UDC 004.42:004.738.5:658.512.2
DOI DOI DOI DOI https://doi.org/10.32782/2663-5941/2026.2.1/35

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THE ROLE OF AUTOMATED FRONTEND-BACKEND SYNCHRONIZATION IN REDUCING DIGITAL PRODUCT TIME TO MARKET

The relevance of the study is determined by the increasing complexity of digital products, the spread of distributed software architectures, and the need to accelerate development processes in the context of highly dynamic digital markets. The purpose of the article is to justify the role of automated synchronization of client-server interaction in digital systems in reducing time to market for digital products and improving the efficiency of software development processes. The study employs methods of analysis and generalization of scientific sources to systematize contemporary approaches to organizing the interaction of software system components, system-structural analysis to determine the relationships among the stages of the development life cycle, a comparative approach to contrast traditional and automated deployment models, as well as analytical modeling and normalization of process metrics to evaluate the effectiveness of synchronized deployment. As a result of the study, contemporary approaches to organizing client-server interaction within the software development life cycle were analyzed. It has been established that automated synchronization of integration and deployment processes shifts change coordination control to the early stages of development, thereby reducing integration delays and increasing release stability. It has been demonstrated that the implementation of an automated deployment pipeline is accompanied by an increased frequency of production deployments, a reduced proportion of failed updates, a shorter lead time for changes to reach the production environment, and a decreased mean time to recovery after disruptions. A systematic effect of front-end/back-end interaction synchronization on reducing time to market for digital products has been identified. The conclusions substantiate that automated synchronization of interaction among software system components constitutes a methodological foundation for improving the efficiency of digital development, ensuring the coordinated evolution of client and server logic, reducing operational risks, and increasing the predictability of the release process. Prospects for further research are associated with the development of models for quantitative assessment of the economic effect of reducing time to market for digital products, the application of intelligent methods for forecasting integration risks, and the creation of adaptive automated deployment systems capable of optimizing the interaction of digital system components in real time.

Keywords: *software lifecycle, continuous integration, continuous deployment, microservice architecture, software interface consistency, software systems engineering, development automation, release management, digital platforms.*

Introduction. The modern digital economy imposes increasing demands on the speed of software development and market entry, making the reduction of the development cycle a critical factor in the competitiveness of digital platforms. At the same time, the traditional separation of the client side of software applications (front end, FE) and the server side of software systems (back end, BE) results in asynchronous changes, inconsistencies in application programming interfaces (APIs), a higher incidence of integration errors, and extended release cycles. The growing complexity of software system architectures, the widespread adoption of microservices architecture, and the implementation of continuous integration and continuous delivery (CI/CD) practices underscore the need for automated mechanisms to synchronize interactions between the client and server layers. Addressing this issue is directly associated with significant scientific and practical objectives, including optimization of the software development life cycle, reduction of technical debt, enhancement of team coordination, and acceleration of time to market for digital products.

Literature Review. A review of current research indicates the gradual formation of a comprehensive scientific concept of synchronized software development,

within which technical, architectural, organizational, and infrastructure solutions are considered interrelated components of a unified digital product life cycle. At the initial stage, studies focus on ensuring continuous data consistency between the FE and BE components of information systems. For example, F. R. de Moraes et al. argue that real time synchronization of microservice application states reduces delays between system components and facilitates faster implementation of new digital product features [1].

This idea is further developed by F. Rasyaad and S. Wibowo, who contend that the use of Backend as a Service (BaaS) architecture enables automated integration of application programming interfaces (APIs) and contributes to reducing the development time of digital monitoring platforms [2]. G. Bortolato and co authors demonstrate that the use of high speed Remote Direct Memory Access (RDMA) networks supports synchronization of computing processes with minimal delay, thereby significantly accelerating the testing of functional changes [3]. S. Guan and colleagues substantiate the effectiveness of digital twins as an environment for continuous synchronization between the user interface and server models, which shortens the testing and validation phase of digital products [4].

Summarizing these approaches, a research team led by M. Maiti concludes that the integration of data flows in financial software facilitates faster implementation of new electronic services through automated coordination of FE and BE levels [5].

Other research approaches address the synchronization of application services in corporate information systems and electronic platforms. In particular, A. Aquino and A. Lino argue that alignment of BE infrastructure configurations with user services directly affects the speed of electronic service delivery and the launch of digital products [6]. Z. Chen and co authors demonstrate that synchronized signal transmission in front end data collection electronics ensures stable integration of information flows in complex digital systems [7]. M. Kumar substantiates the concept of stable real time web architectures, in which automated interaction between FE and BE components minimizes delays in software release cycles [8]. S. Meka in a study of complex financial technology platforms, demonstrates that automation of integration processes is the primary factor enabling rapid scaling of digital products [9].

Another research direction reflects a shift toward modular and reconfigurable development architectures focused on the parallel evolution of system components. For example, S. Tao and co authors propose optimization of micro front end architecture based on cloud computing components, which enables independent updates of functional modules without interrupting overall system operation [10]. X. Zhang and co authors investigate reconfigurable BE architectures that support rapid redesign of digital platforms through flexible synchronization of computing units [11].

M. Dressler shows that innovative organizational development requires simultaneous modernization of client and server components, as asynchronous evolution increases the duration of the innovation cycle [12]. J. Liu and colleagues argue that the use of fiber optic communication channels in BE electronics ensures high speed data transmission and accelerates integration of complex digital experimental systems [13].

The final stage in the evolution of research is associated with the transition to infrastructure level automation of synchronization in distributed digital ecosystems and peripheral computing environments, including Edge Computing. G. Sung and co authors develop a gateway system with protocol conversion that enables automated interaction between devices and server platforms in real time [14]. J. Liu and co authors confirm that infrastructure synchronization through fiber optic networks increases the implementation speed of digital experimental complexes and reduces integration risks [15].

A synthesis of the analyzed studies indicates that automated synchronization of FE and BE interactions is evolving from a localized technical task into a strategic driver of digital development. It contributes to shortening the software product life cycle, improving coordination among development teams, and significantly reducing time to market for digital products.

Despite the active advancement of approaches to organizing interaction between client and server components of software systems, several issues remain unresolved. In particular, systematic synchronization within the software development life cycle and assessment of its impact on the speed of digital product creation require further investigation. Existing studies primarily emphasize individual technological solutions, whereas mechanisms for automated coordination of software interfaces, data contracts, and integration processes within microservices architectures, as well as methodological foundations for synchronized deployment of system components, remain insufficiently developed. Challenges related to service versioning, integration risks, accumulation of technical debt, and organizational inconsistencies among development teams continue to hinder effective reduction of digital product time to market.

The present study seeks to address these gaps through a comprehensive analysis of FE and BE interaction approaches, examination of technological mechanisms for automated API coordination and integration processes, substantiation of the application of CI/CD practices for synchronized deployment, and development of recommendations for an automated synchronization strategy in software development. The findings contribute to an expanded methodological understanding of synchronization of digital system components as a factor in enhancing release stability, optimizing team collaboration, and accelerating the market introduction of digital products.

The **purpose** of this article is to substantiate the role of automated synchronization of interaction between FE and BE components in reducing time to market for digital products and enhancing the efficiency of software development processes.

To achieve this objective, the following tasks are defined:

1) to analyze approaches to organizing interaction between the FE and BE components of software systems and to examine mechanisms for automated coordination of software interfaces and integration processes within microservices architectures;

2) to substantiate the methodological foundations for the application of CI/CD practices and to identify key scientific and practical challenges associated with implementing automated development synchronization;

3) to develop recommendations for establishing a strategy of automated synchronization of digital system components aimed at reducing time to market and improving release stability.

Results. The effectiveness of the software development life cycle is largely determined by the level of organization of FE and BE interaction, as integration of client and server logic defines the readiness of a digital product for release. The transition from sequential development models to integrated approaches is driven by the need for parallel development of functionality, reduction of integration delays, and assurance of change stability in dynamic digital environments. In contemporary IT projects, development speed increasingly depends not on individual technologies but on the selected model of interaction between FE and BE components (Table 1).

Modern development practice demonstrates that the most significant time losses occur during integration stages, when the client side must adapt to changes in server logic after completion of individual tasks. In a sequential model, this issue manifests as delayed testing of component interactions, leading to error accumulation and release delays [10, p. 535].

The transition to parallel development enables teams to work simultaneously by using simulation services to test the user interface before server implementation is finalized. However, in the absence of a formalized data structure specification, this approach often results in functional rework. Contract based interaction has transformed the logic of work organization, as the data exchange structure is defined at early design stages and serves as a unified technical foundation for both FE and BE components. In practice, this approach is implemented in digital e commerce platforms, banking services, and SaaS systems, where a single interface specification supports simultaneous development of client applications, server services, and automated compatibility testing [6, p. 97].

Any modification of the service response structure is detected by the control system prior to the integration stage, which significantly reduces the number of critical errors. Further advancement is reflected in interface oriented architectures, in which server services operate as autonomous modules accessible to multiple clients, including web applications, mobile platforms, and external information systems.

Table 1

Modern approaches to organizing front-end and back-end interaction in the development of digital products

Interaction approach	Basic principle of organization	Features of FE–BE interaction	Impact on product creation speed
Sequential model	Development of the server part before the client part	FE depends on the readiness of services	Extension of the release cycle
Parallel development	Simultaneous creation of functionality	Use of simulation services	Reduction of development time
Contractual interaction	Preliminary agreement on data exchange structure	Uniform interaction specifications	Reduction of integration errors
Interface-oriented architecture	Building a system around API	Independent development of FE and BE	Accelerated scaling
Automated synchronization	Automatic reconciliation of data models and services	Code generation and compatibility testing	Minimization of time-to-market

Source: compiled by the author based on [1, p. 219; 2, p. 424; 5, p. 894; 6, p. 97; 8, p. 234; 9, p. 8588; 10, p. 535]

Under such conditions, the speed of developing new features is determined by the stability of interaction interfaces rather than by the readiness of the system as a whole. The most effective approach in modern digital products is automated synchronization of FE and BE components, in which interface specifications are used to generate data models, client requests, compatibility checks, and integration tests automatically. In product oriented IT companies, this practice shifts consistency verification from manual testing to the development phase, thereby reducing technical debt, stabilizing release cycles, and ensuring a measurable reduction in time to market for digital products.

Within microservices architectures, integration consistency is maintained not through centralized control but through formalized interaction interfaces and automated compatibility management. The independence of life cycles of individual services requires technological mechanisms that enable synchronization of APIs, data contracts, and integration processes without manual coordination of changes among development teams. Automated coordination is achieved through machine readable interface specifications, backward compatibility verification systems, contract testing, and integration of these procedures into continuous build and deployment pipelines. This approach transfers integration control from post hoc testing to the software coding stage (Fig. 1).

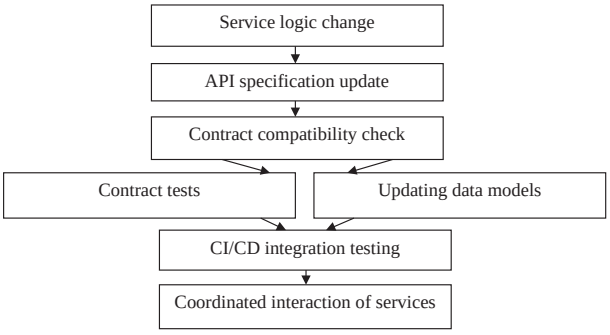

Fig. 1. Diagram of automated coordination of APIs, data contracts, and service integration in microservice architecture

Source: created by the author

The operation of this mechanism is based on transferring responsibility for integration stability from human coordination to development infrastructure. Any modification of a service interface is recorded in the specification, after which its impact on dependent services and client components is automatically verified. If the change violates compatibility, the build system blocks integration or initiates interface versioning, thereby preventing propagation of incompatible modifications in a distributed environment.

In large digital platforms, where catalog, payment, authorization, and analytics services are managed by independent teams, automated contract testing enables parallel update cycles without requiring synchronous release of the entire system [14, p. 93200]. Data schemas serve as the basis for automatic generation of types and queries, eliminating model duplication across services and reducing integration defects. Integration checks are executed within the CI/CD pipeline before changes are deployed to the production environment, ensuring stable interaction continuously rather than only at the final testing stage. This approach supports a high release frequency in microservices systems without increasing operational risks or requiring centralized coordination of changes among all development participants.

Synchronized deployment of client and server components of digital systems under current conditions is associated with the transition from episodic releases to continuous integration of changes. In distributed software environments, asynchronous updates of FE and BE components lead to interface incompatibility, functional regressions, and prolonged post release stabilization. Continuous integration and continuous delivery or deployment practices constitute the methodological foundation for controlled change coordination, as they integrate compatibility verification, automated testing, and deployment management directly into the development life cycle (Table 2).

The systematic application of CI/CD transforms the logic of software updates from periodic component coordination to continuous compatibility monitoring. Synchronization of client and server components is achieved by embedding interaction checks directly into the automated development pipeline, where each code change is compiled, tested, and verified for interface compliance. This approach eliminates the common problem of asynchronous releases, in which updated server logic becomes available to users while the client interface continues to operate with a previous data structure.

In digital banking services and e commerce platforms, this model is implemented through a unified deployment pipeline, within which modifications to interaction interfaces are automatically validated before promotion across development, testing, and production environments. For example, changes to payment processing mechanisms or order structures undergo integration testing together with client side scenarios, enabling detection of inconsistencies prior to

Table 2

Methodological approaches to applying CI/CD practices for synchronized deployment of client and server parts of digital systems

Methodological approach	Content of implementation in CI/CD	FE and BE synchronization mechanism	Expected result
Single build pipeline	Joint automated component assembly	Simultaneous verification of FE and BE changes	Coordinated release versions
API compatibility control	Automatic interface checks	Detection of incompatible changes prior to deployment	Prevention of integration failures
Automated testing	Unit, integration, and contract tests	Component interaction verification	Reducing post-release regressions
Phased deployment	Dev–Test–Stage–Production environments	Gradual synchronization of updates	Stability of implementation
Controlled feature enablement	Feature flags and availability control	Independent enablement of FE and BE features	Flexible release management
Automatic monitoring	Post-deployment checks	Monitoring system behavior after release	Rapid detection of deviations

Source: compiled by the author based on [1, p. 223; 2, p. 426; 6, p. 103; 8, p. 237; 9, p. 8590; 14, p. 93201]

public release [8, p. 237]. Phased deployment supports controlled implementation of changes, as a new server function may be deployed but remain inactive for users until correct client side operation is confirmed.

An essential element of synchronization is automated post deployment monitoring, which enables evaluation of actual interaction among system components based on performance metrics. In large scale digital products, this approach sustains frequent releases without increasing failure rates, as compatibility verification is conducted continuously rather than solely at final testing stages. Consequently, CI/CD practices perform not only an instrumental role but also a methodological function, ensuring coordinated evolution of client and server components and reducing the time interval between functionality development and its practical utilization.

In order to substantiate the impact of automated continuous integration and deployment processes on the synchronization of client-server updates in digital systems, an analytical modeling mini-experiment was conducted. The object of the study was a typical digital product with a split client-server architecture developed within a single 14-day iterative cycle.

Two deployment modes were compared. The first mode reflects the traditional approach, in which changes are integrated after the completion of individual component development, and client and server updates may be implemented asynchronously. The second mode simulates an automated deployment pipeline, in which change consistency is ensured through automatic builds, compatibility testing, integration testing, and the phased introduction of updates into the production environment.

Effectiveness was assessed using the following deployment process indicators: frequency of successful deployments, percentage of failed deployments, lead time for transitioning to the production environment, and recovery time after deployment failures. Since these indicators employ different units of measurement, they were converted to a normalized performance index with values ranging from 0 to 1. Normalization enables accurate comparison of deployment process characteristics within a unified evaluation scale (Fig. 2).

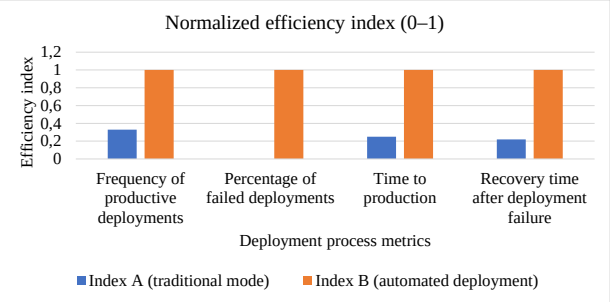

Fig. 2. Comparison of deployment process characteristics in digital systems without synchronized checks and with CI/CD practices applied. Source: author's own development

Source: created by the author

As can be seen in Fig. 2, the use of an automated deployment pipeline ensures coordinated improvement across all studied process characteristics. The increase in the productive deployment index indicates the feasibility of implementing changes in small iterations without accumulating integration risks between the client and server components of the system.

The reduction in the proportion of failed deployments confirms the effectiveness of early error detection during automated compatibility checks, which shifts quality control from the operational stage to the integration stage of changes. The reduction in lead

time for changes to reach the production environment reflects the acceleration of functional updates, while the decrease in recovery time after failures characterizes the improved manageability and stability of the release process.

The results obtained indicate that automated deployment constitutes the methodological foundation for synchronizing the development of client and server components of a digital product and establishes the conditions necessary for reducing time to market for digital solutions.

Despite the demonstrated effectiveness of automated synchronization of client and server components in digital systems, the implementation of corresponding approaches is accompanied by a number of scientific and practical challenges. First, complexity arises at the level of organizational transformation of the development process, as automated deployment requires a shift from the traditional model of team interaction, a transition from sequential to integrated workflows, and the establishment of shared responsibility for the release outcome [9, p. 8590]. An additional challenge involves ensuring the consistency of software interfaces in microservice architecture environments, where an increasing number of independent components elevates the risk of change desynchronization. Practical difficulties are also associated with the need to maintain a unified testing environment, the complexity of automating data compatibility checks, the accumulation of technical debt, and growing qualification requirements for developers and support engineers. A separate issue concerns measuring the economic effect of automated deployment, given that reductions in time to market manifest indirectly through release stability, responsiveness to changes, and reduced operational risks, which complicates the direct quantitative assessment of outcomes.

The strategy for improving the efficiency of synchronized deployment of digital products should be based on the phased integration of automated processes into the development life cycle. The primary focus is on establishing a unified pipeline for building, testing, and deploying changes, in which client and server logic are continuously coordinated throughout the development process rather than at its final stage. It is essential to combine technical automation solutions with management mechanisms for team coordination, standardization of interaction interfaces, and implementation of continuous release quality monitoring. The adoption of such a strategy reduces development inertia, increases the predictability of the release process, and creates the organizational prerequisites for a consistent reduction in time to market for digital products. These outcomes align with the results of the analytical modeling experiment and confirm the systemic nature of the impact of automated front-end/back-end interaction synchronization on the efficiency of digital development.

Conclusions. The study demonstrates that the decisive factor in reducing time to market for digital products is the level of synchronization between the client and server components of software systems throughout the entire development life cycle. The findings show that transitioning from a traditional sequential integration model to automated change coordination shifts compatibility control to the early stages of development. This shift reduces integration delays, enhances release stability, and shortens the time required to implement functional updates. Simulation results confirm that automated deployment increases the frequency of productive releases, decreases the proportion of failed deployments, reduces the time required for changes to reach the production environment, and shortens recovery time after failures. These outcomes indicate the systemic impact of front end and back end synchronization on the efficiency of digital product development.

At the same time, the study identifies key challenges associated with implementing synchronized approaches, including the need for organizational restructuring of development processes, maintaining interface consistency in distributed architectures, heightened requirements for test automation, and the difficulty of quantitatively assessing the economic effect of reduced time to market. The results substantiate that improving the effectiveness of digital projects requires an integrated strategy of automated synchronization that combines standardized component interaction, continuous quality control of changes, and coordinated collaboration among development teams.

Prospects for further research include the development of models for quantitatively measuring the impact of synchronized development on the economic performance of digital products, the application of intelligent methods to predict integration risks, and the creation of adaptive deployment systems capable of automatically optimizing interactions among software system components during operation.

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Піотровський Є.Є. РОЛЬ АВТОМАТИЗОВАНОЇ СИНХРОНІЗАЦІЇ ФРОНТЕНД-БЕКЕНД ВЗАЄМОДІЇ В СКОРОЧЕННІ ТЕРМІНІВ ВИВЕДЕННЯ ЦИФРОВИХ ПРОДУКТІВ НА РИНОК

Актуальність дослідження зумовлена зростанням складності цифрових продуктів, поширенням розподілених архітектур програмного забезпечення та необхідністю прискорення процесів розроблення в умовах високої динаміки цифрових ринків. Мета статті полягає в обґрунтуванні ролі автоматизованої синхронізації взаємодії клієнтської та серверної частин цифрових систем у

скороченні термінів виведення цифрових продуктів на ринок і підвищенні результативності процесів розроблення програмного забезпечення. У роботі застосовано методи аналізу й узагальнення наукових джерел для систематизації сучасних підходів організації взаємодії компонентів програмних систем, системно-структурний аналіз для визначення взаємозв'язків між етапами життєвого циклу розроблення, порівняльний підхід для зіставлення традиційних і автоматизованих моделей розгортання, а також аналітичне моделювання та нормування процесних метрик для оцінювання ефективності синхронізованого розгортання. У результаті дослідження проналізовано сучасні підходи до організації взаємодії клієнтської та серверної частин цифрових продуктів у межах життєвого циклу розроблення програмного забезпечення. Встановлено, що автоматизована синхронізація процесів інтеграції та розгортання забезпечує перенесення контролю узгодженості змін на ранні етапи розроблення, що сприяє зменшенню інтеграційних затримок і підвищенню стабільності релізів. Доведено, що впровадження автоматизованого конвеєра розгортання супроводжується зростанням частоти продуктивних розгортань, зниженням частки невдалих оновлень, скороченням часу проходження зміни до продуктивного середовища та зменшенням часу відновлення після порушень у роботі. Виявлено системний вплив синхронізації фронтенд-бекенд взаємодії на скорочення часу виведення цифрових продуктів на ринок. У висновках обґрунтовано, що автоматизована синхронізація взаємодії між компонентами програмних систем є методичною основою підвищення ефективності цифрової розробки, забезпечуючи узгоджений розвиток клієнтської та серверної логіки, зниження операційних ризиків і підвищення передбачуваності релізного процесу. Перспективи подальших досліджень пов'язані з розробленням моделей кількісного оцінювання економічного ефекту скорочення часу виведення цифрових продуктів на ринок, застосуванням інтелектуальних методів прогнозування інтеграційних ризиків та створенням адаптивних систем автоматизованого розгортання, здатних оптимізувати взаємодію компонентів цифрових систем у реальному часі.

Ключові слова: *життєвий цикл програмного забезпечення, безперервна інтеграція, безперервне розгортання, мікросервісна архітектура, узгодженість програмних інтерфейсів, інженерія програмних систем, автоматизація розроблення, релізний менеджмент, цифрові платформи.*

Дата першого надходження статті до видання: 13.03.2026
Дата прийняття статті до друку після рецензування: 07.04.2026
Дата публікації (оприлюднення) статті 11.05.2026