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Digitization and Automation in Customs Clearance: Structural and Operational Impacts on the Aeronautical Industry from the Perspective of Critical Operations (AOG)

Digitalização e Automação na Liberação Aduaneira: Impactos Estruturais e Operacionais na Indústria Aeronáutica sob a Perspectiva de Operações Críticas (AOG)

Digitalización y Automatización en el Despacho Aduanero: Impactos Estructurales y Operativos en la Industria Aeronáutica desde la Perspectiva de las Operaciones Críticas (AOG)

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Abstract:
The evolution of international aeronautical logistics, especially within critical operations classified as Aircraft on Ground (AOG), is strongly correlated with the ability of customs systems to ensure high levels of agility, predictability, and regulatory compliance. In this context, traditional customs clearance processes have historically been one of the main operational obstacles in the aeronautical supply chain because of their high documentary complexity, the multiplicity of jurisdictions, and the strict regulatory requirements applicable to aeronautical components. Against this background, the digitization and automation of customs systems are emerging as structural drivers of transformation, promoting the reconfiguration of operational flows and the rationalization of control processes. These technological advances directly contribute to increased logistical efficiency, the mitigation of regulatory and operational risks, and the continuity of air operations on a global scale.

Keywords:
aeronautical logistics; AOG; customs clearance; digitization; automation; compliance.

Resumo:
A evolução da logística aeronáutica internacional, especialmente no âmbito de operações críticas classificadas como Aircraft on Ground (AOG), apresenta forte correlação com a capacidade dos sistemas aduaneiros de assegurar níveis elevados de agilidade, previsibilidade e conformidade regulatória. Nesse contexto, os processos tradicionais de desembaraço aduaneiro configuraram-se, historicamente, como um dos principais entraves operacionais na cadeia de suprimentos aeronáutica, em função da elevada complexidade documental, da multiplicidade de jurisdições e do rigor normativo aplicável aos componentes aeronáuticos. Diante desse cenário, a digitalização e a automação dos sistemas aduaneiros emergem como vetores estruturantes de transformação, promovendo a reconfiguração dos fluxos operacionais e a racionalização dos processos de controle. Tais avanços tecnológicos contribuem diretamente para o aumento da eficiência logística, a mitigação de riscos regulatórios e operacionais, bem como para a garantia da continuidade das operações aéreas em escala global.

Palavras-chave:
logística aeronáutica; AOG; desembaraço aduaneiro; digitalização; automação; compliance.

Resumen:
La evolución de la logística aeronáutica internacional, especialmente en el ámbito de las operaciones críticas clasificadas como Aircraft on Ground (AOG), presenta una fuerte correlación con la capacidad de los sistemas aduaneros para garantizar altos niveles de

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agilidad, previsibilidad y cumplimiento normativo. En este contexto, los procesos tradicionales de despacho aduanero se han configurado históricamente como uno de los principales obstáculos operativos de la cadena de suministro aeronáutica, debido a la elevada complejidad documental, la multiplicidad de jurisdicciones y el rigor normativo aplicable a los componentes aeronáuticos. Ante este escenario, la digitalización y la automatización de los sistemas aduaneros emergen como vectores estructurantes de transformación, promoviendo la reconfiguración de los flujos operativos y la racionalización de los procesos de control. Estos avances tecnológicos contribuyen directamente al aumento de la eficiencia logística, a la mitigación de riesgos normativos y operativos, así como a garantizar la continuidad de las operaciones aéreas a escala global.

Palabras clave:
logística aeronáutica; AOG; despacho aduanero; digitalización; automatización; cumplimiento.

1. Historical Context of Customs Clearance in Aviation

Traditionally, customs processes in the aeronautical industry were heavily based on physical documentation, manual checks, and in-person interactions among logistics operators, customs brokers, and tax authorities. This model, predominant until the end of the twentieth century, was characterized by low transparency, high variability in clearance times, and significant exposure to human error.

In the AOG[1] context—where an aircraft remains inoperative because a critical part is unavailable—logistical response time is a determining factor. Each hour of unavailability can represent substantial financial losses for air operators, in addition to reputational and operational impacts. In this scenario, the sluggishness of traditional customs processes constituted a systemic risk factor.

Beginning in the 2000s, driven by international trade facilitation initiatives such as Authorized Economic Operator (AEO)[2] programs and World Customs Organization (WCO)[3] agreements, a gradual transition to electronic customs declaration systems began. However, this initial digitization was fragmented and often limited to replacing paper with digital forms, without effectively reengineering the processes.

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[1] AOG (Aircraft on Ground) denotes the condition in which an aircraft remains inoperative on the ground because a part, component, or service is unavailable, requiring a priority solution. Each hour of unavailability entails significant operational and contractual costs.

[2] The concept of Authorized Economic Operator (AEO/OEA) originates in the World Customs Organization (WCO) SAFE Framework of Standards and Article 7.7 of the WTO Trade Facilitation Agreement, promulgated in Brazil by Decree No. 9,326/2018. In Brazil, the AEO Program is governed by RFB Normative Instruction No. 2,154/2023 and anchored in Article 814-A of the Customs Regulations (Decree No. 6,759/2009).

[3] The WCO promotes the simplification and harmonization of customs regimes and procedures primarily through the Revised Kyoto Convention (International Convention on the Simplification and Harmonization of Customs Procedures), adopted in 1999 and in force internationally since 2006.

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2. Digitization as a Driver of Structural Transformation

The contemporary digitization of customs clearance goes beyond the simple computerization of documents. It is a systemic transformation based on data integration, interoperability among platforms, and the use of emerging technologies such as blockchain, artificial intelligence (AI), and machine learning.

In the aeronautical industry, this transformation has specific features because of the critical nature of the components involved, which often require certifications such as EASA Form 1 or FAA 8130-3.[4] Digitization enables the automated validation of these certifications, significantly reducing documentary analysis time and minimizing noncompliance risks.

In addition, Single Window systems[5] enable the centralized submission of information to multiple government authorities, eliminating redundancies and increasing the efficiency of information flows. In AOG operations, this centralization is particularly relevant because it reduces coordination time among different regulatory bodies.

3. Automation and Operational Intelligence

Automation, when combined with digitization, introduces a new level of operational efficiency. Automated tariff classification systems, for example, use AI algorithms to determine HS (Harmonized System)[6] codes based on technical descriptions of aeronautical parts, reducing errors and accelerating the declaration process.

Additionally, predictive analytics tools make it possible to anticipate customs risks, such as physical inspections or documentary holds. In AOG operations, this predictive capability is critical because it enables the proactive planning of alternative logistics routes or the mobilization of regional inventories to mitigate delays.

Another relevant aspect is the automation of compliance checks. Integrated systems can automatically verify sanctions lists, export restrictions (such as ITAR and EAR),[7] and jurisdiction-specific requirements, ensuring that operations comply with international

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[4] EASA Form 1 (Annex I to Part-21 of the European Union Aviation Safety Agency) and FAA Form 8130-3 (Authorized Release Certificate) are certificates of conformity and release to service that accompany aeronautical components, attesting to their origin, traceability, and airworthiness.

[5] The Single Window model allows an operator to submit, at one point, the information required by different government agencies, eliminating redundancies. In Brazil, it is embodied in the Single Foreign Trade Portal (Portal Único Siscomex).

[6] The Harmonized Commodity Description and Coding System (Harmonized System—HS), maintained by the WCO, is the international tariff classification basis adopted by most countries.

[7] ITAR (International Traffic in Arms Regulations, 22 CFR §§ 120–130) and EAR (Export Administration Regulations, 15 CFR §§ 730–774) are the main United States export-control regimes, particularly relevant to dual-use or military aeronautical items.

regulations.

4. Impacts on AOG Operations Management

The digitization and automation of customs processes directly affect the management of AOG operations, especially in three main dimensions: response time, predictability, and risk control.

Response time: reducing customs clearance time is perhaps the most evident impact. Processes that previously took days can be completed in hours or even minutes, depending on the level of automation and system integration.

Predictability: the use of real-time data and forecasting algorithms allows greater accuracy in estimating clearance times, facilitating logistics planning and communication with stakeholders.

Risk control: automation reduces dependence on manual processes, minimizing human error and increasing regulatory compliance. This is particularly relevant in a sector where traceability and certification are critical requirements.

5. Challenges and Limitations

Despite the advances, the digitization and automation of customs clearance face significant challenges. One of the main challenges is the heterogeneity of global customs systems. While some countries have adopted highly integrated and automated platforms, others still operate with legacy systems or partially digitized processes.

Another challenge is data standardization. The lack of uniformity in product descriptions, tariff codes, and documentary requirements can compromise the effectiveness of automated systems. Standardization initiatives, such as the use of WCO data models, are essential to overcome this limitation.

Moreover, cybersecurity and data protection issues become increasingly relevant as systems become more interconnected. The integrity and confidentiality of information are essential, especially considering the sensitivity of aeronautical data.

6. Future Prospects

The trend is for the digitization and automation of customs clearance to continue evolving, driven by technological advances and the growing demand for logistical efficiency. Technologies such as blockchain have the potential to revolutionize the traceability and

authenticity of documents by creating immutable records shared among different stakeholders.

The integration of customs systems with logistics management platforms (Transportation Management Systems—TMS) and aeronautical maintenance systems (Maintenance, Repair and Overhaul—MRO) will provide end-to-end visibility of the supply chain, facilitating real-time decision-making.

In the AOG context, this integration may enable even faster and better-coordinated responses, significantly reducing aircraft downtime and increasing the operational resilience of airlines.

7. Systemic Integration and Global Interoperability: The Role of Digital Architectures in Customs Fluidity

One of the most relevant developments of customs digitization in the aeronautical industry lies in the growing adoption of interoperable system architectures capable of connecting multiple agents throughout the international logistics chain. In this context, interoperability is not limited to communication among national customs systems; it extends to integration with the private platforms of logistics operators, airlines, manufacturers (OEMs), and maintenance centers (MROs).

Historically, the fragmentation of information systems has been one of the main barriers to logistical efficiency. Each jurisdiction operated with its own requirements, data formats, and communication protocols, resulting in information redundancies and low operational visibility. The evolution toward models based on Application Programming Interfaces (APIs), cloud computing, and international data standards—such as the WCO Data Model[8]—represents a break with this paradigm.

In practice, interoperability allows critical information—such as airworthiness certificates, commercial invoices, air waybills, and export declarations—to be shared in real time among different systems, eliminating the need for manual data reentry. In AOG operations, this capability significantly reduces information latency, that is, the time between the generation of information and its availability to decision-makers.

In addition, system integration enables the concept of end-to-end visibility, allowing continuous monitoring of a shipment's status from its origin to its final destination, including customs stages. This expanded visibility is fundamental to exception management, enabling

[8] The WCO Data Model is a standardized set of data, definitions, and message structures maintained by the WCO and designed to enable interoperability among customs administrations and logistics-chain operators.

rapid intervention in the event of delays, holds, or documentary inconsistencies.

Another critical aspect is the ability to synchronize customs systems with logistics planning platforms. Through integration with Transportation Management Systems (TMS) and Inventory Management Systems (IMS), it becomes possible to align logistics decisions with regulatory constraints in real time. This is particularly relevant in highly critical scenarios, where the choice of an alternative route may depend on the specific customs requirements of certain countries.

However, the consolidation of a truly interoperable ecosystem still faces significant challenges. Issues related to data sovereignty, technological compatibility, and the governance of digital platforms require multilateral coordination and continuous investment. Even so, the trend is unequivocal: systemic interoperability is becoming one of the fundamental pillars for modernizing aeronautical logistics and optimizing customs clearance processes.

8. Digital Governance, Advanced Compliance, and Continuous Auditing in the Era of Customs Automation

The growing digitization of customs processes not only redefines operational efficiency but also profoundly transforms governance and compliance mechanisms in the aeronautical industry. In an environment characterized by strict regulations and high exposure to legal risks—including export controls, international sanctions, and technical certification requirements—automation emerges as a strategic tool for ensuring continuous compliance and auditability.

Traditionally, customs compliance was based on ex post audits conducted after operations were completed. In addition to being reactive, this model had significant limitations regarding the early detection of noncompliance. With the introduction of integrated digital systems, there has been a transition toward compliance-by-design models, in which regulatory controls are incorporated directly into operational flows.

Automated systems can perform real-time checks, including validation of tariff classifications, verification of documentary requirements, and cross-checking against global restricted-party lists. In the aeronautical context, this includes verifying compliance with regimes such as ITAR (International Traffic in Arms Regulations) and EAR (Export Administration Regulations), as well as specific regulations issued by authorities such as the FAA and EASA.

Another significant advance is the implementation of digital audit trails, which record

in detail all interactions and decisions throughout the customs process. These records, frequently stored in secure and immutable environments, enable complete traceability of operations, facilitate internal and external audits, and reinforce transparency before regulatory authorities.

The use of technologies such as blockchain further enhances this capability by ensuring the integrity and authenticity of data shared among different parties. In a scenario where document forgery represents a relevant risk, especially for critical aeronautical parts, the immutability of digital records constitutes a strategic advantage.

Additionally, large-scale data analysis (big data analytics) enables the identification of risk patterns and the implementation of predictive compliance models. This supports a proactive approach in which potential noncompliance is anticipated and mitigated before affecting operations. In AOG operations, this capability is particularly valuable because it prevents delays resulting from unexpected inspections or regulatory blocks.

However, the adoption of advanced digital governance models also poses new challenges. Dependence on automated systems requires high standards of technological reliability, in addition to robust cybersecurity strategies. Protection against unauthorized access, data leaks, and cyberattacks becomes a central element of risk management.

In summary, the digitization of customs clearance redefines the concept of compliance in the aeronautical industry, shifting it from a reactive approach to a continuous, integrated, and data-driven model. This transformation not only strengthens regulatory compliance but also contributes to the sector's operational resilience and global competitiveness.

9. The Brazilian Context: Single Window, AEO Program, and Special Customs Regimes

In Brazil, global movements toward customs digitization and automation materialize primarily in the Single Foreign Trade Portal (Portal Único Siscomex) and the progressive replacement of traditional declarations by the Single Import Declaration (Duimp). These operate as a national single window, centralizing the provision of information to the various consenting agencies.[9] This arrangement reduces documentary redundancies and enables the structured sharing of data between the customs authority and logistics-chain participants.

At the same time, the Brazilian Authorized Economic Operator Program has become the main instrument for facilitation based on trust and risk management, granting certified

[9] In Brazil, the single window is operated through the Single Foreign Trade Portal (Portal Único Siscomex), including the Single Import Declaration (Duimp), which centralizes the provision of information to consenting agencies and integrates customs control in a digital environment.

operators greater predictability, fewer inspections, and priority in customs clearance. For the aeronautical industry, these benefits are particularly relevant in critical operations, where predictability of clearance is as important as its speed.

Regarding special customs regimes, temporary admission plays a structural role. Aircraft used in international transportation are automatically placed under the regime, with full suspension of taxes and without the registration of an import declaration; the regime also encompasses goods intended for maintenance and repair, including parts and components used to replace items in foreign goods.[10] This regulatory architecture is the foundation on which digitization and automation produce efficiency gains by converting historically slow procedures into predictable and auditable flows. Customs facilitation in aviation, in turn, has its international normative basis in Annex 9 to the Chicago Convention.[11]

10. Final Considerations

The digitization and automation of customs clearance processes have become structural elements in the transformation of international aeronautical logistics, especially in highly critical operational scenarios such as Aircraft on Ground (AOG) operations. Over recent decades, the evolution from models based on physical documentation and manual validation to integrated digital ecosystems has redefined the parameters of efficiency, predictability, and regulatory control. This transition has not only reduced response times but also increased the level of traceability and reliability of operations, essential factors in a highly regulated sector that is sensitive to failures.

The incorporation of advanced technologies, combined with increasing interoperability among global systems, significantly expands visibility and coordination throughout the logistics chain. Integration among customs platforms, logistics systems, and aeronautical operational environments enables a truly end-to-end approach, in which data flows in real time and decisions are made based on data-driven intelligence. This new paradigm favors risk mitigation, the anticipation of bottlenecks, and the optimization of routes and processes, all of which are particularly critical in emergency operations requiring

[10] The special customs regime of temporary admission with full suspension of tax payments is governed by RFB Normative Instruction No. 1,600/2015, based on the Customs Regulations (Decree No. 6,759/2009). Aircraft used in international transportation are automatically admitted without registration of an import declaration (Article 5, I); the regime also covers goods intended for maintenance and repair, including parts and components used as replacements in foreign goods (Article 3, II).

[11] The facilitation of customs formalities in civil aviation is based on Annex 9 (Facilitation) to the Convention on International Civil Aviation (Chicago Convention, 1944), which establishes standards and recommended practices to expedite the entry and exit of aircraft, cargo, and passengers.

immediate responses.

At the same time, there has been a profound transformation in customs governance and compliance models. The evolution toward compliance-by-design structures, supported by automation, artificial intelligence, and digital audit trails, redefines how organizations manage regulatory risks. The ability to perform real-time checks, combined with complete traceability of operations, strengthens transparency and adherence to international standards while reducing exposure to penalties and operational interruptions. In this context, technologies such as blockchain and predictive analytics emerge as strategic tools for ensuring integrity, security, and the anticipation of noncompliance.

However, consolidating this digital ecosystem still depends on overcoming relevant structural challenges, including regulatory harmonization among jurisdictions, data standardization, and stronger cybersecurity. The uneven maturity of customs systems around the world and issues related to data sovereignty and governance require coordinated efforts among governments, industry, and international organizations. Even so, the trajectory is unequivocal: customs digitization is not merely a trend, but an indispensable driver of the resilience, competitiveness, and sustainability of the global aeronautical industry in an increasingly dynamic and interconnected environment.

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