

AI- Human Synergy: Accelerating Smarter Customs and Supply Chains

Burcu Alatepeli

Assistant Professor

International Trade and Finance Department

Alparslan Türkeş Science and Technology University

Adana, Türkiye

balatepeli@atu.edu.tr

Abstract

Artificial intelligence is becoming increasingly relevant for customs administrations operating in digitally interconnected trade environments, similar to its growing role in supply chain management. Customs processes such as risk assessment, cargo clearance, and information exchange through Single Window systems involve high levels of uncertainty, large data volumes, and time pressure, making them well suited for AI-supported decision-making. AI applications can support customs operations by learning from historical trade data, identifying patterns and anomalies, and providing officers with timely, evidence-based recommendations rather than replacing human authority. When the interaction between artificial intelligence and human expertise is considered in customs operations, AI performs tasks such as document processing, risk identification, and workflow acceleration. Customs brokers, in contrast, interpret regulatory requirements, evaluate commercial implications, and retain final decision-making authority. Meaningful transformation occurs where algorithmic capabilities and human judgment operate in an integrated and complementary manner. This study examines how artificial intelligence transforms the role of customs brokers in customs operations. A qualitative case study methodology was employed in a high-volume customs brokerage firm. Data were collected through process analysis, document review, and observational insights to explore human–AI interaction in customs decision-making. The findings are analyzed thematically to evaluate the role of AI as a decision-support mechanism rather than a substitute for professional judgment. The study contributes to both theory and practice by demonstrating how AI-enabled systems can enhance decision quality and operational efficiency in customs brokerage while preserving the central role of human judgment in regulatory processes.

Keywords

Artificial Intelligence, Supply Chain, Customs Digital Transformation, Case Study.

1. Introduction

The evolution of international trade has progressed far beyond the initial transition from paper-based systems to "e-customs" frameworks. Today, the industry is undergoing a profound sociotechnical transformation driven by Artificial Intelligence (AI) and Robotic Process Automation (RPA), which are redesigning how authority is exercised and how work is coordinated at the border. While previous waves of digitalization focused on the efficiency of information flows, the current shift toward AI-supported operations targets the very core of trade facilitation: the balance between automated processing and professional discretion (Alatepeli, B., 2022).

The motivation for this research arises from a significant shift in the operational landscape of global trade. High-volume brokerage firms are increasingly pressured to adopt automation to mitigate clerical bottlenecks and reduce repetitive data entry. However, a review of the current evidence reveals a lopsided focus; most existing studies concentrate on customs administrations, border controls, and public-sector risk systems. There is an urgent need to

explore the private sector's experience, specifically how brokerage firms internalize these technologies to maintain compliance and competitive value in an increasingly data-intensive environment (Widdowson, D., 2020; Heijmann, et al., 2020).

Several problem statements define the scope of this inquiry. First, while AI demonstrates clear gains in repetitive, rules-based tasks, it encounters formidable limits when faced with "open-textured" legal criteria, such as complex tariff classification (HS Code selection). In these high-stakes scenarios, machine learning can flag anomalies but cannot yet replace the nuanced expert review necessary for legal accuracy. Second, the introduction of AI does not merely substitute human labor; it redistributes discretion and reshapes occupational identity. This creates a tension where routine clerical work is shrinking, yet the demand for expert intermediation in legally dense environments is deepening (Gwardzińska, E., 2014).

Finally, despite the growing number of technical prototypes and policy frameworks, there remains a critical lack of direct evidence on how AI adoption is "lived" as an organizational change process within brokerage firms. By examining these internal dynamics, this study seeks to bridge the gap between technical potential and the practical reality of human-AI collaboration, ensuring that the transition to "intelligent" customs does not undermine the accountable professional judgment required for global supply chain security.

1.1 Objectives

This study aims to better understand how artificial intelligence is reshaping customs brokerage practices, with particular attention to the interaction between human expertise and algorithmic systems in decision-making processes. It explores the operational advantages brought by AI in terms of efficiency and process optimization, while also examining its limitations in dealing with complex and open-ended regulatory tasks such as tariff classification. At the same time, the study considers how the adoption of AI is influencing professional roles, discretion, and occupational identity within brokerage firms. Building on these dimensions, the research evaluates the broader opportunities and risks associated with AI integration through a SWOT analysis, ultimately highlighting the continued importance of human judgment in ensuring compliance and accountability.

2. Literature Review

In this section, we will explore the existing literature on the application of artificial intelligence in customs operations, with particular attention to its role in risk management, document processing, and decision-support systems, as well as its implications for the evolving role of customs brokers in digitally integrated trade environments. Research on AI in customs brokerage sits at the meeting point of three literatures. One tracks the long shift from paper based clearance to e-customs and shared trade information infrastructures (Tan et al., 2006; Raus, M. 2009; Hintsa et al., 2012). A second examines analytics, machine learning, and automation for declaration processing, tariff classification, risk scoring, and anomaly detection (Laporte, B. 2011; Widdowson, D. 2020; Chen, H. 2021; Chen, Z., 2024; Hu et al., 2025). A third studies how digital control changes discretion, occupational identity, and coordination across public and private actors at the border (Côté-Boucher, K. 2016; Lisle and Bourne, 2019; Mikuriya and Cantens, 2020). Taken together, these studies suggest that AI does not simply replace customs expertise. It redistributes work between systems, customs officers, and brokers, while making data quality, legal interpretation, and exception handling more important (Kafando, 2020; Côté-Boucher, K. 2016; Pius and Murugan 2025). The earlier literature makes clear that customs digitalization was never only about replacing paper with screens. Foundational work on e-customs presents modernization as a redesign of information flows, procedures, and institutional relations across public and private actors (Tan et al., 2006; Henningsson et al., 2011). Later value assessment studies add that the appeal of common e-customs solutions lies in a four part promise: stronger security, lower administrative burden, easier compliance, and better communication (Raus, M. 2009). Survey work from the private sector shows that firms value systems that are simple to use, reduce duplicate entry, and fit existing commercial workflows (Hintsa et al., 2012). Case studies from Estonia, Ghana, and Peru show that implementation outcomes depend as much on organizational alignment and stakeholder cooperation as on the technical system itself (Liutkevicius, et al., 2020; Aryee, et al, 2021; Casco, et al., 2022). The Ghana study is especially important because it resists a purely technical view of digital transformation. It shows that clearance platforms are socially embedded and shaped by competing interests, which helps explain why the same technology can produce uneven operational effects across contexts [Ary21]. This line of work supports the view that AI in customs brokerage should be analysed as a sociotechnical change in work organization rather than as a stand alone software upgrade (Aryee, et al, 2021).

To provide a structured overview of the existing literature, the main studies on artificial intelligence in customs and customs brokerage are summarized in Table 1. The table presents the focus, methodological approach, and key contributions of selected studies. This evidence landscape helps to identify dominant research themes as well as gaps, particularly the limited number of brokerage-focused and qualitative studies.

Table 1. Evidence Landscape of AI in Customs and Customs Brokerage Literature

Study	Weaknesses	Opportunities	Threats
Pius & Murugan (2025)	Customs brokerage digitalization	Qualitative interviews	Faster processing, continued role in compliance & exceptions
Lee (2023)	RPA in declarations	Interviews	Efficiency gains in repetitive tasks; cost & implementation limits
Chen (2024)	AI in customs clearance	Conceptual	AI improves compliance, risk detection, document handling
Hu et al. (2025)	AI assistant systems	System design	AI supports document processing and decision-making
Chen et al. (2021)	HS code validation	Machine learning	AI detects misclassification but cannot replace experts
Antov (2025)	Tariff classification limits	Conceptual	Legal ambiguity limits automation
Kafando (2020)	AI adoption in customs	Policy framework	Organizational and governance factors are critical
Widdowson (2020)	Risk & compliance	Conceptual	Integrated risk management is key in customs systems
Karklına-Admine et al. (2024)	Risk management	Literature review	Data quality and coordination are central challenges
Liutkevicius et al. (2020)	Automated declarations	Case study	Automation depends on institutional alignment
Aryee et al. (2021)	Digital transformation	Multi-case study	Systems shaped by stakeholder interaction
Gwardzińska (2014)	Role of brokers	Professional analysis	Brokers shift toward advisory roles

3. Methods

This study employs a qualitative case study methodology to examine the transformation of customs brokerage practices in the context of artificial intelligence–supported customs operations. The research was conducted in a high-volume customs brokerage firm to explore the interaction between human expertise and AI-supported decision processes. Data were collected through process analysis, document review, and observational insights related to customs clearance and risk assessment procedures. To systematically evaluate the organizational and operational implications of AI adoption, the study applies SWOT analysis as an analytical framework. The SWOT approach enables the identification of internal strengths and weaknesses as well as external opportunities and threats associated with the integration of artificial intelligence into customs brokerage processes. The collected qualitative evidence was interpreted thematically and subsequently structured within the SWOT framework to assess how AI-supported systems influence decision quality, operational efficiency, and the evolving role of customs brokers.

4. Data Collection

This study adopts a qualitative data collection approach in line with the case study design. Data were gathered from a high-volume customs brokerage firm through multiple sources to ensure a comprehensive understanding of AI-supported customs processes. First, process analysis was conducted to examine the operational workflow of customs

clearance and risk assessment procedures. This involved mapping key stages such as document intake, declaration preparation, and control mechanisms where artificial intelligence tools are actively utilized.

Second, document review was carried out on internal and operational documents, including sample customs declarations, process guidelines, and system-generated outputs. These documents provided insights into how AI-supported systems are embedded in daily brokerage practices and how decisions are supported by algorithmic outputs. Third, observational data were collected through direct observation of routine brokerage activities. This allowed the researcher to capture the interaction between human expertise and AI-supported systems in real time, particularly in tasks requiring interpretation, validation, and exception handling.

To enhance the reliability of the findings, data were collected from multiple sources and compared across processes. The combination of process analysis, document review, and observation enabled a more nuanced understanding of how AI is integrated into customs brokerage operations and how it shapes decision-making practices.

5. Results and Discussion

This SWOT is best read as a literature-based assessment of AI adoption in customs brokerage firms, not just customs administrations and used as an analytical framework. A key caveat is that the strongest evidence base is on customs digitalization, risk management, and clearance automation, while broker-specific studies are fewer (Pius and Murugan 2025; Lee, J. 2023; Karklına-Admine et al., 2024).

Table 2. SWOT analysis of generative AI in customs operations

Strengths	Weaknesses	Opportunities	Threats
Faster declaration processing through RPA, machine learning, and AI-assisted workflows	Strong reliance on clean, standardized, and interoperable data infrastructures	Transition from routine filing tasks toward higher-value advisory roles in compliance and exception management	Legal uncertainty in tariff classification limits full automation and increases liability risks
Greater consistency and standardization in repetitive operational tasks Lee23	Uneven adoption of AI capabilities among brokers due to cost, training, and implementation barriers Lee	Emergence of AI-enabled service offerings such as predictive compliance analysis, enhanced classification review, and risk-preparation services	Risk of disintermediation if brokers remain focused on clerical intermediation rather than advisory expertise
Improved risk visibility and anomaly detection supporting more informed decision-making and pre-clearance preparation	AI systems struggle with novel, exceptional, or context-dependent cases where tacit professional judgment is essential	Deeper integration with digital trade platforms, single window systems, and trusted trader infrastructures	Regulatory changes, platform redesigns, and shifts in customs systems may rapidly undermine existing workflows and capabilities
Increased auditability and transparency when customs processes are effectively digitized	Organizational transformation challenges, including workflow redesign, governance adaptation, and human oversight requirements	Competitive advantages through improved service quality, faster processing, and reduced error rates in complex compliance environments	Excessive reliance on opaque AI systems may weaken trust, accountability, and professional discretion

The SWOT analysis highlights several structural patterns in the integration of artificial intelligence within customs brokerage operations. Overall, the most visible strengths appear in operational efficiency. AI-driven tools and automation systems are particularly effective in brokerage activities characterized by high-volume, repetitive, and rule-based procedures, such as document intake, declaration preparation, and routine validation tasks. As suggested

in the literature, the use of AI in these areas can increase processing speed, improve consistency, and support more accurate risk targeting, thereby enhancing both operational efficiency and decision support in customs processes (Lee, J.2023; Chen, Z.2024; Hu et al., ; Chen, B., 22011; Grigoriou C.2019).

At the same time, the analysis reveals important weaknesses that are primarily organizational and informational rather than purely technological. Effective AI deployment depends heavily on the availability of structured and reliable data, interoperable digital platforms, and well-defined governance frameworks. However, these conditions are not uniformly present across customs environments. In addition, certain legally complex tasks—most notably tariff classification and the handling of exceptional cases—remain difficult to fully codify within automated systems. As a result, the complete replacement of professional expertise with automated decision-making remains unrealistic (Antov, M.,2025).

The findings also point to significant opportunities arising from AI adoption. As routine filing and administrative tasks become increasingly automated, customs brokers may shift their professional focus toward higher-value activities. These include compliance advisory services, interpretation of regulatory risks, trader guidance, and the management of complex or exceptional cases. Furthermore, the literature suggests emerging opportunities for the development of AI-supported advisory services, such as classification review, document intelligence, and pre-clearance risk preparedness (Widdowson, 2020; Gwardzińska,2014; Llanto et al., 2013). However, the analysis also identifies several strategic threats. One key risk is that brokerage firms may remain confined to traditional clerical functions while the value of manual intermediation declines due to automation. In such a scenario, firms that fail to develop advisory, analytical, and systems-related capabilities may experience increasing competitive pressure or partial disintermediation. Another concern relates to governance challenges. Poor data quality, opaque algorithmic systems, legal uncertainties, and unclear responsibility structures may generate new compliance and trust issues rather than resolving existing ones.(Antov,M., 2025 ; Côté-Boucher, K., 2016).

Taken together, the findings suggest that artificial intelligence is likely to act as a powerful driver of process efficiency within customs brokerage operations. The literature consistently indicates that AI technologies significantly improve the performance of tasks that are structured, repetitive, and data-intensive. In this sense, AI primarily enhances the operational layer of customs brokerage rather than replacing the profession itself (Lee, J.2023).

At the same time, the results reinforce the continued importance of human expertise in areas requiring contextual interpretation, legal reasoning, and tacit professional judgment. Tasks such as complex tariff classification, regulatory interpretation, and exception management remain highly dependent on human expertise and are unlikely to be fully automated in the foreseeable future.(Antov, M., 2025; Pius and Murugan,2025). From a strategic perspective, the findings suggest that the future competitive position of customs brokers will depend on their ability to move beyond clerical intermediation. Firms that successfully reposition themselves as expert intermediaries—providing advisory, compliance, and analytical services supported by AI-enabled tools—are more likely to remain relevant in increasingly digitalized trade environments. In contrast, those that continue to rely primarily on routine filing and procedural intermediation may face declining margins and growing competitive pressures (Gwardzińska, E., 2014; Llanto et al., 2013). Overall, the literature indicates that AI does not eliminate the role of customs brokers but instead reshapes it. The most sustainable model appears to be a hybrid structure in which automated systems handle standardized operational processes while human professionals focus on interpretation, advisory functions, and complex regulatory decision-making.

6. Conclusion

The findings of this study suggest that AI in customs brokerage should be viewed less as a simple replacement of human labor and more as a reconfiguration of work. Its strongest contribution appears in repetitive, rules-based processes, where it can improve speed, consistency, and workflow efficiency. At the same time, customs brokerage continues to depend on human expertise in areas such as legal interpretation, exception handling, and compliance judgment.

From a strategic perspective, the main opportunity lies in the evolution of the broker's role. As automation reduces the value of routine clerical intermediation, brokers may become more important as compliance advisers, coordinators, and interpreters of complex customs requirements. The main risks are legal ambiguity, weak data quality,

implementation challenges, and the possibility that firms that fail to adapt may lose relevance in an increasingly digital customs environment.

As an exploratory qualitative study, this research also opens several avenues for future research (Helo,P., Hao Y., 2022). Future studies may further investigate the organizational, technological, and regulatory factors influencing AI adoption in customs brokerage. In particular, the role of data quality, governance structures, and human–AI interaction in decision-making processes deserves deeper empirical examination. Additionally, comparative studies across different countries or brokerage environments could provide further insights into how institutional contexts shape AI integration in customs operations.

References

- Alatepeli,B., Developing An Acceptance Model Using The Structural Equality Model for Factors Affecting the use of Single Window System in Turkey, Ph.D. Thesis, *Department of Çukurova University Business Administration, Ulusal Tez Merkezi | Anasayfa*
- Antov,M., Challenges of Using AI in Tariff Classification of Goods for Customs Purposes, *Conference: ACCOUNTING AND CONTROL* Apr. 11, 2025. DOI:[10.56065/ACCOUNTCONT/2025.131](https://doi.org/10.56065/ACCOUNTCONT/2025.131)
- Aryee, J., Andersen,C., and Hansen, A.S., The Social-Political Embeddedness of Import Clearance: 20 Years of Digital Transformation at Tema, Ghana, *World Customs Journal*, Mar. 2021, <https://doi.org/10.55596/001c.116432>.
- Chen,H., B. van Rijnsoever, Molenhuis, M., D. van Dijk, Tan,Y-H., and B. Rukanova, The use of machine learning to identify the correctness of HS Code for the customs import declarations,2021 *IEEE 8th International Conference on Data Science and Advanced Analytics (DSAA)*, pp. 1–8, Oct. 2021, DOI:[10.1109/DSAA53316.2021.9564203](https://doi.org/10.1109/DSAA53316.2021.9564203)
- Chen, Z., AI-Powered Customs Clearance: Optimizing Trade Compliance and Border Management, *Journal of AIDriven Trade Facilitation Engineering and Single Window Systems*, Jun. 2024, DOI:[10.6914/sw.010105](https://doi.org/10.6914/sw.010105)
- Côté-Boucher,K., The Paradox of Discretion: Customs and the Changing Occupational Identity of Canadian Border Officers, *The British Journal of Criminology*, Volume 56, Issue 1, January 2016, Pages 49–67,2016. <https://doi.org/10.1093/bjc/azv023>
- Helo,P., Hao,Y., Artificial intelligence in operations management and supply chain management: an exploratory case study, *Production Planning & Control*, 33:16, 2022, <https://doi.org/10.1080/09537287.2021.1882690>
- Grigoriou, C., Revenue Maximisation Versus Trade Facilitation: The Contribution of Automated Risk Management, *World Customs Journal*, Sep. 2019, <https://doi.org/10.55596/001c.116215>.
- Gwardzińska, E., The Role of Customs Brokers in Facilitating International Trade, *World Customs Journal*, Mar. 2014, <https://doi.org/10.55596/001c.93042>
- Heijmann, F., Tan,Y., Rukanova, B., and Veenstra,A., The Changing Role of Customs: Customs Aligning With Supply Chain and Information Management, *World Customs Journal*, 14(2), 131–142.2020. <https://doi.org/10.55596/001c.116423>.
- Henningsson,S., Gal,U., Bjørn-Andersen,N., and Tan,Y.H., The Next Generation Information Infrastructure for International Trade, *J. Theor. Appl. Electron. Commer. Res.*, vol. 6, pp. 1–15, Apr. 2011, <https://doi.org/10.4067/S0718-18762011000100002>
- Hintsä, J.,Männistö T., Urciuoli, L., and Granqvist, M.,Future Development of e-Customs: A Survey Study with Swiss Companies, *International Journal of Electronic Government Research*, vol. 8, pp. 1–13, Oct. 2012, DOI:[10.4018/jegr.2012100101](https://doi.org/10.4018/jegr.2012100101)
- Hu,R., Liu,S., Qi,P., Liu,J., and Li,F., ICCA-RAG: Intelligent Customs Clearance Assistant Using Retrieval-Augmented Generation (RAG), *IEEE Access*, vol. 13, pp. 39711–39726, 2025, DOI:[10.1109/ACCESS.2025.3544408](https://doi.org/10.1109/ACCESS.2025.3544408)
- Kafando, I., How Can Customs Better Leverage Emerging AI Technologies for More Sustainable and Smarter Operations? *World Customs Journal*, Sep. 2020, <https://doi.org/10.55596/001c.116424>
- Karkliņa-Admine, S., Čeveris, A., Kovalenko A., and Auziņš, A., Challenges for Customs Risk Management Today: A Literature Review, *Journal of Risk and Financial Management*, Jul. 2024, <https://doi.org/10.3390/jrfm17080321>
- Laporte, B., Risk Management Systems: Using Data Mining in Developing Countries Customs Administrations, *World Customs Journal*, Mar. 2011, <https://doi.org/10.55596/001c.92448>

- Lee J., Robotics Process Automation (RPA) And The Import/Export Customs Declaration Process, *Global Trade and Customs Journal*, Oct. 2023, <https://doi.org/10.54648/gtcj2023042> .
- Lisle D. and Bourne M., The many lives of border automation: Turbulence, coordination and care, *Social Studies of Science*, vol. 49, pp. 682–706, Sep. 2019, <https://doi.org/10.1177/0306312719870868>
- Liutkevicius, M., Pappel, K.I., Butt, S., and Pappel, I., Automatization of Cross-Border Customs Declaration: Potential and Challenges - A Case Study of the Estonian Customs Authority, *International Conference on Electronic Government*, pp. 96–109, 2020, https://doi.org/10.1007/978-3-030-57599-1_8.
- Llanto, G., Navarro, A., Detros, K.C., and Ortiz, M., Customs Brokerage Services and Trade Facilitation: A Review of Regulatory Coherence, Oct. 2013, DOI: <https://doi.org/10.62986/dp2013.48>.
- Mikuriya K. and Cantens T., If Algorithms Dream of Customs, Do Customs Officials Dream of Algorithms? A Manifesto for Data Mobilisation in Customs, *World Customs Journal*, Sep. 2020, <https://doi.org/10.55596/001c.116414>
- Pius J., and Murugan S., Critical Analysis of Customs Digitalization-Customs Broker Perspective, *Journal of Vasyl Stefanyk Precarpathian National University*, Jun. 2025, <https://doi.org/10.15330/jpnu.12.2.65-79>
- Raus, M., Value Assessment of Business-to-Government Innovations: a Case Study, *22nd Bled eConference, eEnabement: Facilitating an Open, Effective and Representative eSociety* Bled, Slovenia, June 14-17, p. 7, 2009.
- Tan, Y., H., Klein, S., Rukanova, B., Higgins, A., and Baida, Z., eCustoms Innovation and Transformation: A Research Approach, *19th Bled eConference, Bled, Slovenia, June 5-7*, p. 41, 2006
- Widdowson, D., Managing Customs Risk and Compliance: An Integrated Approach, *World Customs Journal*, Sep. 2020, <https://doi.org/10.55596/001c.116418>
- Widdowson, D. Managing Customs Risk and Compliance: An Integrated Approach, *World Customs Journal*, 14(2), 63–80, Sep. 2020, <https://doi.org/10.55596/001c.116418>

Biography

Burcu Alatepeli is an Assistant Professor in the Department of International Trade at Alparslan Türkeş Science and Technology University, Turkey. She holds a Ph.D. in Production Management from Çukurova University, where she was awarded the YÖK 100/2000 Doctoral Scholarship in the thematic field of Supply Chain Management. She earned her Master's degree in Engineering and Technology Management from the Department of Industrial Engineering at Çukurova University and her Bachelor's degree in Business Administration. Dr. Alatepeli has professional experience in international trade, customs operations, and supply chain management, having previously worked in global manufacturing firms. She has published journal articles and conference papers on digitalization in international trade, customs single window systems, supply chain management, logistics, blockchain technologies, and decision-support systems. Her current research interests focus on artificial intelligence in customs operations, digital trade facilitation, e-logistics, and human-AI interaction in supply chain and regulatory processes.