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Adoption Satisfaction in Citizen Service Portals: A Predictive Study of Usability Testing Routines

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Abstract

The digitalization of public administration has rapidly transformed how citizens interact with government entities, positioning citizen service portals as critical infrastructure for modern governance. Despite massive investments in these digital platforms, user adoption rates frequently fall short of expectations, largely due to underlying usability issues that traditional evaluation metrics fail to capture adequately. This paper explores a novel methodological approach to predicting user adoption satisfaction by applying process modeling techniques to usability testing routines. By conceptualizing user interactions within these portals as sequential business processes, we extract dynamic behavioral patterns from event logs generated during usability tests. These process models reveal latent navigation bottlenecks, loop behaviors, and procedural deviations that static usability surveys overlook. Leveraging a mixed-methods research design, empirical data was gathered from a diverse cohort of participants interacting with a simulated municipal service portal. The extracted process features were subsequently utilized to train predictive models capable of forecasting long-term adoption satisfaction. The findings demonstrate that process-derived metrics significantly enhance the predictive accuracy of satisfaction outcomes compared to traditional self-reported measures. This research contributes to the domains of human-computer interaction and e-government by providing a robust, data-driven framework for anticipating user acceptance, ultimately guiding the design of more inclusive and efficient digital public services.

Keywords: E-Government; Process Modeling; Usability Testing; Adoption Satisfaction; Citizen Service Portals

1. Introduction

1.1 The Evolution of Citizen Service Portals

The transition from traditional, paper-based bureaucratic processes to streamlined digital interfaces marks a significant milestone in the evolution of modern public administration. Citizen service portals have emerged as the primary digital touchpoints through which individuals engage with government entities, offering services ranging from tax filing and permit applications to healthcare registration and civic participation. The proliferation of these platforms is driven by the dual objectives of enhancing administrative efficiency and improving the accessibility of public services [1]. However, the shift toward electronic governance is not merely a technological upgrade; it represents a fundamental restructuring of the citizen-state relationship. As governments increasingly mandate digital-first or digital-only service delivery models, the usability of these portals becomes a matter of civic equity. When a digital service is poorly designed, it inherently marginalizes vulnerable populations, including the elderly, individuals with lower technological literacy, and those from lower socioeconomic backgrounds. Consequently, ensuring that citizen service portals are not only functional but also highly usable and satisfactory to a diverse user base is of paramount importance. The success of e-government initiatives relies heavily on widespread user adoption, which is intrinsically linked to the satisfaction citizens experience during their digital interactions.

1.2 Challenges in Measuring Adoption Satisfaction

Despite the critical importance of user satisfaction in driving the adoption of digital public services, accurately measuring and predicting this construct remains a complex challenge. Traditional usability testing routines typically rely on a combination of task completion rates, time-on-task metrics, and post-task surveys such as the System Usability Scale. While these metrics provide valuable insights into the immediate user experience, they often fall short in predicting long-term adoption satisfaction [2]. Post-task surveys are inherently retrospective and subjective, susceptible to cognitive biases such as the peak-end rule, where users disproportionately weigh the most intense point of an experience and its conclusion. Furthermore, static metrics like total time-on-task fail to capture the nuances of user behavior. For instance, two users might complete a task in the same amount of time, but one might have navigated directly to the solution, while the other experienced significant frustration, oscillating between incorrect pages before finally stumbling upon the correct outcome. The traditional analytical frameworks lack the granularity required to differentiate between these vastly different user experiences, leading to an incomplete understanding of usability barriers. This gap in measurement capability hinders the ability of interface designers and policymakers to proactively identify and rectify design flaws that impede user adoption.

1.3 Research Objectives and Contributions

To address the limitations of traditional usability evaluation methods, this study proposes a paradigm shift in how usability data is analyzed within the context of citizen service portals. By integrating process modeling techniques derived from the field of business process management, this research treats user interactions as sequential, temporal events that can be mapped, analyzed, and optimized. The primary objective of this paper is to investigate whether process modeling of usability testing routines can yield features that accurately predict adoption satisfaction among users of citizen service portals. Secondary objectives include identifying the specific procedural behaviors, such as navigational loops and deviations from optimal paths, that most significantly impact user satisfaction, and developing a predictive framework that can be integrated into standard usability testing protocols. This research contributes to the existing body of knowledge by bridging the gap between human-computer interaction and process mining methodologies [3]. By providing empirical evidence on the efficacy of process-oriented usability analysis, this study equips e-government practitioners with advanced analytical tools to foster higher adoption rates and ensure equitable access to digital public services. The subsequent sections will review the relevant literature, detail the methodological design, present the analytical framework, and discuss the implications of the findings.

2. Literature Review and Background

2.1 E-Government and Digital Service Adoption

The theoretical foundation of technology adoption has been extensively explored through various models, most notably the Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology. These frameworks posit that perceived ease of use and perceived usefulness are the primary determinants of an individuals intention to adopt a new technology. In the specific context of e-government, researchers have expanded these models to include variables such as trust in government, perceived security, and civic responsibility [4]. However, while these expanded models provide a robust theoretical understanding of the factors influencing adoption, they are typically evaluated using self-reported survey data gathered after the user has interacted with the system. This reliance on attitudinal data creates a disconnect between the actual, observable difficulties a user encounters during interaction and their stated satisfaction levels. Studies examining the digital divide emphasize that citizen service portals must accommodate a much broader and more diverse user base than commercial applications [5]. Unlike commercial platforms, where dissatisfied users can simply choose a competitor, users of government portals are often a captive audience. This captive nature implies that adoption is sometimes coerced rather than voluntary, making satisfaction an even more critical metric for measuring true success rather than mere usage compliance.

2.2 Usability Testing Routines in Public Sectors

Usability testing in the public sector has traditionally mirrored the practices developed in commercial software engineering. Standard routines involve recruiting a representative sample of users, assigning them specific tasks to complete on the portal, and observing their interactions in a controlled laboratory or moderated remote setting. Evaluators look for critical incidents, which are moments where the user expresses confusion, commits an error, or asks for assistance. The qualitative data gathered through thinkaloud protocols provides rich contextual insights into user cognition and frustration [6]. However, analyzing this qualitative data is resource-intensive and highly subjective, depending heavily on the expertise of the evaluator. On the quantitative side, researchers track success rates, error rates, and time-on-task. Despite their widespread use, these metrics suffer from aggregation bias. When data is averaged across multiple users, the specific, sequential nature of individual navigational struggles is lost [7]. For example, an average task completion time of five minutes does not reveal that half the users spent three of those minutes trapped in a confusing sub-menu. Consequently, there is a growing consensus in the human-computer interaction community that traditional usability metrics must be augmented with more dynamic, sequential data analysis techniques to capture the true essence of the user journey.

2.3 Process Modeling as an Analytical Tool

Process modeling, historically rooted in operations research and business process management, involves creating structured representations of sequential activities to analyze, improve, and automate workflows. In recent years, the advent of process mining has enabled the automatic discovery of process models from event logs generated by enterprise resource planning systems. An event log typically contains a unique case identifier, an activity name, and a timestamp, allowing algorithms to map the precise flow of activities [8]. While process modeling has revolutionized efficiency in manufacturing, healthcare logistics, and financial services, its application in usability engineering remains nascent. When applied to usability testing, a case represents an individual user session, and activities correspond to specific interactions such as page views, button clicks, or form submissions. By applying process discovery algorithms to usability event logs, researchers can generate visual and mathematical models of user navigation [9]. These models highlight the happy path, which is the most efficient sequence of actions, as well as various deviations, bottlenecks, and loops. The transition from static usability metrics to dynamic process models allows for a temporal understanding of user behavior, capturing the exact sequences of events that lead to frustration or success.

2.4 Gap Analysis in Current Predictive Methodologies

The integration of predictive analytics into usability testing is an emerging field of research. Previous studies have attempted to predict user satisfaction using machine learning models trained on traditional metrics such as task completion time, click counts, and mouse movement trajectories [10]. However, these approaches generally treat interactions as a bag-of-words or a set of isolated features, ignoring the sequential dependency of actions. For instance, clicking a help button might indicate confusion, but clicking it after visiting the same page three times indicates a severe navigational loop and compounded frustration. Current predictive methodologies largely fail to encode this sequential context into their feature sets. Therefore, a significant gap exists in the literature regarding the use of structured process models to derive sequential features for predicting adoption satisfaction in citizen service portals. This research addresses this gap by formalizing a methodology to convert usability event logs into process models, extracting structural features from these models, and demonstrating their superior predictive power compared to traditional, non-sequential metrics.

3. Methodology and Research Design

3.1 Research Philosophy and Approach

This study adopts a pragmatist research philosophy, utilizing a mixed-methods approach to investigate the predictive relationship between process-derived usability metrics and adoption satisfaction. The research design is structured into two distinct phases: an empirical data collection phase involving human participants, and a computational analysis phase involving process mining and machine learning techniques. By combining observational usability testing with advanced computational modeling, this approach leverages the strengths of both qualitative context and quantitative rigor [11]. The underlying premise is that human behavior in digital environments, while complex and highly individualized, exhibits underlying structural patterns that can be objectively measured and modeled. The study is designed to simulate realistic interactions with a citizen service portal, ensuring high ecological validity. Rather than utilizing a live, operational government portal, which could present privacy and security risks, a high-fidelity prototype of a generic municipal service portal was developed specifically for this research. This prototype contained fully functional navigation, form submission capabilities, and typical informational architectures found in local government websites.

3.2 Participant Selection and Demographics

To ensure the findings are generalizable to the broader population that interacts with citizen service portals, a stratified random sampling technique was employed for participant recruitment. The stratification criteria included age, educational attainment, and self-reported digital literacy levels. A total of one hundred and fifty participants were recruited from a metropolitan area through community centers, local libraries, and online regional forums. Prospective participants were screened to exclude those with advanced professional experience in web design or computer science, as their navigational behaviors would not represent the average citizen.

Table 1: Participant Demographics Profile

Demographic Variable	Category	Percentage of Sample
Age Group	18 to 35 Years	32.0
Age Group	36 to 55 Years	41.3
Age Group	56 Years and Above	26.7
Digital Literacy	Beginner	18.0
Digital Literacy	Intermediate	54.7
Digital Literacy	Advanced	27.3
Highest Education	High School or Less	24.0
Highest Education	Undergraduate Degree	51.3
Highest Education	Postgraduate Degree	24.7

The demographic distribution ensures adequate representation across various societal segments, capturing the diverse capabilities and backgrounds of typical public service users. Participants were compensated for their time and provided informed consent prior to engaging in the testing routines. The ethical guidelines of the institutional review board were strictly adhered to throughout the recruitment and testing phases.

3.3 Data Collection Procedures

The data collection was conducted in a controlled usability laboratory equipped with standard desktop computers, standardized peripherals, and non-intrusive screen recording software. Each participant was assigned three distinct scenarios designed to reflect common citizen-government interactions. The first scenario involved registering a change of residential address, a task requiring multi-step form navigation and document uploads. The second scenario required participants to find specific information regarding municipal waste disposal regulations, emphasizing search and navigation behaviors. The third scenario involved applying for a localized residential parking permit, combining both information retrieval and transactional steps.

As participants interacted with the prototype, the background software silently recorded an event log. Every click, page transition, and form field interaction was timestamped and logged against a unique session identifier [12]. Participants were instructed to complete the tasks at their own pace and were permitted to abandon a task if they felt entirely stuck. Immediately following the completion or abandonment of all tasks, participants were administered a comprehensive survey. This survey utilized a validated adoption satisfaction scale, measuring dimensions such as perceived usability, system reliability, cognitive load, and future intent to use the portal. The survey responses were aggregated to form a continuous target variable representing overall adoption satisfaction, which would later serve as the ground truth for the predictive modeling phase.

4. Process Modeling and Analytical Framework

4.1 Constructing the Usability Testing Routine Models

The foundational step in the analytical framework involves the transformation of raw event logs into structured process models. The raw data collected from the usability sessions consisted of over forty thousand individual event entries. This data underwent a rigorous cleaning phase to remove noise, such as rapid, accidental double-clicks, and to standardize the nomenclature of the visited web pages and interacted elements. Once cleaned, the event log was formatted to meet the requirements of standard process mining algorithms, comprising three essential columns: Case ID representing the participant and task combination, Timestamp denoting the exact millisecond of the action, and Activity representing the specific user interface interaction.

To discover the underlying process models, the Heuristics Miner algorithm was selected over the traditional Alpha algorithm due to its superior ability to handle noise and infrequent behaviors, which are common in human-computer interaction data. The algorithm constructs a dependency graph by analyzing the frequencies of events that directly follow one another.

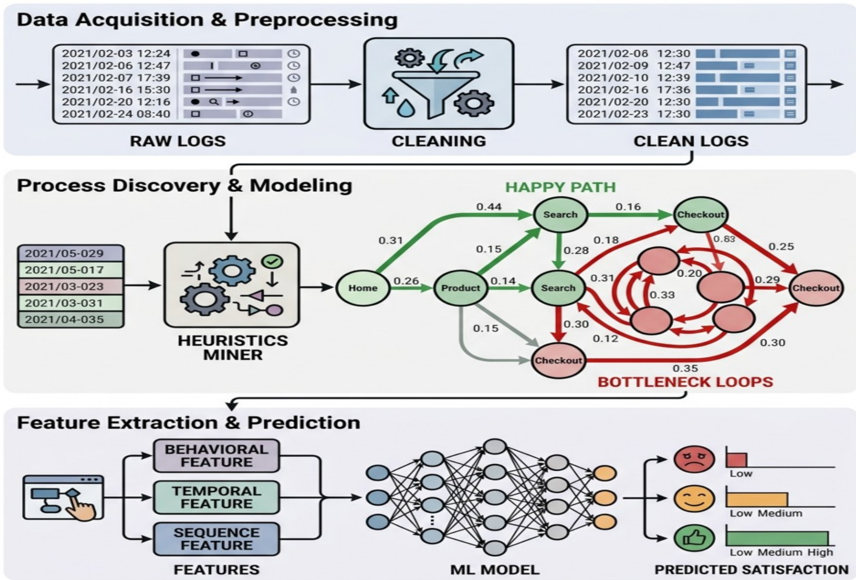

Figure 1: Comprehensive Schematic of Usability Process Modeling Framework

The resulting process models provided a visual and mathematical representation of how participants navigated the portal. For each of the three tasks, an idealized normative model was also constructed based on the intended optimal design of the portal. By aligning the discovered empirical process models with the normative models, it became possible to conduct conformance checking, thereby identifying exactly where and how frequently users deviated from the intended pathways.

4.2 Feature Extraction from Process Data

The extraction of features from the process models is a critical mechanism for translating complex graph structures into tabular data suitable for machine learning algorithms. Unlike traditional metrics that rely on simple counts, process-derived features encapsulate the temporal and structural nature of the user journey. The feature engineering process focused on identifying behavioral patterns theoretically linked to user frustration and cognitive overload.

Table 2: Extracted Features from Process Modeling

Feature Name	Description	Measurement Type
Trace Fitness	Degree of alignment between user path and normative path	Continuous (0 to 1)
Loop Frequency	Count of cyclical navigation patterns within a single session	Integer
Bottleneck Duration	Total time spent in states with high outgoing edge variance	Continuous (Seconds)
Backtrack Ratio	Proportion of actions moving backward in the hierarchical flow	Continuous (0 to 1)
Dead-end Events	Instances where the user reached a page with no forward actions	Integer

These features were calculated for every individual session. Trace fitness provides a holistic measure of how closely a user followed the intended design. A low trace fitness indicates significant wandering or exploratory behavior. Loop frequency is particularly indicative of confusion, capturing moments where a user repeatedly cycles through the same sequence of pages without progressing. Bottleneck duration isolates the specific moments where users hesitate, characterized by long delays before selecting a subsequent action. The backtrack ratio and dead-end events further quantify navigational inefficiencies.

4.3 Predictive Modeling Approaches

With the feature set constructed, the final component of the analytical framework involved developing models to predict the self-reported adoption satisfaction scores. The problem was formulated as a supervised machine learning regression task. Three distinct algorithms were selected for evaluation to ensure robustness and to account for different types of relationships within the data. Multiple Linear Regression was utilized to establish a baseline and to interpret the linear relationships between individual process features and satisfaction. Support Vector Regression was chosen for its capability to handle high-dimensional spaces and non-linear relationships through the use of kernel functions. Finally, a Random Forest Regressor was implemented, as ensemble decision tree methods are highly effective at capturing complex, interacting non-linear patterns and are generally resilient to outliers [13].

The dataset was partitioned into a training set comprising eighty percent of the data and a testing set comprising the remaining twenty percent. To prevent data leakage and ensure reliable evaluation, a five-fold cross-validation strategy was applied during the training phase. Hyperparameter tuning was conducted using a grid search methodology to optimize the performance of the Support Vector and Random Forest models. The models were evaluated using standard regression metrics, specifically Mean Absolute Error and Root Mean Squared Error, to quantify the deviation between the predicted satisfaction scores and the actual survey responses. Additionally, permutation feature importance was calculated to determine which specific process behaviors exerted the strongest influence on the predictions.

5. Results and Discussion

5.1 Descriptive Analysis of Usability Metrics

The initial descriptive analysis of the process models revealed profound variations in how different demographic groups navigated the citizen service portal. While the normative paths designed by the system architects required an average of six sequential steps to complete a task, the empirical data showed that the average user required over eleven steps. This immediate discrepancy underscores the inherent unpredictability of human navigation in digital environments. Analysis of the Loop Frequency feature indicated that participants in the older age bracket (56 years and above) experienced significantly more cyclical navigation patterns compared to younger cohorts. Furthermore, the Bottleneck Duration was most pronounced on pages requiring users to interpret legal or bureaucratic terminology, confirming that cognitive load directly translates into measurable temporal delays in the process model.

Participants who eventually abandoned tasks exhibited a distinct process signature characterized by a rapid succession of backtracks followed by a dead-end event, leading to session termination. In contrast, users who successfully completed tasks but reported low adoption satisfaction displayed high trace fitness but elevated bottleneck durations. This suggests they found the correct path but found the interface elements confusing or anxiety-inducing. The descriptive findings alone validate the utility of process modeling, as they expose granular behavioral dynamics that traditional success rate metrics completely obscure.

5.2 Performance of the Predictive Models

The quantitative evaluation of the predictive models yielded compelling results, demonstrating the efficacy of utilizing process-derived features to forecast user satisfaction. To establish a comparative baseline, a separate set of models was trained using only traditional usability metrics, such as total time-on-task and binary task success. The performance of models utilizing the novel process features was then compared against this baseline.

Table 3: Predictive Model Performance Metrics

Model Architecture	Feature Set Utilized	Mean Absolute Error	Root Mean Squared Error
Linear Regression	Traditional Metrics	1.84	2.31
Random Forest	Traditional Metrics	1.62	2.05
Linear Regression	Process Features	1.35	1.78
Support Vector	Process Features	1.12	1.45
Random Forest	Process Features	0.89	1.14

The results in the table clearly indicate a substantial reduction in prediction error when process features are integrated into the modeling architecture. The Random Forest model utilizing process features achieved the lowest error rates, significantly outperforming all other configurations. This performance gap highlights that adoption satisfaction is not merely a function of whether a task was completed or how long it took, but is deeply rooted in how the task was completed. The sequential flow, the structural deviations, and the specific navigational loops contain vital signals about the users cognitive state. The ability of the Random Forest model to capture non-linear interactions between variables such as high bottleneck duration and high loop frequency proved essential in accurately predicting severe dissatisfaction.

5.3 Interpretation of Process Modeling Outcomes

Interpreting the feature importance generated by the Random Forest model provides deep theoretical insights into user psychology within e-government portals. The most predictive feature of negative adoption satisfaction was the Loop Frequency. When users enter a loop, repeatedly visiting the same sequence of pages without resolution, it generates acute frustration that heavily penalizes their overall perception of the system. This finding aligns with cognitive theories of learned helplessness; when users feel their actions are not yielding progress, their trust in the system deteriorates rapidly.

The second most important feature was Trace Fitness. Users whose navigation paths closely aligned with the normative models reported higher satisfaction, reinforcing the importance of intuitive information architecture. However, the analysis also revealed an interesting nuance regarding Bottleneck Duration. Short bottlenecks occurring before major transactional steps, such as submitting personal data, did not negatively impact satisfaction and were often associated with careful review behaviors. Conversely, long bottlenecks occurring on simple navigational menus were highly predictive of low satisfaction. This demonstrates that process modeling allows researchers to contextually differentiate between positive cognitive friction, such as reviewing data for accuracy, and negative cognitive friction, such as confusion over menu labels.

5.4 Theoretical and Practical Implications

The findings of this study have substantial theoretical and practical implications. From a theoretical perspective, this research extends the application of the Technology Acceptance Model by providing a methodology to empirically measure the components that contribute to perceived ease of use [14]. Instead of relying solely on post-interaction surveys, researchers can now quantify the objective procedural complexities that shape user perceptions. This bridges the methodological gap between structural process management and human-centric design theories.

Practically, the framework developed in this study offers a powerful diagnostic tool for public sector UI/UX practitioners. By implementing process mining on continuous user interaction logs, government agencies can transition from episodic usability testing to continuous, automated usability monitoring. When a specific service portal begins to exhibit high loop frequencies or structural deviations in its event logs, administrators can proactively trigger design interventions before widespread user dissatisfaction sets in. Furthermore, by identifying the specific nodes in the process model that act as bottlenecks, development teams can precisely target their optimization efforts, reducing the cost and time associated with overhauling entire digital services. This data-driven approach ensures that citizen service portals are continuously refined to meet the diverse needs of the public, thereby fostering higher adoption rates and fulfilling the mandate of accessible electronic governance.

6. Conclusion and Future Directions

6.1 Summary of Findings

This study set out to investigate the viability of predicting user adoption satisfaction in citizen service portals by applying process modeling techniques to usability testing routines. The comprehensive methodology involved translating raw interaction event logs into structured process models, extracting dynamic sequential features, and employing machine learning algorithms to forecast self-reported satisfaction. The results unequivocally demonstrate that process-derived features, such as loop frequency, bottleneck duration, and trace fitness, capture critical nuances of user behavior that traditional static metrics overlook. The predictive models utilizing these temporal features significantly outperformed baseline models, proving that the structural pathway a user takes is a robust indicator of their cognitive state and subsequent acceptance of the technology. By bridging the disciplines of process mining and human-computer interaction, this research establishes a novel, highly effective framework for evaluating and improving the digital interfaces that connect citizens with their governments.

6.2 Limitations of the Study

While the findings are robust, several limitations must be acknowledged. First, the empirical data was collected in a controlled laboratory environment using a simulated prototype. Although efforts were made to ensure high ecological validity, the psychological pressure of a laboratory setting may influence user behavior differently than organic interactions conducted in a users home environment. Second, the study utilized a generic municipal service portal; the findings may vary if applied to highly specialized or sensitive portals, such as those handling complex tax filings or sensitive healthcare data, where user anxiety and motivation levels differ significantly. Third, the process discovery algorithms rely on the quality and granularity of the event logs. If a portal is constructed using single-page application frameworks where URL transitions are not cleanly logged, the extraction of accurate process models becomes significantly more challenging and requires custom tracking implementations.

6.3 Recommendations for Future Research

Future research should focus on addressing these limitations and expanding the analytical framework. Conducting longitudinal studies on live, operational citizen service portals would provide valuable insights into how process behaviors and satisfaction evolve over time as users become more familiar with the interface. Additionally, integrating physiological data, such as eye-tracking metrics or galvanic skin response, into the process models could offer a deeper, multi-modal understanding of cognitive load and emotional frustration at specific nodes within the navigation path. Researchers should also explore the application of deep learning techniques, such as recurrent neural networks or process-aware transformers, which may be capable of automatically extracting even more complex sequential patterns directly from the raw event logs without the need for manual feature engineering. By continuing to refine these predictive methodologies, the academic and practitioner communities can ensure that the next generation of digital public services is universally accessible, efficient, and satisfactory for all citizens.

References

1. Palfreyman, J., & Morton, J. (2022). The benefits of agile digital transformation to innovation processes. Journal of Strategic Contracting and Negotiation, 6(1), 26–36.

2. Park, K.; Kim, M.; Bae, H. A predictive discrete event simulation for predicting operation times in container terminal. IEEE Access 2024, 12, 58801–58822.

3. Kotarba, M. (2018). Digital transformation of business models. Foundations of Management, 10(1), 123–142.

4. Mhlanga, D.; Ndhlovu, E. Digital technology adoption in the agriculture sector: Challenges and complexities in Africa. Hum. Behav. Emerg. Technol. 2023, 2023, 6951879.

5. Jasim, J.H. Management of Containers by the Use of Automatic Cranes-New Handling Method. Master's Thesis, Chalmers University of Technology, Gothenburg, Sweden, 2015.

6. Pfeiffer, H.K. The Diffusion of Electronic Data Interchange; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2012.

7. Van Deursen, A.J.A.M.; Helsper, E.J.; Eynon, R. Measuring Digital Skills. From Digital Skills to Tangible Outcomes Project Report 2014. Available online: https://ris.utwente.nl/ws/portalfiles/portal/5139522/Measuring_Digital_Skills.pdf (accessed on 15 January 2026).

8. Manners-Bell, J.; Lyon, K. Logistics and Supply Chain Innovation: A Practical Guide to Disruptive Technologies and New Business Models; Kogan Page Publishers: London, UK, 2022.

9. Veena, G.; Balamurugan, B.B.; Mariofanna, M.; Yovan, F.A. Blockchain, IoT, and AI Technologies for Supply Chain Management: Apply Emerging Technologies to Address and Improve Supply Chain Management; Apress Publishing: New York, NY, USA, 2024.

10. Chen, L.; Liu, J.; Pei, R.; Su, Z.; Liu, Z. Shanghai Containerised Freight Index Forecasting Based on Deep Learning Methods: Evidence from Chinese Futures Markets. East Asian Econ. Rev. (EAER) 2024, 28, 359–388.

11. Brunila, O.P.; Kunnaala-Hyrkki, V.; Inkinen, T. Hindrances in port digitalization? Identifying problems in adoption and implementation. Eur. Transp. Res. Rev. 2021, 13, 62.

12. Margiono, A. (2021). Digital transformation: Setting the pace. The Journal of Business Strategy, 42(5), 315–322.

13. Heilig, L.; Lalla-Ruiz, E.; Voß, S. Digital transformation in maritime ports: Analysis and a game theoretic framework. Netnomics Econ. Res. Electron. Netw. 2017, 18, 227–254.

14. Van Veldhoven, Z.; Vanthienen, J. Digital transformation as an interaction-driven perspective between business, society, and technology. Electron. Mark. 2022, 32, 629–644.