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An AI-Enabled Automation Framework to Increase Efficiency and Accuracy in International Logistics Transit Declaration Processes

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ABSTRACT: Increasing global trade volumes and increasingly complex customs regulations have increased the need for accurate and traceable document management in international logistics. Manual preparation of transit declarations has become a significant challenge, especially after the transition to NCTS Version 5, which imposes higher data requirements and stricter validation rules. This study proposes a scalable, AI-powered automation framework that combines digital archiving, OCR-based data extraction, machine learning-assisted validation, data normalization, and automated declaration generation. The proposed system performs content analysis on multiple logistics documents, including CMRs, invoices, insurance policies, and T1/T2 forms, while conducting logical consistency checks using learning-based algorithms. Declaration packages are generated end-to-end and transmitted to customs authorities via SGS Transitnet using a REST-based interface. Real-world operational results show that processing time has been reduced from 20 minutes to approximately 3 minutes, and erroneous entries have been reduced by 84.6%. These findings demonstrate the technical and industrial applicability of the proposed model in high-volume transit operations and highlight the potential for fully autonomous, customs-compliant digital declaration execution in future developments

Keywords: Artificial Intelligence, transit declaration automation, OCR, operational efficiency.

Contents

1. Introduction

Globalizing trade volumes have significantly increased the complexity of supply chains and the need for digitalization in logistics operations. The diversity of customs regulations, the density of document flow, and the need for data accuracy, particularly in road transport, are compelling businesses to implement faster, more error-free, and more traceable process management. Transit declaration processes require a high level of document traffic between transportation companies, guarantor organizations, and official customs authorities. Manual data entry and document verification create operational risks due to high workload, time losses, and their vulnerability to human error. Therefore, automated data processing and AI-based solutions play a critical role in the digital transformation of the logistics sector.

In recent years, OCR (Optical Character Recognition) and AI-supported document processing systems have become effectively used in the data collection and document verification stages of logistics. Willcocks and Lacity have demonstrated that robotic process automation (RPA) reduces costs while improving accuracy and speed in business processes [1]. Ferrara et al. have emphasized the sustainability and scalability of web and document-based data extraction methods compared to manual data entry [2]. Other research shows that digitalization of customs processes directly impacts supply chain performance, reducing document-related delays and minimizing legal compliance issues [3, 4].

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In this context, NCTS, used in the European Union and regional trade areas, is a system that moves the declaration process to the electronic environment. However, the transition to version 5 of the NCTS has created additional workload for businesses due to the expansion of customs standards, increased data fields, and tightened verification processes. This leads to hours of declaration preparation and a high probability of errors, especially for companies operating manually.

This study proposes an AI-powered automation architecture designed to accelerate transit declaration preparation processes and reduce human error. Using a digital archive management and OCR-based data extraction layer, the system automatically scans, classifies, and analyzes documents with high precision. Furthermore, learning algorithms flag missing or incorrect fields and generate correction suggestions. The output of this system can be integrated with guarantor platforms such as SGS Transitnet to automatically generate transit declarations. The system's targeted benefits can be modeled as follows:

$$E_{\text{total}} = E_{\text{manuel}} - (E_{\text{OCR}} + E_{\text{AI}}) \tag{1.1}$$

In this formula:

- E_{manuel} represents the total error rate resulting from manual data entry,
- E_{OCR} represents the margin of error eliminated by the OCR layer,
- E_{AI} represents the error rate corrected by the AI verification layer.

By this definition, when $E_{\text{OCR}} + E_{\text{AI}} > 0$, the total error rate decreases and the quality of the process increases. The literature shows that similar AI solutions in machine learning, natural language processing, and RPA integrations reduce document processing time by 80% and error rates by 90% [5]. Artificial intelligence and machine learning are critical to the creation and improvement of intelligent systems [6].

2. Literature

Digitalization in global supply chains has become a strategic necessity, particularly for international transport and customs procedures [7]. Increasing trade volumes, the complexity of multinational supply networks, and time pressures have driven businesses to pursue faster, more accurate, and more traceable processes. Document processing, data flow, and regulatory compliance have a direct impact on the performance of logistics operations [5, 8].

Digitalization and Automation in Logistics Operations

Document management, data transfer, and data processing are among the largest cost drivers in the' operational processes of logistics companies. Studies have shown that businesses can reduce process costs, reduce error rates, and improve customer service quality through digital data management systems. It emphasizes that logistics performance is directly affected by the accuracy and speed of information flow [9, 10]. Therefore, automation of data collection, verification, and archiving is critical to the logistics field.

OCR and Artificial Intelligence-Based Document Processing In recent years, OCR-based document processing systems have achieved high accuracy rates in text extraction, data recognition, and classification of image files. Automatic data extraction methods are stated to be scalable, faster and more reliable than manual processing [2]. Although OCR systems alone provide significant improvements, these systems achieve their highest efficiency with AI-supported debugging and verification layers [11]. A typical OCR process accuracy rate can be modeled as follows:

$$D_{\text{OCR}} = \frac{T_{\text{true}}}{T_{\text{true}} + T_{\text{false}}} \tag{2.1}$$

In this formula:

- T_{true} denotes the number of characters correctly recognized by the system,
- T_{false} represents incorrectly identified characters.

When an AI-based verification layer (Δ_{AI}) is added, the total accuracy becomes:

$$D_{\text{total}} = D_{\text{OCR}} + \Delta_{\text{AI}} \tag{2.2}$$

When $\Delta_{\text{AI}} > 0$, the system accuracy can reach levels even higher than human observation. Pingili's study found that this rate is approximately 90% accurate in operational processes with AI-powered automation, while robotic process automation saves approximately 80% of document processing time [5].

Digital Transformation in Customs and Transit Systems Document compliance in international trade is a critical issue for the prevention of smuggling, transportation security, and tax audits. In recent years, many countries have digitalized their transit operations. This has made automation processes in port and transit logistics operations, as well as the increase in data density in container and land transport operations, critical to the control mechanisms of this digital environment [5]. The European Union's NCTS system provides a standardized digital declaration system for land transport. However, the increasing workload in digital customs systems is increasing the need for AI-enabled solutions.

Gap in Literature The dynamic nature of logistics, the diversity of declarations, and the use of different methods increase the risk of human error in manual processes [13]. On the other hand, while numerous studies have been conducted in the field of OCR-based document recognition and automation [10, 14, 15, 16, 17, 18], most existing approaches focus solely on text extraction or basic classification processes. Full automation is especially needed for processes requiring high accuracy and regulatory compliance, such as transit declarations. The diverse structural characteristics of multi-format customs documents used in transit processes highlight the need for AI-powered error correction mechanisms to eliminate the need for manual verification. It is also noteworthy that studies in the literature on integrated systems that enable end-to-end data flow between collateral providers, such as SGS Transitnet, and customs authorities are quite limited. This points to a significant research gap in the logistics sector regarding operational speed, regulatory compliance, and error reduction.

This study fills this gap and proposes a comprehensive solution model for automating transit declaration processes. The proposed system features an OCR + AI architecture capable of processing multi-format documents from a single point, learning algorithms that flag error areas and offer correction suggestions, and the ability to automatically generate declarations based on verified data. Furthermore, digital archive integration ensures sustainable storage, tracking, and reprocessing of documents when necessary. This architecture, which aims to prepare declarations without requiring human intervention, offers a more comprehensive and applicable model than existing approaches in literature, making a unique contribution to the field of international logistics.

3. System Architecture and Methodology

The architecture proposed in this study is a multi-layered, AI-based solution model developed to automate transit declaration processes used in international road transport. The system consists of six main components: (i) Digital Archive Retrieval Layer, (ii) OCR-Based Data Extraction Engine, (iii) AI-Based Error Correction Module, (iv) Data Validation, Normalization, and Matching Layer, (v) Transit Declaration Automation Engine, and (vi) SGS Transitnet Integration. The workflow of the method is presented in Figure 1.

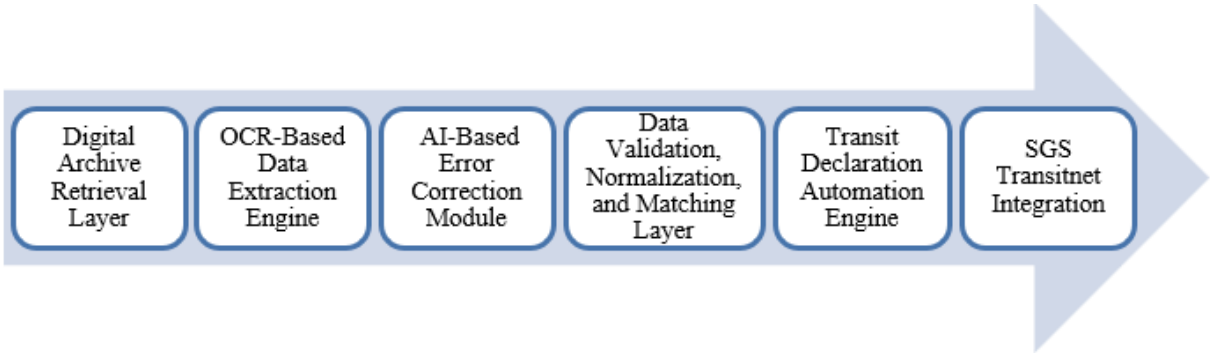

Figure 1: AI-powered transit declaration automation architecture and workflow

This workflow demonstrates the key components of the proposed AI-powered transit declaration automation architecture. The first step of the developed method begins with scanning transit cargo documents and digitally integrating them into the system via the archive layer. Text data is then extracted from the documents using OCR-based image processing engines. An AI-powered error correction module then checks data consistency across voyages and cargo, identifies incorrect, missing, or inaccurate data, and notifies operators. A data validation, normalization, and matching layer validates and synchronizes this data into a standard declaration format. The automation engine makes the necessary corrections to automatically generate the declaration by the system and forwards the data to the next layer. In the final stage, the declaration is transmitted to the collateral provider platform via SGS Transitnet integration, completing the process instantly. This structure minimizes human intervention, increasing the speed and accuracy of the process.

Digital Archive Retrieval Layer

Documents used in transit transactions, such as invoices, delivery notes, T1/T2 documents, CMRs, TIR carnets, and insurance certificates, are imported into the system in various formats (PDF, JPG, PNG, TIFF, GIF). This layer tags the files with metadata and saves them to the corporate digital archive. This process is crucial for traceability and sustainable data storage in data management [19].

OCR-Based Data Extraction Engine

The accuracy of OCR technologies significantly impacts how digital documents are indexed, referenced, and used [14]. Digitally archived files are transferred to the OCR engine. During the OCR process, character classification and image processing techniques are applied to convert the image into text format [15]. OCR outputs are generated with a specific confidence score. The system automatically determines when the threshold value of this confidence score is acceptable.

AI-Based Error Correction Module

The AI-powered error correction module forms the main intelligence layer of the designed structure. After the OCR engine converts the documents into machine-readable text, the resulting information is transformed into a structured structure at the shipment and vehicle level, including elements such as carrier details, tractor and trailer license plates, CMR numbers, container IDs, gross weight, HS (GTIP) codes, invoice IDs, and exporter/importer information. On top of this structured layer, a hybrid structure combining rule-based verification with learning-based anomaly detection is added to identify inconsistent, missing, or suspicious information.

In the rule-based layer, business rules and customs regulations are encoded with specific logical checks. These checks include verifying inconsistencies between carrier information, tractor and trailer license plates, and CMR numbers; checking the consistency between container specifications, gross weight, and declared goods value; checking for missing and formatting exporter/importer tax identifiers; and identifying missing or inconsistent data in required fields. Verifying the compliance of MRN and invoice numbers with customs standards; Structural and range checks are performed on country/customs codes using HS

(GTIP) numbers. These logical checks determine whether each area conforms to the expected regulatory or operational model.

To formalize this detection mechanism, each field is evaluated using the following decision function:

$$H(x) = \begin{cases} 1, & \text{if the area is suspicious or missing} \\ 0, & \text{otherwise} \end{cases} \tag{3.1}$$

While rule-based systems identify structural inconsistencies, learning-based systems complement these detections by modeling normal behavior using historical declaration data. Each field value is trained with a machine learning classification model to determine whether it is "consistent" or "suspicious" based on contextual shipping characteristics such as route, carrier, material type, weight profiles, and document history. This method allows the system to detect more complex and non-linear anomalies that deterministic rules cannot capture; for example, small discrepancies between declared invoice amounts and normal goods profiles, or unusual matches between license plates and transportation routes.

For each declaration, the model generates a confidence score for each extracted field. Fields with a confidence score below a predetermined threshold are flagged as potential errors. Based on the confidence level, these fields are either automatically corrected (often in cases of widespread OCR confusion or standard code mismatches) or forwarded to an operator for review. Thus, the module operates in a human-in-the-loop structure where low-risk discrepancies are automatically corrected, and high-risk or uncertain situations require human oversight.

The overall correction performance of the module is quantified using the following metric:

$$B = \frac{D_{\text{corrected}}}{D_{\text{total}}} \tag{3.2}$$

where $D_{\text{corrected}}$ represents the number of detected fields successfully corrected by the system and D_{total} denotes the total number of suspicious or inconsistent fields identified. This ratio measures the module's ability to resolve erroneous values and reduce operator workload.

In practical applications, classification metrics such as precision, recall, and F1-score are also used to evaluate the learning-based component on a labeled test set. The empirical analysis conducted in this research demonstrates that the AI-powered error correction module significantly improves the reliability of declared data. In the operational environment tested, the module demonstrated its effectiveness in high-volume transportation operations by reducing erroneous transaction entries by 84.6% compared to a fully manual process.

Data Validation, Normalization and Matching Layer

In this study, the data obtained through OCR showed significant variation in structure and presentation, and a systematic normalization process was required to ensure compatibility with standardized transit declaration templates. All time information was converted to a single ISO-compliant date format and normalized using EU/UN-ECE reference lists to ensure consistent semantics for country, location, and customs codes. Textual errors detected by OCR, such as irregular spaces, missing punctuation, and incorrect character identification, were corrected using rule-based and pattern-based filters. Numeric fields originating from different documents were cross-checked with equivalence checks to identify anomalous deviations and ensure consistency across documents. Following these normalization processes, the matching layer combined the validated fields into a unified, shipment-level data model suitable for automatic declaration generation.

Transit Declaration Automation Engine

Transit declaration automation combines verified and standardized information with relevant elements from the official declaration schema to create a fully structured declaration. Human intervention is only required when the AI module detects low-confidence fields. Operating on a unified shipment-level data model, the engine automatically assembles the declaration and converts it into an XML file that complies with NCTS and SGS Transitnet standards. This conversion includes schema validation, mandatory field checking, and hierarchical consistency testing to ensure regulatory compliance. Thanks to this automated, standards-based architecture, the engine offers a precise and efficient way to create transit declarations suitable for direct electronic shipment.

SGS Transitnet Integration

The resulting declaration is transferred to the German Customs Administration system via the SGS Transitnet API. The integration model works with REST-based service calls. This structure enables real-time monitoring of declaration submissions, nonconformity/error notifications, and approval status.

The overall process flow can be mathematically modeled as follows:

$$T_{\text{total}} = T_{\text{OCR}} + T_{\text{AI}} + T_{\text{automation}} \tag{3.3}$$

The manual process is:

$$T_{\text{manual}} = T_{\text{read}} + T_{\text{write}} + T_{\text{control}} \tag{3.4}$$

System improvement is defined as:

$$\Delta T = T_{\text{manual}} - T_{\text{total}} \tag{3.5}$$

It is expressed as follows. If $\Delta T > 0$, the system saves time.

4. Application, Testing and Findings

This section evaluates the findings obtained from testing the applicability of the proposed AI-powered automation model in international road transport operations. The implementation and testing were conducted on the transit declaration preparation process of an international logistics company. The company uses SGS Transitnet in its operations. The test data is based on the daily entry of an average of 40 randomly selected vehicles from Türkiye to Germany or from Europe to Türkiye.

Manual Process

The traditional declaration preparation process consists of the following steps:

- Collecting invoices, CMRs, and transport documents,
- Manually reading the information on the document,
- Transferring data to the declaration form,
- Checking for available fields,
- Signing and submitting for approval.

In an average manual process, processing a declaration takes approximately 15–18 minutes. While the error rate varies depending on the human input, manual data entry error rates range from 2% to 5%.

Use of the Recommended Automation System

The implementation stages of the automation system proposed in this study are as follows:

- Documents are entered into the system via scanner or digital upload.
- The OCR engine extracts all text on the document.
- The artificial intelligence module detects missing or incorrect fields.
- Standard data templates are created.
- The transit declaration is automatically prepared.
- It is sent electronically to SGS Transitnet.

Table 1: Comparison of Manual and Automatic Processing Times

Processing Stage	**Manual Processing Time (minutes)**	**Automatic Processing (minutes)**
Document Collection and Archive	5–7	1
Data Reading and Entry	6–10	0 (automatic)
Internal Control and Correction	4–6	1–2
Statement Creation and Submission	1–2	0–1
Total Time (average)	**20 minutes**	**3 minutes**

With this process, a single declaration can be completed in approximately 2–4 minutes. This represents a significant gain in automated processing compared to manual processing time.

Time Savings Analysis

In this study, the comparative results regarding the processing times of the manual method and the AI-supported automation approach for customs declaration documents consisting of an average of 30 pages are presented in Table 1. Considering the total processing times obtained in Table 1, the total time savings provided by the automation system compared to the manual method are as follows:

$$\Delta T = T_{\text{manual}} - T_{\text{automatic}} = 20 - 3 = 17 \text{ minutes} \tag{4.1}$$

This benefit is calculated based on an average of 40 daily declarations:

$$\Delta T_{\text{daily}} = 40 \times 17 = 680 \text{ minutes} = 11.3 \text{ hours} \tag{4.2}$$

A savings of approximately 11.3 hours corresponds to nearly 1.5 working days of time savings for a business.

Error Transaction Rate

Before using the improved application, an average of 78 incorrect transaction data entries per month were encountered in manual declaration preparation processes, but with the introduction of the new system, this number dropped to 12. Error reduction rate:

$$R = \frac{H_{\text{manuel}} - H_{\text{otomatik}}}{H_{\text{manuel}}} \times 100 \tag{4.3}$$

$$R = \frac{78 - 12}{78} \times 100 = 84.6\% \tag{4.4}$$

This significant reduction in the number of incorrect transactions yielded approximately 84.6% efficiency for the business in this area.

5. Discussion

The findings of this study demonstrate that the proposed AI-powered transit declaration automation architecture significantly increases operational efficiency in international road transport processes. The results clearly demonstrate that automation reduces document processing time, minimizes human errors, accelerates decision-making, and strengthens regulatory compliance. The observed 17-minute savings per declaration and 84.6% monthly error reduction position the model as a significant improvement over traditional manual process. These results align with previous research demonstrate that digital automation reduces workload, human dependency, and operational bottlenecks in logistics processes [1, 5, 8].

The key contribution of this study lies in its end-to-end automation capabilities. Unlike most existing studies, where OCR methods are limited to text extraction or pre-classification, the presented architecture integrates OCR, AI-based semantic validation, normalization, and SGS Transitnet API submission into a single workflow. This integration eliminates repetitive manual checks and enables real-time customs

document preparation. These results fill a critical gap in literature, as previous studies rarely address full automation in legally binding customs procedures, particularly in multimodal and multiformat data environments.

The results also demonstrate that the system supports business sustainability by reducing operational costs and improving process traceability. Integrating a digital archive further strengthens data governance frameworks by ensuring long-term accessibility, reusability, and reuse of documents. From a managerial perspective, reducing human intervention minimizes labor dependency and supports lean logistics methodologies. Quantitative results of time savings equivalent to approximately 1.5 working days per operational shift demonstrate tangible economic value for logistics companies. This supports the findings of Willcocks and Lacity [1], who stated that RPA-based automation significantly reduces financial and administrative overheads.

In addition to efficiency gains, the model also offers important implications for customs security and compliance. Verification layers that detect anomalies such as MRN structures, license plates, GTIP codes, invoice numbers, and identification information reduce the likelihood of regulatory penalties and shipment delays. This aligns with current digital customs frameworks that emphasize risk management, data reliability, and document transparency [3, 12]. Given the increasing data density in NCTS-5, the proposed architecture could serve as a strategic tool for companies struggling to comply with new customs obligations.

However, despite the robust empirical findings, some limitations must be acknowledged. First, the model was tested on road transport declarations integrated with SGS Transitnet, and therefore its performance in maritime, rail, or multimodal environments requires further investigation. Second, OCR accuracy can vary depending on document quality, language, and layout complexity. While AI-based correction mitigates these limitations, extremely low-resolution or handwritten documents still require human oversight. Third, the study focused on structured and semi-structured data; fully unstructured documents (e.g., free-text attachments or non-standard invoices) may require advanced NLP or deep learning layers.

Future research could focus on expanding the model in various directions. Integrating deep learning-based document intelligence could improve semantic accuracy in complex invoice formats. Blockchain-based audit trails can improve customs data traceability and authentication. Furthermore, machine learning algorithms can be trained on larger international datasets to improve anomaly detection, benchmarking, and predictive routing decisions. Cross-platform integrations, such as with port community systems, e-cargo platforms, and customs brokerage systems, can further improve end-to-end logistics continuity.

In summary, the findings demonstrate that the proposed automation system offers a scalable, highly accurate, and operationally viable solution for international transit declarations. By fully automating the processes of data extraction, verification, normalization, declaration creation, and submission, the model addresses both academic gaps and real-world industry challenges. Therefore, this study contributes to the growing body of knowledge on digital customs transformation and provides a valuable resource for logistics service providers seeking faster, more secure, and more cost-effective declaration management.

6. Conclusion

This study presented a scalable, AI-powered automation architectural solution for transit declaration processes in international road transport. By integrating digital archiving, OCR-based text extraction, machine learning-assisted verification, data normalization, automatic declaration generation, and SGS Transitnet submission, the system automates every key stage of a process traditionally reliant on manual processes. The study results demonstrate that the model significantly improves operational efficiency, accuracy, and regulatory compliance. Key benefits derived from the system are summarized in Table 2.

As can be seen in Table 2, the system proposed in this study not only improves processing speed and error reduction, but also interoperability, scalability, and legal compliance. One of the study's unique contributions is its AI-powered development of a nearly fully automated and scalable transit declaration creation system without requiring human intervention. Intelligent consistency check mechanisms reduce human dependency, prevent discrepancies between document fields, and validate practical usability through true SGS Transitnet integration. The findings confirm that the proposed framework is both technically feasible and operationally sustainable for real-world logistics environments.

Table 2: Key Strengths of the Proposed System

Performance Criterion	**Explanation**
Time Efficiency	Reduced manual declaration processing time from an average of 18 minutes to 3 minutes, resulting in significant workforce savings in high-volume logistics environments.
Error Reduction	The OCR + AI verification mechanism has reduced human-caused data entry errors from an average of 78 errors per month to approximately 12 errors.
Integration Capability	Real-time integration with SGS Transitnet enables commercial distribution and expansion to additional collateral platforms.
Scalability	The implemented architecture allows processing thousands of documents simultaneously and offers a scale applicable to large carriers and/or 3PL/4PL logistics providers.
Regulatory Compliance	Learning-based standardization provides a structure compatible with EU customs legislation and international transit regulations.

This system has significant potential for future advancement. Machine learning-based automated GTIP code recommendation modules could significantly reduce expert intervention and further streamline declaration workflows. The addition of anomaly detection for security could increase accuracy and auditability by automatically flagging suspicious or inconsistent records. Expanding the integration infrastructure with other guarantor and customs platforms could create a fully autonomous approval cycle where declarations are prepared, verified, and transmitted as much as possible without human intervention. Furthermore, deep learning-based multilingual OCR engines, particularly for Turkish, English, and German document sets, would increase data extraction accuracy in various formats and strengthen its international applicability. Such solutions could also contribute to the architecture's transformation into a next-generation smart customs processing system.

In conclusion, this study proposes an innovative and applicable AI-powered solution for the logistics sector that provides faster processing, lower operational costs, increased data reliability, and sustainable digital archiving. With its strong performance in reducing processing times (i.e., time efficiency, error reduction, scalability, and legal compliance), the proposed model offers both theoretical contribution and practical value. Future enhancements to automated GTIP classification, anomaly detection, and multilingual OCR capabilities have the potential to transform the architecture into a fully autonomous, AI-powered digital customs ecosystem, demonstrating that the system could be a key component of next-generation smart transit operations.

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References

[1] L. Willcocks, M. C. Lacity, and A. Craig., *Robotic Process Automation: Strategic Transformation Lever for Global Business Services?*, London, U.K.: Palgrave Macmillan, 2019.

[2] E. Ferrara, P. De Meo, G. Fiumara, and R. Baumgartner., *Web data extraction, applications and techniques: A survey.*, *Knowledge-Based Systems*, vol. 70, pp. 301–323, 2014. doi: 10.1016/j.knosys.2014.07.007

[3] J. Jeevan, S.-L. Chen, and S. Cahoon., *Determining the influential factors of dry port operations: worldwide experiences and empirical evidence from Malaysia*, Maritime Economics & Logistics, Palgrave Macmillan Ltd., 2017.

[4] J. Heydari, K. Govindan, H.R. Ebrahimi Nasab, and A.A. Taleizadeh, *Coordination by quantity flexibility contract in a two-echelon supply chain system: Effect of outsourcing decisions.*, *International Journal of Production Economics*, vol. 225, pp. 107586, 2020. doi: 10.1016/j.ijpe.2019.107586.

[5] P. Ramesh Aguirre, *AI-driven intelligent document processing for healthcare and insurance. International Journal of Science and Research Archive*, 14(01), 1063-1077 (2025). doi: 10.30574/ijsra.2025.14.1.0194.

[6] E. Şahinaslan, M. Günerkan, and Ö. Şahinaslan, *A An alternative solution method to the use of categorical data encoding techniques in machine learning. Journal of Intelligent Systems: Theory and Applications (jista)*, 6(1), 1–11 (2023). doi: 10.38016/jista.1140499

[7] S. V. Smerichevska, L. Prodanova, and O. Yakushev., *Digitization of logistics and supply chain management Intellectualization of Logistics and Supply Chain Management*, vol. 26, pp. 113–123 (2024). doi: 10.46783/smart-scm/2024-26-9

[8] E.C. Chinomona and M.B. Bikissa-Macongue, *The impact of green supply-chain management on logistics performance in the construction sector in South Africa.*, *Journal of Transport and Supply Chain Management*, Vol. 16, pp. 752 (2022) doi: 10.4102/jtscm.v16i0.752

[9] S. Angelopoulos, E. Bendoly, J. C. Fransoo, K. Hoberg, C. X. J. Ou, and A. Tenhiälä, *Digital transformation in operations management: Fundamental change through agency reversal*, *Journal of Operations Management*, Vol. 69 (6), pp. 876–889 (2023) doi: 10.1002/joom.1271.2

[10] A. A. Atieh, A. Abu Hussein, S. Al-Jaghoub, A. F. Alheet, and M. Attiany, *The impact of digital technology, automation, and data integration on supply chain performance: Exploring the moderating role of digital transformation*, *Logistic*, 9(1), pp 11 (2025). doi: 10.3390/logistics9010011

[11] M. D. Alahmadi and M. Alshangiti, *Optimizing OCR performance for programming videos: The role of image super-resolution and large language models. Mathematics,*, vol. 12, no. 7, p. 1036 (2024). doi: 10.3390/math12071036

[12] Y. Cao, Q. Zeng, H. Haralambides, Z. Wang, and A. Yang, *Digital twins: Digitalization of automated container terminals in seaports. Maritime Economics & Logistics*, 1-22 (2025). doi: 10.1057/s41278-025-00315-6

[13] M. Günerkan, E. Şahinaslan, and Ö. Şahinaslan, *Gümrük beyannamesi sürecinde öğrenmeye dayalı algoritmaların etkinliğinin incelenmesi. Acta Infologica* , Vol. 6 (2), 175–188 (2022). doi: 10.26650/acin.1057060

[14] M. C. Traub., *Impact analysis of OCR quality on research tasks in digital archives.* in Proceedings of the International Conference on Theory and Practice of Digital Libraries (TPDL), Springer, pp. 252–263 (2015), doi: 10.1007/978-3-319-24592-8_19.

[15] A. Jain and J. Sharma, *Classification and interpretation of characters in multi-application OCR system.*, in Proceedings of the 2014 International Conference on Data Mining and Intelligent Computing (ICDMIC), Delhi, India, 2014, pp. 1–6, doi: 10.1109/ICDMIC.2014.6954231.

[16] G. Kim, T. Hong, M. Yim, J. Nam, J. Park, J. Yim, and S. Park, *OCR-free document understanding transformer. Proc. Eur. Conf. Comput. Vis. (ECCV)*, Cham, Switzerland: Springer Nature, Oct. 2022, pp. 498–517.

[17] Ö. Aydın, *Classification of documents extracted from images with optical character recognition methods.*, *Computer Science*, 6(2), 46-55. (2021).

[18] S. V. Mahadevkar, S. Patil, K. Kotecha, L. W. Soong, and T. Choudhury., *Exploring AI-driven approaches for unstructured document analysis and future horizons. Journal of Big Data*, 11(1), pp 92. (2024).

[19] P. Netinant, N. Saengsuwan, M. Rukhiran, and S. Pukdesree., *AEnhancing data management strategies with a hybrid layering framework in assessing data validation and high availability sustainability. Sustainability*, 12(20), 15034 (2023). doi: 10.3390/su152015034

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