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ԲԱՐՁՐ ՏԵԽՆՈԼՈԳԻԱՆԵՐԻ ՏԵՂԵԿԱԳԻՐ
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LEGAL FRAMEWORK FOR ACCOUNTABILITY IN THE ORGANIZATION OF DESIGN WORK IN THE REPUBLIC OF ARMENIA: CHALLENGES AND REFORM DIRECTIONS

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Abstract

In the Republic of Armenia, the misalignment between engineering requirements and contractual terms in design work commissioned by state and local authorities creates risks to

work quality, timely completion, and financing. The causes of these discrepancies need to be identified, and directions for reforming the legal framework governing the responsibilities and liability of clients, designers, and design reviewers need to be substantiated.

The research draws on an analysis of published studies on design durations, investment costs, and regulatory issues, together with documented cases and legal acts. It examines the completeness of baseline data, the determination of timeframes and prices commensurate with the scope and technical complexity of the work, the independence and accountability of design review, the acceptance of deliverables, and the fulfilment of payment obligations.

Mechanisms are proposed for substantiating design conditions in advance, establishing the minimum necessary duration of work, ensuring legal protection, overseeing pricing calculations, assuring the quality of design review, and addressing the financial consequences of payment delays.

The study substantiates an approach that treats the organization of design work as an integrated process, from preliminary planning through the acceptance of deliverables and payment.

Keywords: design work, engineering complexity, baseline data, design duration, pricing, design review, client liability, legal framework.

Introduction

A decision-based conceptual model for organizational optimization, in which resource audit serves as the principal diagnostic and management tool, makes it possible to identify systemic inconsistencies, including inefficient resource allocation, technological mismatches, and problems with compliance with regulatory and legal requirements [1].

Preliminary cost estimation for public investment projects is a fundamental stage in project planning and financing because it directly affects project feasibility, budget planning, and subsequent implementation efficiency. However, preliminary cost development often lacks a comprehensive engineering assessment methodology, which may result in substantial differences between the financial envelopes presented in investment proposals and actual project costs. A comprehensive engineering approach is therefore needed to assess the financial realism of projects before funding is approved and to reduce subsequent budgetary, technical, and organizational risks [2].

The scope of work specified in an invitation to tender for design services, the availability of baseline data, and the design schedule can affect construction costs, safety, and completion. Therefore, assessing the effectiveness of a design contract solely on the basis of the tender price or the contractual deadline cannot capture the overall outcome of a public project. The objectives of the Republic of Armenia's Law on Procurement include obtaining an appropriate result for commensurate remuneration and conducting the procurement process economically and efficiently [3]. This approach provides a basis for examining not only how the tender is organized, but also the conditions under which the selected bidder must perform the work. A short timeframe or a low initial price is not in itself evidence of efficiency if its calculation does not reflect the scope and specific characteristics of the work.

H.V. Tokmajyan, V.G. Khachaturyan, A.Kh. Markosyan, G.H. Martirosyan, E.Yu. Galstyan

LEGAL FRAMEWORK FOR ACCOUNTABILITY IN THE ORGANIZATION OF DESIGN WORK IN THE REPUBLIC OF ARMENIA: CHALLENGES AND REFORM DIRECTIONS

The outcome of design work is produced through interrelated activities: collecting and examining baseline data, carrying out the necessary investigations, developing technical solutions, obtaining approvals, conducting expert review, and submitting the final documentation. In this process, the designer's fulfilment of its obligations also depends substantially on the client's actions.

Article 757 of the Civil Code of the Republic of Armenia requires the client to provide the design brief and other baseline data necessary for preparing the design documentation. Articles 758–760 of the same Code govern the obligations of the client and the contractor and the contractor's liability for defects in design documentation [4]. Consequently, assessing the performance of a design contract requires examining both the availability of the required outcome and each party's fulfilment of the obligations undertaken to produce it.

Substantiating timeframes is a separate issue in organizing design work. It requires consideration of the facility's purpose, the scope and complexity of the work, the need for investigations, and the sequence of individual stages. Regulatory documents establish approaches to calculating average design durations and define their scope and conditions of application [5]. The duration calculated under the applicable standards and the contractual schedule must also be coordinated with the provision of baseline data and the approval process. Otherwise, part of the contractual period may elapse before the conditions necessary for performing the relevant work have been established.

Similar interdependencies exist between design pricing, expert review, and payment. A price calculation that does not correspond to the scope and technical complexity of the work may restrict the resources available for necessary investigations and professional services. At the same time, defining the designer's liability does not remove the client's obligations to clarify the brief, provide the necessary data, accept the deliverables, and pay for them. The existence of expert review also requires the functions of developing design solutions and checking them to be examined separately. Effective regulation of these relationships requires liability to be linked to the breach of a specific obligation and its consequences, rather than merely to a formal record of the final contractual outcome or deadline.

International approaches to public procurement likewise emphasize management of the entire process. The OECD Recommendation of the Council on Public Procurement considers the procurement cycle from needs assessment through contract management and payment, emphasizing risk management, oversight, and a clear allocation of responsibility [6]. The World Bank's Procurement Framework provides for procurement approaches to be tailored to specific needs, circumstances, and risks in order to achieve value for money [7].

For design services, these principles provide a basis for assessing tender conditions together with the quality of the resulting deliverables and the requirements of project implementation. In this context, a central issue in the legal framework for organizing design work is the alignment of obligations, the conditions necessary for their fulfilment, and liability.

Requirements for design preparation and the provision of baseline documents are also established by Government Decision No. 596-N of 19 March 2015 [8]. Paragraph 73 of

Annex 1 requires the architectural planning assignment issued under the prescribed procedure and the technical specifications prepared by the developer to be attached to the design contract, except where an architectural planning assignment is not required. It also stipulates that the technical specifications and the design permit may not contain conflicting provisions. Paragraph 78 of the same procedure allows the collection of certain baseline documents to be assigned to the designer by contract [8]. These provisions demonstrate the importance of the availability of baseline documents and a clear allocation of the obligations to provide them. The solutions proposed in the reform package under consideration must be assessed in the context of the obligations established by existing regulation and the need to amend them.

Regulations in other countries also treat design preparation as a distinct client function. Under Articles L2421-1 and L2421-2 of the French Public Procurement Code, the public client's functions include a preliminary assessment of project feasibility and appropriateness, determining the location, preparing the project programme, establishing the preliminary financial envelope, and securing financing. The programme prepared by the client must reflect the facility's objectives, the needs to be met, and urban planning, architectural, functional, technical, economic, and environmental requirements [9]. This approach is relevant to defining the scope of the work and the conditions for its implementation before procuring design services.

The consequences of the client's failure to perform necessary actions are also regulated by the German Civil Code. Section 642 provides for the contractor's right to reasonable compensation where the client's failure to perform an action necessary for the work places the client in default of acceptance. The amount of compensation takes into account the duration of the default, the agreed remuneration, the expenses saved by the contractor, and the income that could be earned through other use of its labour. Section 643 establishes a procedure for giving the client a reasonable period to perform the necessary action and terminating the contract if the client fails to do so. Section 650p, concerning architectural and engineering services, in turn provides for the submission of a preliminary planning basis and a cost estimate for the client's approval where essential design objectives have not yet been agreed [10]. These provisions illustrate an integrated approach to regulating client participation, design stages, and the financial consequences of non-performance.

The United States Federal Acquisition Regulation reflects the specific characteristics of design services in provider selection and the definition of liability. Under FAR 36.602-1, the criteria for evaluating architectural and engineering service providers include professional qualifications, specialized experience, technical competence, capacity to perform the work within the required timeframe, and past performance concerning quality, costs, and schedules. FAR 36.609-1 and 36.609-2 distinguish between the correction of design errors and cost changes caused by circumstances beyond the designer's control. The designer's own errors are corrected at no additional cost to the client, whereas unforeseeable increases in material costs or undue client delay may remove the obligation to redesign without charge in order to comply with the funding limitation [11]. This distinction is important for linking liability to the actual cause of a change.

The organization of technical control of construction in France provides a comparative example of review independence. Under Article L125-1 of the Construction and Housing Code, the technical controller acts at the client's request and provides an opinion on technical issues, particularly the structural soundness of the facility and the safety of persons. Article L125-3 makes technical control incompatible with activities involving the design, execution, or expert assessment of a structure [12]. Although the scope of this control is not entirely identical to the expert review of design and cost-estimate documentation in Armenia, it provides an example of organizational separation between design and independent checking.

In the United Kingdom, payment obligations are also protected through terms implied into contracts by law. Section 68 of the Procurement Act 2023 establishes, subject to specified exceptions, a 30-day payment period for public contracts and an obligation to notify the payee without undue delay if an invoice is considered invalid or disputed. These payment terms cannot be overridden by a conflicting contractual provision [13]. This mechanism is comparable to the approach of the reform package under consideration, which seeks to define acceptance and payment deadlines independently of the client's discretion.

International pricing practices are not uniform. Germany's HOAI links the calculation of fees for design services to the types and stages of work, complexity, and calculation bases. Since 2021, however, fees have primarily been determined by agreement between the parties, while the tabulated values serve as guidance [14]. This experience therefore supports the importance of a calculation method that identifies the scope and complexity of work, but does not in itself establish the need for a mandatory minimum price.

The interrelationship between client actions, design documentation quality, and project outcomes has also been examined in scientific studies. Love and Li's study of two construction projects identified client- and end-user-initiated changes, together with errors and omissions in contract documentation, among the principal causes of rework [15]. Love and Edwards' study of 161 Australian projects likewise identified the significance of client-initiated changes in the occurrence of rework [16]. Assaf and Al-Hejji's research on major construction projects in Saudi Arabia examined schedule deviations with the participation of clients, consultants, and contractors, identifying multiple causes of delay [17]. These studies support the need to distinguish between the causes of changes and delays. Their findings nevertheless relate to the construction projects examined and cannot be directly generalized to all design service contracts in Armenia without further assessment.

Conflict Setting

Examining the rules on baseline data, timeframes, pricing, expert review, acceptance, and payment for design work in isolation may overlook the effect of an impediment arising at one stage on subsequent stages. As a result, contractual liability may be attributed to a participant whose actions did not cause the impediment, while the liability of the participant obliged to remove it remains insufficiently defined.

The statutory establishment of individual obligations is insufficient in itself unless the sequence of their fulfilment, their interdependencies, and the consequences of non-performance are clarified. It is therefore necessary to assess both the existence of liability and

the mechanism for applying it in terms of the breach of an obligation, its effect on performance, and identification of the responsible participant.

The package of amendments examined in this study addresses this problem through interrelated provisions on securing the data necessary for design, substantiating timeframes and initial prices, establishing the independence and liability of expert review, clarifying procedures for contract termination, acceptance, and payment, and regulating the tax consequences of client payment default. The research problem is therefore to substantiate legal mechanisms for organizing design work that align participants' obligations, their actual ability to fulfil them, and liability for the consequences of breach, treating the organization of design work as a unified process.

Materials and Methods

The research materials include Armenian legal acts concerning the organization of design work, design duration standards, international public procurement principles, foreign legal regulations, and scientific studies of the causes of changes, rework, and delays in design and construction processes [3–17]. A separate body of material comprises the authors' draft amendments concerning procurement organization, civil liability, licensing, and tax regulation, together with their explanatory rationale. These are treated as proposals to be assessed and substantiated within the study.

Legal, comparative, and systems analysis methods were applied. Legal analysis examined the obligations of the client, the designer, and the expert reviewer, the conditions for their fulfilment, and the consequences of breach. The proposed provisions were compared with the relevant legal rules to distinguish solutions clarifying procedures for fulfilling existing obligations from amendments requiring a new legislative basis.

Comparative analysis was organized by regulatory subject: provision of baseline data, substantiation of design timeframes and prices, independence and liability of expert review, and acceptance and payment. Armenian approaches were compared with those of the countries examined in these areas [8–14]. The purpose was to identify the functions and conditions of application of the relevant mechanisms in order to assess their potential use in the legal and contractual relationships applicable in Armenia. Scientific studies were used to analyse the causes of changes and delays and the interaction between the actions of process participants [15–17].

Systems analysis treated the organization of design work as an interconnected process, from preparation of the brief and provision of baseline data through design, expert review, acceptance, and payment. Each stage was examined in the following sequence: the participant's obligation, the condition necessary for its fulfilment, a possible impediment, the effect on subsequent stages, and the basis for attributing liability. This approach was also used to assess the mutual consistency of the proposed amendments and the documentation required for their implementation.

The study has a legal and organizational focus. The effectiveness and overall financial impact of the proposed mechanisms remain subject to further assessment using actual data on contract performance, expert review, payments, and the liability measures applied.

Research Results

Comparison of the legal regulations and proposed amendments identified six interrelated areas in the organization of design work: provision of baseline data, substantiation of timeframes, calculation of the initial price, organization of expert review, acceptance and payment, and regulation of the financial consequences of client default. Their combined analysis provided the basis for developing an approach to allocating liability that links a participant's obligation, the conditions necessary for its fulfilment, the cause of breach, and the resulting consequence.

Provision of Baseline Data and Attribution of Liability

Examination of the organization of design work indicates that the contractual deadline alone is insufficient to determine responsibility for a delay. It is necessary to establish when the baseline data required for the relevant work became available and how their absence affected the design process.

Reading the Civil Code provisions on the delivery of the design brief and other necessary baseline data together with the development permitting procedure provides a basis for treating data provision as a distinct obligation in organizing design work [4, 8]. Fulfilment of that obligation must be reflected in the contractual schedule and the conditions for delivery of the outcome.

The proposed mechanism records the list of baseline data, the party responsible for providing them, the delivery deadline, and the actual delivery date. The calculation of the performance period for the relevant work is linked to the complete provision of the data necessary for that work. This makes it possible to distinguish the period caused by the client's non-performance from delay attributable to the designer.

The relationships between client changes, documentation omissions, and rework identified in scientific studies also support the need to distinguish the causes of delay [15–17]. The solution proposed in this study incorporates that distinction into the documentation of contract performance.

Aligning Design Duration with the Contractual Schedule

Analysis of timeframes identified two distinct issues: substantiating the duration necessary to perform the work and determining the starting point for calculating that duration. Regulating only one of these does not ensure a realistic deadline. Part of a duration substantiated under the applicable standards may elapse before baseline data are provided, while timely provision of data does not resolve the problem of a timeframe too short for the scope of work.

It is proposed that the procurement preparation stage include a substantiated calculation of design duration specifying the scope of work, applicable standards, calculation parameters, coefficients, and sequence of stages. Opportunities to perform stages concurrently must be reflected in the schedule rather than mechanically adding their durations together.

Application of the regulatory document [5] requires compliance with its defined scope and calculation conditions. The duration of work outside the relevant standard's scope requires a separate technical justification. The proposed legal protection must therefore apply to the necessary duration calculated on an applicable basis. Under this approach, delay

attributable to the designer is first determined for the purposes of contract termination and delay penalties. An inventory and assessment of completed work preserve the basis for resolving acceptance and payment issues if the contract is terminated.

Substantiating the Initial Price of Design Services

Pricing analysis distinguished between the estimated construction cost, the calculated price of design services, the initial tender price, and the contractual price offered by the bidder. These distinctions are necessary, above all, to identify the source of a calculation discrepancy. The proposed oversight concerns the justification of the initial price established by the client. It is assessed on the basis of the same scope of work, technical complexity, pricing date, and tax treatment. A bidder's voluntary reduction from a substantiated initial price must be distinguished from an omission in the client's calculation. The study proposes presenting the initial price calculation in verifiable components: calculation base, pricing rule applied, coefficients, and services included. The cost of separately procured expert review or a subsequently modified brief must be separated to ensure that the subject of comparison remains identical. This structure makes it possible to assess procurement preparation while preserving the bidder's independence in submitting a price. It is consistent with the public procurement principle of selecting an approach appropriate to needs and risks [6, 7].

Independence of Expert Review and Differentiation of Liability

Analysis of expert review distinguished between developing a design solution and checking it. The designer is responsible for the documentation it prepares, while the expert reviewer's liability must relate to defects falling within the scope of review that should have been checked and identified. Commissioning design and commissioning expert review are separate functions. Persons involved in preparing the same documentation must also be excluded from reviewing it. This solution seeks to prevent conflicts of interest arising from self-review and is comparable to the approaches to independent technical control examined in the study [12].

A positive expert opinion does not remove the designer's liability to correct its own errors. Establishing the expert reviewer's liability requires identification of the undetected defect, the obligation to check for it, and the resulting consequence. Alongside its financial impact, the significance of the defect for safety must also be assessed, since the two may not coincide.

Acceptance of Deliverables and Calculation of Payments and Penalties

Comparison of acceptance and payment procedures identified the need for a clear distinction between the deadlines for submission of deliverables, completion of expert review, formalization of acceptance, and payment. The date of each event must be documented, and its legal and financial consequences must be established in the contract in advance.

The proposed regulation limits the possibility of shifting the payment deadline by delaying the signing of the acceptance document. Its application also requires clear identification of the version of the documentation to be accepted when corrections have been made during expert review. It is proposed that delay penalties be calculated on the value of the obligation breached: the unperformed portion in the designer's case and the unpaid amount in the client's case. This distinction links the extent of liability to the actual breach.

Establishing a definite payment deadline and consequences for its breach is comparable to the international regulatory approaches examined [13].

Coordinating Client Payment Default with Tax Obligations

Systems analysis identified a continuing chain of consequences arising from client payment default: an unpaid contractual amount, a shortage of the contractor's working capital, and difficulty meeting tax obligations. A contractual payment claim and a tax obligation have different bases, but their coincidence in time may aggravate the contractor's financial difficulties. A mechanism is proposed for temporarily deferring the payment of relevant tax obligations within the amount of a documented overdue debt owed by a state or municipal client. Its application is linked to confirmation of the debt, recording the relevant amount, and settling the tax obligation after payment is received from the client. The proposed mechanism supplements acceptance and payment protection by addressing the subsequent financial constraints arising from client default. Its budgetary impact and conditions of application must be assessed using actual data on overdue payments and the tax obligations coinciding with them.

Combining these areas produces an integrated regulatory model for organizing design work. Its principal outcome is the linkage between the sequence of obligation fulfilment, documentation of the necessary conditions, and causal allocation of liability. Quantitative evaluation of the model's effectiveness requires further examination of actual contract performance data.

Discussion of Results

The research provides a basis for assessing the effectiveness of the organization of design work throughout the fulfilment of contractual obligations. Contractual timeframes, prices, and liability measures are interrelated: late provision of necessary data may reduce the time actually available for design, while delayed acceptance or payment may create financial difficulties in relation to work already completed. Consequently, the effect of an individual regulatory amendment also depends on the rules applied at other stages.

The proposed approach centres on clarifying the factual basis for attributing liability. Each participant's obligation must be considered together with the conditions necessary for its fulfilment and the consequences of breach. Identifying this relationship requires documents confirming the dates of data delivery, brief modifications, review comments, acceptance, and payment. Without them, even a clear allocation of obligations may fail to ensure justified application of liability.

This approach is consistent with the direction of scientific studies addressing changes, documentation omissions, and causes of rework [15–17]. However, the findings from the construction projects examined in those studies do not directly substantiate the timeframes or percentage rates proposed for design services in Armenia. The contribution of those studies lies in distinguishing causes and identifying interaction between participants' actions. The proportionality of the specific rates proposed requires separate assessment based on experience with domestic contracts.

Comparison of international regulations demonstrates the need to consider the functions of different instruments together. The client's preparatory obligations, provision of

necessary cooperation, selection of professional services, independence of technical control, and protection of payment deadlines are regulated through different legal structures [9–14]. Their applicability in Armenia must be assessed in conjunction with contractual relationships, oversight capacity, and dispute resolution procedures.

The effectiveness of the proposed mechanism for protecting timeframes depends on the verifiability of the calculation. The scope of work, stage dependencies, and relevance of the standards applied must be substantiated. Changes arising during contract performance must also be documented, demonstrating their effect on the schedule. Under these conditions, it will be possible to distinguish an initially unsubstantiated timeframe from delay arising during performance.

Strengthening the substantiation of initial prices and the liability associated with expert review may complement protection of timeframes. Oversight requirements must, however, be supported by clear calculation methods. Otherwise, different assessments may be produced for the same work because of differing interpretations of the calculation base, coefficients, or services included. In expert review, assessment of the financial consequence must be accompanied by examination of the technical significance of the defect.

The proposals on acceptance of the design, payment, and tax deferral form an interconnected sequence of financial protection. Clarifying the fact of acceptance establishes the basis for determining the payment deadline; liability for payment default creates an incentive to meet it; and tax deferral may limit the subsequent effects of non-payment on the contractor's operations. Applying these mechanisms also requires timely recording of changes in payments and obligations.

Evaluation of the proposed amendments requires joint consideration of contract durations, delay attributable to the designer, design defects, the possibilities for unilateral termination, and payment delays. The comparison must take into account the purpose and complexity of facilities, the scope of work, and clients' organizational capacities. These data will make it possible to assess the extent to which the proposed regulations contribute to timely delivery of quality outcomes and a justified allocation of liability.

Conclusions

1. The legal framework for organizing design work requires interconnected regulation of baseline data provision, substantiation of timeframes and prices, expert review, acceptance, and payment. The approach developed in this study is based on ensuring that liability for the consequences of breach is specifically allocated in accordance with a participant's obligation and the conditions necessary for its fulfilment.
2. Recording the baseline data required, the party responsible for their provision, and their actual delivery date creates a verifiable basis for assessing the design schedule and delay. It is proposed that the commencement of the period for the relevant work be linked to the complete provision of the data necessary for that work, while its duration is substantiated by the scope, complexity, sequence of stages, and applicable standards.
3. Oversight of the justification of the initial tender price for design work requires distinguishing between the estimated construction cost, the calculated price of design

services, and the contractual price established through the tender. Prices must be compared on the basis of the same scope of work, pricing date, and tax treatment, distinguishing an omission in the client's calculation from a bidder's voluntary price reduction.

4. Liability in connection with expert review of a design must be linked to each participant's breach of obligation and its consequences, assessing the significance of the defect for safety alongside its financial impact.
5. Documenting the submission, acceptance, and payment of design deliverables is necessary to ensure certainty of the payment deadline. It is proposed that the basis for calculating delay penalties be linked to the value of the obligation breached. The contract termination procedure must provide for assessment of the causes of delay, substantiation of the decision, and an inventory of properly completed work to resolve acceptance and payment issues.
6. Temporary deferral of tax obligations arising in connection with an overdue debt owed by a state or municipal client may supplement the contractor's financial protection. The proposed mechanism requires documentary confirmation of the debt, a limit on the amount deferred, and a verifiable procedure for settling the tax obligation after payment by the client.
7. The outcome of the research is an integrated regulatory model for the performance of design work and the substantiation of legal mechanisms governing that process. The proportionality of timeframes, delay penalty and fine rates, and liability measures, together with the overall financial impact, must be assessed using actual contract data, taking into account work quality, performance duration, and public expenditure.

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ՆԱԽԱԳԾԱՅԻՆ ԱՇԽԱՏԱՆՔՆԵՐԻ ԿԱԶՄԱԿԵՐՊՄԱՆ ՈԼՈՐՏՈՒՄ ՊԱՏԱՍԽԱՆԱՏՎՈՒԹՅԱՆ ԻՐԱՎԱԿԱՆ ԱՊԱՀՈՎՄԱՆ ԽՆԴԻՐՆԵՐԸ ԵՎ ԲԱՐԵՓՈԽՄԱՆ ՈՒՂՂՈՒԹՅՈՒՆՆԵՐԸ ՀԱՅԱՍՏԱՆԻ ՀԱՆՐԱՊԵՏՈՒԹՅՈՒՆՈՒՄ

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Հետազոտությունը հիմնված է նախագծման ժամկետների, ներդրումային արժեքների և կարգավորման խնդիրների վերաբերյալ հրապարակված ուսումնասիրությունների, փաստաթղթավորված օրինակների և իրավական ակտերի վերլուծության վրա: Քննարկվում է ելակետային տվյալների ամբողջականությունը, աշխատանքների ծավալին ու տեխնիկական բարդությանը համապատասխան ժամկետների և գների որոշումը, փորձաքննության անկախությունն ու պատասխանատվությունը, արդյունքների ընդունումը և վճարման պարտավորությունների կատարումը:

Առաջարկվում են նախագծման պայմանների նախնական հիմնավորման, անհրաժեշտ նվազագույն տևողության, իրավական պաշտպանվածության, գնային հաշվարկների վերահսկողության, փորձաքննության որակի ապահովման և վճարման ուշացումներից առաջացող ֆինանսական հետևանքների կարգավորման մեխանիզմներ:

Հիմնավորվում է նախագծային աշխատանքների կազմակերպումը միասնական գործընթաց դիտարկելու մոտեցումը՝ նախնական պլանավորումից մինչև արդյունքների ընդունում և վճարում:

Բանալի բառեր՝ նախագծային աշխատանքներ, ինժեներական բարդություն, ելակետային տվյալներ, նախագծման տևողություն, գնագոյացում, նախագծերի փորձաքննություն, պատվիրատուի պատասխանատվություն, իրավական ապահովում:

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LEGAL FRAMEWORK FOR ACCOUNTABILITY IN THE ORGANIZATION OF DESIGN WORK IN THE REPUBLIC OF ARMENIA: CHALLENGES AND REFORM DIRECTIONS

ПРОБЛЕМЫ ПРАВОВОГО ОБЕСПЕЧЕНИЯ ОТВЕТСТВЕННОСТИ В СФЕРЕ ОРГАНИЗАЦИИ ПРОЕКТНЫХ РАБОТ И НАПРАВЛЕНИЯ РЕФОРМИРОВАНИЯ В РЕСПУБЛИКЕ АРМЕНИЯ

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В При организации проектных работ, выполняемых по государственным и муниципальным заказам в Республике Армения, несоответствие инженерных требований и договорных условий создаёт риски для качества работ, соблюдения сроков их выполнения и финансирования. Необходимо выявить причины этих несоответствий и обосновать направления совершенствования правового обеспечения ответственности заказчика, проектировщика и лица, осуществляющего экспертизу.

Исследование основано на анализе опубликованных исследований по вопросам сроков проектирования, инвестиционных затрат и регулирования, документально подтверждённых примеров и нормативных правовых актов. Рассматриваются полнота исходных данных, определение сроков и цен в соответствии с объёмом и технической сложностью работ, независимость и ответственность экспертизы, приёмка результатов и исполнение платёжных обязательств.

Предлагаются механизмы предварительного обоснования условий проектирования, установления минимально необходимой продолжительности работ, обеспечения правовой защищённости, контроля ценовых расчётов, обеспечения качества экспертизы и регулирования финансовых последствий задержек платежей.

Обосновывается подход к организации проектных работ как к единому процессу, от предварительного планирования до приёмки результатов и оплаты.

Ключевые слова: проектные работы, инженерная сложность, исходные данные, продолжительность проектирования, ценообразование, экспертиза проектов, ответственность заказчика, правовое обеспечение.

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ECONOMIC AND CONTRACTUAL CONSEQUENCES OF DISCREPANCIES IN TIMEFRAMES AND PRICING IN PUBLIC PROCUREMENT OF DESIGN SERVICES AND ASSOCIATED CORRUPTION RISKS

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Abstract

In the Republic of Armenia, the misalignment between engineering requirements and contractual terms in design work commissioned by state and local authorities creates risks to work quality, timely completion, and financing. The causes of these discrepancies need to be identified, and directions for reforming the legal framework governing the responsibilities and liability of clients, designers, and design reviewers need to be substantiated.

The research draws on an analysis of published studies on design durations, investment costs, and regulatory issues, together with documented cases and legal acts. It examines the completeness of baseline data, the determination of timeframes and prices commensurate with the scope and technical complexity of the work, the independence and accountability of design review, the acceptance of deliverables, and the fulfilment of payment obligations.

Mechanisms are proposed for substantiating design conditions in advance, establishing the minimum necessary duration of work, ensuring legal protection, overseeing pricing calculations, assuring the quality of design review, and addressing the financial consequences of payment delays.

The study substantiates an approach that treats the organization of design work as an integrated process, from preliminary planning through the acceptance of deliverables and payment.

Keywords: design work, engineering complexity, baseline data, design duration, pricing, design review, client liability, legal framework.

Introduction

The effectiveness of public procurement of design services depends not only on the organization of tender procedures and the economical use of financial resources but also on ensuring the technical, organizational, and contractual conditions necessary for the execution of design works. The preparation of design and cost-estimate documentation is a multi-stage engineering process, the duration and cost of which depend on the purpose of the facility being designed, its technical complexity, the scope of work, the completeness of initial data, the required engineering investigations, and approval procedures. Consequently, the

establishment of design deadlines and initial procurement prices should be based on appropriate calculations reflecting the composition, scope, and complexity of the work.

International approaches to evaluating public procurement effectiveness do not regard the lowest price as a sufficient condition for the efficient use of public funds. The *Value for Money* principle applied in the World Bank's procurement regulations provides for the combined assessment of costs and benefits, risks, non-price criteria, and, where appropriate, life-cycle costs. Procurement procedures should correspond to the nature and complexity of the works or services being procured and the risks associated with their implementation [1]. This approach is particularly important for design services, as the quality of their outputs may directly affect subsequent construction costs, safety, and operational efficiency.

The economic justification of price proposals is also emphasized in European Union public procurement regulations. Article 69 of Directive 2014/24/EU of the European Parliament and of the Council provides that contracting authorities shall require tenderers to explain their proposed prices or costs where tenders appear to be abnormally low in relation to the works or services concerned [2]. Although this provision directly concerns bids submitted by tenderers, it reflects the importance of assessing the economic justification of prices in public procurement. In the case of design services, it is also necessary to assess whether the initial procurement price established by the contracting authority corresponds to the actual scope, complexity, and conditions of the work.

Issues concerning the justification of project costs and implementation schedules have been extensively examined in international scientific literature. Flyvbjerg et al. [7], analyzing data from 258 transport infrastructure projects, identified a systematic tendency to underestimate initial project costs. Their findings demonstrate the importance of reliable economic justifications for the efficiency of public investment. Assaf and Al-Hejji [8], investigating the causes of delays in construction projects, identified the influence of actions taken by clients, consultants, and contractors. Their research indicates that delays in project implementation may result from the actions of different participants and therefore require a comprehensive assessment of cause-and-effect relationships.

Issues relating to public procurement effectiveness and contractual relationships are also addressed in OECD studies. OECD publications emphasize that the entire public procurement process, from needs assessment to contract implementation and final payment, is exposed to governance and integrity risks [3, 4]. The OECD's 2025 study pays particular attention to procurement planning, risk management, monitoring of contract implementation, and the effectiveness of accountability mechanisms [5]. Under this approach, public procurement effectiveness is assessed not only by the outcome of tender procedures but also by the fulfillment of contractual obligations and the quality of the services procured.

The studies by Fazekas, Tóth, and King [9], as well as Fazekas and Kocsis [11], are particularly significant for assessing corruption risks in public procurement. These authors developed methods for identifying corruption risks using public procurement data and indicators associated with restrictions on competition, the organization of tender procedures, and contract awards. Their studies demonstrate that corruption risk assessment can be based

on verifiable factual data and quantitative indicators. At the same time, the presence of risk indicators cannot, in itself, be regarded as evidence of a specific act of corruption.

The relationship between contractual arrangements and corruption risks has also been examined through economic modeling. Burguet [10] demonstrated that the structure of public procurement contracts and the conditions governing quality control of completed works may influence the economic incentives for corrupt behavior. Celis Galvez et al. [12], examining reforms in the Czech public procurement system, assessed the effects of contracting authorities' discretionary powers and political favoritism on the economic outcomes of contracts. Arozamena et al. [13] investigated corruption risks arising during contract renegotiation, showing that contractual incompleteness may, under certain conditions, contribute to lower initial prices and higher final expenditures. Fazekas et al. [14] examined the organizational mechanisms of corrupt relationships in public procurement, highlighting the significance of informal networks of influence.

Contemporary approaches to preventing corruption risks in public procurement are also presented in the OECD's 2026 report [6]. The report examines risks characteristic of different stages of procurement and the challenges associated with their management. It emphasizes the importance of identifying conditions conducive to potential abuses, applying appropriate oversight measures, and ensuring equal and transparent conditions for public procurement participants.

The international studies reviewed provide a basis for assessing public procurement effectiveness not only in terms of tender prices and contractual deadlines but also with regard to the actual scope of work, implementation conditions, the allocation of obligations between contracting parties, and the economic conditions that may facilitate potential abuses. At the same time, the studies examined primarily address the overall costs of infrastructure projects, delays in construction works, or general mechanisms of corruption risks in public procurement. Their findings provide an important theoretical and methodological foundation but cannot fully explain the specific characteristics of contractual relationships in public procurement of design services.

In the Republic of Armenia, issues concerning the justification of deadlines and prices in public procurement of design services have been examined in previous studies. Galstyan [15], analyzing procurement procedures for the design of water supply and irrigation systems, identified substantial discrepancies between contractual and normative design periods. In the cases examined, design periods of 20–30 days were compared with normative or professionally justified durations of 90–120 days, with deviations reaching 75–83% in certain projects. Tokmajyan et al. [16], investigating the pricing of design services for water infrastructure projects, proposed the Project Complexity Score (PCS) and Design Price Adequacy Ratio (DPAR) indicators. Their study identified discrepancies between the technical complexity of projects, the actual scope of engineering work, and the financial resources allocated for design activities.

These studies primarily focused on the quantitative justification of design durations and prices. However, the economic and legal consequences arising from the interaction between such discrepancies and the application of contractual liability, as well as the possible

mechanisms through which contractual pressure and corruption risks may emerge, have not been examined as separate research subjects.

The relevance of the present study stems from the need to assess the potential consequences of discrepancies in design deadlines and prices in public procurement from a broader perspective. The scientific novelty of this research lies in the integrated examination of unjustifiably short design deadlines, discrepancies in initial procurement prices, and the conditions governing the application of contractual liability, with a view to identifying possible mechanisms through which contractors' economic dependence, contractual pressure, and risks of corrupt practices may arise. This approach makes it possible to assess the effectiveness of public procurement of design services not only in terms of work organization and contract performance but also from the perspectives of the balance of contractual relationships between the parties and the efficient use of public funds.

Conflict Setting

The aim of this study is to identify, through documentary and engineering-economic analysis, the interrelationship between unjustifiably short deadlines, initial procurement prices, and contractual liability in public procurement of design services, to assess their potential economic and legal consequences, and to distinguish the conditions whose combination may create opportunities for corrupt practices.

The study examines how the allocation of obligations, the enforcement of liability, and the subsequent use of design documentation may affect the economic balance between contracting parties. Particular attention is paid to circumstances in which completion depends on initial documents that the contracting authority must provide.

Materials and Methods

The study was conducted using a combination of documentary, comparative, engineering-economic, and contractual-legal analysis methods. The subject of the study is the interrelationship between discrepancies in deadlines and prices established in public procurement of design services, the allocation of contractual obligations, and the potential economic and legal consequences of enforcing contractual liability.

Assessing the consequences of discrepancies requires an examination of the actual conditions of contract performance, the obligations of the parties, the sequence of their fulfillment, and the grounds for enforcing contractual liability.

Research Materials

The information base of the study consists of documents relating to public procurement procedures for design services and the performance of the corresponding contracts in the Republic of Armenia. The analysis draws on procurement invitations, technical specifications, contracts, design schedules, justifications of initial procurement prices, contractual liability provisions, and documents concerning contract performance, acceptance, and termination.

Particular attention is paid to the deadlines for providing initial design data, architectural and planning assignments, technical conditions, and other mandatory documents required for design, as well as their impact on the feasibility of completing the design works.

To assess the actual course of contractual relationships, official correspondence between the parties, documents concerning completed works, information on the submission and acceptance of design materials, and documents substantiating the grounds for contract termination are also examined, where available.

Methodological Basis of the Study

The assessment of the justification of deadlines and prices in public procurement procedures for design services is based on the findings of previous studies [15, 16].

The discrepancies between contractual and normative design periods identified in Galstyan's study [15] are used as a basis for assessing potential inconsistencies between the objectively required time for design and the deadlines established by contract.

The Project Complexity Score (PCS) and Design Price Adequacy Ratio (DPAR) indicators proposed by Tokmajyan et al. [16] are used as a methodological basis for assessing the complexity of design works and the justification of their financing.

The calculation methods for these indicators are not repeated in the present article. Instead, the study focuses on how discrepancies in deadlines and prices, combined with the conditions governing the enforcement of contractual liability, may affect the contractor's economic position and the balance of contractual relationships between the parties.

Assessment of Contractual Performance

Contractual relationships are analyzed by comparing the obligations of the parties with their actual fulfillment.

For each contract examined, the analysis considers the grounds for establishing design deadlines, obligations concerning the provision of initial data, conditions for performing design works, grounds for enforcing liability, the possibility of unilateral contract termination, and procedures for accepting and paying for completed works.

Particular attention is given to cases in which the performance of design works depends on documents to be provided or actions to be undertaken by the contracting authority. For this purpose, contractual events are examined chronologically, identifying the dates of contract conclusion, provision of mandatory documents, preparation and submission of design materials, presentation of comments, and possible contract termination.

Chronological analysis makes it possible to assess the causes of missed deadlines and determine whether the grounds for enforcing liability against the contractor arise exclusively from the contractor's actions or whether circumstances related to the contracting authority's fulfillment of its obligations may also have contributed.

Assessment of the Economic Consequences of Contractual Liability

The economic consequences of contractual liability are assessed by identifying the components of potential financial losses incurred by the contractor.

These may include the value of completed but unpaid design works, contractual penalties, loss of contract performance security, and additional documented expenses directly associated with contract termination.

The total amount of potential financial losses is estimated using the following expression:

$$L = W_u + P + S + C \quad (1)$$

where: L - total potential financial losses of the contractor (AMD), W_u - justified value of completed but unpaid works (AMD), P - amount of contractual penalties actually imposed or potentially applicable (AMD), S - actual loss or potential forfeiture of contract performance security (AMD), C - additional justified expenses directly associated with contract termination (AMD).

Actual and potential losses are distinguished in the calculations. The same economic loss is not counted more than once under different components. The value of completed but unpaid works is assessed separately, taking into account the actual degree of completion, the contractual value, and the relevant acceptance documentation.

The proposed expression is intended to assess the potential economic consequences of contractual liability and cannot, in itself, be regarded as the legally established amount of damages suffered by the contractor.

Assessment of the Economic Significance of Contractual Pressure

To assess the economic significance of contractual liability measures, the contractor's potential financial losses are compared with the total contract value.

For this purpose, the relative contractual financial impact indicator is defined as follows:

$$K_f = \frac{L}{V_c}\ 100\ \% \quad (2)$$

where: K_f - relative contractual financial impact indicator (%), L - total potential financial losses of the contractor (AMD), V_c - total contract value (AMD).

The indicator characterizes the magnitude of potential financial losses relative to the contract value. A high value may indicate that contractual liability measures have substantial economic significance for the contractor. However, it does not, in itself, establish the existence of contractual pressure. Such an assessment also requires examination of the grounds for enforcing liability, the actions of the parties, and the actual conditions of contract performance.

Approach to Corruption Risk Assessment

The assessment of corruption risks is based on an integrated analysis of contractual conditions and the potential consequences of their enforcement.

Three interrelated levels are distinguished.

At the first level, documented discrepancies are identified, including unjustifiably short design deadlines, prices that do not correspond to the actual scope and complexity of the work, delays in providing mandatory initial data, and other deficiencies in the fulfillment of contractual obligations.

At the second level, their potential economic and contractual consequences are assessed, including the likelihood of missed deadlines, the possibility of enforcing liability, the contractor's financial losses, and changes in the balance of contractual relationships.

At the third level, conditions that, in combination, may create an environment conducive to potential abuses are examined. These include the use of the possibility of unilateral contract termination, refusal to pay for completed works, forfeiture of contract performance security, and the potential subsequent use of design documentation without due consideration of the original contractor's rights and legitimate interests.

The assessment distinguishes between documented circumstances, their potential economic consequences, and hypothesized mechanisms of corrupt practices.

Methodological Limitations

The findings of the study depend on the completeness and reliability of the documentation concerning the contracts examined and their performance.

Conclusions concerning corruption risks are based on documentary and engineering-economic analysis and are presented as assessments of conditions that may facilitate potential abuses, rather than as legal determinations of unlawful conduct by specific individuals or organizations.

Results and Discussion

Main Characteristics of the Engineering Design Services Procurement Contract

This study examines a public procurement procedure for engineering design services conducted by the Vagharshapat Municipality in the Armavir Region of the Republic of Armenia. On March 11, 2026, Contract No. RA-AMVH-GHTSDZB 26/2-1 was concluded between the Vagharshapat Municipality and the Academician I. V. Yeghiazaryan Institute of Water Problems and Hydraulic Engineering. The study focuses on Lots 1, 12, and 19 of the contract, with a total value of AMD 6,108,000. The contractual values and performance deadlines for the engineering design services are presented in Tab. 1.

Table 1

Main Characteristics of the Contract Under Study

Indicator	Lot 1	Lot 12	Lot 19
Contract value, AMD	2,988,000	1,440,000	1,680,000
Performance period, calendar days	50	30	30
Deadline specified by the contracting authority	30 April 2026	10 April 2026	10 April 2026

The technical specifications of the contract included the preparation of design documentation, its coordination with the contracting authority, and procedures related to expert examination. For each lot, the technical specifications stipulated that the municipality was required to provide the designer with an architectural and planning assignment. In addition, Lot 19 required the provision of technical conditions and a property ownership certificate for the relevant site.

Thus, the complete performance of the engineering design services depended not only on the professional activities of the designer but also on the contracting authority’s provision of the necessary initial documentation and completion of the relevant coordination procedures. This circumstance is important when assessing the feasibility of meeting

contractual deadlines, since the completion of certain design stages depends on the results of preceding stages and the availability of mandatory initial documentation.

Circumstances Relating to the Fulfillment of Contractual Obligations and Unilateral Termination

During the performance of the contract under study, a dispute arose between the parties concerning compliance with the deadlines for engineering design services and the contracting authority's obligations to provide the necessary documentation. By Letter No. 6440 dated September 28, 2026, the Vagharshapat Municipality notified the contractor of the unilateral termination of Lots 1, 12, and 19 of the contract on the grounds of failure to meet the deadlines for the engineering design services.

The same letter demanded that the contractor pay a penalty of AMD 334,842 and announced the initiation of proceedings to recover the amount secured by the bank guarantee provided as performance security.

Under the relevant provision of Clause 2.1.3 of the contract, the contracting authority was entitled to terminate the contract unilaterally in the event of a material breach by the contractor. Furthermore, failure to meet the deadline for providing the services was classified as a material breach under the contract.

Clause 5.3 of the contract stipulated that, in the event of a delay in providing the services, a penalty of 0.05% of the value of the services due but not provided would be calculated for each working day of delay.

According to the contractor, the contracting authority failed to provide the architectural and planning assignments required for the three lots during contract performance, thereby preventing the final coordination of the design documentation and its submission for expert examination.

The contracting authority, in turn, maintained that the technical specifications contained the information necessary to carry out the preliminary work and that the contractor had not provided adequate notification of the obstacles arising from the absence of the required documentation.

Consequently, the central issue in the dispute between the parties is not merely whether the contractual deadline was exceeded. It is also necessary to assess the circumstances that prevented the complete performance of the work within the specified period. Of particular importance is determining whether the absence of documentation that the contracting authority was obliged to provide prevented the submission of the final contractual deliverables and whether the contractor duly notified the contracting authority of these obstacles.

A combined assessment of these circumstances is necessary to determine the extent to which attributing full responsibility for the delay to the contractor was justified.

Economic Consequences of Contractual Liability

The financial consequences of termination are assessed using Equation (1) and summarized in Tab. 2. The penalty of AMD 334,842 represented approximately 5.48% of the total contractual value of AMD 6,108,000.

Following unilateral contract termination, the contractor paid the assessed penalty and a performance security amount of AMD 800,000.

The combined amount was AMD 1,134,842, equivalent to 18.58% of the total contract value.

Additional expenses arose in connection with the judicial proceedings. Court filing fees calculated at rates of 1% of the contract value and 1% of the disputed penalty amounted to AMD 64,428.42.

The contractual fee for legal representation was AMD 250,000, while AMD 44,000 was paid for the issuance of the bank guarantee.

Thus, the total estimated financial impact associated with contract performance, termination, and the subsequent judicial dispute amounted to AMD 7,601,270.42, equivalent to 124.45% of the contract value.

This indicator must not be equated with the contractor's final financial loss. It includes the contractual value of completed but unpaid design work, the penalty and performance security amounts paid, estimated court expenses, the contractual legal representation fee, and the bank guarantee issuance fee.

These components differ in their economic and legal nature.

In particular, the bank guarantee issuance fee represents an initial cost of contract performance, whereas court filing fees and legal representation expenses are associated with the judicial dispute arising from contract termination.

Furthermore, the contractual value of the completed design work includes VAT.

Consequently, the calculated figure of 124.45% characterizes the relationship between the aggregated contractual amounts and expenses and the contract value rather than the contractor's net economic loss.

Table 2

Potential Economic Consequences of Contract Termination

Indicator	**Amount**
Contract value, including VAT	AMD 6,108,000
Penalty paid	AMD 334,842
Performance security amount paid	AMD 800,000
Estimated court filing fees	AMD 64,428.42
Contractual legal representation fee	AMD 250,000
Bank guarantee issuance fee	AMD 44,000
Total estimated economic impact	**AMD 7,601,270.42**

The amounts in Tab. 2 must be distinguished by their status: the penalty and performance security are reported as paid, court filing fees are estimated, and legal representation is stated at its contractual fee.

The legal validity of the liability measures remains a matter for the judicial dispute.

Treating the full contractual value as the value of unpaid work requires verification of the actual degree of completion, compliance with contractual requirements, and the relevant acceptance documentation.

Distinguishing Between the Right and the Obligation to Terminate a Contract Unilaterally

The legal analysis distinguishes the existence of grounds for unilateral termination from the justification for exercising that right in the circumstances of the case.

A distinction is required between the fact that the contractual deadline has been exceeded and the contractor's liability for that breach and the justification for exercising the right to terminate the contract. Article 466 of the Civil Code of the Republic of Armenia provides for the possibility of amending or terminating a contract on the grounds established by law or by the contract. The same article also regulates the consequences of unilateral refusal to perform a contract.

Engineering design requires initial data, technical conditions, approvals, and coordination. Where the contract assigns responsibility for providing these to the contracting authority, the deadline and the procedure for supplying the documents must be assessed as interrelated contractual conditions.

Where the applicable legal or contractual framework grants the contracting authority the right to terminate the contract, the existence of that right does not necessarily mean that termination is mandatory whenever a deadline is exceeded.

In such circumstances, it is necessary to assess the factual grounds on which the contracting authority decided to terminate the contract and whether the obstacles encountered during contract performance were duly considered.

Relationship Between the Enforcement of Contractual Liability and Corruption Risks

Corruption risks arising during the performance of engineering design service contracts in public procurement may be associated not only with the organization of tender procedures but also with the specific features of fulfilling contractual obligations and enforcing liability.

Setting deadlines shorter than the time objectively required for design work may increase the likelihood of contractual breaches.

If, under such circumstances, the contracting authority fails to provide the necessary initial documentation in a timely manner, completion of the design work may become additionally dependent on the contracting authority's actions.

In such situations, the right to terminate a contract unilaterally on the grounds of delay may become a means of exerting economic influence, particularly when termination is followed by the assessment of penalties, recovery of performance security amounts, or disputes concerning payment for completed work.

The economic significance of such measures may increase where the contractor has already completed a substantial portion of the design work but the results have not been accepted or paid for.

The implications for the subsequent use of design documentation are examined separately below.

From the perspective of corruption risks, the relevant issue is not merely the existence of the right to terminate a contract but also the justification, predictability, and accountability of its exercise.

Where a contracting authority applies different approaches to different contractors in comparable circumstances, or where a termination decision is made without properly assessing the causes of a contractual breach, risks of selective treatment and improper exercise of contractual powers may arise.

The Vagharshapat case provides a basis for examining contractual risk conditions but does not establish that specific individuals committed corrupt acts.

Relationship Between Design Deadlines, Pricing, and Contractual Liability

The duration and pricing discrepancies identified in previous studies [15, 16] provide a broader context for the Vagharshapat case. The present analysis connects those procurement conditions with the allocation of obligations and the economic consequences of enforcing contractual liability.

Based on the combined findings, the following potential sequence of contractual risk formation can be identified:

1. Establishment of a deadline or price that does not correspond to the actual scope and technical complexity of the design work.
2. Delay in, or failure to provide, the initial documentation required for contract performance.
3. Impossibility or difficulty of submitting the final design deliverables within the contractual deadline.
4. Enforcement of contractual liability and unilateral contract termination on the grounds of delay.
5. Emergence of financial losses, unpaid work, and litigation expenses for the contractor.
6. Increased economic dependence of the contractor and greater potential for contractual pressure.

The sequence presented represents a potential mechanism through which contractual risks may arise. Not all stages necessarily occur in every procurement procedure, and the examination of a single contract is insufficient to draw general conclusions regarding the prevalence of such a mechanism.

Risks Associated with the Subsequent Use of Design Documentation and Duplicate Expenditure of Public Funds

The consequences of unilateral termination of engineering design service contracts in public procurement may also extend to the subsequent use of design documentation already developed.

This issue is particularly important where design work has been performed but its results have not been formally accepted or paid for.

The outputs of engineering design services consist of graphical, computational, and textual documentation that may be retained in electronic or paper form, regardless of whether the contractual acceptance procedure has been completed.

Consequently, contract termination does not, in itself, mean that previously developed design documentation loses its technical significance.

During the period under study, no new procurement procedure was announced for the same engineering design work. Accordingly, the case provides no identified instance of another contractor using the materials or of duplicate public expenditure.

If, following contract termination, a contracting authority initiates a new procurement procedure for the design of the same facility, it is necessary to establish the extent of the work previously performed, the legal grounds for using the developed documentation, and the composition of the work required under the new contract.

A risk of duplicate financing of the same design work may arise where previously developed and technically usable design materials are incorporated into the performance of a new contract without proper accounting for the work already performed and the corresponding payments.

Furthermore, selective disclosure of the previous contractor's design materials to participants in a new tender may create unequal competitive conditions.

These circumstances may create opportunities for unequal treatment and improper exercise of contractual powers. In the case examined, they are potential risks rather than documented events.

Conclusions

Based on a comprehensive examination of the justification of deadlines and prices, the fulfillment of contractual obligations, and their economic consequences in public procurement of engineering design services, the following main conclusions have been drawn.

1. Unjustifiably short design deadlines may increase exposure to contractual liability. Findings on duration and pricing discrepancies from previous studies should therefore be considered when assessing the feasibility of procurement conditions.
2. Where the contracting authority must provide initial documentation, responsibility for delay should be assessed against the timing and completeness of that provision and its effect on the delivery of the contractual outputs.
3. The economic consequences of termination extend beyond penalties. Paid liability amounts, unpaid contractual work, estimated litigation expenses, and initial performance costs must be distinguished rather than treated as a single measure of net loss.
4. A combination of inadequate deadlines, dependence on documents supplied by the contracting authority, and unilateral termination powers may increase the contractor's economic dependence and exposure to contractual pressure.
5. Subsequent procurement should account for the status and permissible use of previously developed design documentation to reduce risks of duplicate financing and unequal competitive conditions.
6. Procurement contracts should substantiate design deadlines and prices against the scope and complexity of the work, specify deadlines for providing initial documentation, and regulate the consequences of non-provision and the grounds for enforcing liability.

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ՆԱԽԱԳԾԱՅԻՆ ԾԱՌԱՅՈՒԹՅՈՒՆՆԵՐԻ ՊԵՏԱԿԱՆ ԳՆՈՒՄՆԵՐՈՒՄ ԺԱՄԿԵՏՆԵՐԻ ԵՎ ԳՆԱԳՈՅԱՑՄԱՆ ԱՆՀԱՄԱՊԱՏԱՍԽԱՆՈՒԹՅՈՒՆՆԵՐԻ ՏՆՏԵՍԱԿԱՆ ՈՒ ՊԱՅՄԱՆԱԳՐԱՅԻՆ ՀԵՏԵՎԱՆՔՆԵՐԸ ԵՎ ԴՐԱՆՑ ՀԵՏ ԿԱՊՎԱԾ ԿՈՌՈՒՊՑԻՈՆ ՌԻՍԿԵՐԸ

Է.Յու. Գալստյան

Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Հետազոտությունը հիմնված է նախագծման ժամկետների, ներդրումային արժեքների և կարգավորման խնդիրների վերաբերյալ հրապարակված ուսումնասիրությունների, փաստաթղթավորված օրինակների և իրավական ակտերի վերլուծության վրա: Քննարկվում է ելակետային տվյալների ամբողջականությունը, աշխատանքների ծավալին ու տեխնիկական բարդությանը համապատասխան ժամկետների և գների որոշումը, փորձաքննության անկախությունն ու պատասխանատվությունը, արդյունքների ընդունումը և վճարման պարտավորությունների կատարումը:

Առաջարկվում են նախագծման պայմանների նախնական հիմնավորման, անհրաժեշտ նվազագույն տևողության, իրավական պաշտպանվածության, գնային հաշվարկների վերահսկողության, փորձաքննության որակի ապահովման և վճարման ուշացումներից առաջացող ֆինանսական հետևանքների կարգավորման մեխանիզմներ:

Հիմնավորվում է նախագծային աշխատանքների կազմակերպումը միասնական գործընթաց դիտարկելու մոտեցումը՝ նախնական պլանավորումից մինչև արդյունքների ընդունում և վճարում:

Բանալի բառեր՝ նախագծային աշխատանքներ, ինժեներական բարդություն, ելակետային տվյալներ, նախագծման տևողություն, գնագոյացում, նախագծերի փորձաքննություն, պատվիրատուի պատասխանատվություն, իրավական ապահովում:

E.Yu. Galstyan

ECONOMIC AND CONTRACTUAL CONSEQUENCES OF DISCREPANCIES IN TIMEFRAMES AND PRICING IN PUBLIC PROCUREMENT OF DESIGN SERVICES AND ASSOCIATED CORRUPTION RISKS

ЭКОНОМИЧЕСКИЕ И ДОГОВОРНЫЕ ПОСЛЕДСТВИЯ НЕСООТВЕТСТВИЙ В СРОКАХ И ЦЕНООБРАЗОВАНИИ ПРИ ГОСУДАРСТВЕННЫХ ЗАКУПКАХ ПРОЕКТНЫХ УСЛУГ И СВЯЗАННЫЕ С НИМИ КОРРУПЦИОННЫЕ РИСКИ

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При организации проектных работ, выполняемых по государственным и муниципальным заказам в Республике Армения, несоответствие инженерных требований и договорных условий создаёт риски для качества работ, соблюдения сроков их выполнения и финансирования. Необходимо выявить причины этих несоответствий и обосновать направления совершенствования правового обеспечения ответственности заказчика, проектировщика и лица, осуществляющего экспертизу.

Исследование основано на анализе опубликованных исследований по вопросам сроков проектирования, инвестиционных затрат и регулирования, документально подтверждённых примеров и нормативных правовых актов. Рассматриваются полнота исходных данных, определение сроков и цен в соответствии с объёмом и технической сложностью работ, независимость и ответственность экспертизы, приёмка результатов и исполнение платёжных обязательств.

Предлагаются механизмы предварительного обоснования условий проектирования, установления минимально необходимой продолжительности работ, обеспечения правовой защищённости, контроля ценовых расчётов, обеспечения качества экспертизы и регулирования финансовых последствий задержек платежей.

Обосновывается подход к организации проектных работ как к единому процессу, от предварительного планирования до приёмки результатов и оплаты.

Ключевые слова: проектные работы, инженерная сложность, исходные данные, продолжительность проектирования, ценообразование, экспертиза проектов, ответственность заказчика, правовое обеспечение.

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THE USE OF WIND POWER AND THE CONVECTION EFFECT OF AIRFLOW IN THE ENERGY SECTOR

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Abstract

This article examines trends in the development of technologies for harnessing wind power for human benefit, ranging from ancient sails and windmills to modern generators, which—for economic efficiency—are grouped into onshore and offshore wind farms and are increasing their share of the global energy balance year by year. At the same time, the article examines the growing environmental problems that are being pushed into the background due to humanity's urgent need for renewable energy sources. From this perspective, the article reviews the stages of development of convection-based energy generation methods, which are characterized by high environmental performance. Several methods for increasing the efficiency of "solar tube" technology are proposed; an analysis of the properties of its new design is conducted based on computer modeling; and a comparison with existing technologies is carried out.

Keywords: renewable energy sources, wind turbine, onshore and offshore wind farms, solar trough in the energy sector, solar tower.

Introduction

Humans have known about the destructive power of the wind since the earliest days of their conscious existence—the wind toppled the huts in their settlements, uprooted trees, and whipped up waves at sea. It was not until the fourth millennium B.C. that people learned to harness the wind for their own benefit. The oldest depiction of a sailboat was found on an Egyptian vase dating back to 3500 B.C. The Egyptians took advantage of their region's unique geography: ships sailed north along the Nile's current to the Mediterranean Sea, and returned by traveling upstream, propelled by a tailwind that blew steadily from the north into

the sun-warmed African continent. It should be noted that the technique of utilizing tailwinds, characteristic of the use of "straight" sails, persisted for several millennia in both river and maritime navigation, the latter of which became extremely widespread.

However, it was precisely on such ships—equipped with several rows of oars and using sails only when sailing with the wind—that the Phoenicians not only explored the entire Mediterranean Sea but also ventured into the Atlantic and circumnavigated Africa. The square sail remained in use during the period of Greek dominance at sea. Several centuries later, Rome began to travel and wage war under this sail, while also establishing great trade routes. It was not until the 8th century that the wind came to fully serve seafarers, with the invention of the "gaff sail," which allowed ships to sail at an acute angle to the wind. This sail, combined with the use of oars, was skillfully employed by the Vikings, who gave a powerful impetus to the development of medieval civilization. Shipbuilding abandoned oars and switched entirely to wind power only in the 15th century, when the Portuguese caravels—famous for Columbus's voyages—began to be built.

The idea of using wind for mechanical work on land emerged much later than the sail. However, over the centuries, this idea came to be used not only for grinding grain, but also for pumping water, powering sawmills, in cloth manufacturing, and in other industrial applications. The first windmills were built in Central Asia in the 8th century and later spread to China and India. They did not appear in Europe until the 12th century, and by the 17th century had been significantly improved in the Netherlands, where there was an urgent need to continuously pump water from land reclaimed from the sea and where a method was developed to orient the blades toward the wind to increase efficiency. In the late 18th century, mechanisms were invented in Great Britain and France that automatically adjusted the blade area to the wind speed.

In the 19th century, the use of windmills declined significantly due to the invention of the steam engine and electric motors. However, it was during this period that the idea arose to convert windmill mechanisms into devices for generating energy. The world's first wind turbine was built in Cleveland (U.S.) in 1888 and had a diameter of 17 meters and a capacity of 12 kW. Since then, over the course of less than 140 years, the wind energy sector has demonstrated remarkable growth—between 2015 and 2025 alone, wind energy generation tripled and accounted for 12% of the global energy mix [1]. However, as our understanding of how wind turbines operate has deepened, undesirable environmental impacts have begun to emerge; some of these are already evident, while the cumulative effects of others will become apparent many years from now, by which time significant sums will already have been spent on their widespread construction.

From this perspective, it seems advisable to investigate the potential for generating electricity from the convective energy of air currents, which is based on the same process of the sun heating various surfaces—a process that gives rise to such a common phenomenon as a horizontal wind. However, the convective flow moves vertically, which requires different methods for converting its energy into electricity; this makes it possible to develop designs using turbine-type wind generators and move closer to the concept of absolute environmental sustainability.

Trends in the Development of Offshore and Onshore Wind Farms

The most powerful impetus for the accelerated development of wind energy came in the 1950s with the invention of three-bladed horizontal-axis turbine designs and the development of an improved aerodynamic profile for blades cast from lightweight composite materials. Since 2000, the wind energy sector has been marked by a sharp increase in the pace of innovation, rising from 2,000 patents per year to 9,000 patents by 2016 and up to 14,000 patents by 2025. Over the 10-year period from 2015 to 2025, 169,822 patents for wind turbines and wind power plants were granted worldwide [2]. As a result, by 2000, wind turbines with a rotor diameter of 50 m and a capacity of 1 MW had entered mass production, and by 2010, the capacity of the turbines had increased to 3 MW with a diameter of 100 m. In 2025, turbines with a rotor diameter of 250 m began to be commissioned, and the capacity of a single wind turbine reached 16 MW.

This rapid pace of development in the wind energy sector began to reveal certain trends driven by economic feasibility. As wind turbines grew in size, the challenges of transporting their components to the assembly site increased year by year. Transporting a 100-meter blade along winding roads seemed practically impossible. This necessitated the construction of special roads and access routes to each wind turbine, which increased the overall cost of construction. An obvious solution to this problem was to select sites for wind turbines where they could be installed in large groups, requiring only a single access road. A similar situation arose with regard to the transmission of generated energy—a single wind turbine required a separate substation and kilometers of cables to connect to the main grid. In a wind farm, hundreds of turbines can be connected to a single powerful distribution substation, which drastically reduces energy logistics costs. Maintenance of a wind farm, calculated per unit of capacity, is significantly cheaper compared to sending a team of specialists to individual wind turbines, especially considering the need to transport specialized equipment—such as heavy cranes, forklifts, and other machinery—to each one.

The world's first wind farm was built in the U.S. state of New Hampshire in 1980 and consisted of 20 wind turbines, each with a rotor diameter of 12 meters and a capacity of 30 kW. The power plant demonstrated the high efficiency of the wind farm concept and dramatically increased interest in wind energy, especially against the backdrop of the oil crisis of the 1970s. Wind farms began to be built everywhere, and the diameter and capacity of the turbines increased year after year (Fig. 1). The "Alta" wind farm, built in California in 2014 [3], already comprised 586 wind turbines with rotor diameters ranging from 90 m to 100 m and an average capacity of 1.5–3 MW each. The total capacity of the power plant was 1,548 MW. Capital expenditures, driven by economies of scale, reached a record low for that time of $1,870 per 1 kW of rated capacity. It should be noted that the capital costs for installing a single wind turbine—which stood at $5,600 per 1 kW of capacity in 1990 and had been steadily declining by an average of $100 per year—had reached $3,200 per 1 kW of capacity by that time [4]. However, China leads the way in this area thanks to its large-scale,



Fig. 1 Onshore wind farms consist of thousands of turbines.

well-established wind turbine manufacturing industry, whose capacity not only meets the country's own needs but also enables China to participate in 72% of wind projects under construction worldwide [1]. A prime example of this is the "Zhangjiakou" wind farm, which was built in 2022 to provide "green" energy for the Winter Olympics. The wind farm consisted of 5,300 turbines with rotor diameters ranging from 140 m to 165 m and an average capacity of 2.5–6 MW. The wind farm's total capacity was 21.2 GW, and capital costs amounted to $1,270 per 1 kW of capacity, which was due to the exclusive use of domestic production resources.

At the same time, the concentration of a large number of wind turbines at a single site requires compliance with specific technical standards related to the properties of the composite material used in the blades and their failure due to aging or casting defects. If a blade breaks, its rotational inertia causes it to fly hundreds of meters and potentially damage neighboring wind turbines, triggering a so-called "domino effect." Consequently, a minimum permissible distance between wind turbines has been established, which, according to standards in various countries, ranges from 5 to 10 times the turbine's rotor diameter. Taking this distance into account, the "Zhangjiakou" wind farm covers an area of 3,500 square kilometers, which, when calculated in terms of generated power, amounts to 60 kW per hectare. It is interesting to note, however, that solar panels convert only 15–22% of the solar energy reaching their surface into electricity, and each hectare of the Earth's surface receives 10 MW of solar energy, based on the standard test value for solar panel irradiance of 1,000 W/m². Consequently, a solar panel can generate approximately 1,800 kW of power per hectare, which is 30 times more than a wind farm.

However, in the real-world context of constructing solar power plants, there are also technical standards governing the distances between solar panels, which are dictated both by the need for maintenance aisles and by the "shading" effect on neighboring panels. Consequently, the efficiency of land use for solar power plants is significantly reduced; this is also due to the fact that daily insolation starts and ends at zero and reaches its maximum at noon only in equatorial regions. For example, the "Bhadla" solar power plant (India) generates 2,245 MW of power over an area of 56 square kilometers, which corresponds to a land-use efficiency of 400 kW/ha, while the "Tengger" power plant (China) generates 1,547 MW of power over an area of 43 square kilometers (360 kW/ha), which is nonetheless

six times higher than the figure for the "Zhangjiakou" wind farm (60 kW/ha). This pattern is also observed at other well-known wind farms—the 240 turbines at the "Fantanele-Cogelac" wind farm (Romania) cover an area of 120 square kilometers and generate 600 MW of power, which corresponds to a land-use coefficient of 50 kW/ha, while at the "Markbigden" wind farm (Sweden), 1,101 turbines are located across an area of 460 square kilometers and generate 2,007 MW of power (45 kW/ha). Consequently, wind farms are far less space-efficient than solar power plants, which is a significant drawback that is most pronounced in densely populated European countries. For this reason, wind farms are most prevalent in countries with large uninhabited or desert areas, such as the United States, India, China, Australia, Latin American countries, and Central Asian countries.

This distinction among countries based on the feasibility of constructing wind farms on their land became the main driving force behind the trend of moving wind farms out to sea, a move whose feasibility was also dictated by a number of technical considerations. The steady increase in turbine size year after year complicated the process of delivering them from the manufacturer to the customer's site, while offshore wind farm construction technology made it possible to build shipyards for manufacturing the most bulky turbine components, such as blades, right on the shore and transport them unimpeded to the installation site on special vessels (Fig. 2). It was precisely this that made it possible to install wind turbines with the aforementioned rotor diameter of 250 m and achieve capacities of 16 MW. In addition, offshore winds are significantly stronger and more consistent, as they are not obstructed by hills, forests, or ravines. Consequently, the capacity factor for offshore turbines reaches 45–55%, whereas for onshore turbines, a good result is 30–35% [5].



Fig. 2 An offshore wind farm and the construction process.

The first offshore wind farm, "Vindeby," was built in Denmark in 1991 and consisted of 11 wind turbines, each with a capacity of 450 kW. The project was experimental in nature; to study how the turbines would perform in salt-laden sea air, their housings were sealed, and air conditioners were installed inside to maintain stable humidity and temperature levels. After 25 years of stable operation, the wind farm was dismantled in 2017 for research purposes and to be replaced with more advanced wind turbine models. The experience gained from its construction and operation served as the foundation for the rapid development of offshore wind energy. As early as 2019, construction began on the Hornsea wind farm (United Kingdom), which consisted of 339 wind turbines with an average capacity of

7–8 MW and rotor diameters ranging from 154 m to 167 m [6]. The wind farm covered an area of 869 square kilometers and generated 2,604 MW of power, which corresponded to a land-use coefficient of only 30 kW/ha—half that of onshore wind farms—but was justified by the use of vast offshore expanses. At the same time, capital expenditures of $4,000 per 1 kW of capacity reflected a natural increase in the cost of constructing offshore wind farms compared to onshore ones. This was primarily due to the use of expensive, marine-corrosion-resistant materials in all structural components, the high cost of constructing platforms for installing wind turbines—whose foundations were driven into the seabed at a depth of 40–60 meters—and the expensive cables used to transmit energy to shore, which were equally costly to lay along the seabed. However, all these costs were offset by high energy generation from strong offshore winds and the conservation of vast land areas, which contributed to increased interest in the construction of offshore wind farms in all countries. The “Hai Long” wind farm (Taiwan), completed in late 2025, utilized turbines with a diameter of 222 m and a capacity of 14 MW each. These turbine specifications made it possible to generate 1,044 MW of power on just 150 square kilometers (70 kW/ha) and significantly increase land-use efficiency compared to “Hornsea.” The more advanced technology of 2025 also made it possible to slightly reduce capital expenditures, which amounted to $3,735 per 1 kW of capacity.

However, the further development of offshore wind energy was hindered by the variability of the seabed topography—over time, it became difficult to find areas sufficiently far from the adverse effects of the coastline that had a seabed depth of no more than 60 meters, within the technical limits of driving piles into the seabed. This served as the driving force behind yet another trend in offshore wind energy—the installation of wind turbines on floating platforms, which could be transported far out to sea and anchored to the seabed. The first experimental prototypes using this method began testing as early as 2009 [7], and it was not until 2017 that the world’s first offshore wind farm on steel “semi-submerged” platforms, “Hywind Scotland” (Fig. 3), and as early as 2023, the “Hywind Tampen” wind farm was built in Norway “Hywind Tampen” (Fig. 4) was built in Norway, in which the wind turbines were mounted on hollow reinforced concrete “floats” 18 m in diameter and 107 m long, 90 m of which were submerged.

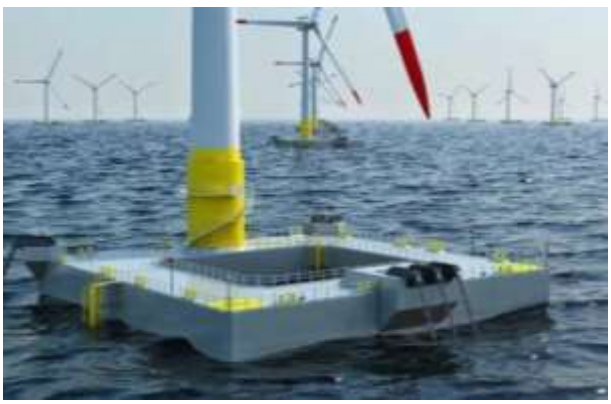

Fig. 3. A wind farm on floating platforms.



Fig. 4. A wind farm on floating buoys.

The obvious technical advantages of this method have inevitably affected the cost of wind farms. Capital investments in the construction of wind farms with fixed towers driven into the seabed average $4,000 per 1 kW of capacity, while the new technology currently costs significantly more—ranging from $6,000 to $8,000 per 1 kW. This is primarily due to the current lack of mass production, complex mooring systems, a sharp increase in the length of the cables connecting to the shore, and the extremely high material intensity of floating platforms compared to standard towers. A modern offshore wind turbine weighs 1,000–1,600 metric tons, with its center of gravity located at a height of 150–200 meters; given the wind pressure on the blades—which enables the generation of 10–16 MW of power—this creates a colossal overturning moment. Therefore, to ensure the platform's stability, its weight must be many times greater than that of the wind turbine itself, and its center of gravity must be located at the lowest point of its structure in the form of ballast. By comparison, fixed supports (Fig. 2) weigh 600–1,500 metric tons, a floating steel platform (Fig. 3) weighs 3,000–5,000 metric tons, while a reinforced concrete "float" weighs as much as 10,000–20,000 metric tons (Fig. 4), since its stability is achieved through the weight of ballast in its lower section, rather than through the width of the steel platform's base. The decision to use concrete was driven by its resistance to deterioration in the corrosive marine environment—tests have shown that concrete breakwaters last up to 100 years without any maintenance. Also of great interest is the highly expensive technology used to manufacture the "floats"—concrete is poured into "sliding" formwork directly at sea on special platforms and lowered into the water as it sets.

The remarkable technological advances in wind energy and the ever-increasing global demand for electricity are overshadowing the multifaceted spectrum of environmental problems that grows with each passing day, the dominant effects of which will be scientifically studied only with a further expansion of the research base and presented to the governments of leading countries by the time it is already impossible to abandon this form of energy generation. Turbulent air flows, as they exit contact with the blades, generate infrasound at a frequency that is highly harmful to humans and animals. It travels for many kilometers and, unlike frequencies in the audible range, has a high penetrating ability—neither the walls of houses nor the ear protection worn by maintenance personnel can shield against it. It causes headaches, dizziness, nausea, and a general feeling of malaise [8]. This makes it impossible for people to live near wind farms or to graze livestock beneath them; in addition to the effects of infrasound, the livestock are also frightened by the shadows cast by the blades, which reduces milk yield and overall weight. Vibrations from the turbine mechanisms are transmitted through the support structures to the ground, scaring away snakes and rodents, which leads to the proliferation of pests; as a result, any crops grown beneath wind farms are completely destroyed. Therefore, wind farms are built only in desert areas or in areas that soon become desert-like (Fig. 1). It is regrettable to note that this also applies to offshore wind farm areas, with the sole difference being that the absence of visible changes on the sea's surface masks the destructive impact of wind turbines on the life of seabed inhabitants, and vibrations from the towers travel through the water for tens of kilometers, causing precisely those higher marine mammals—which possess echolocation and the ability

to communicate with one another through sound—to be washed ashore in large numbers. Wind turbines also pose a danger to birds—American scientists from the wildlife protection service have determined that in just one year, wind turbine blades killed 440,000 birds, and this figure will continue to rise. Among the slowly emerging threats is the fact that the composite materials used in the blades cannot be recycled at the end of their service life, and by 2050 we will have to address the problem of disposing of approximately 40 million metric tons of end-of-life blades [8], a practice that progressive countries such as Austria and Germany have already banned by law within their territories.

Development of "Solar Tube" Technology

Power plants that use the "solar tube" concept operate on a principle similar to that of wind turbines—generating energy from airflow—but are more environmentally friendly because they do not produce infrasound, mechanical vibrations, or industrial waste that requires disposal or landfill. Such a power plant requires an area of several hundred hectares, covered with glass or transparent plastic at a height of 2–3 meters, which creates the power plant's collector heating zone. The air heated by the sun rises and is drawn into a pipe located in the center of the collector, at the base of which a turbine is installed to generate energy. This design eliminates the possibility of harm to birds within the power plant's operational zone, thereby addressing the aforementioned drawback of wind power plants and bringing performance closer to that of hydroelectric power plants, which are completely environmentally friendly. The use in such power plants of a tube that concentrates the kinetic energy of air masses from the entire collector area defines the unique characteristics of these power plants. Multi-bladed turbine-type wind generators are installed inside the tube; these operate at significantly higher wind speeds than traditional three-bladed wind turbines. The resulting higher rotational speeds eliminate low-frequency vibrations, and the design of the turbines—which do not exceed 10 meters in diameter—allows them to be manufactured entirely from metal, which not only increases their durability but also ensures that the equipment's depreciation processes are waste-free.

The first recorded use of rising air currents in history was achieved by Leonardo da Vinci as far back as 500 years ago. His "smoke rotisserie" used a gear system to rotate an animal carcass over a fire by turning a wheel with blades attached to it inside the chimney. It was not until 1896 that a patent was officially granted for a "convection mill"; a model of this mill, built in 1919 by the company "Albert Holmes & Son," is on display at the Science Museum in London. The device was a kind of "thermal engine," whose blades were set in motion by the heat flow generated by a gas burner, a lamp, or a candle. The design was intended primarily to demonstrate the phenomenon of convective flows and for use in relatively large devices; however, it later became popular in Christmas pyramids, where the heat from candles caused the figurines to move in a circle.

Between 1931 and 1981, numerous patents were filed for industrial-scale solar-powered convection power plants, and it was not until 1982 that a prototype of such a power plant was built in Manzanares (Spain) [9]. The project was funded by the German Federal Ministry of Research and Technology (BMFT); construction cost 5.6 million German marks, which at today's exchange rate would amount to $4.5 million. The diameter of the

plant's heat-collecting tube was 244 m, corresponding to an area of 4.7 hectares; the tube was 195 m high and 10 m in diameter (Fig. 5), providing an output power of 50 kW. The power plant had a very low efficiency—only 0.5 percent—meaning that only 1/200th of the solar



Fig. 5. A solar tower in Spain and a view of it through the collector's transparent roof.

energy reaching its surface was converted into electricity. As noted above, solar panel power plants generate an average of 400 kW of power per hectare of surface area. Consequently, if the surface area of the Mansanares power plant were used to install solar panels, it would produce 1.88 MW of power—which is incomparably greater than its rated 50 kW and underscores the unprofitability of using the surface area for this method of energy generation. This explains why the power plant was not rebuilt after the severe storm in 1989 that toppled its chimney, which was constructed from steel sheets only 1.25 mm thick and held in place by tension rods that were not protected against corrosion.

Further development of this technology was marked by a number of unfinished projects. In 2010, the first phase of such a power plant, generating 200 kW of power, began operating in the desert area of Jinshawan Beach (China). By 2013, the plan was to make capital investments totaling $208 million and generate 27.5 MW of power on a 277-hectare site. The project's estimated figures correspond to construction costs of $7,600 per 1 kW of capacity (40% higher than the record-high figures for nuclear power—$5,500 per 1 kW of capacity), and the land utilization coefficient is 100 kW per hectare, which is four times lower than that of solar panel power plants. Consequently, the project was discontinued after the collector glass cracked due to incompatibility with the thermal expansion coefficient of the steel frames into which it was inserted.

In 2001, the Australian company "EnviroMission" announced the start of construction of the "Solar Updraft Tower" in Burunga, with plans to build similar power plants in Texas and Arizona in the future. The company's experts calculated that for a rated capacity of 200 MW, the collector's radius would need to be 7 km (3,847 hectares), and the tower's height 1,000 m—which was necessary to achieve sufficient draft due to the large difference in

atmospheric pressure between the tower's top and bottom. However, the land-use efficiency was half that of the Chinese project—50 kW/ha. The estimated cost of the project was $1 billion, which corresponded to a capital investment of $5,000 per 1 kW and was comparable to that of nuclear power. Although the project was never implemented, it is notable for the engineering innovations it involved in addressing the challenges of constructing a 1,000-meter-tall pipe. Australian experts proposed placing such a pipe on a mountainside and using it as a support, thereby resolving the issues of the pipe's stability and the high cost of its construction. However, even in this version, the "solar tube" project was not implemented due to a number of technical reasons—airflow resistance increases sharply in an inclined tube. Furthermore, both inclined and vertical tubes require perfect thermal insulation, which entails corresponding costs, since as the air moves away from the collector, it begins to cool and the draft decreases. Mountains with suitable topography may be located far from major cities and in hard-to-reach areas, making the delivery of construction materials and equipment there very expensive. From this perspective, the use of solar panels appears significantly more cost-effective, especially given that, following the invention in 1980 the development of thin-film solar cells in 2010, this technology has accelerated its growth, and over the past 10 years, the cost of its products has fallen by 80–90%.

"Solar Tower" Technology

Nevertheless, "solar tower" technology retains its environmental appeal compared to solar panel technology, which—despite all its noted comparative advantages—has a highly harmful production cycle [10] and unresolved issues regarding the disposal of panels at the end of their service life—according to estimates by the Foundation for Environmental Education (FEE), by 2050 the mass of discarded end-of-life panels sent to landfills worldwide will total 160 million metric tons. Therefore, the Armenian University of Architecture and Construction has developed several technical improvements to solar tube technology [11] that increase its efficiency and reduce construction costs, which could make it competitive in the global energy market, given its high environmental sustainability. The new design (Fig. 6) is notable in that each of the proposed technical solutions can be used on any scale in the construction of power plants, regardless of whether the others are appropriate for the application.

The first design improvement is achieved by considering the movement of air beneath the collector, where it is drawn in unimpeded and only then gains the energy needed to move upward and spin the turbine. Consequently, the kinetic energy of the air entering beneath the collector can be fully converted into electricity if the entire perimeter of the collector, down to its base, is enclosed by a casing made of the same material as the turbines (Fig. 6)—the collector's size has been significantly reduced for a clear illustration of all structural elements. With a central pipe diameter of 10 m, the collector must contain 12 turbines, each 3 m in diameter, so as not to restrict the flow of air into the central pipe. In this case, the same volume of air that is drawn into the central pipe will pass through the collector's turbines; therefore, the total power they generate will correspond to the power of the central pipe, thereby doubling the power plant's output without increasing its footprint. It should be noted that the power plant will operate more efficiently if the collector's surface has at least a slight

slope toward its center, since if it is positioned horizontally, the heated air will expand in all directions and be partially forced back out of the collector. The power plant's performance can also be improved by using well-known methods of solar energy storage—if the ground beneath the collector is covered with metal shields, which have a higher solar energy absorption coefficient than soil or desert sand. The power plant's efficiency will increase even further if tanks containing water or vegetable oil are installed beneath the shields, since the heat accumulated by the ground cannot sustain round-the-clock operation of the power plant, as its builders claim.

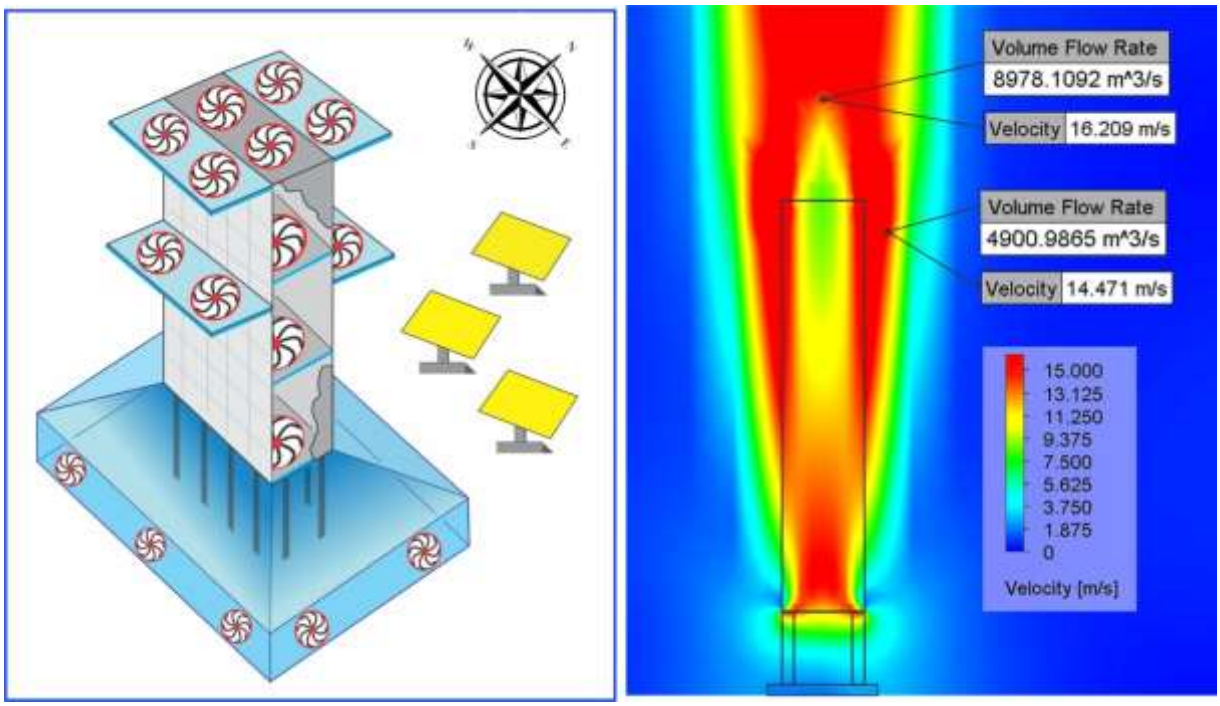

Fig. 6. A solar tower and its computer model (cross-section from the east).

The next improvement to the "solar tube" technology aims to eliminate a drawback caused by the air cooling as it moves upward through the tube, which reduces the draft within it. In the simplest case, this can be avoided if the tube's design allows it to be heated by the sun; to achieve this, it must be made of a heat-absorbing material and shaped like a polyhedron, with each face becoming very hot when oriented perpendicular to the sun and transferring heat to adjacent faces. For full-scale implementation of this technology, the pipe must be replaced with a rectangular tower made of heat-absorbing material, with its wide side facing south; this tower may also be designed to allow for additional heating of its northern wall using heliostats (Fig. 6). Such a design will not only maintain the temperature in the pipe generated by the collector but will also generate an updraft itself, in accordance with the phenomenon—common in the architecture of large cities—of hurricane-force winds forming at the base of skyscrapers, caused by an updraft of air along their facades, which are heavily heated by the sun. Computer simulations of solar heating of the Bridgewater Place skyscraper (England), which is 112 m tall and 80 m wide [12] , show that at noon on June 22 (the summer solstice), it heats up to 73^0C and generates an updraft with a speed of 11 m/s and a

power of 830 kW, resulting in winds with speeds of 20–30 m/s forming on the streets near the skyscraper.

A study of the potential industrial applications of this physical phenomenon [10] shows that 3-mm-thick AD1 (1050) aluminum panels, when coated with Thurmalox 250 selective paint—which reduces the thermal emissivity coefficient—can heat up to 200^0C, while a vertical surface measuring 100 × 100 m (1 ha), when heated by the sun to 100–130^0C, generates an updraft with an average power of up to 2 MW during both the winter and summer seasons. Computer modeling of the central tower in the structure shown in Fig. 6, clad with 3-millimeter panels heated by the sun to 130^0C, shows that their uniform heating throughout their entire thickness contributes to the formation of the noted airflow both on the tower's outer surfaces and inside it. Such a structure not only makes it possible to install turbines on both sides of each wall but also allows them to be installed along the entire height of the tower, since the air, after exiting each turbine, gains additional energy from the heated wall and accelerates its upward movement.

The calculations based on the computer model of the tower were performed assuming a height of 100 m, a width of 50 m, and a distance between the walls of 20 m. A gradient of decreasing air temperature with increasing distance from the tower walls was entered into the simulation program; measurements based on the computer model of temperature distribution within the tower show that within a distance of 40 cm from the walls, the average temperature is 125 ^{0}C. Calculation results for this temperature value and the averaging zone show that an updraft with a power of 1.44 MW is generated in the central part of the tower, while on the outer side of the walls, an updraft with a power of 0.65 MW is generated (the kinetic energy of the airflow, given the known air density and the values of velocity and volume of the updraft measured on the model). Thus, the proposed design (even without a collector) generates three updrafts with a total power of 2.74 MW, which—taking into account the Betz limit (59.3%), corresponds to an output power of 1.62 MW and is 32 times greater than that of the solar tower in Manzanares (50 kW over an area of 4.7 hectares). This design utilizes two vertical surfaces measuring 100 × 50 m with a total area of 1 hectare, which—based on the standard test value for solar panel irradiance of 1,000 W/m²—corresponds to an efficiency of 16.2%. This falls within the efficiency range of solar panels; however, the design in question possesses the aforementioned high environmental performance characteristics of a "solar tube" and provides a 10-fold saving in land area, since its active surfaces are arranged vertically and occupy an area of only 0.1 hectares (20 × 50 m).

Thus, replacing the "passive" solar tube design with a "solar tower" that generates its own updraft lays the foundation for a new direction in the energy sector, allowing power plant capacity to be scaled up by adding stories—similar to skyscrapers—thereby conserving urban land. A particularly interesting challenge is determining the optimal distance between turbines, which will ensure the multiple utilization of the updraft's power—a power that will be replenished at a rate dependent on the turbines' power, the tower's temperature, and its cross-sectional area. A solution can be found both experimentally and through the use of specialized computer simulation software, which will significantly increase the output power of power plants designed on this principle compared to the calculated values of the tower's

updraft at its upper cross-section. This is precisely the fundamental difference between the proposed design and the "solar tower" in Manzanares, which allows for only a single heating of the air in the collector area and is described by the simplest chimney formula—the application of which is no longer valid for the case under consideration, involving additional heating of the chimney along its entire length, which requires a fundamentally new analytical method. The mode of autonomous generation of an updraft in the tower makes it possible to significantly reduce the size of the collector, limiting its purpose to the function of pre-drawing in, from all adjacent areas, volumes of air sufficient for the effective operation of the turbines in the tower.

A computer model of temperature distribution on both sides of the tower shows that as the air moves away from the walls, which are heated to 130^0C, the temperature begins to drop and reaches ambient temperature at a distance of 8–10 m from the walls. At the same time, the average temperature inside the tower is 58.60^0C, and on the outer surface of the walls it is 46.30^0C, which broadens the range of turbine options based on their maximum operating temperature. The low operating temperature of the proposed design allows for the use of a significantly smaller number of heliostats than in the "Gemasolar" tower-type solar power plant in Spain [13], where 2,650 heliostats heat water to a temperature of 600^0C, sufficient for operating steam turbines. In this design, however, the energy of the rising flow is directly converted into the rotational energy of the turbines without multiple energy conversions in steam turbines. Another comparison with "Gemasolar" is particularly interesting if the tower shown in Fig. 6 were scaled to the dimensions of the plant in Manzanares—a tower height of 195 m and a collector diameter of 244 m.

This structure will consist of two vertical surfaces, each measuring 195 × 244 m, spaced 20 m apart and aligned along the central axis of a base with a diameter of 244 m and an area of 4.7 hectares, the southern portion of which will be reserved for the collector, and the northern portion for the heliostats. Simulations using a computer model of this structure show that it generates three updrafts with a combined capacity of 15.4 MW, which is comparable to the capacity of the "Gemasolar" plant (19.9 MW), located on a 185-hectare site. This represents a 10-fold increase in land-use efficiency, with the potential to further increase capacity by accounting for the preheating of air in the collector and installing multiple tiers of turbines within the tower, all within the same area.

This comparison can be extended to solar panels, which, as noted above, generate 1.88 MW of power from an area of 4.7 hectares—8.2 times less than the power output of the structure under consideration (15.4 MW), located on the same site. This allows for a new assessment of the inexhaustible potential of solar energy [14, 15]—to supply the entire planet with electricity, it would be sufficient to install solar panels across a country the size of Spain (505,994 square kilometers). It is highly symbolic that the scientists' calculations were performed specifically for the country that was the first to build a "solar tube"; however, the comparison provided shows that "solar towers" could supply all of humanity with energy if they were installed on an area just one and a half times the size of Switzerland (41,290 square kilometers). Consequently, the proposed "solar tower" technology is many times more efficient than all known "solar technologies"—solar panels, solar towers, and tower-type solar

power plants. In addition, this technology could pose serious competition to traditional wind turbines, since the turbine-type generators it uses are completely environmentally friendly [10], and the tower's design allows it to generate its own airflow for the turbines on any terrain, regardless of its "wind rose." The construction of such power plants and the subsequent maintenance of their internal turbine structures—with a diameter of no more than 10 m and metal components—will be incomparably cheaper than working at heights of 100–200 m with modern wind turbines that have blades up to 120 m long.

Thus, "solar tower" technology—which is based on the unconventional "solar tube" technology—has the potential to compete effectively in the global energy market, which justifies the need for scientists to conduct comprehensive research on it in order to maximize its technical performance and develop methods for constructing power plants.

Conclusion

The rapid growth of the wind energy sector is the dominant factor driving its integration into economically viable onshore and offshore wind farms and the development of increasingly advanced offshore turbine designs. At the same time, there is a clear and growing threat of environmental problems—wind turbines generate infrasound and low-frequency vibrations that are hazardous to humans and animals, making it impossible for people to live within tens of kilometers of wind farms, as well as for livestock grazing and agricultural activities in these areas. Assessing the destructive impact of offshore wind farms on the ocean's ecology is complicated by the specific nature of deep-sea research, and its consequences will only become apparent in the future, when it will be impossible to abandon this form of energy. From this perspective, convection-based energy generation methods appear to be significantly more environmentally friendly, although they have not yet been sufficiently developed due to their low efficiency. The methods proposed in this article for improving "solar tube" technology allow for a significant enhancement of its technical characteristics. Furthermore, computer modeling of the "solar tower" reveals a number of advantages over other "solar" technologies and, in particular, a 10-fold increase in surface utilization efficiency due to the ability to increase the power plant's capacity by adding additional floors equipped with turbine-type wind generators.

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ՔԱՄՈՒ ՈՒԺԻ ԵՎ ԿՈՆՎԵԿՑԻԱՅԻ ԵՐԵՎՈՒՅԹԻ ՕԴԻ ՀՈՍՔԻ ՕԳՏԱԳՈՐԾՈՒՄԸ ԷՆԵՐԳԵՏԻԿԱՅՈՒՄ

Մ. Վ. Մարկոսյան, Հ. Հ. Այվազյան
Երևանի կապի միջոցների ԳՀԻ ՓԲԸ

Հոդվածում դիտարկված են քամու ուժի օգտագործման տեխնոլոգիաները սկսած նախնադարյան արագաստներից և հողմաղաձներից մինչև ժամանակակից հողմագեներատորները, որոնք տնտեսական նպատակահարմարությունից ելնելով, միավորված են ցամաքային և ծովային հողմապարկերում և տարեց տարի ավելացնում են էներգիայի արտադրման բաժնեմասը համաշխարհային էներգետիկ հաշվեկշռում: Միաժամանակ հոդվածը դիտարկում է էկոլոգիական խնդիրների աճ, որոնք անտեսվում են հանրության կյանքում էլեկտրական էներգիայի խիստ անհրաժեշտության պատճառով: Այդ կտրվածքով հոդվածը դիտարկում է էներգիայի ստացման կոնվեկցիոն տեխնոլոգիաներ, որոնք բնութագրվում են բարձր էկոլոգիական ցուցանիշներով: Առաջարկված են նախկինում հայտնի «արևային խողովակի» տեխնոլոգիայի մի քանի կատարելագործում, իրագործված է նրա նոր կառուցվածքի հատկությունների

հետազոտություն համակարգչային մոդելավորման հիման վրա, կատարված է համեմատություն հայտնի տեխնոլոգիաների հետ:

Բանալի բառեր՝ վերականգնվող էներգիայի աղբյուրներ, հողմագեներատոր, ցամաքային և ծովային վետրոպարկեր, արևային խողովակը էներգետիկայում, արևային աշտարակ:

ИСПОЛЬЗОВАНИЕ СИЛЫ ВЕТРА И ЭФФЕКТА КОНВЕКЦИИ ВОЗДУШНОГО ПОТОКА В ЭНЕРГЕТИКЕ

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В статье рассмотрены тенденции развития технологий использования силы ветра в интересах человека, начиная с древних парусов и ветряных мельниц до современных генераторов, которые в целях экономической целесообразности объединяются в наземные и морские ветропарки и с каждым годом увеличивают свою долю в мировом энергетическом балансе. Вместе с тем статья рассматривает нарастание экологических проблем, которые отодвигаются на второй план в связи с острой потребностью человечества в возобновляемых источниках энергии. В этом ракурсе статья рассматривает этапы развития конвекционных методов получения энергии, технология которых характеризуется высокими показателями экологичности. Предложено несколько методик по увеличению эффективности технологии "солнечной трубы", реализован анализ свойств её новой конструкции на основе компьютерного моделирования, проведено сравнение с известными технологиями.

***Ключевые слова*:** возобновляемые источники энергии, ветровой генератор, наземные и морские ветропарки, солнечная труба в энергетике, солнечная башня.

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DEVELOPMENT OF AN EDUCATIONAL PROGRAM FOR VISUALIZATION OF THE FOUR-COLOR THEOREM

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Abstract

The four-color theorem is one of the most interesting theorems in graph theory. The theorem is also interesting because, in addition to its rigorous mathematical formulation, it can also be easily illustrated on real maps, which makes it easier to understand the nature of the theorem. This is especially important in the educational field, where a visual or schematic explanation can significantly facilitate the understanding of complex theoretical material. Although the theorem was proposed more than 170 years ago and has been studied extensively, there are few software tools that can illustrate the application of the theorem to real maps. Some of the available tools work only with a map of a specific country, while others allow you to color the map yourself. The goal of this work is to design and develop a software tool that will display not only the result of map coloring, but also all the steps of the applied algorithms: the transition from a map to a planar graph, the enumeration of vertices, and the proper vertex coloring of the graph. The tool developed in the work allows to apply the four-color theorem to maps of different countries, as well as a comparison is made between some well-known coloring algorithms.

Keywords: planar graphs, four color theorem, vertex coloring of a graph, proper coloring of a map, greedy algorithm, Dsatur, backtracking.

Introduction

Graph theory is one of the modern branches of discrete mathematics, and planar graphs are one of the most important subfields of graph theory. One of the fundamental results of planar graph theory is the four-color theorem. On October 23, 1852, mathematician Francis Guthrie, while coloring a map of the counties of England, noticed that it was enough to use four colors to color the map [2]. The exact formulation of the theorem was given by Arthur Cayley (1879). The theorem states the following: *Any geographical map can be colored using four colors, so that countries with a common border (neighboring) are colored in different colors* (here we understand that the territory of each country consists of a single connected region and we consider two countries to be neighbors if they have a common border in the form of a line, not a point) [1]. Or, equivalently, *for any* ***planar graph*** *G (a*

graph that can be drawn without edge intersections or self-intersections), its chromatic number is less than or equal to 4, i.e. $\chi(G) \leq 4$.

The theorem was proved more than 100 years later, on June 21, 1976, by Kenneth Appel and Wolfgang Haken of the University of Illinois [3]. The theorem was proved using a computer and was one of the first major mathematical proofs performed on a computer.

Conflict Setting

Since a geographical map is easily reduced to a planar graph (each administrative-territorial region is assigned a vertex, and the vertices are connected by an edge, if these regions have a common border, in fact a dual graph is constructed), then the problem of visualizing the four-color theorem is reduced to the problem of performing the proper vertex coloring of a planar graph with 4 colors (when neighboring vertices have different colors). The main goal of the developed educational tool is to graphically demonstrate the application of the theorem on real maps. To achieve this, geographical maps taken from the GADM version 4.1 database [7] were used. The maps are presented in json format, according to different levels of division (level-0: the entire country as a single unit, level-1: the country divided into administrative-territorial regions, level-2: regions divided into communities, etc.). Maps of countries that have a level-1 division and the theorem test makes sense for the given map (the regions have a common border, not enclaves or archipelagos) were taken. The main steps of the program are as follows:

1. Transition from a map to a planar graph
2. Application of any coloring algorithm to perform a proper vertex coloring
3. Demonstration of the construction of the graph and the coloring of the regions step by step in the animation format.

To implement this, a graphical user interface (GUI) was created using the Python customtkinter library, which allows the user to select the map of the desired country from the given list of countries, specify whether to show the construction of the graph or only the coloring and get the result in the form of an interactive animation. The map of the selected country is loaded into the program from a json file and saved using tools of the geopandas library. A list is created in the program, where the administrative-territorial regions of the selected map are stored as vertices. Then, pairs of vertices that are adjacent are stored as edges. Note that since the maps are given as sequences of boundary coordinates, in some cases there is a small gap between administrative-territorial units, which prevents accurate verification of the adjacency of regions. To solve this problem, a safety buffer was added that extends the boundary line by a small amount. As a result of experiments, a buffer value of 0.00001 degrees (~1.11 meters) was chosen, which solves the problem but does not distort the accurate data (it does not connect areas that are slightly distant from each other but do not have a common border with an edge). The created graph is stored in a networkx library object. After performing the coloring, the result is displayed in the program in an animation format using the matplotlib library.

Experimental procedures

The main problem that the developed program must solve is the proper vertex coloring of a planar graph obtained from a map. One of the well-known algorithms for vertex coloring

of a graph is the greedy algorithm. The essence of the algorithm is as follows: *traverse the vertices of the graph, and at each step, color the given vertex with the smallest possible color, making sure that none of the neighboring vertices is already colored with the same color* [1]. According to the fundamental property of greedy coloring, for an arbitrary graph $G = (V, E)$ the inequality $\chi(G) \leq d + 1$ holds, where d is the largest of the degrees of the vertices of the graph, $d = \Delta(G)$ [1].

It is known that in the case of greedy coloring, the ordering of the vertices is vital, since different orderings result in different colorings and the number of colors used may differ. That is, greedy coloring does not always give the best result, and therefore, the greedy coloring problem is reduced to the problem of ordering the vertices of a graph. One of the ordering options is LDF (Largest Degree First) [6]. In this algorithm, the vertices of the graph are first ordered in decreasing order of vertex degree, and then the greedy coloring algorithm is applied.

Although this and other coloring algorithms discussed later are available in the networkx library as functions, they were not used in our program and the coloring functions were implemented by ourselves, since in addition to coloring, the sequence in which the algorithm steps were performed is also necessary to create a coloring animation. By implementing coloring with this algorithm and applying it to the map of the Republic of Armenia, the following result was obtained (Fig. 1):



Fig. 1. Result of greedy coloring with LDF vertex ordering for the map of the Republic of Armenia

Applying the algorithm to maps of different countries shows that this algorithm does not always provide an optimal coloring, and in some cases more than four colors are used. For example, when coloring the map of the Federal Republic of Germany with this algorithm, the following result was obtained (Fig. 2):



Fig. 2 Result of greedy coloring with LDF vertex ordering for the map of the Federal Republic of Germany

The result shows that in this case 5 colors were used. A similar problem also arises when coloring maps of some other

countries, for example, the map of the Russian Federation. Therefore, this algorithm cannot be used to demonstrate the 4-color theorem.

To avoid this problem, let us consider another coloring algorithm, the Dsatur (Degree of Saturation) algorithm, which was proposed in 1979 by Daniel Brelas [4]. Before describing the steps of the algorithm, let us introduce the concept of vertex saturation.

*The **saturation degree** of a vertex is the number of different colors with which the neighboring vertices of the considered vertex are colored*.

The main steps of the algorithm are as follows:

1. Order the vertices of the graph in decreasing order of vertex degree
2. Color the first vertex with color 1
3. Select the vertex with the highest saturation degree from the uncolored vertices (if there are several vertices with the same saturation, then select the vertex with the most uncolored neighbors)
4. Color the selected vertex with the color of the smallest possible number
5. If there are still uncolored vertices, proceed to step 3, otherwise finish coloring.

By implementing coloring with this algorithm and applying it to the map of the Federal Republic of Germany, the following result was obtained (Fig. 3):



Fig. 3 The result of coloring with the Dsatur algorithm for the map of the Federal Republic of Germany

The result shows that for the same map, a more optimal coloring was obtained and four colors were used. By implementing an automated testing program that iterates through all the maps and returns the number of colors used for coloring each, the algorithms were verified for the remaining maps. It was found that in the case of greedy coloring, 6 countries were colored with 1 color, 16 with 2 colors, 73 with 3 colors, 96 with 4 colors, and 16 with 5 colors. The same check for the Dsatur algorithm showed that 6 countries were colored with 1 color, 16 with 2 colors, 87 with 3 colors, 92 with 4 colors, and 6 countries with 5 colors (Liechtenstein, Philippines, Puerto Rico, Uganda, Venezuela, Yemen). Although a better result was obtained, there are still countries that are colored with more than 4 colors (Fig. 4). Therefore, let us present another algorithm that will improve the obtained result.

To obtain a better coloring and solve the problem, the Backtracking algorithm [5] was used. The basic principle of the algorithm is as follows: *perform the coloring step by step, and if in one of the steps all four possible colors for the current vertex are exhausted, then go back one step and try to apply a different color to the previous vertex*. The main steps of the algorithm are as follows:

1. Order the vertices of the graph in decreasing order of vertex degree.

2. Select the current vertex and try to color it with the smallest possible color, trying the colors from the smallest to the largest.
3. If it is not possible to color the given vertex with any of the 4 colors, then go back to the previous vertex, change the color of that vertex and try again.

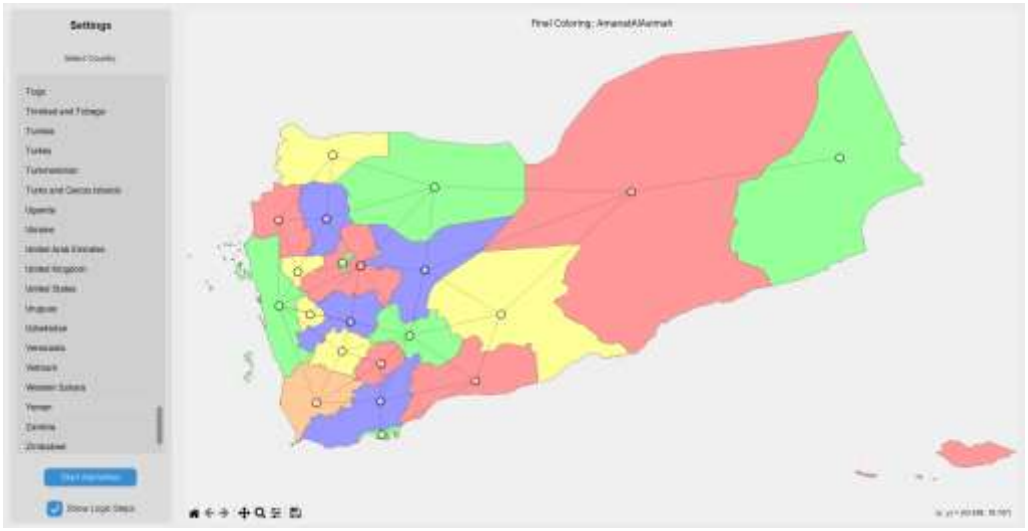

Fig. 4 The result of coloring with the Dsatur algorithm for the map of the Republic of Yemen

The concept of a recursive function was used in the software implementation. The backtrack function calls itself for the next vertex and returns "True" if the coloring was successful. Otherwise, the coloring of the given vertex is canceled and the vertex is colored with the next available color. This process continues until all vertices are colored or all possible search options are exhausted.

By implementing the coloring with this algorithm and applying the check, it turned out that 6 countries were colored with 1 color, 16 with 2 colors, 87 with 3 colors, 97 with 4 colors, and 1 country (Liechtenstein) with 5 colors.

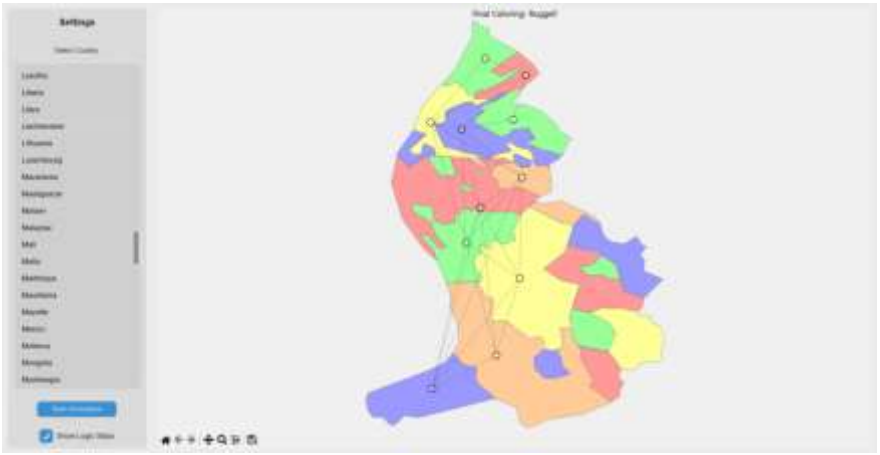

Fig. 5. The result of coloring with the Dsatur algorithm for the map of the Principality of Liechtenstein

Note that 5 colors were used when coloring the map of the Principality of Liechtenstein, since there are exclaves in the map, that is, the administrative-territorial unit is divided into several separate pieces and the geographical map contradicts the definition of a flat graph (an administrative-territorial unit is not a connected region). The figure below clearly shows that a number of polygons do not have a vertex, since they geographically belong to other administrative-territorial units (Fig. 5).

In this case, the map should be viewed not in terms of geographical units, but in terms of visible polygons (connected regions), where the polygons will be considered different administrative-territorial units. We will not address this in our work.

Research Results

By comparing the result of the backtracking algorithm with those previously obtained using Dsatur algorithm for the map of the Republic of Yemen – which had been colored with 5 colors, the following was got (Fig. 6):

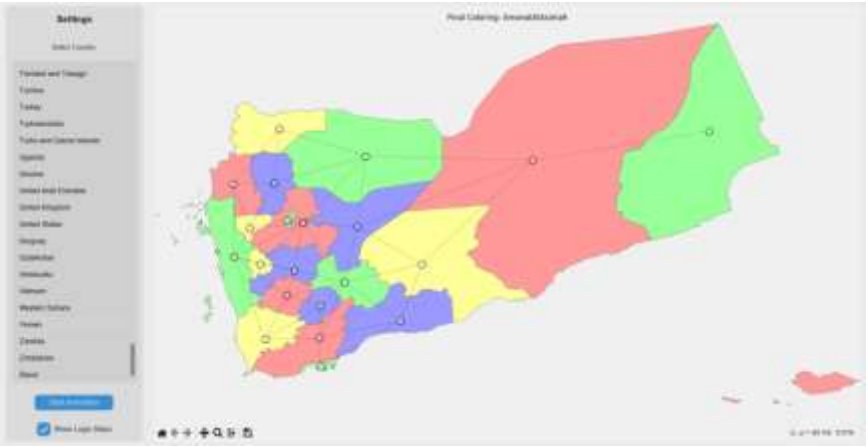

Fig. 6. Backtracking algorithm coloring result for the map of the Republic of Yemen

The more optimal result obtained shows that this algorithm can be used to verify the 4-color theorem. However, since the algorithm uses recursive functions, it can be very slow for countries with a large number of administrative units, such as the Russian Federation or the United States of America, which is not desirable. To circumvent this problem, a check has been added to the program and this algorithm is applied only for the 6 countries mentioned (for which the Dsatur algorithm uses five colors), and in other cases the faster Dsatur algorithm is used.

Conclusion

The study conducted during the development of the Four-Color Theorem visualization software tool showed that the errors in the geographical map data used do not allow for accurate verification of the proximity of administrative units and there is a need to use a safety buffer. The application of the Four-Color Theorem for maps divided by geographic units does not always give the desired result, since the enclaves and exclaves present in real geographic data contradict the construction of a planar graph. In such cases, the map is divided not geographically, but according to geometric polygons. The study and application of different coloring algorithms showed that the greedy coloring algorithm in the case of LDF ordering of vertices does not always give optimal results for real maps. The Dsatur algorithm finds a more optimal coloring, but in some cases more than 4 colors are used. The backtracking algorithm is the most optimal of the algorithms examined, but it is not advisable to use it in the entire program, since due to the use of recursive functions it works slowly with large amounts of input data. For this reason, a hybrid approach was used, using the two algorithms mentioned above depending on the country being colored. The created automatic testing tool allows to easily check the accuracy of coloring for a large number of maps. The developed software tool will help students researching the theorem to better understand the

essence of the theorem and visualize its application. The created software tool is available at the following link: https://github.com/nsarg4/four-color-theorem-vizualization

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ՉՈՐՍ ԳՈՒՅՆԵՐԻ ԹԵՈՐԵՄԻ ՊԱՏԿԵՐԱՎՈՐՄԱՆ ԿՐԹԱԿԱՆ ԾՐԱԳՐԻ ՄՇԱԿՈՒՄ

Ն.Ա. Սարգսյան
Երևանի պետական համալսարան

Չորս գույների թեորեմը գրաֆների տեսության ամենահետաքրքիր թեորեմներից մեկն է: Թեորեմի հետաքրքրաշարժությունը պայմանավորված է նաև նրանով, որ բացի խիստ մաթեմատիկական ձևակերպումից այն կարելի է նաև հեշտությամբ պատկերավոր ցուցադրել իրական քարտեզների վրա, ինչը թեորեմի բնույթը պարկերացնելն ավելի հեշտ է դարձնում: Այս հանգամանքը հատկապես կարևոր է կրթական ոլորտում, երբ պատկերավոր կամ սխեմատիկ բացատրությունը կարող է բավականաչափ հեշտացնել բարդ տեսական նյութի յուրացումը: Չնայած թեորեմն առաջ է քաշվել ավելի քան 170 տարի առաջ և այն խորապես ուսումնասիրված է, փոքրաթիվ են այնպիսի ծրագրային գործիքները, որոնք պատկերավոր կցուցադրեն թեորեմի կիրառումը իրական քարտեզների վրա: Առկա գործիքների մի մասը աշխատում է միայն կոնկրետ երկրի քարտեզի հետ, մյուսները հնարավորություն են տալիս ինքնուրույն գունավորել քարտեզը: Այս աշխատանքի նպատակն է նախագծել և մշակել ծրագրային մի գործիք, որը կցուցադրի ոչ միայն իրական քարտեզի ներկման արդյունքը, այլ նաև կիրառված ալգորիթմների բոլոր քայլերը՝ քարտեզից հարթ գրաֆի անցումը, գագաթների համարակալումը և գրաֆի գագաթային ճիշտ ներկումը: Աշխատանքում մշակված գործիքը հնարավորություն է տալիս կիրառել չորս գույների թեորեմը տարբեր երկրների

քարտեզների վրա, ինչպես նաև համեմատություն է կատարվում ներկման որոշ հայտնի ալգորիթմների միջև:

Բանալի բառեր. հարթ գրաֆներ, չորս գույների թեորեմ, գրաֆի գագաթային ներկում, քարտեզի ճիշտ ներկում, ագահ ալգորիթմ, Dsatur ալգորիթմ, backtracking ալգորիթմ

РАЗРАБОТКА ОБРАЗОВАТЕЛЬНОЙ ПРОГРАММЫ ДЛЯ ВИЗУАЛИЗАЦИИ ТЕОРЕМЫ О ЧЕТЫРЕХ КРАСКАХ

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Теорема о четырех красках — одна из самых интересных теорем в теории графов. Теорема также интересна тем, что, помимо строгой математической формулировки, её легко проиллюстрировать на реальных картах, что облегчает понимание её сути. Это особенно важно в образовательной сфере, где наглядное или схематическое объяснение может значительно облегчить понимание сложного теоретического материала. Хотя теорема была предложена более 170 лет назад и глубоко изучалась, существует немного программных инструментов, способных проиллюстрировать её применение к реальным картам. Некоторые из доступных инструментов работают только с картой конкретной страны, в то время как другие позволяют раскрасить карту самостоятельно. Цель данной работы — разработать программный инструмент, который будет отображать не только результат раскраски карты, но и все этапы применяемых алгоритмов: переход от карты к планарному графу, нумерацию вершин и правильную раскраску графа. Разработанный в данной работе инструмент позволяет применять теорему о четырех красках к картам разных стран, а также проводится сравнение некоторых известных алгоритмов раскраски.

Ключевые слова: Планарные графы, теорема о четырех красках, вершинная раскраска графа, правильная раскраска карты, жадный алгоритм, алгоритм Dsatur, поиск с возвратом.

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COMPARATIVE ANALYSIS AND IMPLEMENTATION OF EXISTING EMG-CONTROLLED INTERFACE UNITS FOR AUXILIARY DEVICES DESIGNED FOR INDIVIDUALS WITH UPPER-LIMB IMPAIRMENTS

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Abstract

This paper presents the challenges and research related to the development of a control unit for an assistive device designed for individuals with upper limb impairments. A comparative analysis of existing technological platforms, including soft robotic gloves, exoskeleton systems, and functional electrical stimulation (FES) devices, is provided. Their technological limitations and potential optimization approaches are discussed in terms of accessibility, response time, and personalization.

A solution based on the processing of electromyographic (EMG) signals using the ESP32 microcontroller is proposed. The advantages of the proposed system are justified in terms of accuracy, compactness, and low cost. The system processes EMG signals captured from muscle activity, amplifies and filters them using an AD8226 instrumentation amplifier, and performs signal processing through the ESP32 microcontroller. Control commands are generated using PWM signals to drive servo motors.

The results of experimental testing and mathematical modeling demonstrate the reliability and effectiveness of the proposed control system. The developed approach provides a practical and cost-effective solution for rehabilitation technologies and assistive devices for individuals with upper limb motor impairments.

Keywords: EMG signal, ESP32, AD8226, assistive device, upper limbs, PWM control, mathematical modeling, robotic glove, paralysis.

Introduction

The development of assistive devices for people with upper limb impairments is one of the most relevant areas of biomedical engineering.

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M.V. Mkrtchyan, A.L. Smbatyan
COMPARATIVE ANALYSIS AND IMPLEMENTATION OF EXISTING EMG-CONTROLLED INTERFACE UNITS FOR AUXILIARY DEVICES DESIGNED FOR INDIVIDUALS WITH UPPER-LIMB IMPAIRMENTS THEOREM

This work is devoted to the development of a control unit for an assistive device intended for individuals with upper limb impairments and controlled on the basis of EMG signals. Existing technological platforms have certain drawbacks that complicate the formalization of control. The choice of the solution method was made taking into account the limitations of existing technological platforms. The study addresses the following questions: which methods of EMG signal processing and classification make it possible to improve the accuracy and reliability of recognizing control commands, and which technical solutions ensure effective interaction between the biosignal acquisition system and the actuator. As a result of the analysis, it was decided to use biosignal (EMG) processing in combination with a microcontroller-based control system. Methods for optimizing existing solutions and the extent of their applicability are considered. The results of the conducted experiments are also presented, and the corresponding conclusions are formulated.

Analysis of Existing Systems



There are various solutions for assistive devices for people with upper limb impairments. Modern solutions can be conditionally divided into three main categories.

Fig. 1 – Exoskeleton device

Exoskeleton systems provide high precision and control of movements through rigid mechanical structures and actuators [1, 4]. An example is shown in Fig. 1.

Fig. 2 – Soft robotic glove

Soft robotic gloves - are based on flexible materials and pneumatic or cable-driven mechanisms [2]. An example is shown in Fig. 2.



Functional electrical stimulation (FES) - systems activate muscles by means of electrical impulses [3, 6]. An example is shown in Fig. 3.



Fig. 3 – Electrical stimulation device

The results of the comparative analysis of these solutions are presented in Tab. 1. The comparison takes into account the following main characteristics: As can be seen from Table 1, the most suitable option is a control system based on EMG signal processing.

Table 1

Characteristics of the solutions

Criteria	Soft Robotic Gloves	Exoskeletons	Functional Electrical Stimulation (FES) Devices
Purpose	Assistance in restoring mobility and home-based rehabilitation	Precise control of movements and active rehabilitation	Stimulation of muscle activity and neuromuscular control
Technology	Pneumatic or cable-driven activation mechanism	Rigid mechanical skeletal structure with motors and sensors	Electrical impulses for muscle stimulation
Advantages	Lightweight, mobile, safe	Precise movements, strong activation	Restoration of natural muscle activity
Disadvantages	Limited force and precision	Heavy structure, complex control	Dependence on precise electrode placement and skin condition
Areas of application	Home rehabilitation, mobility assistance	Medical rehabilitation centers	Treatment of neurological disorders by means of external stimulation
Cost	Medium (relatively affordable)	High	Medium (relatively affordable)
Examples	Soft Robotic Glove (Harvard Biodesign Lab)	Hand Exoskeleton (CyberGlove Systems)	Bioness H200 Wireless

Proposed Solution

A control system based on EMG signal processing is proposed. Fig. 4 shows the complete diagram of the system, which uses EMG sensors that record the user's muscle activity. The resulting analog signal is amplified and filtered using the AD8226 instrumentation amplifier [5] and is then fed to the ESP32 microcontroller [8], where analog-to-digital conversion (ADC [9]) is performed. Next, a threshold-based signal processing algorithm is applied, on the basis of which control commands for the servo drives are generated. Control is carried out by means of PWM signals, which ensures precise and stable control of movements.

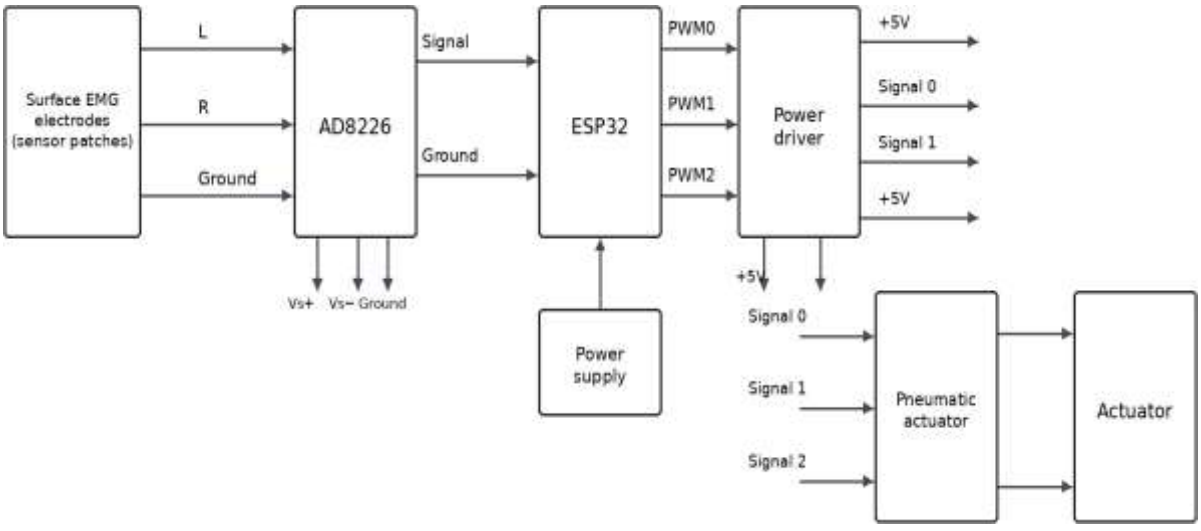

Fig. 4. Diagram of the EMG signal control unit

Advantages of the System

The main advantages of the proposed system are: Low cost of components (ESP32 [8]; AD8226 [5]); Compact design. High response speed; Possibility of individual adjustment of threshold parameters; Possibility of further system expansion thanks to the built-in Wi-Fi and Bluetooth interfaces.

Experimental Studies

To evaluate the performance of the system, experimental studies of EMG signal acquisition were carried out. The sensors were placed on the user's forearm muscles. The signal was amplified using the AD8226 [5] and fed to the ESP32 [8] for further processing. During the experiments, changes in the amplitude of the EMG signal were analyzed at different levels of muscle tension. When a predefined threshold value was exceeded, the system activated the servo drives, performing the "open" or "close" action.

Mathematical Modeling

To analyze the behavior of the signal, a model represented in the following form was used: $EMG(t) = A \cdot \sin(\omega t) + n(t)$, where: A is the signal amplitude, ω is the angular frequency, n(t) is the noise component.

The modeling made it possible to select optimal threshold values for the gain and to reduce the probability of false activations of the system.

Conclusion

In this work, a control unit for an assistive device for individuals with upper limb impairments, based on EMG signal processing, was developed and studied. The comparative analysis showed that the proposed solution provides an optimal combination of accuracy, cost, and design simplicity. The results of the experimental tests confirmed the operability and practical applicability of the developed system. The proposed model can serve as a basis for further research and improvements, as well as for implementation in rehabilitation technologies.

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ՎԵՐԻՆ ՎԵՐՋՈՒՅԹՆԵՐԻ ԽՆԴԻՐՆԵՐ ՈՒՆԵՑՈՂ ԱՆՀԱՏՆԵՐԻ ՀԱՄԱՐ ԷՄԳ ԱԶԴԱՆՇԱՆՆԵՐՈՎ ԿԱՌԱՎԱՐՎՈՂ ՕԺԱՆԴԱԿ ՍԱՐՔԵՐԻ ԱՌԿԱ ԿԱՌԱՎԱՐՄԱՆ ՄԻԱՎՈՐՆԵՐԻ ՀԱՄԵՄԱՏԱԿԱՆ ՎԵՐԼՈՒԾՈՒԹՅՈՒՆ և ԴՐԱ ԻՐԱԿԱՆԱՑՈՒՄԸ

Մ. Վ. Մկրտչյան, **Ա. Լ. Սմբատյան**
Ճարտարապետության և շինարարության Հայաստանի ազգային համալսարան

Քննարկում է օժանդակ սարքի կառավարման միավորի մշակման մարտահրավերները, որը նախատեսված է վերին վերջույթների ֆունկցիան վերականգնելու համար հարակից հաշմանդամություն ունեցող անձանց մոտ: Ներկայացվում է առկա տեխնոլոգիական հարթակների համեմատական վերլուծություն, ներառյալ փափուկ ռոբոտիկ ձեռնոցները, էկզոկմախքային համակարգերը և ֆունկցիոնալ էլեկտրական խթանման (FES) սարքերը: Քննարկվում են դրանց տեխնոլոգիական սահմանափակումները և օպտիմալացման հնարավորությունները՝ մատչելիության, արձագանքման արագության և հարմարեցման առումով: Առաջարկվում է լուծում, որը հիմնված է ESP32 միկրոկառավարիչի միջոցով EMG ազդանշանի (electromyography) մշակման վրա: Հիմնավորվում են առաջարկվող համակարգի առավելությունները՝ ճշգրտության, կոմպակտության և ցածր գնի առումով: Ներկայացվում են իրական փորձերի և մաթեմատիկական մոդելավորման արդյունքները:

Բանալի բառեր՝ EMG-ազդանշան, ESP32, AD8226, օժանդակ սարք, վերին վերջույթներ, PWM կառավարում, մաթեմատիկական մոդելավորում, ռոբոտացված ձեռնոց, կաթվածահարություն:

СРАВНИТЕЛЬНЫЙ АНАЛИЗ СУЩЕСТВУЮЩИХ УЗЛОВ УПРАВЛЕНИЯ ВСПОМОГАТЕЛЬНЫМИ УСТРОЙСТВАМИ, УПРАВЛЯЕМЫЕ EMG-СИГНАЛАМИ ДЛЯ ЛИЦ С НАРУШЕНИЯМИ ФУНКЦИЙ ВЕРХНИХ КОНЕЧНОСТЕЙ И ЕЕ РЕАЛИЗАЦИЯ

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Рассматриваются проблемы разработки узла управления вспомогательного устройства, предназначенного для восстановления функций верхних конечностей лиц с соответствующими нарушениями. Представлен сравнительный анализ существующих технологических платформ, включая мягкие роботизированные перчатки, экзоскелетные системы и устройства функциональной электрической стимуляции

(FES). Рассмотрены также их технологические ограничения и возможности оптимизации с точки зрения доступности, скорости реакции и индивидуализации. Предложено решение на основе обработки EMG-сигналов (electromyography) с использованием микроконтроллера ESP32. Обоснованы преимущества предлагаемой системы с точки зрения точности, компактности и низкой стоимости. Представлены результаты реальных экспериментов и математического моделирования.

Ключевые слова: EMG сигнал, ESP32, AD8226, вспомогательное устройство, верхние конечности, PWM управление, математическое моделирование, роботизированная перчатка, паралич.

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THE CHARACTERISTICS OF STRATEGIC MARKETING TOOLS AND THE SPECIFICS OF THEIR APPLICATION IN THE AGRO-PROCESSING SECTOR

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Abstract

Strategic marketing encompasses a set of various marketing tools that serve as the fundamental pillars for the development of marketing strategies. In international marketing practice, marketing tools are also subject to certain transformations driven by the development of artificial intelligence and the continuous changes in market conditions. The research conducted in this paper primarily focuses on improving approaches to the development of marketing strategies, as well as enhancing mechanisms for their targeted implementation within the agro-processing system. Taking into account the specific characteristics of the agri-food system, the marketing models presented and the proposed tools are primarily aimed at optimizing the development of consumer-oriented products, as well as at the targeted classification of modern consumers' needs. Based on the above, the paper considers an innovative approach to classifying consumer needs in contemporary marketing practice. This approach, on the one hand, is consistent with the behavioral characteristics of today's consumers and, on the other hand, addresses the requirements for developing modern marketing strategies.

Keywords. marketing briefing, brand vulnerability, status-related needs, budget segment, FMCG model, target market.

Introduction

The continuous changes taking place in the modern world, together with the emerging challenges driven by the development of artificial intelligence, necessitate, on the one hand, a certain reassessment of strategic-level marketing models and, on the other hand, their comprehensive adaptation to the conditions of the international Marketplace [1].

The implementation of marketing briefing plays a pivotal role in ensuring the effectiveness of any marketing strategy and competitive policy. It involves identifying the medium- and long-term objectives and priorities that the overall marketing strategy is intended to address and achieve.

Within the agri-food system, identifying target issues through the collection of comprehensive information at the briefing stage significantly reduces the risks associated with

developing marketing strategies and helps assess the extent to which the expected outcomes of a marketing strategy are realistic and achievable.

Problem Statement

The primary objective of this article is to assess, through empirical research, the extent to which strategic-level marketing tools within the agri-food system are aligned with contemporary consumer behavioral characteristics and market transformations taking place in global markets. Although the proposed set of tools is primarily interconnected with traditional marketing approaches in its essence, the synchronized adaptation of the proposed solutions to both digitalization and artificial intelligence, as well as their application in the targeted development of modern marketing strategies, remains of strategic importance. Regardless of the approaches employed in marketing practice and global developments taking place in the sector, one of the key challenges remains ensuring the relevance and targeted nature of marketing research, as well as continuously improving its accuracy.

Analysis

According to the findings of a study conducted by the Institute of Practitioners in Advertising (IPA), 33% of marketing budget losses are associated with inadequate targeting and incomplete briefing processes. According to the data provided by the aforementioned source, 90% of independent marketing consultants and 92% of marketing agencies specializing in the field acknowledge that, despite being one of the most important strategic tools in marketing practice, the marketing brief has not yet received adequate recognition in today's marketplace. The findings of the same study indicate that 69% of independent marketing professionals and 73% of agencies also confirm the view that marketing briefing constitutes an ongoing process, while any changes made to the briefing process entail various resource requirements and additional financial costs (IPA, 2021) [2]. Nevertheless, conducting appropriate reviews and updates of the marketing brief is of considerable importance in order to ensure a targeted response to fundamental changes occurring in the market environment.

The effectiveness of marketing briefing also largely depends on whether the experts involved in the briefing process possess a sufficient understanding of both the agro-processing market and the specific characteristics of the agri-food sector.

Meeting this requirement has a significant impact on ensuring alignment between the market conditions prevailing in the real sector and the marketing strategies developed.

The proposed approach to marketing briefing is considered appropriate for application both by small and medium-sized enterprises (SMEs) operating within the agri-food system and by large-scale industrial organizations.

In contemporary food industry practice, branding is another factor of considerable importance. In the agro-processing sector, the key challenges associated with branding include ensuring both a high level of brand awareness and the desired brand reputation within the target market [3].

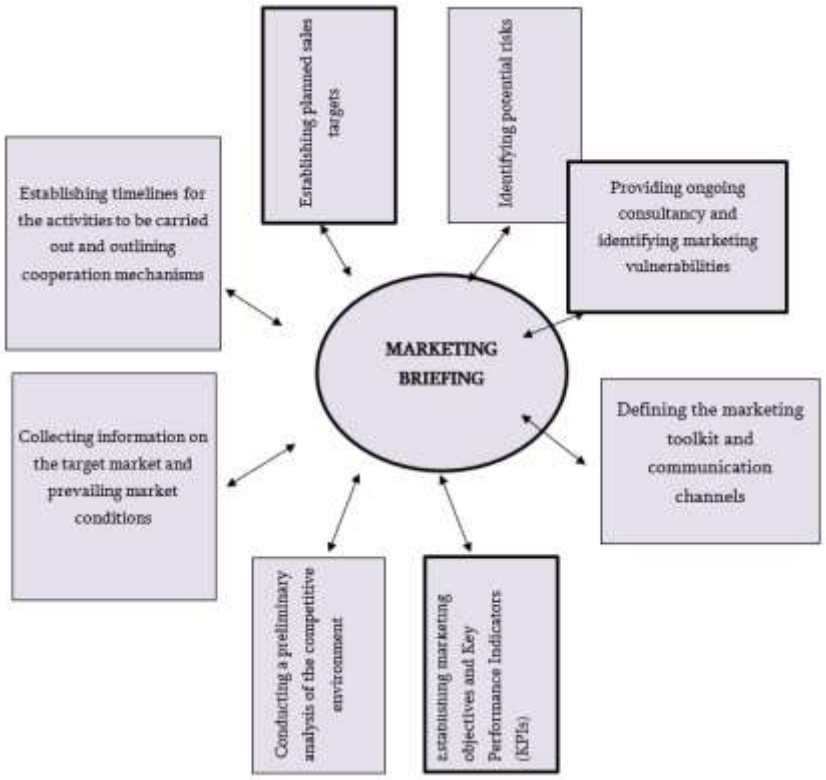

Fig. 1 Key Attributes of Marketing Briefing in the Agri-Food System

Driven by developments in today's highly competitive marketplace, branding-related risks continue to increase due to various factors, with the vast majority falling within the medium and medium-to-high risk categories.

At the same time, the following factors have the most adverse impact on brand vulnerability in the agro-processing sector:

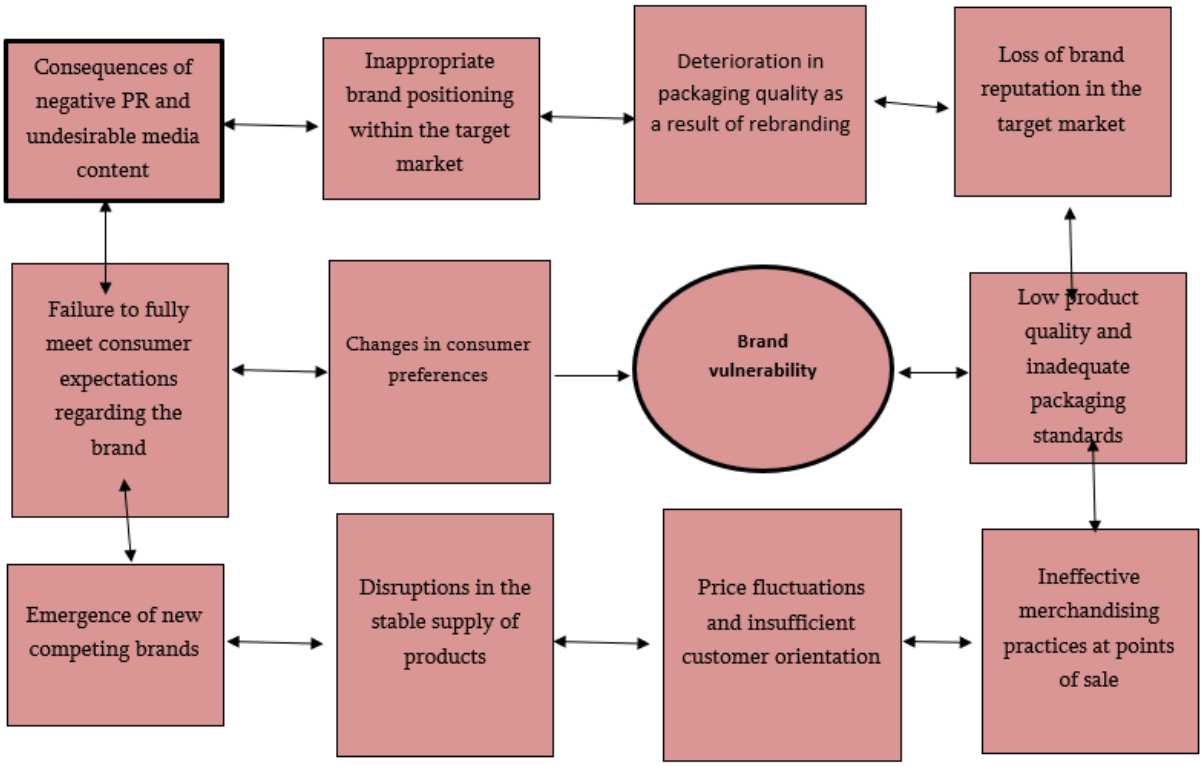

Fig. 2 Key Factors Affecting Brand Vulnerability in the Agri-Food System

Brand vulnerability is an inherent risk that continuously exists among local, international, and globally recognized brands alike. In view of this risk factor, one of the most significant challenges in contemporary branding practice is not limited to the creation of

brands and the ongoing management of their development, but also includes conducting continuous monitoring to assess brand health.

In today's highly competitive environment within the agri-food system, the constant emergence of new brands and evolving market trends further intensify competition, while also driving fundamental transformations in the approaches applied in branding.

Given the need to identify potential risks associated with brand vulnerability, respond to behavioral changes among buyers in the target market through appropriate marketing policies, and select relevant marketing tools, the flexible application of the Customer Persona Model may be of strategic importance to marketing practices within the agro-processing system.

The Customer Persona Model represents a strategically significant tool that makes it possible not only to identify customer identities and develop Buyer Personas within the target market, but also to obtain comprehensive information about buyers' behavioral characteristics and emerging trends. This also involves identifying the underlying motivations and unexpressed desires of target customers, as well as their consumer preferences and habits, which significantly influence purchasing decisions when choosing among the brands available in the market.

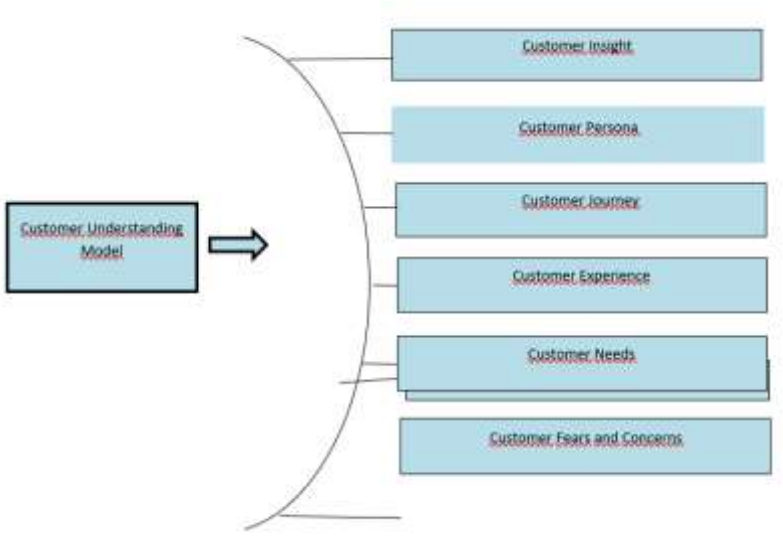

Fig. 3 Key Dimensions of the Customer Understanding Model in Agri-Food Marketing

From a strategic marketing perspective, regardless of whether buyers and consumers in the target market have developed positive, neutral, or negative experiences with a particular brand, continuously monitoring their actual expectations regarding the products offered remains critically important. In contemporary marketing practice, particularly within the agro-processing system, timely identification and prevention of potential concerns and fears among actual buyers and consumers regarding the products offered is essential for mitigating potential failures in marketing approaches, regardless of the existing level of demand for the products concerned.

Considering that products offered within the agri-food system are exclusively intended for consumer use, this factor is particularly relevant to both budget-oriented and premium brands.

Taking into account changes in the consumer market and the behavioral characteristics of buyers in today's B2C segment, it is advisable, from a strategic marketing perspective, to classify buyers' needs according to the following model.

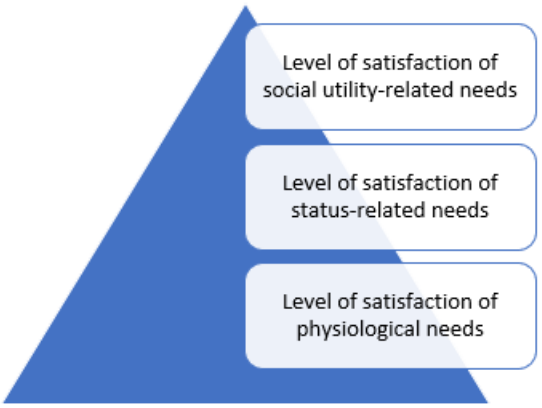

Fig. 4 A Contemporary Approach to the Classification of Consumer Needs in Marketing Practice

In the process of satisfying physiological needs, the vast majority of buyers primarily focus on meeting their basic and essential subsistence requirements. Among this consumer segment, brand reputation does not play a decisive role from a branding perspective. Furthermore, buyers in this segment are generally characterized by pronounced consumption-oriented behavior and relatively low purchasing power. Their primary objective is to acquire the most affordable range of goods and various products in terms of price accessibility.

At the level of status-related needs, consumer purchasing behavior is associated with the acquisition of products that, alongside satisfying various needs, enable buyers to emphasize their affiliation with a higher social status.

For the customer segment characterized by the satisfaction of social utility-related needs, an important consideration is the opportunity to contribute to social and charitable projects through purchases made to satisfy their own needs. Among buyers belonging to this segment, brand integrity plays a pivotal role.

This factor largely explains why numerous companies representing brands with regional and international reputations, both in the agro-processing sector and across various other industries, allocate a certain proportion of their revenue, within the framework of their Corporate Social Responsibility (CSR) policies, to financing various socially oriented initiatives and projects that promote sustainable development.

Representatives of the segment characterized by social utility-related needs predominantly prefer to pay a relatively higher price in exchange for purchasing products from brands that demonstrate a strong commitment to social responsibility in the marketplace. Buyers belonging to this segment are generally characterized by medium, upper-medium, and high purchasing power.

According to a study conducted by the E+Change and Better agencies, the vast majority of contemporary consumers, approximately 86%, expect brands to implement large-scale and continuous sustainable development initiatives. Furthermore, 52% of respondents believe that both established brands and those in the development stage should play a significant role in socially oriented initiatives, while 76% emphasize their involvement in environmentally oriented projects.

The study findings indicate that 64% of contemporary consumers are more inclined to purchase products offered by brands demonstrating a high level of integrity, whereas 74% of target customers consider discontinuing their patronage of brands that demonstrate undesirable social responsibility practices.

The research findings also indicate that, for approximately 56–57% of contemporary buyers, the presence of social responsibility is an important consideration when choosing a

consumer product or service. Moreover, approximately 60% of modern customers express greater trust in brands distinguished by their commitment to corporate responsibility [4].

The application of the proposed model within the agri-food system would be particularly relevant for conducting accurate behavioral analysis and market segmentation based on the classification of customer needs in the target market.

In marketing practice, the application and adaptation of the FMCG model, taking into account the specific characteristics of agro-processing marketing, plays an important role in synchronizing sales activities and marketing policies with the behavioral characteristics of the target segment [5].

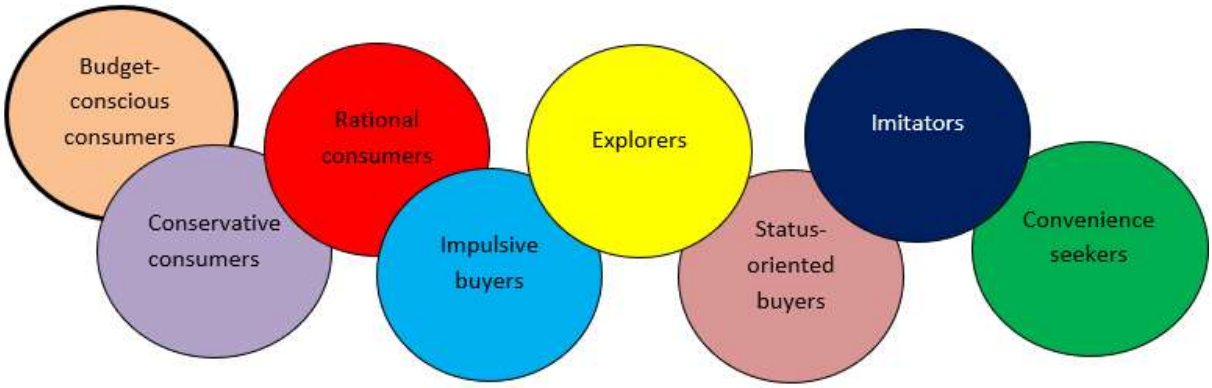

Fig. 5 A Strategic Approach to Buyer Segmentation in Agri-Food Marketing Based on the FMCG Model

In today's marketplace, the budget segment constitutes an integral part of the agri-food system. This segment often includes not only consumers with limited financial resources but also buyers with medium and upper-medium income levels. Therefore, the price–quality ratio is considered the primary determinant of customer satisfaction within this segment. Alongside ensuring sufficient competitiveness when targeting this consumer group, it is important to take into account its high sensitivity to discounts and promotional offers.

Rational consumers are also generally inclined to prioritize the price–quality ratio, whereas conservative buyers tend to prefer brands with which they have already established positive experiences. Unlike rational consumers, buyers with conservative behavioral patterns are distinguished by long-term brand loyalty. Minor price fluctuations in the market do not have a significant impact on the consumer behavior patterns of this segment.

In marketing practice, emotion-driven purchases play a particularly dominant role among exploratory and impulsive consumers. Explorers within these segments are more inclined to seek products distinguished by certain innovative features, whereas among impulsive buyers, unplanned purchases driven by immediate emotions and situational influences play a more significant role.

Representatives of the status-oriented segment differ considerably from all other buyer groups in terms of their consumer behavior. Their preference for premium-category products is primarily driven both by their previous positive experiences with particular brands and by the motivation to express their identity and social status through purchasing decisions. Unlike imitators, this segment is clearly distinguished by both its high purchasing power and its pronounced resistance to emotionally driven purchases.

Conclusion

In summary, examining the specific characteristics of strategic-level marketing tools in marketing practice, it can be concluded that within the agro-processing system, these tools constitute both a set of complementary models and targeted approaches aimed at improving marketing policies. Market transformations bring about not only continuous changes in buyers' behavioral characteristics but also the development of various practical tools for classifying their needs. Based on the above, this article proposes, as an original contribution, a marketing model for assessing the consumer needs of contemporary buyers, adapted to the specific characteristics of today's consumer market and the challenges facing the FMCG sector [6].

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Z.M. Baghryan

THE CHARACTERISTICS OF STRATEGIC MARKETING TOOLS AND THE SPECIFICS OF THEIR APPLICATION IN THE AGRO-PROCESSING SECTOR

ՄԱՐՔԵԹԻՆԳԱՅԻՆ ՊՐԱԿՏԻԿԱՅՈՒՄ ՌԱԶՄԱՎԱՐԱԿԱՆ ՄԱԿԱՐԴԱԿԻ ԳՈՐԾԻՔԱԿԱԶՄԵՐԻ ՅՈՒՐԱՀԱՏԿՈՒԹՅՈՒՆՆԵՐԸ և ԱԳՐՈՎԵՐԱՄՇԱԿՄԱՆ ՀԱՄԱԿԱՐԳՈՒՄ ԴՐԱՆՑ ԿԻՐԱՌՄԱՆ ՆՐԲՈՒԹՅՈՒՆՆԵՐԸ

Զ.Մ. Բաղրյան

Հայաստանի պետական տնտեսագիտական համալսարան

Ռազմավարական մարքեթինգն իրենից ներկայացնում է տարբեր տեսակի շուկայավարման գործիքակազմերի ամբողջություն, որոնք են մարքեթինգային ռազմավարությունների մշակման գլխավոր հենասյուներ: Միջազգային մարքեթինգային պրակտիկայում շուկայավարման գործիքակազմերը նույնպես ենթարկվում են որոշակի տրանսֆորմացիաների՝ պայմանավորված արհեստական բանականության զարգացմամբ և շուկայական իրավիճակների շարունակական փոփոխմամբ: Աշխատանքում իրականացված ուսումնասիրությունները հիմնականում կենտրոնացված են և մարքեթինգային ռազմավարությունների մշակման մոտեցումների բարելավմանը, և ագրովերամշակման համակարգում դրանց թիրախային ներդրման մեխանիզմների կատարելագործմանը: Ագրոպարենային համակարգի առանձնահատկություններից ելնելով, ներկայացված մարքեթինգային մոդելները և առաջարկվող գործիքակազմերը հիմնականում ուղղված են սպառողական ուղղվածությամբ պրոդուկտների մշակման լավարկմանը, ինչպես նաև ժամանակակից գնորդների պահանջմունքների թիրախային դասակարգմանը: Ելնելով վերոնշյալից հոդվածում որպես նորարարություն է դիտարկվել շուկայավարման պրակտիկայում գնորդների պահանջմունքների դասակարգման ժամանակակից այնպիսի մոտեցում, որը մի կողմից՝ համադրելի է այժմյան գնորդների վարքագծային առանձնահատկություններին, իսկ մյուս կողմից ժամանակակից մարքեթինգային ռազմավարությունների մշակման պահանջներին:

Բանալի բառեր. մարքեթինգային բրիֆինգ, բրենդի խոցելիություն, կարգավիճակային պահանջմունքներ, բյուջետային սեգմենտը, FMCG մոդել, թիրախային շուկա

Z.M. Baghryan

THE CHARACTERISTICS OF STRATEGIC MARKETING TOOLS AND THE SPECIFICS OF THEIR APPLICATION IN THE AGRO-PROCESSING SECTOR

ОСОБЕННОСТИ ИНСТРУМЕНТАРИЯ СТРАТЕГИЧЕСКОГО УРОВНЯ В МАРКЕТИНГОВОЙ ПРАКТИКЕ И НЮАНСЫ ЕГО ПРИМЕНЕНИЯ В СИСТЕМЕ АГРОПЕРЕРАБОТКИ

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Стратегический маркетинг представляет собой совокупность различных маркетинговых инструментов, которые выступают основополагающими элементами разработки маркетинговых стратегий. В международной маркетинговой практике маркетинговые инструменты также подвергаются определённым трансформациям, обусловленным развитием искусственного интеллекта и непрерывными изменениями рыночной конъюнктуры. Исследования, проведённые в рамках данной работы, преимущественно сосредоточены, с одной стороны, на совершенствовании подходов к разработке маркетинговых стратегий, а с другой — на совершенствовании механизмов их целевого внедрения в системе агропереработки. С учётом специфики агропродовольственной системы представленные маркетинговые модели и предлагаемый инструментарий направлены преимущественно на оптимизацию разработки продуктов потребительской направленности, а также на целевую классификацию потребностей современных покупателей. Исходя из вышеизложенного, в статье в качестве инновационного элемента рассматривается современный подход к классификации потребностей покупателей в маркетинговой практике, который, с одной стороны, соответствует поведенческим особенностям современных покупателей, а с другой — требованиям, предъявляемым к разработке современных маркетинговых стратегий.

***Ключевые слова*:** маркетинговый брифинг, уязвимость бренда, статусные потребности, бюджетный сегмент, модель FMCG, целевой рынок.

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ASSESSING THE EFFICIENCY OF THE REPUBLIC OF ARMENIA'S FOREIGN TRADE UNDER REGIONAL ECONOMIC INTEGRATION

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Abstract

This study examines the efficiency of the Republic of Armenia's foreign trade in relation to the dynamics of external and mutual trade, its geographical and commodity composition, comparative advantages, and the effects of regional economic integration. Its objective is to assess trade efficiency, identify the main structural constraints, and propose ways to improve foreign trade competitiveness.

The methodology combines comparative, structural, and dynamic analysis with the calculation of comparative advantage coefficients. The analysis draws on publications of the Statistical Committee of the Republic of Armenia, the World Bank, the World Trade Organization, the Eurasian Economic Commission, and other international databases.

The findings indicate that Armenia's foreign trade remains characterised by a deficit, substantial dependence on imports, limited export diversification, and geographical concentration. Positive comparative advantage coefficients are recorded mainly for prepared food products and precious metals, while most commodity groups retain negative values. A comparative analysis of benefits from external economic activity within the EAEU indicates a relatively weak position for Armenia, suggesting an uneven distribution of integration outcomes.

The study argues that improving Armenia's trade efficiency requires commodity and geographical export diversification, production with higher value added, better logistics infrastructure, and a review of regional economic cooperation mechanisms.

Keywords: foreign trade, trade efficiency, Armenia, comparative advantage, exports, imports, EAEU, trade balance, export diversification.

Introduction

Foreign trade is a major factor in socioeconomic development, competitiveness, the expansion of productive capacity, and international economic integration. With globalisation, economic interdependence, and the expansion of international markets, trade efficiency becomes particularly relevant to economic growth, macroeconomic stability, and national economic security. Trade expands markets for domestic production and also facilitates investment, technological progress, deeper production specialisation, and structural transformation [1].

Trade efficiency is especially important for small, open, landlocked economies. Limited domestic markets, high transport costs, dependence on external markets, and geopolitical risks require flexible and effective external economic policies. Geographical and commodity diversification, stronger export competitiveness, and effective international cooperation arrangements are therefore central prerequisites for sustainable development [2].

As a small, open, landlocked economy, Armenia depends substantially on foreign trade. Trade remains central to economic development, production stability, and national income formation. Its trade system nevertheless exhibits limited export diversification, substantial import dependence, persistent deficits, and concentration in particular countries and economic blocs. Assessing efficiency and identifying opportunities for improvement therefore have both theoretical and practical significance [3].

These WITS observations refer to 2023, not 2025.

This study treats trade efficiency as a multifactor economic concept describing the ability of trade to improve national competitiveness, upgrade export composition, strengthen economic security, and maximise the economic returns from external activity. Assessment consequently extends beyond absolute export and import values to structural, competitive, integration-related, and macroeconomic outcomes.

Important dimensions include commodity and geographical export diversification, the development of comparative advantages, trade balance stability, benefits from external economic activity, and outcomes within regional integration. Trade efficiency must therefore be assessed using quantitative, structural, and qualitative criteria [4]. The WITS market concentration indicator should be distinguished from the commodity concentration calculated in this article.

Armenia's participation in regional integration, particularly the Eurasian Economic Union (EAEU), substantially influences its trade development. The common economic space, coordinated customs policy, and common trade regulation mechanisms expand flows while creating new competitive and structural challenges. Differences in development, fiscal systems, productive capacity, and benefits from external economic activity generate uneven efficiency outcomes across EAEU members [5].

The objective is to assess Armenia's trade efficiency through the composition and geographical direction of external and mutual trade, export and import dynamics, comparative advantage indicators, and economic relations under regional integration. Particular attention is paid to structural shifts, the efficiency of external economic activity, and asymmetries within the EAEU.

The study's scientific contribution is a multidimensional, integrated assessment that treats trade as a system of economic efficiency, competitiveness, structural stability, and regional integration outcomes, alongside its quantitative export and import dimensions.

Quantitative, structural, competitive, and integration-related criteria are combined to identify constraints in trade volumes as well as in its composition and qualitative characteristics.

A principal contribution is the joint use of comparative advantage coefficients, export diversification, geographical concentration, and integration efficiency. This approach assesses how far Armenia's current trade structure supports competitive socioeconomic development over the long term.

The findings suggest that the principal problem is not confined to the trade deficit. Limited structural efficiency is also reflected in weak diversification, import dependence, market concentration, and asymmetrical integration outcomes.

A further contribution is a comparative assessment of integration efficiency within the EAEU, revealing asymmetries in the distribution of benefits from external economic activity. The study argues that regional integration is effective when members obtain relatively balanced economic outcomes and competitive opportunities.

The findings can inform strategic approaches to Armenia's external economic policy, export promotion, trade diversification, industrial policy, and more effective regional cooperation.

The practical significance lies in the potential application of the analysis and conclusions to external economic policy, export promotion strategies, and public programmes for improving trade efficiency.

The assessment of quantitative, structural, competitive, and integration-related efficiency identifies the principal constraints and development opportunities in Armenia's external economic system. The findings can be used to:

- develop commodity and geographical export diversification strategies;
- formulate policies supporting production with higher value added;
- improve mechanisms for strengthening foreign trade competitiveness;
- develop approaches to reducing external economic dependence;
- protect Armenia's economic interests and improve integration efficiency within the EAEU;
- identify priorities for logistics and transport infrastructure development;
- design public industrial development and export promotion programmes.

The results can also support economic research, external economic policy evaluation, and university courses in international economics, foreign trade, and regional economic integration.

1. Literature Review

Foreign trade is a major driver of global economic development, national competitiveness, and growth. As globalisation and international integration deepen, trade efficiency has become a central research topic. It encompasses the export–import relationship, export composition, comparative advantages, competitiveness in external markets, and economic returns from external activity [5].

The theoretical foundations of trade emerged within classical economics. Adam Smith associated its benefits with the international division of labour and absolute advantage. David Ricardo formulated comparative advantage theory, showing that even countries without an absolute advantage can benefit by specialising in relatively more efficient activities. This remains a major theoretical foundation for assessing trade efficiency [6], [7].

Comparative advantage indicators are widely used in contemporary research. Bela Balassa's revealed comparative advantage (RCA) approach is particularly important for assessing export competitiveness and commodity specialisation. His work demonstrates how export composition can reveal an economy's competitive strengths and weaknesses [8].

New trade theories developed by Paul Krugman, Elhanan Helpman, and others also inform efficiency analysis. They link trade outcomes to economies of scale, market size, production concentration, and technological development. Krugman shows that trade can develop between economies with similar structures because scale economies and market expansion provide additional benefits [1].

Regional integration also affects trade efficiency. Integration theory considers customs unions, free trade areas, and common markets. Integration can create trade, expand markets, and deepen specialisation, but may also divert trade and increase dependence. Richard Baldwin's research highlights dynamic effects associated with resource reallocation, investment, and economic concentration [5].

Contemporary studies also assess trade efficiency through openness, export diversification, the trade balance, and technological composition. World Bank and WTO research indicates that small landlocked economies depend on transport infrastructure, logistics efficiency, and market diversification as well as export volumes [2].

Studies of Armenia generally focus on export composition, import dependence, EAEU integration, and geographical trade directions. EAEU members, especially Russia, have

become particularly important partners. Commodity and geographical concentration nevertheless remain high, increasing vulnerability to external shocks [3], [9]. The World Bank report discusses re-export-driven trade expansion during 2022–2024.

According to WITS data for 2023, Armenia's five largest export destinations were Russia, the UAE, Hong Kong, China, and the Netherlands. Leading exports included gold, communications equipment, jewellery, copper ore, and diamonds. These observations describe 2023 and do not replace Armstat's 2025 statistics [3].

Trade efficiency within the EAEU is also actively examined in international and regional research. Differences in development, fiscal systems, and benefits from external economic activity produce an uneven distribution of integration outcomes. Small economies face particular risks of trade dependence, constrained competitiveness, and reduced economic autonomy [5].

Existing Armenian trade studies mainly examine individual indicators or sectors. Relatively few integrate structural changes, comparative advantage measures, regional integration effects, and external economic outcomes within one methodology. This gap motivates the present study and establishes its scientific relevance.

2. Materials and Methods

The methodology combines international trade theory, regional integration concepts, approaches to absolute and comparative advantage, and structural trade analysis. Efficiency is treated as a multifactor concept encompassing export and import values, export composition, comparative advantages, geographical concentration, trade balance dynamics, and integration effects.

The theoretical framework comprises classical and contemporary trade theories, particularly Ricardo's comparative advantage theory, the Heckscher–Ohlin model, new trade theories, and regional integration approaches. Modern methods for assessing competitiveness, diversification, and economic efficiency are also employed [7], [1].

The information base comprises official data from Armstat, the World Bank, the WTO, World Integrated Trade Solution (WITS), the Eurasian Economic Commission (EEC), UNCTAD, the OECD, and other international databases. External and mutual trade data for 2024–2025 are analysed by country group, individual partner, and commodity section [10], [3], [11], [12]. The World Development Indicators trade-to-GDP measure includes goods and services. Comparisons with merchandise trade indicators require identical coverage.

The following principal methods are employed:

- comparative analysis;
- structural and dynamic analysis;
- statistical grouping and classification;
- a systems approach;
- induction and deduction;
- comparative advantage assessment;
- comparative assessment of regional economic integration;
- graphical and tabular presentation.

Comparative analysis evaluates Armenia's main trade directions, changes in export and import composition, and differences in external economic efficiency across EAEU members.

Structural and dynamic analysis examines changes in turnover, exports, imports, and their respective shares over time.

Criteria for Assessing Foreign Trade Efficiency

The assessment combines quantitative, structural, competitive, and integration-related approaches. Efficiency describes the capacity to improve export competitiveness, sustain economic stability, maximise external economic outcomes, and reduce external dependence.

Quantitative Efficiency

Quantitative efficiency is assessed through turnover, export and import values, growth rates, and the trade balance. These measures describe overall dynamics and the intensity of external economic activity [10].

The principal indicators are:

- foreign trade turnover;
- the export–import ratio;
- the trade balance;
- trade growth rates;
- trade relative to GDP.

An increase in trade volumes alone does not demonstrate higher efficiency unless accompanied by improvements in competitiveness, structural stability, and economic outcomes.

Structural Efficiency

Structural efficiency is assessed through the commodity and geographical composition of exports and imports, revealing diversification, concentration, and dependence on external markets [4].

The principal criteria are:

- commodity export diversification;
- geographical export concentration;
- the share of products with high value added;
- the share of raw materials and low-technology exports;
- dependence on a limited number of trading partners.

Structural assessment matters because concentrated exports increase external risks and weaken trade stability [2].

Competitive Efficiency

Competitive efficiency is assessed by calculating comparative advantage coefficients (CA). This identifies commodity groups in which Armenia has relative competitive advantages in external markets [8]. The ratio $(X - M)/(X + M)$ is a normalised trade balance index, not Balassa's revealed comparative advantage index.

The principal criteria are:

- comparative advantage coefficients;
- export competitiveness;
- import dependence;
- export specialisation.

CA indicators describe qualitative and competitive trade characteristics alongside volume-related outcomes [8].

Integration Efficiency

Integration efficiency is assessed through a comparative analysis of external economic cooperation within the EAEU, identifying how benefits are distributed under regional integration.

The principal criteria are:

- the share of revenue from external economic activity;
- the comparative distribution of benefits across EAEU members;
- dependence on integrated markets;
- the effect of regional cooperation on exports.

This approach rests on the proposition that integration is effective when members obtain relatively balanced economic outcomes and benefits [5].

Several calculated indicators and models are used. The growth rate of trade turnover is calculated as follows:

$$G_t = \frac{B_t - B_{t-1}}{B_{t-1}}, \quad (1)$$

where G_t is the growth rate of trade turnover, B_t is current-year turnover, and B_{t-1} is previous-year turnover.

Trade relative to GDP is measured using the following indicator [11]:

$$R_{GDP} = \frac{FT_t}{GDP_t} \times 100, \quad (2)$$

where R_GDP is trade relative to GDP, FT_t is trade turnover, and GDP_t is gross domestic product.

Competitive efficiency and commodity specialisation are assessed using the comparative advantage coefficient (CA): [8]

$$CA_i = \frac{X_i - M_i}{X_i + M_i} \quad (3)$$

where CA_i is the comparative advantage coefficient, X_i is exports, and M_i is imports.

The indicator ranges from −1 to +1.

Values approaching +1 indicate export predominance and relative competitive strength in a commodity group, while values approaching −1 indicate import predominance and comparative weakness [8].

A relative revenue approach is also used to compare integration efficiency, assessing revenue from external economic activity as a share of EAEU members' budget revenues [12].

Particular attention is paid to geographical concentration, commodity composition, comparative advantages, and the distribution of integration benefits. Trade and fiscal indicators for Armenia, Russia, Kazakhstan, and Kyrgyzstan are compared.

The methodology integrates absolute indicators, structural shifts, comparative advantages, integration, and external economic outcomes to provide a comprehensive assessment of Armenia's trade trends, constraints, and development opportunities.

Econometric Assessment of External Economic Revenue and Fiscal Structure

Pooled ordinary least squares (OLS) estimation is used to examine the relationship between integration and fiscal efficiency in EAEU countries. The objective is to assess the association between revenue from external economic activity and major components of fiscal structure.

The following regression model is employed:

$$ATG_{it} = \alpha + \beta_1 PIT_{it} + \beta_2 VAT_{it} + \beta_3 BGDP_{it} + \varepsilon_{it} \quad (4)$$

where: ATG_{it} is revenue from external economic activity as a share of consolidated government budget revenue; PIT_{it} is the personal income tax share; VAT_{it} is the value added tax share; $BGDP_{it}$ is consolidated budget revenue relative to GDP; i denotes the country; t denotes the period; ε_{it} is the random error term.

Estimation uses 2023–2025 data for four EAEU members: Armenia, Kazakhstan, Kyrgyzstan, and Russia. Official EEC statistics are employed [12].

Given the short time series, the model is an exploratory pooled OLS assessment providing preliminary evidence on integration-related and fiscal structural relationships.

Econometric Model of Foreign Trade Efficiency

Econometric analysis is used to assess the main determinants of trade efficiency. The objective is to examine the relationship between Armenia's trade efficiency and structural, competitive, and integration-related factors.

Efficiency is measured using a composite Trade Efficiency Index (TEI), combining the export–import ratio, structural export concentration, and comparative advantage. The TEI is an indicator proposed by the authors in this article.

The TEI is calculated as follows:

$$TEI = \frac{Exports}{Imports} \times (1 - HHI) \times (1 + RCA) \quad (5)$$

where: Exports denotes exports of goods and services; Imports denotes imports of goods and services; HHI is the Herfindahl–Hirschman index of export concentration; RCA is the comparative advantage coefficient.

The following regression model is estimated:

$$TEI_t = \alpha + \beta_1 RCA_t + \beta_2 DIV_{t+}\beta_3 OPEN_t + \beta_4 EAEU_t + \beta_5 HHI_t + \varepsilon_t \qquad (6)$$

where: TEI_t is the composite trade efficiency indicator; RCA_t is the comparative advantage coefficient; DIV_t is export diversification; $OPEN_t$ is trade openness; $EAEU_t$ is the EAEU share in Armenia's foreign trade; HHI_t is the export concentration index; ε_t is the random error term.

OLS estimation draws on official data from Armstat, World Development Indicators, WITS, and the EEC [10], [11], [3]. The econometric results are the authors' calculations.

The model assesses structural efficiency, competitiveness, and integration stability alongside volume changes. It therefore treats trade as a multidimensional system of economic efficiency.

Dynamics and Structure of Armenia's Foreign Trade

Foreign trade remains a major component of Armenia's economic development. In a small open economy, it supports growth, production expansion, consumer market supply, and international cooperation. The system nevertheless retains structural imbalances, substantial import dependence, and a limited range of partners.

Quantitative assessment first requires an examination of turnover, exports, imports, and the trade balance.

Table 1

Principal Indicators of Armenia's External and Mutual Trade Turnover, 2024–2025 [10]

Country groups	2024	Share, %	2025	Share, %	2025/2024, %	Trade balance 2024	Trade balance 2025
Total	30,201,567.0	100.0	21,430,317.3	100.0	71.0	-3,928,725.8	-4,639,535.1
CIS countries	12,912,569.4	42.8	8,240,500.0	38.5	63.8	-6,031,154.6	-1,666,258.2
EAEU countries	12,750,960.7	42.3	8,040,008.8	37.5	63.1	-5,971,308.7	-1,601,385.0
Russian Federation	12,422,740.9	41.1	7,661,436.8	35.8	61.7	-6,057,214.7	-1,732,552.0
EU countries	2,334,972.0	7.7	2,502,755.1	11.7	107.2	-1,111,829.1	-1,169,049.9
Other countries	14,954,025.3	49.5	10,687,062.3	49.9	71.5	3,214,257.9	-1,804,227.1
United Arab Emirates	5,337,301.3	17.7	2,133,509.9	10.0	40.0	5,172,581.7	1,975,473.1
China	2,823,795.0	9.3	2,641,004.8	12.3	93.5	-628,776.2	-1,113,821.8

Tab. 1 shows that turnover fell by approximately 29.0% in 2025 relative to 2024. Imports continued to exceed exports and the deficit widened [10].

According to Armstat, Armenia's 2025 exports at FOB prices amounted to USD 8,395.4 million, imports at CIF prices to USD 13,034.9 million, and external and mutual trade turnover to USD 21,430.3 million. The balance was −USD 4,639.5 million, indicating substantial import predominance and persistent structural imbalance [10].

Turnover equalled 71.0% of its 2024 level, declining by 29.0% as export and import values changed substantially. The widening deficit nevertheless shows that export growth has not been sufficient to offset import growth. Such conditions are typical of small import-dependent economies where consumption and production rely substantially on imported goods and raw materials [10].

Table 2

Geographical Composition of Armenia's Foreign Trade, 2024–2025, % [10]

Country	**Exports**		**Imports**			
	2024	2025	By exporting country		By country of origin	
			2024	2025	2024	2025
CIS COUNTRIES	26,2	39,2	56,9	39,6	55,5	38,0
including						
EAEU countries	25,8	38,4	56,2	38,5	54,9	37,0
EU COUNTRIES	4,6	7,9	11,9	16,4	10,1	14,1
OTHER COUNTRIES	69,2	52,9	31,2	44,0	34,4	47,9
including						
United Arab Emirates	40,0	24,5	2,6	3,3	0,5	0,6

Table 2 indicates continued geographical concentration, particularly towards the EAEU and Russia. The increasing EU share suggests relative diversification of external economic links [10].

CIS countries, particularly EAEU members, remain principal directions of external and mutual trade. In 2025, the CIS accounted for 38.5% of turnover and the EAEU for 37.5%. Russia alone accounted for 35.8%, indicating substantial concentration [10].

Russia's dominant position reflects the EAEU customs area, historical links, transport and logistics connections, and the importance of its market for Armenian goods and services. This concentration also increases vulnerability to economic and geopolitical risks [5], [2].

The EU share increased from 7.7% in 2024 to 11.7% in 2025. Turnover with the EU reached 107.2% of its previous-year level, growing by 7.2%, suggesting some diversification. Other countries retained approximately 50%, indicating substantial trade across regions outside a common integration framework [10].

Exports remain dominated by a limited number of commodity groups. Precious and semi-precious stones, precious metals, and articles thereof constituted the largest group in

2024–2025. Exports in this group fell from USD 8,050.1 million in 2024 to USD 2,854.1 million in 2025, but the group remained dominant [10].

Prepared food products, mineral products, machinery and equipment, and textiles also play important roles. Prepared food exports grew by 28.7% in 2025, suggesting improved competitiveness in this sector. Machinery, equipment, and mechanical appliance exports remained relatively high, relevant to greater technological complexity in export composition [10].

Imports are dominated by machinery, equipment and mechanical appliances, vehicles, chemicals, mineral products, and consumer goods. This composition indicates continued dependence on external markets, particularly for production equipment, technological products, and energy [10].

Limited export diversification remains evident. Concentration in a few groups amplifies external shocks, especially global price fluctuations and shifts in international demand. This challenges external economic policy by weakening trade stability and long-term competitiveness.

Both geographical and commodity analysis reveal substantial concentration. EAEU and Russian markets remain important destinations, while a few product groups dominate exports. Improving efficiency therefore requires diversification and new markets.

Research Results

Quantitative Structural and Competitive Assessment of Armenia's Foreign Trade Efficiency

Assessing efficiency requires an integrated analysis of absolute turnover and structural, competitive, and integration outcomes. Armenia's performance is evaluated through quantitative, structural, and competitive criteria, accounting for diversification, comparative advantages, geographical concentration, and integration effects.

Quantitative Assessment

Trade supports Armenia's development through growth, production expansion, consumer supply, and cooperation. Increasing volumes alone, however, do not demonstrate higher efficiency unless competitiveness, structural stability, and external economic outcomes improve. Armstat reports 2025 exports of USD 8,395.4 million at FOB prices, imports of USD 13,034.9 million at CIF prices, and turnover of USD 21,430.3 million. The −USD 4,639.5 million balance indicates import predominance and persistent structural imbalance [10].

Turnover fell to 71.0% of its 2024 level, a decline of 29.0%. The export–import relationship shows that quantitative expansion has not yet improved external balance. Declining exports and relatively high imports widened the deficit [10].

CIS and EAEU countries play an important quantitative role. In 2025, the CIS share was 38.5%, including an EAEU share of 37.5%. Russia accounted for 35.8%, reflecting strong geographical concentration [10]. The EU share increased from 7.7% to 11.7%, although geographical concentration persisted. Other countries retained approximately 50%, demonstrating both integration-based and multidirectional external links [10].

Trade volume growth has not translated into equivalent gains in stability and competitiveness. Persistent deficits, import dependence, and external concentration remain major constraints on efficiency.

Structural Assessment

Structural efficiency matters for long-term development, competitiveness, and external stability. It describes trade's capacity to diversify exports, support production with higher value added, and reduce dependence on external markets.

A few commodity groups continue to dominate exports. Precious and semi-precious stones, precious metals, and articles thereof formed the largest group in 2024–2025. Their exports declined from USD 8,050.1 million to USD 2,854.1 million, while retaining the leading position [10].

Prepared foods, mineral products, machinery, and equipment are also important. Growth in prepared food exports suggests relative competitiveness, although overall diversification remains limited.

Geographical concentration is another structural issue. Exports remain concentrated in a limited number of markets, notably Russia and the EAEU, increasing risk and dependence on individual markets [10].

Import composition indicates continued dependence on machinery, equipment, technological products, chemicals, and vehicles from external markets, suggesting limited industrial and technological self-sufficiency [10].

The limited share of high-value-added products is also problematic. Many exports remain raw materials or products with limited processing, weakening long-term stability and competitiveness.

Overall, limited diversification, geographical concentration, and import dependence constrain trade's contribution to long-term competitive development.

Export Concentration

Export concentration is a central component of structural assessment. High concentration makes export earnings dependent on a few products or markets. Global price fluctuations, demand shifts, and geopolitical risks can consequently affect external economic stability substantially.

The Herfindahl–Hirschman Index (HHI), widely used to assess market and export concentration, is calculated as follows [4]:

$$HHI = \sum_{i=1}^{n} s_i^2 \quad (7)$$

where s_i is the share of an individual commodity group in exports.

Higher HHI values indicate greater concentration; lower values indicate diversification. Values below 0.15 are generally interpreted as low, 0.15–0.25 as moderate, and above 0.25 as high concentration. These thresholds are borrowed from the 2010 US merger guidelines and applied here provisionally; they are not universally accepted thresholds for export concentration [13]. The US merger-guideline thresholds of 1500 and 2500 relate to

competitive markets. They are used here only as provisional descriptive benchmarks for export composition.

Armenia's export composition remains relatively concentrated. Precious metals and stones, mineral products, and prepared foods account for substantial shares. Precious metal dominance increases exposure to global price fluctuations and constrains structural stability.

These conditions establish diversification, high-technology production, and exports with higher value added as priorities for improving efficiency.

Table 3

Concentration of Armenia's Export Composition Using the HHI, 2025

Commodity groups	**Export share, %**	**s_i^2**
Precious metals and stones	34.0	0.1156
Machinery and equipment	15.8	0.0250
Prepared food products	14.9	0.0222
Mineral products	14.5	0.0210
Other commodity groups	20.8	0.0433
HHI	100.0	0.2271

Source: Authors' calculations [10].

Tab. 3 indicates relatively high concentration. The calculated HHI is approximately 0.23, suggesting concentration above the middle of the moderate range.

Precious metals and stones, machinery and equipment, mineral products, and prepared foods dominate exports. The high precious metal share increases exposure to global price fluctuations and external risks.

This concentration constrains structural stability and resilience to shocks. Diversification, high-technology production, and exports with higher value added are therefore central priorities.

Geographical Concentration [8]

Geographical composition is an important dimension of efficiency. Concentration increases dependence on a limited number of markets and external risks. Economic, political, or geopolitical changes in individual countries can then substantially affect trade stability.

Armenia's geographical trade composition remains concentrated. In 2025, EAEU countries accounted for 37.5% of external and mutual turnover, Russia for 35.8%, and the EU for 11.7%. Substantial trade therefore remains dependent on a limited number of directions.

Russia's dominant position indicates considerable external dependence. It increases sensitivity to regional economic developments, sanctions, currency fluctuations, and transport constraints [8]. The relative increase in the EU share indicates gradual diversification, although the overall geographical composition remains concentrated.

Geographical diversification, new markets, and broader cooperation are therefore priorities for improving efficiency.

Competitive Assessment

Commodity trade imbalances are assessed using the normalised trade balance indicator termed CA in the source document. It is calculated from each commodity group's export and import values.

$CA_i = (X_i - M_i) / (X_i + M_i)$, and export coverage of imports is $C_i = 100 \times X_i / M_i$.

X_i and M_i denote exports and imports of commodity group i, measured in the same year and currency.

CA is dimensionless and ranges from −1 to +1. It is undefined when exports and imports are both zero.

Positive CA indicates export predominance, negative CA import predominance, and zero a balanced trade value. This formula is not Balassa's RCA index. A positive value does not establish high production efficiency, and a negative value does not measure imports as a share of domestic consumption.

Table 4 presents exports, imports, balances, coverage, and CA for 25 selected groups in 2025. The authors' selection includes food, fuel, pharmaceuticals, clothing, and household products. It is neither an official classification of the 25 most important groups nor a ranking of the 25 largest import groups.

Table 4

Trade Indicators for 25 Selected Consumer and Essential Commodity Groups in Armenia, 2025 [14]

HS	Commodity group	Exports	Imports	Balance	Coverage %	CA
02	Meat and meat products	0.041	148.131	-148.090	0.03	-0.999
03	Fish and seafood	79.800	23.472	56.328	339.98	0.545
04	Dairy products, eggs and honey	20.198	116.044	-95.846	17.41	-0.704
07	Vegetables and roots	86.962	45.577	41.385	190.80	0.312
08	Fruit and nuts	112.555	115.500	-2.945	97.45	-0.013
09	Coffee, tea and spices	37.509	87.593	-50.084	42.82	-0.400
10	Cereals	0.336	124.949	-124.612	0.27	-0.995
11	Milling products and groats	1.096	24.333	-23.237	4.50	-0.914
15	Animal and vegetable oils and fats	1.341	89.818	-88.476	1.49	-0.971
16	Prepared meat and fish	9.203	33.861	-24.658	27.18	-0.573
17	Sugar and sugar confectionery	2.561	69.893	-67.332	3.66	-0.929
18	Cocoa and cocoa products	25.837	103.085	-77.248	25.06	-0.599
19	Prepared flour and cereal products	3.697	94.753	-91.056	3.90	-0.925
20	Prepared vegetables and fruit	62.227	60.880	1.347	102.21	0.011
21	Other prepared foods	26.299	82.188	-55.889	32.00	-0.515
22	Beverages and vinegar	434.734	139.700	295.034	311.19	0.514
24	Tobacco and substitutes	671.829	288.420	383.409	232.93	0.399
27	Mineral fuels and petroleum products	81.812	1133.921	-1052.109	7.21	-0.865

HS	Commodity group	Exports	Imports	Balance	Coverage %	CA
30	Pharmaceutical products	40.422	236.545	-196.123	17.09	-0.708
33	Perfumery and cosmetics	41.066	160.481	-119.415	25.59	-0.593
34	Soap, detergents and cleaning products	9.118	59.237	-50.119	15.39	-0.733
61	Knitted clothing	75.046	148.503	-73.457	50.53	-0.329
62	Non-knitted clothing	204.661	174.797	29.864	117.08	0.079
64	Footwear and related products	66.554	144.966	-78.412	45.91	-0.371
94	Furniture and bedding	34.461	184.117	-149.656	18.72	-0.685
—	Total of 25 selected groups	2129.367	3890.763	-1761.397	54.73	-0.293

Tab. 4 uses ArmStatBank Table FT-1-2025, with data retrieved on October 13, 2026, and the authors' calculations. [14].

Note: Export, import, and balance values are in USD million. Product names are abbreviated; group boundaries follow two-digit commodity nomenclature codes (HS chapters). CA and coverage are calculated from unrounded data. Aggregate CA is based on total exports and imports rather than the simple mean of the 25 coefficients.

Exports exceed imports in 6 of the selected groups; 19 have deficits. Aggregate exports are USD 2,129.367 million, imports USD 3,890.763 million, and the balance −USD 1,761.397 million. Aggregate CA is −0.293 and export coverage is 54.73%, indicating import predominance by value.

The strongest positive positions are fish and seafood (CA 0.545), beverages and vinegar (0.514), tobacco and substitutes (0.399), and vegetables (0.312). Beverage exports are USD 434.734 million against imports of USD 139.700 million; tobacco exports are USD 671.829 million against imports of USD 288.420 million. These surpluses mitigate the aggregate deficit.

Fruit and nuts are close to balance, with CA −0.013. Prepared vegetables and fruit have a small positive value of 0.011, and non-knitted clothing 0.079. The difference between knitted clothing (−0.329) and non-knitted clothing (0.079) demonstrates that related products cannot necessarily be assessed through one general conclusion.

The deepest relative deficits occur in meat and meat products (−0.999), cereals (−0.995), animal and vegetable oils and fats (−0.971), sugar and sugar confectionery (−0.929), and prepared cereal and flour products (−0.925). Exports are small relative to imports in these groups. The cereal result covers all of chapter 10, not wheat alone; meat exports are almost zero but not zero.

Mineral fuels and petroleum products have the largest absolute deficit, −USD 1,052.109 million, with CA −0.865. This broad group includes other energy commodities and cannot be equated solely with petrol and diesel. Pharmaceuticals have a deficit of −USD 196.123 million and CA −0.708. Priorities include supplier diversification, justified reserves, energy efficiency, and economically viable domestic production.

Methodological limitation: Imports cannot be equated with domestic consumption. Actual import dependence or self-sufficiency requires comparable data on production, exports, imports, and stock changes. In a simplified commodity balance, domestic use equals production + imports − exports − stock accumulation. Imported goods can be re-exported or used in production. Conclusions from CA are therefore limited to trade relationships by value.

Data comparability: The ArmStatBank 2025 series used here reports total exports of USD 8,311.417 million and imports of USD 13,031.650 million. These differ from USD 8,395.391 million and USD 13,034.926 million in The Socioeconomic Situation of the Republic of Armenia in January–December 2025.

Without official clarification, the two versions are not combined in one calculation. Every row in Table 4 uses the same ArmStatBank series; the initial summary tables retain the January–December publication version. The publication year of the 2025 yearbook does not mean all its indicators concern reporting year 2025; the present addition uses the annual 2025 series itself.

Integration Efficiency of Armenia's Foreign Trade within the EAEU

Regional integration expands markets, deepens cooperation, reduces trade barriers, and improves resource allocation. Its efficiency nevertheless varies with economic structure, competitiveness, productive capacity, and external dependence [5].

EAEU membership substantially affects Armenian trade efficiency. A common customs area, free movement arrangements, and common external customs policy facilitate trade between members. Efficiency also depends on members' ability to obtain relatively balanced economic benefits [5].

EAEU countries remain important partners. In 2025, they accounted for 37.5% of turnover and 38.4% of exports. Russia retained a dominant position, representing more than one third of Armenia's turnover [10].

Table 5

Consolidated Budget Revenues and Their Ratio to GDP in EAEU Countries, 2023–2025

Country	Average annual revenue (bn national currency)	Growth 2025/2023, %	Budget revenue / GDP, % (2025)
Armenia	2,729.7	33.0	26.8
Kazakhstan	27,588.3	19.0	18.9
Kyrgyzstan	587.7	65.0	38.5
Russia	68,529.7	28.0	35.4

Source: Eurasian Economic Commission (EEC); authors' calculations [12].

Note: The indicators describe consolidated budget revenues in relation to economic activity in EAEU countries.

Tab. 5 shows substantial differences in consolidated revenues and their economic ratios. Armenia's revenue-to-GDP ratio was 26.8% in 2025, below those of Russia and Kyrgyzstan.

Kyrgyzstan's particularly high ratio and revenue growth suggest different levels of economic and fiscal efficiency within the integration system.

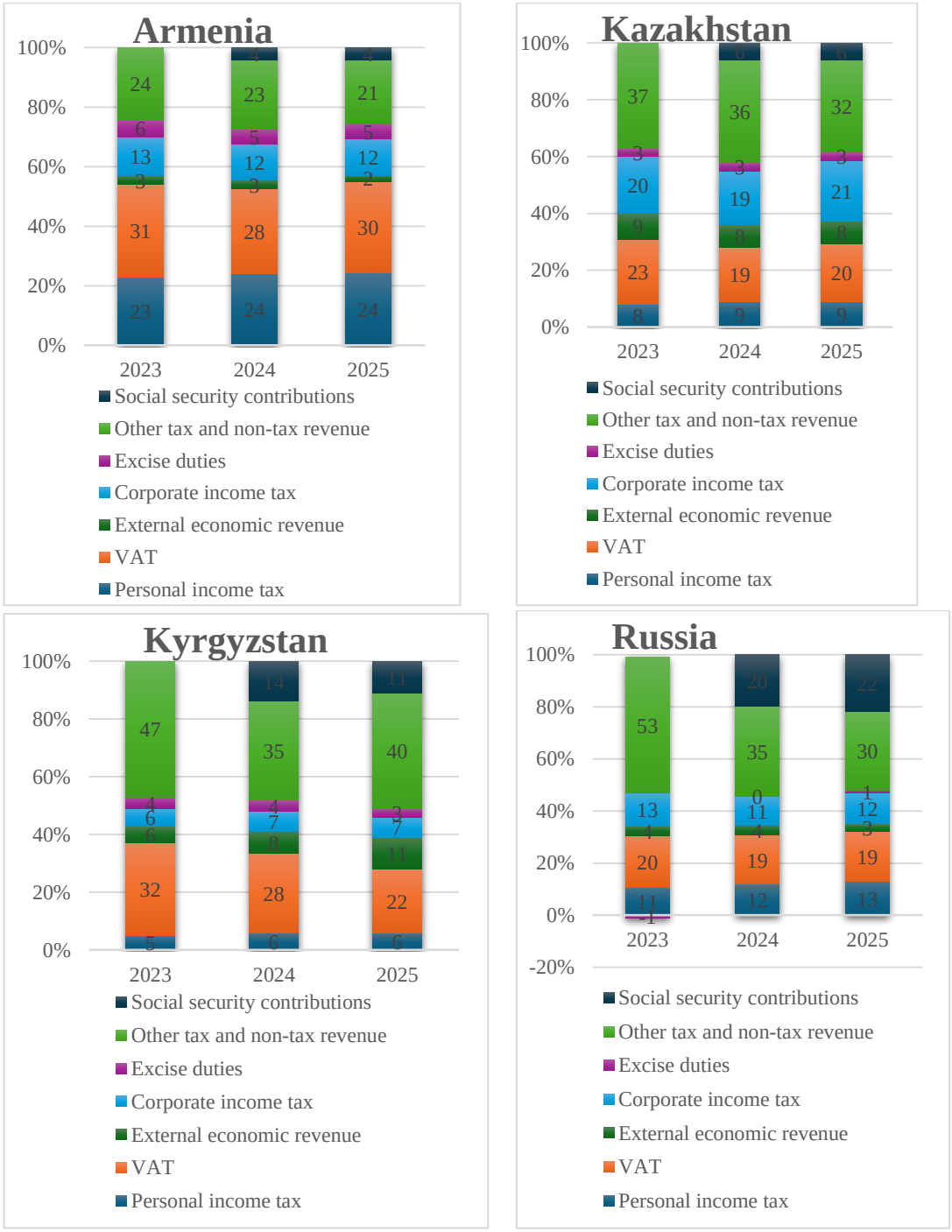

Fig. 1. Comparative Assessment of Consolidated Budget Revenue Composition in EAEU Countries, 2023–2025, % [12]

Table 6

Composition of Consolidated Budget Revenues in EAEU Countries, 2025, %

Revenue type	Armenia	Kazakhstan	Kyrgyzstan	Russia
Personal income tax	24	9	6	13
Corporate income tax	13	21	7	12
VAT	30	20	22	19
Excise duties	5	3	3	1
External economic	2	8	11	3

Revenue type	Armenia	Kazakhstan	Kyrgyzstan	Russia
revenue				
Social contributions	4	6	11	22
Other revenue	21	32	40	30

Source: Eurasian Economic Commission (EEC); authors' calculations [12].

Tab. 6 shows substantial differences in revenue composition. VAT and personal income tax remain Armenia's main sources, while external economic activity revenue accounts for a relatively small share.

In 2025, external economic activity represented only 2% of Armenian revenue, compared with 8% in Kazakhstan and 11% in Kyrgyzstan, suggesting relatively low fiscal efficiency from external integration in Armenia.

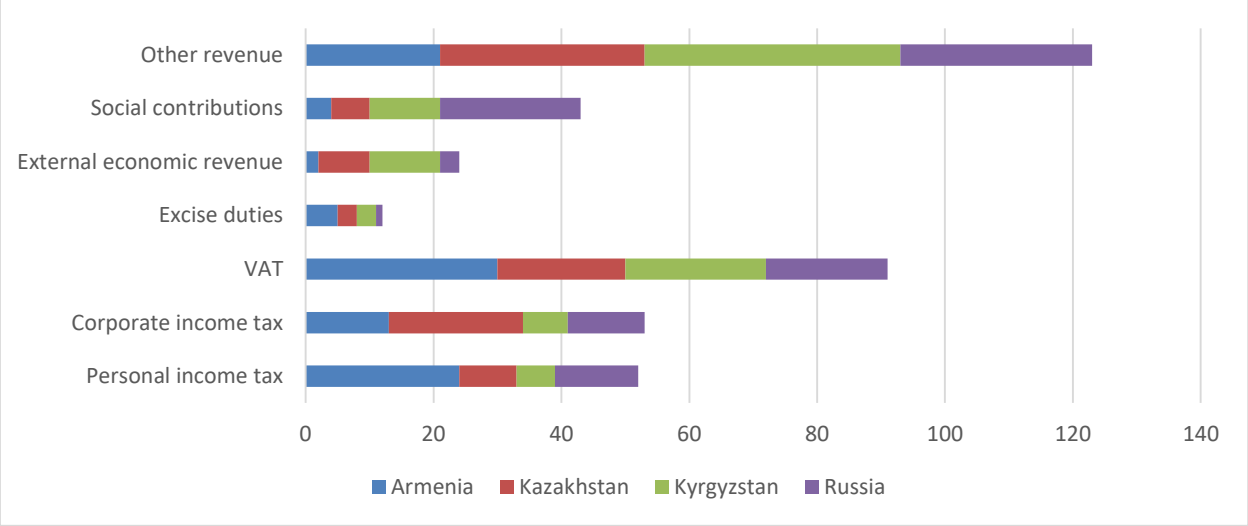

Fig. 2. Budget Revenue Composition in EAEU Countries, 2025 [12]

Comparing tax receipt composition helps assess members' economic activity, import dependence, and fiscal efficiency.

Table 7

Tax and Levy Receipts in Selected EAEU Countries, 2025

Indicator	Armenia	Kazakhstan	Kyrgyzstan	Russia	Unit
VAT	914	6112	164	14571	bn national currency
Domestic VAT	438	2784	47	10421	bn national currency
Import VAT	476	3327	117	4150	bn national currency
Excise duties	164	1040	23	847	bn national currency
Domestic excise duties	90	923	5	651	bn national currency
Import excise duties	74	117	17	196	bn national currency

Source: Eurasian Economic Commission (EEC); authors' calculations [12].

Tab. 7 indicates substantial differences in tax composition. VAT remains a major component of Armenian tax revenue, demonstrating the important role of indirect taxation.

Table 8

Pooled OLS Estimation Results for EAEU Countries

Variables	Coefficient	t-statistic	p-value
Constant	13.682	3.905	0.005
PIT (personal income tax)	-0.354***	-4.049	0.004
VAT	0.002	0.019	0.985
BGDP (budget revenue / GDP)	-0.121	-1.367	0.209
R^2	0.689	—	—
Adjusted R^2	0.572	—	—
F-statistic	5.909**	—	0.020

Note: The table presents pooled OLS estimates of the relationship between fiscal structure and external economic activity revenue in EAEU countries. Source: Eurasian Economic Commission (EEC); authors' calculations.

The dependent variable is external economic activity revenue as a share of consolidated budget revenue (ATG).

Regressors include the personal income tax share (PIT), the VAT share (VAT), and consolidated budget revenue relative to GDP (BGDP).

Estimation uses official 2023–2025 data for Armenia, Kazakhstan, Kyrgyzstan, and Russia [12].

R^2 measures explanatory power, adjusted R^2 the adjusted fit, and the F-statistic the model's overall statistical significance.

Given the short time series, results should be treated as exploratory pooled OLS evidence.

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 8 indicates statistically discernible relationships between fiscal structure and external economic activity revenue. A higher personal income tax share is negatively associated with the external revenue share. This may indicate that economies with stronger domestic fiscal bases attach relatively less weight to external economic revenue.

The VAT effect is statistically insignificant, suggesting that its structural share alone does not explain differences in external economic activity revenue.

$R^2 = 0.689$ indicates that the regressors explain approximately 69% of variation in external economic revenue. Despite the short series, the findings suggest structural differences in fiscal systems and integration efficiency across members.

Substantial import VAT receipts also indicate continuing import dependence. Particularly high receipts in Russia and Kazakhstan reflect larger economies and greater fiscal returns from natural resource use.

The table presents OLS estimates of trade efficiency. The dependent variable is the TEI, calculated from the export–import ratio, export concentration (HHI), and comparative advantage (RCA). Regressors include RCA, export diversification (DIV), openness (OPEN), the EAEU share in Armenia's trade (EAEU), and HHI.

Table 9

Estimation Results for the Foreign Trade Efficiency Model of EAEU Countries

Variables	Coefficient	t-statistic	p-value
Constant	0.412	2.11	0.041
RCA	0.428***	3.84	0.001
DIV	0.317**	2.76	0.009
OPEN	0.205*	1.94	0.061
EAEU	0.184	1.53	0.134
HHI	-0.557***	-4.21	0
R^2	0.78	—	—
Adjusted R^2	0.74	—	—
F-statistic	19.6***	—	—

Estimation uses official Armenian statistics for 2000–2025. Sources include Armstat, World Development Indicators (WDI), WITS, and EEC publications [10], [11], [3], [12].

R^2 measures explanatory power; adjusted R^2 accounts for the number of regressors. The F-statistic assesses overall significance. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The model indicates positive effects of diversification and comparative advantage on efficiency, while greater structural concentration negatively affects stability and competitiveness.

Tab. 9 indicates that comparative advantage and export diversification have the strongest significant positive effects on EAEU countries' trade efficiency. Concentration has a negative effect, supporting the study's hypothesis concerning structural dependence and limited competitiveness.

Diversification, high-technology production, and reduced external dependence are principal directions for improving Armenia's efficiency.

External economic revenue is important for comparative integration assessment. Armenia's share in consolidated revenues is substantially below several other EAEU members: 3% in 2024 and 2% in 2025, compared with approximately 8% in Kazakhstan and 11% in Kyrgyzstan.

These observations indicate asymmetric integration conditions. As a small economy with limited productive capacity, Armenia has not yet secured a position allowing relatively high returns from external cooperation.

Differences in fiscal and competitive conditions also matter. EAEU members differ substantially in tax burdens and the composition of income, profit, and indirect taxes. Armenia's personal income taxation remains relatively high, while Kyrgyzstan's is substantially lower. Such differences may affect capital, investment, and activity allocation, producing unequal competitive conditions.

Geographical concentration also constrains integration efficiency. Dependence on Russia increases external risks and limits policy flexibility, particularly amid geopolitical change, sanctions, and regional instability.

Geographical and transport constraints remain important. Closed borders with Türkiye and Azerbaijan, transit dependence, and high logistics costs constrain competitiveness even within an integrated market. Integration efficiency therefore depends on transport and

infrastructure as well as customs and institutional conditions [15], [16], [17]. Rail shipments of petroleum products from Azerbaijan to Armenia via Georgia began in December 2025. According to a publication reporting Armenian State Revenue Committee data, goods imported from Azerbaijan between December 23, 2025 and July 20, 2026 amounted to approximately USD 20 million. Imports included petrol, diesel fuel, and thermal insulation construction panels. Wheat, fertilisers, and coal were also transported from Russia to Armenia in transit through Azerbaijan and Georgia.

Armenian exports within the EAEU remain insufficiently diversified. Raw materials and products with limited processing dominate substantial flows, restricting long-term competitive advantages from integration cooperation.

Regional integration can be effective when members have relatively balanced competitive opportunities, developed export structures, and equitable benefit distribution. Otherwise dependence, structural imbalances, and competitive differences can deepen.

EAEU membership provides relatively stable export markets and cooperation opportunities but also deepens dependence, geographical concentration, and asymmetries in integration efficiency.

Policy priorities should include commodity and geographical diversification, production with higher value added, improved logistics, and stronger protection of economic interests within integration. The Armenian Government's Crossroads of Peace initiative and the Armenian–US Trump Route for International Peace and Prosperity (TRIPP) project aim to address these issues and unblock regional transport connections [18], [19]. For the Armenian–US agreements, see the Armenian Council Research Centre's comprehensive analysis and the Ministry of Foreign Affairs' framework-agreement statement.

Conclusions

Foreign trade remains a major contributor to Armenia's development, international cooperation, and competitiveness. Efficiency assessment nevertheless reveals structural constraints, import dependence, and concentrated external markets.

Combining quantitative, structural, competitive, and integration approaches shows that increasing trade volumes alone does not imply higher efficiency without improvements in competitiveness, structural stability, and economic outcomes.

Turnover has grown in recent years, but deficits remain substantial. In 2025, exports were USD 8,395.4 million, imports USD 13,034.9 million, and the balance −USD 4,639.5 million, indicating continuing import predominance and external imbalance.

Structural assessment shows substantial export concentration in a few groups, particularly precious metals, mineral products, and certain foods. Limited diversification and geographical concentration increase risk and weaken long-term stability.

Analysis of 25 selected groups in 2025 indicates export predominance in 6 and import predominance in 19. Aggregate exports were USD 2,129.367 million, imports USD 3,890.763 million, and the deficit USD 1,761.397 million. Combined CA was −0.293 and coverage 54.73%. Fish and seafood (0.545), beverages and vinegar (0.514), tobacco and substitutes (0.399), and vegetables (0.312) had the strongest positive positions. Meat (−0.999), cereals (−0.995), and animal and vegetable oils and fats (−0.971) had the deepest relative deficits. Mineral fuels and petroleum products had an absolute deficit of USD 1,052.109 million. The

findings support supplier diversification, export expansion, energy efficiency, and economically viable domestic production. CA measures the relative trade balance and does not independently establish comparative production advantage or domestic consumption's import dependence.

The principal problem extends beyond the deficit to limited structural efficiency. Low technological complexity, dependence on individual markets, and import reliance constrain trade's contribution to long-term competitive development.

Integration outcomes are unevenly distributed across EAEU members. Armenia's external economic revenue share remains relatively low, indicating that returns depend substantially on structure, competitiveness, and productive capacity.

Geographical and logistics constraints also matter. Closed borders, transit dependence, and high transport costs constrain competitiveness and increase vulnerability.

Improving efficiency requires coordinated policies for commodity and geographical diversification, higher-value-added and technological production, industrial policy improvements, reduced dependence, and logistics development.

Improving regional integration requires more balanced cooperation mechanisms that enable small economies to secure greater returns and competitive opportunities.

Efficiency improvement is a comprehensive structural, competitive, and integration-related process alongside turnover expansion. Long-term policy effectiveness depends on export modernisation, competitiveness, and reduced dependence.

Trade remains a major factor in development, international competitiveness, and growth. Its significance is greater for Armenia because of its small open economy, landlocked position, limited domestic market, and external dependence. Assessment and improvement consequently have strategic importance.

Armenia's trade system retains structural imbalances and substantial import dependence. In 2025, exports were USD 8,395.4 million, imports USD 13,034.9 million, and the balance −USD 4,639.5 million, demonstrating a widening deficit.

Geographical composition remains concentrated, with substantial turnover involving the EAEU, particularly Russia. This provides access to integration benefits while increasing dependence and vulnerability to shocks.

A few commodity groups, particularly precious metals, mineral products, and certain foods, dominate exports. This concentration limits stability and increases the effect of global price fluctuations on Armenia.

Comparative advantage coefficients suggest relative competitive strengths mainly in prepared food products and in precious and semi-precious stones, precious metals, and articles thereof. Most groups have negative CA values, indicating import dependence and limited export competitiveness [8].

Economic efficiency conditions within the EAEU are asymmetric. Armenia's external economic revenue share is substantially below those of other members. Benefit distribution is uneven and depends on structure, productive capacity, and competitiveness.

The principal constraints include limited diversification, import dependence, logistics and transport restrictions, geographical concentration, and limited technological production.

Closed borders, transit dependence, and sensitivity to external markets continue to weaken efficiency.

Significant improvement opportunities nevertheless exist: commodity and geographical diversification, higher-value-added production, technological modernisation, industrial policy reform, new markets, and better international logistics links.

The findings support coordinated economic policies directed towards:

- improving export competitiveness;
- increasing the technological complexity of production;
- diversifying external markets;
- reducing external economic dependence;
- developing logistics infrastructure;
- improving regional economic cooperation.

Greater trade efficiency can provide an important basis for long-term development, macroeconomic stability, and international competitiveness.

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ՀԱՅԱՍՏԱՆԻ ՀԱՆՐԱՊԵՏՈՒԹՅԱՆ ԱՐՏԱՔԻՆ ԱՌԵՎՏՐԻ ԱՐԴՅՈՒՆԱՎԵՏՈՒԹՅԱՆ ԳՆԱՀԱՏՈՒՄԸ ՏԱՐԱԾԱՇՐՋԱՆԱՅԻՆ ՏՆՏԵՍԱԿԱՆ ԻՆՏԵԳՐՄԱՆ ՊԱՅՄԱՆՆԵՐՈՒՄ

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Հոդվածում գնահատվում է Հայաստանի Հանրապետության արտաքին առևտրի արդյունավետությունը՝ արտաքին և փոխադարձ առևտրի դինամիկայի, ապրանքային ու աշխարհագրական կառուցվածքի, առևտրային հաշվեկշռի և տարածաշրջանային տնտեսական ինտեգրման արդյունքների համադրման միջոցով: Հետազոտության մեթոդաբանական հիմքը կազմում են համեմատական, կառուցվածքային և դինամիկ վերլուծությունը, նորմավորված առևտրային հաշվեկշռի ցուցանիշը, Հերֆինդալ–Հիրշմանի ինդեքսը և տնտեսաչափական գնահատումները: Օգտագործվել են ՀՀ վիճակագրական կոմիտեի, Համաշխարհային բանկի, WITS-ի և Եվրասիական տնտեսական հանձնաժողովի տվյալները: 2025 թվականին Հայաստանի արտահանումը կազմել է 8395.4 մլն ԱՄՆ դոլար, ներմուծումը՝ 13034.9 մլն, իսկ առևտրային հաշվեկշիռը՝ −4639.5 մլն ԱՄՆ դոլար: Արտաքին և փոխադարձ առևտրաշրջանառությունը 2024 թվականի համեմատ նվազել է 29.0%-ով: ԵԱՏՄ երկրների բաժինը կազմել է 37.5%, Ռուսաստանի Դաշնությանը՝ 35.8%, իսկ ԵՄ երկրներինը՝ 11.7%: Ընտրված 25 սպառողական և կենսական նշանակության ապրանքախմբերից 6-ում արտահանումը գերազանցել է ներմուծմանը, իսկ 19-ում արձանագրվել է պակասուրդ: Այդ խմբերի գումարային ՀԱԳ-ը կազմել է −0.293, իսկ արտահանմամբ ներմուծման ծածկույթը՝ 54.73%: ԵԱՏՄ չորս երկրների 2023–2025 թվականների համակցված OLS գնահատումը ներկայացնում է հարկաբյուջետային կառուցվածքի և արտաքին տնտեսական գործունեությունից ստացվող եկամուտների կապերի նախնական գնահատում: Արդյունքները մատնանշում են արտահանման սահմանափակ դիվերսիֆիկացիան, աշխարհագրական կենտրոնացվածությունը և ինտեգրման արդյունքների անհամաչափությունները: Արտաքին առևտրի արդյունավետության բարձրացման առաջնահերթություններն են ապրանքային և աշխարհագրական դիվերսիֆիկացիան, բարձր ավելացված արժեք ունեցող արտադրության զարգացումը, լոգիստիկ ենթակառուցվածքների բարելավումը և տարածաշրջանային համագործակցության առավել հավասարակշռված մեխանիզմների ձևավորումը:

Բանալի բառեր. արտաքին առևտուր, արտաքին առևտրի արդյունավետություն, Հայաստան, նորմավորված առևտրային հաշվեկշիռ, արտահանում, ներմուծում, ԵԱՏՄ, արտահանման դիվերսիֆիկացիա:

M.A. Markosyan, E.N. Matevosyan, A.Kh. Markosyan, S.H. Tokmajyan
ASSESSING THE EFFICIENCY OF THE REPUBLIC OF ARMENIA'S FOREIGN TRADE UNDER REGIONAL ECONOMIC INTEGRATION

ОЦЕНКА ЭФФЕКТИВНОСТИ ВНЕШНЕЙ ТОРГОВЛИ РЕСПУБЛИКИ АРМЕНИЯ В УСЛОВИЯХ РЕГИОНАЛЬНОЙ ЭКОНОМИЧЕСКОЙ ИНТЕГРАЦИИ

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В статье оценивается эффективность внешней торговли Республики Армения посредством комплексного анализа динамики внешней и взаимной торговли, товарной и географической структуры, торгового баланса и результатов региональной экономической интеграции. Методологическая основа включает сравнительный, структурный и динамический анализ, нормированный индекс торгового баланса, индекс Херфиндаля–Хиршмана и эконометрические оценки. Использованы данные Статистического комитета Республики Армения, Всемирного банка, WITS и Евразийской экономической комиссии. В 2025 г. экспорт Армении составил 8395,4 млн долл. США, импорт — 13034,9 млн долл., а торговый баланс — −4639,5 млн долл. Внешнеторговый оборот сократился на 29,0% по сравнению с 2024 г. Доля стран ЕАЭС составила 37,5%, Российской Федерации — 35,8%, стран ЕС — 11,7%. В 6 из 25 выбранных групп потребительских и жизненно важных товаров экспорт превышал импорт, тогда как в 19 группах наблюдался дефицит. Совокупный нормированный индекс торгового баланса выбранных групп составил −0,293, а покрытие импорта экспортом — 54,73%. Объединённая оценка OLS для четырёх стран ЕАЭС за 2023–2025 гг. рассматривается как предварительное исследование связей между бюджетно-налоговой структурой и доходами от внешнеэкономической деятельности. Результаты указывают на ограниченную диверсификацию экспорта, географическую концентрацию и неравномерное распределение интеграционных результатов. Приоритетами повышения эффективности являются товарная и географическая диверсификация, развитие производства с высокой добавленной стоимостью, совершенствование логистической инфраструктуры и формирование более сбалансированных механизмов регионального сотрудничества.

Ключевые слова: внешняя торговля, эффективность внешней торговли, Армения, нормированный торговый баланс, экспорт, импорт, ЕАЭС, диверсификация экспорта.

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1	Թոքմաջյան Հ.Վ., Խաչատուրյան Վ.Գ., Մարկոսյան Ա.Խ., Մարտիրոսյան Գ.Հ., Գալստյան Է.Յու.	ՀԱՅԱՍՏԱՆԻ ՀԱՆՐԱՊԵՏՈՒԹՅՈՒՆՈՒՄ ՆԱԽԱԳԾԱՅԻՆ ԱՇԽԱՏԱՆՔՆԵՐԻ ԿԱԶՄԱԿԵՐՊՄԱՆ ՊԱՏԱՍԽԱՆԱՏՎՈՒԹՅԱՆ ԻՐԱՎԱԿԱՆ ԿԱՐԳԱՎՈՐՈՒՄԸ. ՀԻՄՆԱԽՆԴԻՐՆԵՐ ԵՎ ԲԱՐԵՓՈԽՄԱՆ ՈՒՂՂՈՒԹՅՈՒՆՆԵՐ	3
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