DIGITAL INTEROPERABILITY AND THE COST OF ORGANISATIONAL FRAGMENTATION: A COMPARATIVE FRAMEWORK FOR EUROPEAN PORT ECOSYSTEMS

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Study purpose
This study examines how digital interoperability and Port Digital Twins can reduce the economic costs generated by fragmented information and coordination processes in European port ecosystems, focusing on labour frictions, operational inefficiencies and cross-organisational integration.

Relevance / originality
The paper moves beyond technology adoption and digital maturity by economically interpreting organisational fragmentation at ecosystem level. Its originality lies in linking interoperability, transaction costs and port ecosystem governance through a comparative framework applicable to shared digital infrastructures.

Methodology / approach
An exploratory comparative analysis of Rotterdam, Hamburg, Antwerp-Bruges, Valencia and Trieste combines an Interoperability Adoption Index with a Cost of Fragmentation indicator. Five interoperability dimensions are scored and compared with harmonised scenario estimates of labour and operational inefficiencies.

Main results
Higher interoperability is consistently associated with lower estimated fragmentation costs. Ports above the operational threshold record average costs of EUR 4.00 per traffic unit, compared with EUR 8.30 below the threshold, indicating a descriptive difference of approximately 52 per cent.

Theoretical / methodological contributions
The study conceptualises interoperability as a collective organisational capability and Digital Twins as ecosystem coordination infrastructure. Methodologically, it introduces the dual IAI-CoF framework, connecting digital integration with measurable labour and operational costs and generating a testable interoperability-threshold proposition.

Social / management contributions
The framework helps port authorities, terminal operators and policymakers prioritise interoperability investments that reduce manual coordination, waiting and re-planning It also supports shared standards, inclusive data governance and participation by smaller actors, strengthening efficiency, accountability and collective value creation across port ecosystems

Keywords: Digital Twin, Interoperability, port ecosystem, coordination costs, Innovation