ONE Record and TIC4.0 Data Model - Compatibility Analysis

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Terminal Industry Committee 4.0

1. INTRODUCTION

The European Union's ambitious drive toward climate neutrality by 2050 hinges critically on transforming freight transport systems. Multimodal transport, which integrates multiple transport modes within a single logistics chain, offers substantial potential for reducing environmental impact while enhancing operational efficiency. Yet despite clear advantages and strong policy support, multimodal solutions remain underutilized across Europe. A fundamental barrier impeding this transition is the persistent lack of digital interoperability between transport modes, where fragmented data systems and incompatible standards create operational silos that fragment the logistics chain.

The maritime and aviation sectors exemplify this challenge. Both industries have developed sophisticated digital ecosystems to manage complex operations within their respective domains. The Terminal Industry Committee 4.0 (TIC4.0) has established comprehensive data standards for port operations, while the International Air Transport Association (IATA) has advanced the ONE Record initiative to digitize air cargo documentation and create a unified data sharing framework. However, when cargo transitions between sea and air transport, these well-structured systems encounter interoperability gaps that force stakeholders to revert to traditional, inefficient communication methods such as email, phone calls, and paper documentation. This digital discontinuity at modal interfaces undermines the efficiency gains achieved within individual transport modes and creates bottlenecks that discourage multimodal integration.

The challenge extends beyond technical incompatibility. Legacy systems across the logistics sector have been designed with mode-specific or organization-specific requirements in mind, rarely considering interoperability with external systems or alternative transport modes. Even where digital platforms exist, such as Port Community Systems (PCS), their influence typically diminishes beyond the immediate operational ecosystem, leaving multimodal transitions dependent on manual data translation and re-entry. This fragmentation not only increases operational costs and delays but also limits visibility across the supply chain, hindering optimization and sustainability efforts.

Addressing these interoperability challenges requires more than incremental improvements to individual systems. It demands a fundamental examination of whether semantic and syntactic compatibility can be achieved between established data models from different transport modes. If successful, such harmonization could enable seamless data exchange across modal boundaries, transforming fragmented transport networks into integrated, efficient multimodal corridors. This approach aligns with broader European initiatives such as the Digital

Europe Programme and the European Green Deal, which recognize standardized digital infrastructure as essential for achieving sustainable, efficient logistics.

This paper investigates the practical feasibility of achieving data model compatibility between TIC4.0 and IATA ONE Record through empirical case study analysis. Specifically, we examine two distinct multimodal transport scenarios within the European context: seaport-to-airport cargo movements in Greece and seaport-to-urban-subway distribution in Spain. Through detailed analysis of operational requirements, stakeholder needs, and data exchange patterns at modal interfaces, we evaluate the extent to which these established data models can be harmonized to support seamless multimodal operations.

Our research addresses two fundamental questions: First, can semantic and syntactic data interoperability be achieved in multimodal freight transport contexts? Second, to what extent can existing, well-established data models like TIC4.0 and ONE Record be harmonized to facilitate practical multimodal logistics operations? By answering these questions through real-world implementation and validation, this study contributes empirical evidence to advance multimodal transport standardization and demonstrates a pathway toward more integrated, sustainable European freight systems.

2. COMPATIBILITY FRAMEWORK

2.1. Overview of the Compatibility Framework

The compatibility between TIC4.0 and IATA ONE Record data models represents a practical solution to one of the most persistent challenges in multimodal logistics: enabling seamless data exchange across transport modes without requiring stakeholders to abandon their existing systems. Rather than imposing a single universal standard, the approach creates a translation layer that allows different data models to communicate effectively while maintaining their core structures and functionalities.

2.2. Understanding the Two Data Models

TIC4.0 Data Model Architecture

The TIC4.0 data model was designed specifically for standardizing port and maritime terminal operations. Its architecture follows a sentence-like structure that combines multiple elements to create unambiguous, machine-readable statements about logistics operations.

Each data statement in TIC4.0 consists of six key components:

- Header Information provides the contextual framework, including origin, destination, timestamp, and unique reference identifiers that enable traceability across the logistics chain.
- Subject identifies the entity executing or embodying the concept being described. In port operations, this might be a terminal, quay, vessel, or specific equipment.
- Concept defines what action or state the subject is performing or experiencing. This could include operations like loading, unloading, moving, or storing cargo.
- Observed Property specifies what aspect is being measured or reported, such as quantity, volume, weight, time duration, or counter values.
- Point of Measurement clarifies when or where the observation occurs, distinguishing between planned, actual, or forecasted values.
- Value contains the actual measured result in appropriate units (TEUs, tons, cubic meters, etc.).

For example, a typical TIC4.0 statement might read: terminal.quay.cycle.move_and_unloading.counter.actual.output.teu: 458.548. This clearly communicates that at the terminal's quay, during a loading/unloading cycle, the actual output counter measured 458.548 TEUs.

This structured approach ensures that anyone or any system interpreting the data understands exactly what was measured, where, when, and by whom, eliminating ambiguity that often plagues logistics data exchange.

IATA ONE Record Data Model Architecture

ONE Record takes a fundamentally different architectural approach, built around four core principles that distinguish it from traditional cargo documentation systems.

- Piece-Centric Design: Unlike document-centric systems, ONE Record focuses on individual physical pieces of cargo. Each piece receives a unique digital identifier and becomes the primary unit of data organization. This shift enables granular tracking and management of cargo at the individual item level rather than at the shipment or document level.
- Physics-Oriented Structure: The model attempts to create a digital twin of physical cargo operations. Data objects represent real-world physical entities and their relationships, mirroring how cargo actually moves through the supply chain rather than how paperwork describes it.
- Single Source of Truth: Information remains with its authoritative source rather than being copied across multiple systems. When a freight forwarder updates shipment details, that information stays in their system, and other

stakeholders access it directly rather than maintaining separate copies. This approach ensures data integrity and eliminates synchronization issues.

- Data-First, Not Document-First: ONE Record organizes information as structured data objects rather than digital replicas of paper documents. The Air Waybill, for instance, becomes a collection of data fields that can be accessed programmatically rather than a scanned or digitized form.

The model employs "Logistics Objects" as its fundamental building blocks. These objects define specific types of cargo, shipments, organizations, locations, and events, along with their properties and relationships to other objects.

2.3. The Compatibility Challenge

The fundamental challenge in creating compatibility between these models stems from their different architectural philosophies. TIC4.0 uses a structured sentence format optimized for terminal operations and equipment management, while ONE Record uses object-oriented data structures optimized for cargo tracking and stakeholder coordination.

Additionally, each model was developed with mode-specific requirements. TIC4.0 emphasizes container handling, berth scheduling, and yard management relevant to maritime operations. ONE Record prioritizes airway bills, flight schedules, and cargo security requirements specific to aviation.

The practical consequence is that when cargo moves from a port using TIC4.0 to an airport using ONE Record, no native interoperability exists. A container's discharge from a vessel, recorded perfectly in TIC4.0 format, cannot be directly understood by an airport cargo management system expecting ONE Record format.

2.4. The Compatibility Solution: Semantic and Syntactic Alignment

Semantic Compatibility

Semantic compatibility addresses the question: "Do both models understand the same concepts, even if they express them differently?"

The compatibility analysis revealed substantial semantic overlap. Both models track cargo identity, location, quantity, stakeholder information, transportation equipment, and timing. A "shipment" in ONE Record corresponds conceptually to cargo movements tracked in TIC4.0. A "piece" in ONE Record aligns with container or package units in TIC4.0.

However, gaps exist. ONE Record includes aviation-specific concepts like Air Waybill numbers, flight details, and security screening requirements that have no direct equivalent in TIC4.0. Similarly, TIC4.0 includes maritime-specific concepts

like vessel IMO numbers, berth assignments, and tidal restrictions absent from ONE Record.

The solution involved creating a common semantic layer—essentially a shared glossary—that defines how concepts from one model map to concepts in the other. When TIC4.0 refers to "container discharge," the semantic layer translates this to relevant ONE Record objects representing cargo arrival and custody transfer.

Syntactic Compatibility

Syntactic compatibility addresses the question: "Can both models exchange data in formats each can process?"

TIC4.0's sentence structure differs fundamentally from ONE Record's object notation. A TIC4.0 statement like terminal.gate.in.truck.identification.actual: TRUCK-12345 needs translation into ONE Record's object structure where truck identification appears as a property of a TransportMeans object.

The solution involved creating translation algorithms that parse TIC4.0 statements, extract their semantic components, and reconstruct them as ONE Record objects, and vice versa. This translation preserves meaning while adapting format.

2.5. Extending TIC4.0 for Multimodal Coverage

Analysis of the case studies revealed that TIC4.0 required extensions to fully support multimodal operations, particularly for air transport integration.

Aviation-Specific Extensions

New fields were added to TIC4.0 to accommodate aviation requirements:

Air Waybill (AWB) Integration: TIC4.0 was extended to include AWB numbers and related aviation documentation fields. This allows port systems to track cargo that will continue via air transport and associate it with the correct air shipment documentation.

- Flight Information: Fields for flight numbers, departure times, arrival times, and airport codes were incorporated, enabling port systems to coordinate with flight schedules.
- Aviation Security Requirements: Fields for security screening status, restricted goods declarations, and customs clearance specific to aviation were added.
- Aircraft Loading Parameters: Information about cargo dimensions, weight distribution, and loading constraints relevant to aircraft were included.

These extensions maintained TIC4.0's core structure while expanding its vocabulary to speak meaningfully about air transport operations.

Handling Cargo Disaggregation

A significant challenge emerged in Case Study 2 (Spain), where maritime containers arriving at the port were deconsolidated into individual parcels for urban distribution via subway.

TIC4.0 was originally designed for indivisible shipping containers—large standardized units moving as single pieces. The subway distribution scenario required tracking hundreds of individual parcels derived from a single container.

The solution involved creating new object types within TIC4.0 to represent parcels as child objects of containers. Each parcel inherited certain properties from its parent container (origin, initial shipper, customs status) while maintaining its own unique properties (final destination, recipient, dimensions).

This hierarchical structure enabled tracking cargo transformations: a container arriving at the port could be digitally "unpacked" into constituent parcels, each maintaining its data lineage back to the original maritime shipment while gaining new properties relevant to urban distribution.

Additional parameters were incorporated for sustainability tracking, including greenhouse gas emissions calculations and cost allocations at the parcel level, supporting the project's environmental objectives.

2.6. Validation

Case Study 1: Greece Seaport-Airport Operations

The compatibility layer was first validated in Greece, where containerized cargo moves from Piraeus port to Athens International Airport. The test focused on "Gate In" and "Gate Out" procedures—critical handover points where custody transfers between port and airport operations.

When a truck carrying a container cleared the port gate, the port system generated TIC4.0-formatted data including container number, Bill of Lading reference, truck identification, exit timestamp, and destination. The compatibility layer translated this into ONE Record format, creating appropriate Logistics Objects for the piece (container), transport means (truck), and logistics events (gate out, in-transit to airport).

At the airport gate, receiving systems using ONE Record can immediately access this information, cross-reference the Air Waybill number (which had been added to the TIC4.0 data during translation), and update the shipment status without manual data entry.

Case Study 2: Spain Seaport-Subway Urban Distribution

The Spanish case presented greater complexity, involving vessels, trucks, mini-vans, and subway cars in a last-mile urban distribution scenario. Cargo moved from Valencia port to warehouses for deconsolidation, then to subway depots, and finally to urban lockers.

The Port Community System (PCS) managed data exchange effectively within the port environment, but its influence diminished beyond port boundaries. The subway operator lacked cargo management systems and coordinated with logistics partners through informal channels.

The TIC4.0 compatibility layer was implemented to create a unified data pool. As containers arrived at the port, data was captured in TIC4.0 format. At the warehouse, when containers were deconsolidated, the system created parcel objects as described earlier. Each parcel received its own identifier while maintaining linkage to the original container and maritime shipment.

As parcels moved through subsequent stages—loading into vans, transfer to subway depots, loading into subway cars, delivery to lockers—each event can be captured in TIC4.0 format and made accessible to all stakeholders. The subway operator, despite having no sophisticated cargo system, could access a web interface showing parcel locations and statuses in real-time, all derived from TIC4.0-standardized data.

Environmental tracking proved particularly valuable. By standardizing how emissions and costs were calculated and reported at each stage, the project could demonstrate the sustainability benefits of subway-based urban distribution compared to conventional truck delivery.

2.7. Benefits Realized Through Compatibility

Operational Benefits

- Elimination of Manual Data Re-entry: Stakeholders no longer need to re-enter information when cargo crossed modal boundaries. Data flowed automatically through the compatibility layer.
- Improved Visibility: All parties can gain -time access to cargo status across the entire multimodal chain, not just within their own operational domain.
- Reduced Communication Overhead: The volume of phone calls, emails, and paper documentation decreases substantially as systems could query each other directly for needed information.

- Faster Exception Resolution: When problems occur (delays, missing cargo, documentation errors), all stakeholders could see the same data simultaneously, accelerating diagnosis and resolution.

Strategic Benefits

- Proof of Concept for Standardization: The successful compatibility demonstration proved that different data models can work together without requiring wholesale replacement of existing systems—a critical consideration given the massive installed base of legacy systems in logistics.
- Scalability Framework: The approach provides a template for extending compatibility to additional modes (rail, road) and additional interfaces, gradually building a comprehensive multimodal data ecosystem.
- Foundation for Advanced Analytics: Standardized, consistent data across the entire logistics chain enables sophisticated analytics, machine learning applications, and optimization algorithms that were previously impossible with fragmented data.
- Support for Sustainability Goals: Comprehensive data standardization enables accurate measurement and reporting of environmental impacts across multimodal chains, supporting EU climate objectives.

Limitations and Ongoing Challenges

While the compatibility demonstration succeeded, several limitations require acknowledgment.

- Incomplete Automation: Some data fields, particularly those unique to specific modes, still require manual input or validation. Full automation depends on all systems implementing necessary extensions.
- Legacy System Integration: The compatibility layer assumes systems can export and import data programmatically. Many older legacy systems lack this capability, requiring additional middleware or manual intervention.
- Governance and Maintenance: Maintaining the semantic mappings and translation rules requires ongoing governance as both TIC4.0 and ONE Record evolve. Without sustained coordination, compatibility could degrade over time.
- Partial Deployment Benefits: The value of standardization increases exponentially with network effects. Compatibility between port and airport systems provides limited benefits if the connecting road transport, warehousing, and other intermediary steps remain non-standardized.

Future Development Directions

The successful compatibility demonstration opens several avenues for future development.

- Extension to Additional Modes: The methodology can be applied to integrate rail (using UIC standards) and road transport (using eCMR and eFTI frameworks), progressively building comprehensive multimodal coverage.
- Enhanced Real-Time Capabilities: Current implementations focus on transactional data exchange. Future versions could incorporate streaming data for real-time equipment tracking, dynamic routing, and predictive analytics.
- Blockchain Integration: Distributed ledger technology could enhance trust and transparency in multimodal data sharing, particularly for customs, security, and financial transactions.
- AI-Powered Optimization: Standardized data enables machine learning algorithms to optimize multimodal routing, mode selection, and resource allocation across the entire logistics chain.
- Policy and Regulatory Alignment: As technical compatibility advances, regulatory frameworks (customs, security, liability) must evolve to support seamless multimodal operations, an area requiring continued attention.

2.8. Conclusions

The TIC4.0 and ONE Record compatibility framework demonstrates that semantic and syntactic interoperability across transport modes is not only theoretically possible but practically achievable. By creating translation layers that respect the integrity of existing systems while enabling data exchange, the approach offers a pragmatic path toward multimodal standardization without requiring disruptive system replacements.

The real-world validation in Greek and Spanish case studies proves the concept works under operational conditions, delivering tangible benefits to stakeholders while supporting broader EU objectives for sustainable, efficient logistics. As the framework extends to additional modes and interfaces, it promises to transform fragmented transport networks into truly integrated multimodal systems.