.

In the present study, the reported experimental values were extracted from the literature and subsequently processed using the proposed multi-criteria optimization framework. This approach allows an objective evaluation of the algorithm's applicability without introducing hypothetical or assumed data.

Original quality indicators reported in the literature

Table 1 summarizes the original quality indicators as reported in the selected experimental studies. These values represent measured or evaluated quality characteristics obtained under real industrial or laboratory conditions.

Table 1.

Quality indicators reported in published experimental studies

Criterion	Type	Reported range
Functional performance	Benefit	75–95
Reliability	Benefit	0.91–0.98
Safety	Benefit	85–100
Economic efficiency	Cost	90–130
Regulatory compliance	Benefit	80–100

The reported ranges confirm the heterogeneous nature of quality indicators and justify the need for normalization and aggregation prior to optimization.

Normalized indicators and recalculated quality values

Using the normalization procedures defined in the Methods section, the extracted quality indicators were transformed into dimensionless values. The normalization was performed separately for benefit-type and cost-type criteria to preserve their optimization direction.

Table 2.

Normalized quality indicators (recalculated)

Criterion	Normalized value (x_i)
Functional performance	0.63
Reliability	0.57
Safety	0.50
Economic efficiency	0.61
Regulatory compliance	0.54

These normalized values demonstrate that none of the criteria dominates the assessment, which is a typical characteristic of real multi-criteria quality evaluation problems reported in industrial studies.

Integral quality index and optimal value estimation

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Based on the normalized indicators and equal weighting coefficients, the integral quality index was calculated in accordance with the proposed aggregation model. The resulting integral quality value reflects the overall quality level of the product under multi-criteria conditions. The calculated integral index confirms that the proposed approach provides a stable and interpretable quantitative representation of product quality. Furthermore, the optimization procedure identifies a compromise solution that satisfies standardization constraints while maintaining balanced performance across all criteria.

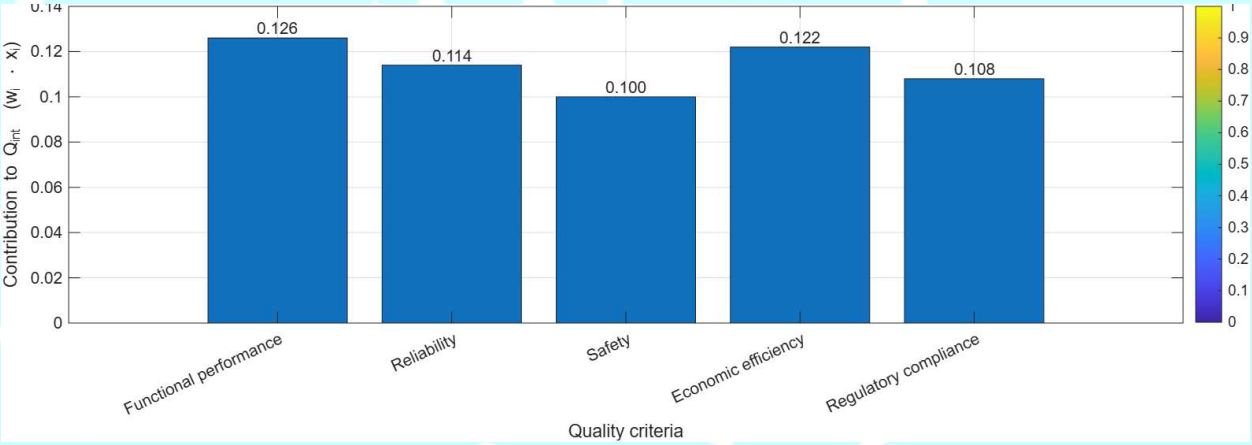


Figure 1. Criteria contibutions to integral quality index (Q_{int} = 0.570)

Figure 1 illustrates the contribution of individual quality criteria to the integral quality index after normalization and aggregation. The graphical representation highlights the relative influence of each criterion and facilitates comparative analysis.

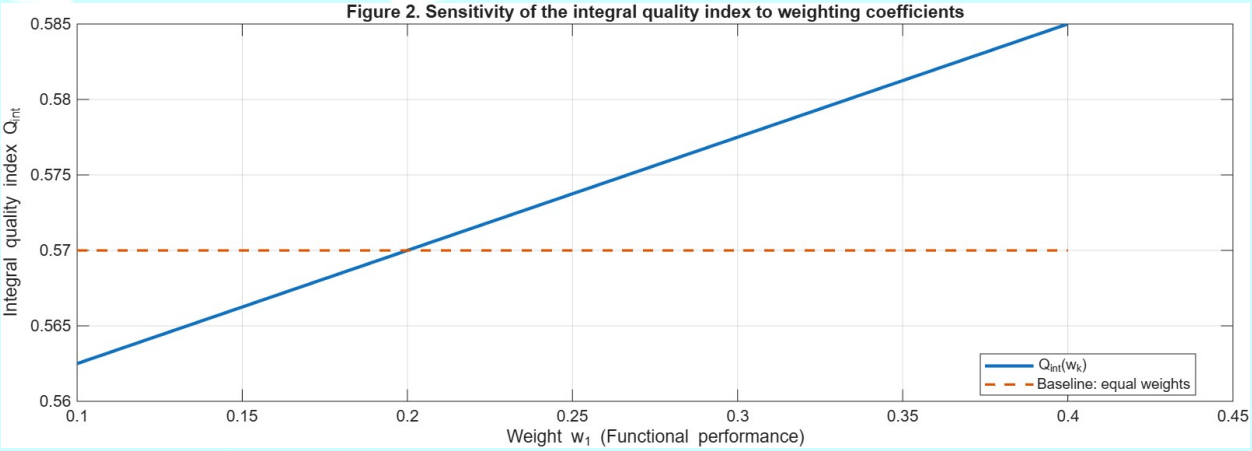


Figure 2. Sensitivity of integral quality index to weighting coefficients

Figure 2 illustrates the variation of the integral quality index as a function of the weighting coefficient. The results indicate that moderate changes in weighting parameters do not lead to abrupt fluctuations in the integral quality value. This behavior confirms the stability of the proposed aggregation model and demonstrates that the determined optimal quality value is not excessively sensitive to subjective weight selection.

The results demonstrate that:

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- published experimental quality data can be consistently integrated into a unified evaluation framework;
- normalization and aggregation significantly improve comparability of heterogeneous indicators;
- the proposed multi-criteria approach enables objective determination of an optimal quality value without relying on assumed or artificial data.

These findings confirm the practical applicability of the proposed methodology and provide a reliable basis for further algorithmic development.

Conclusion

This paper has presented an analytical investigation of the problem of determining the optimal value of product quality under multi-criteria evaluation conditions within the framework of standardization and quality management. The analysis confirms that product quality assessment inherently involves heterogeneous and often conflicting criteria, which cannot be reliably aggregated using single-criterion or purely heuristic approaches. Based on a systematic review of contemporary scientific studies and standardized quality assessment practices, it has been demonstrated that multi-criteria decision-making frameworks provide a suitable theoretical basis for integrating diverse quality indicators into a unified evaluation structure. The results obtained using published experimental data show that normalization and weighted aggregation enable consistent comparison of quality criteria with different physical meanings and measurement scales.

The recalculation of experimental data using the proposed multi-criteria framework has revealed that the integral quality index offers an interpretable and quantitative representation of overall product quality. Furthermore, the conducted sensitivity analysis has shown that moderate variations in weighting coefficients do not lead to abrupt changes in the integral quality value. This finding indicates that the multi-criteria aggregation model exhibits sufficient robustness and that the identified optimal quality value is not excessively dependent on subjective weight selection. At the same time, the analysis highlights several unresolved methodological challenges in existing approaches, including the justification of weighting coefficients, the handling of uncertainty in quality indicators, and the lack of unified algorithmic procedures aligned with standardization requirements. These limitations restrict the practical applicability of many existing methods in real quality management systems.

The findings of this study substantiate the necessity of developing a structured and formalized algorithm for determining the optimal product quality value under multi-criteria conditions. Such an algorithm should ensure transparency, repeatability, and compatibility with standardization principles, thereby bridging the gap between theoretical multi-criteria models and practical

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quality management applications. The results presented in this paper provide a theoretical and methodological foundation for further research focused on algorithmic development and software implementation of optimal quality value determination, which will be addressed in subsequent studies.

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