THE COST-BENEFIT ANALYSIS OF DIGITAL TIMESTAMPING IN MARITIME LOGISTICS: THE CASE OF AIKATIETO

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This study evaluates the costs and benefits of a digital timestamping service implemented in Finland for commercial maritime traffic. Using qualitative interviews and procurement document analysis, we examine its impact on various stakeholders, including ports, ship operators, and regulators. Our findings reveal that while the service's acquisition cost was relatively modest, the total cost across the stakeholder network was approximately ten times higher due to connected investments required to fully leverage the service. Benefits clustered around three primary areas: improved coordination among maritime stakeholders, enhanced data quality, and better system integration. Unforeseen consequences include a shift in balance between participants and ancillary actors. The study provides insights for cost-benefit analysis methodologies for public digital infrastructure investments by making positive network effects visible for multiple stakeholders.

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1 Introduction

Maritime logistics is a dynamic and interconnected domain involving a wide range of stakeholders whose activities must be closely coordinated. With the increasing adoption of digital technologies, the sector is seeing advancements in smart navigation, efficient port operations, and proactive infrastructure management (LVM, 2020; Tijan et al., 2021; Paulauskas et al., 2021; Heikkilä et al., 2022; 2024). One critical enabler of these improvements is the availability of reliable and precise Estimated Time of Arrival (ETA) data for vessels, which plays a central role in planning and operational efficiency (Elbert & Walter, 2014; Arbabkhah et al., 2024). However, conventional ETA records provided by ships are often inaccurate, limiting their usefulness for berth scheduling and real-time coordination at ports (Yoon et al., 2023).

Despite the clear need for improved ETA information, individual actors are often reluctant to invest, as the benefits appear too marginal at the individual level - resulting in a collective action problem. In Finland, this was addressed by Fintraffic Vessel Traffic Services Ltd (VTS), which launched the Aikatieto service to provide centralized, high-quality ETA estimates to Finnish ports.

Public investments in digital infrastructure, like Aikatieto, are difficult to evaluate using traditional cost-benefit analysis (CBA) methods. Benefits tend to be long-term, indirect, and spread across multiple stakeholders, often beyond the initial investors (Heikkilä et al., 2018; Korpela & Mäkitalo, 2008). In networked sectors such as maritime logistics, these limitations become particularly pronounced.

This paper examines Aikatieto as a case study to explore its implementation, costs, benefits, and the distribution of value across stakeholders. It addresses two key research questions:

1. What are the direct and indirect costs and benefits of the Aikatieto service, and how are they distributed among stakeholders?
2. What improvements are needed in public investment evaluation methods to better reflect the characteristics of networked digital infrastructure?

By analyzing this case, we aim to inform public authorities, researchers, and industry stakeholders on how to design, justify, and assess similar investments.

2 Public Investment Evaluation

Public investment evaluations, particularly in digital infrastructure, face growing criticism for relying on traditional methodologies like cost-benefit analysis (CBA), which often fail to capture the complex, dynamic, and networked nature of digital systems. Lau (2007) observes that CBA and similar tools typically emphasize short-term, quantifiable benefits, overlooking indirect, qualitative, and long-term public value outcomes that are critical for digital government initiatives. Hüging et al. (2014) argue that public officials often struggle with the monetization of intangible externalities, particularly when evaluating small-scale yet innovative urban infrastructure initiatives. Heikkilä et al. (2018) similarly argue that conventional evaluation models overlook network effects and dynamic feedback loops in digital ecosystems. Benefits in a digital infrastructure context tend to diffuse across many stakeholders making it hard for a single actor's CBA to reflect the collective and long-term value.

A deeper understanding of the underlying challenges is provided by classics of economic theory. Building on Coase (1937), Williamson (1985) proposed Transaction Costs Economics (TCE) detailing how governance structures - especially in high-uncertainty or asset-specific environments - can economize on transaction costs through tailored institutional arrangements; While simple, low-specificity transactions can be governed by markets through prices and competition, highly specialized investments and uncertain future contingencies require adaptive governance structures that facilitate renegotiation and trust-building. Hart's (1995) theory of incomplete contracts further reinforces the inadequacy of traditional evaluation tools. It asserts that contracts cannot specify all future outcomes in complex projects, particularly those involving innovation. Thus, governance models should allocate control rights and establish flexible decision-making frameworks to respond to unforeseen developments. Complementing this, Elinor Ostrom's (1990) research emphasizes the importance of adaptive rules and collective decision-making.

These insights are especially applicable in public investments in digital infrastructure, where rapid technological change and evolving policy landscapes make rigid, ex ante performance evaluations ineffective. Therefore, Frydlinger et al. (2019) propose formal *relational contracting* to manage the uncertainty and complexity inherent in large-scale digital projects. Rather than specifying rigid outputs, these contracts focus on shared principles, collaborative processes, and mechanisms for renegotiation. Still, in the EU, public procurement is highly regulated with requirements for neutrality and transparency (VM, 2023). Traditional procurement procedures - like requiring fixed specifications and competitive tendering - can clash with the iterative, co-development practices often necessary for digital infrastructure projects. Also, Finland's processes for public information management investments follow government requirements, though these have been criticized for being vague and overly focused on data safety and security rather than architectural compliance with related services and supporting innovation. Recognizing this, recent EU reforms have introduced mechanisms like the Innovation Partnership and pre-commercial procurement (EC, 2021) to better support experimentation and long-term value creation. Nevertheless, challenges remain, including administrative burden, fragmented governance across EU and national levels, and limited flexibility for novel solutions (VM, 2023).

To understand these governance challenges in practice, we conducted an in-depth empirical investigation of the Aikatieto case. This case allows us to explore how costs and benefits of digital infrastructure investments are distributed across a network of stakeholders, and whether current evaluation and procurement models are adequate in capturing these dynamics.

3 Methodology

This case study (Yin, 2018) employed a mixed-methods approach to analyse the Aikatieto service, combining document analysis with qualitative interviews. We selected this approach to gain a comprehensive understanding of both the formal agreements and expectations surrounding the service and the experiences of stakeholders using the system. Our data collection process involved three primary methods:

1. Document Analysis: The team, consisting of all authors of this paper, examined non-public procurement documents, contracts, and proofs of concepts related to the Aikatieto service. This included reviewing the original tendering documentation, service specifications, and formal evaluation criteria. These documents and discussions with the person responsible for the tendering process provided insights into the formal expectations and requirements for the service.
2. Semi-structured Interviews: Team conducted site visits and face-to-face interviews with key stakeholders at five Finnish ports as well as the service vendor (Table 1). Ports were selected to represent a range of sizes, geographical locations, and use of Aikatieto. The interviews lasted between one and two hours and explored topics including service usage, benefits, costs, and implementation challenges.
3. Follow-up Validation: Interviewees validated the interview transcripts, ensuring accuracy and completeness of our analysis. The results of the analysis were presented to VTS.

Table 1: Interview Participants

Port	Interviewees	Port Size
HA	Harbor Master	Medium
UU	Managing Director, Traffic Manager	Small to
KO	Harbor Master, Development Manager	Large
HE	IT Manager, Traffic Manager	Large
HK	Deputy Manager	Large
Service provider	Service Manager, Director	N/A

All interviews were recorded, transcribed, and analysed using NVivo and Excel. Our analytical process was as follows: **Coding**: To ensure inter-rater reliability, two researchers coded the interview transcripts in NVivo to identify key themes related to costs, benefits, implementation challenges, and stakeholder relationships. After the initial round, the team compared coding results and discussed discrepancies to reach consensus (Barbour, 2014). This iterative process led to the refinement of our coding categories and ensured a consistent interpretation of key themes. **Thematic Analysis**: The team identified recurring themes and patterns across the interviews. **Cost-Benefit Mapping**: The team first conducted a cross-tabulation of stakeholder groups and associated benefits in Excel to visualize how value was distributed across the network. Based on this analysis, the first author then created a graphical

sociogram showing the expressed value of the asssociated stakeholders to each other.

To enhance the reliability and validity of our findings, we used methodological triangulation by combining document analysis with qualitative interviews. We validated interview transcripts through follow-up communications with participants and maintained transparency in our analytical process by documenting coding decisions systematically. Investigator triangulation - where multiple researchers independently analysed the data - helped minimize individual bias and enhanced the credibility of the findings (Archibald, 2016). This collaborative approach not only allowed confirmation of interpretations but also encouraged the integration of diverse perspectives, enriching the overall analysis (Cornish et al., 2013).

4 Findings

In Finland, VTS procured the Aikatieto service, which provides improved estimates of vessel arrival times by utilising machine learning algorithms that enhance ETA predictions.

4.1 The Aikatieto Service procurement process

The roots of Aikatieto originate from 2018 when the VTS examined the status of maritime logistics information sharing in Finland. **A working group** of stakeholders, established in 2019, identified potential for improvement in maritime information sharing, particularly regarding ETA information: 41,000 port calls from 2018 were analysed, finding that estimated time of arrival (ETA) deviated from actual arrival time (ATA) by an average of 33 minutes, with greater variations in tramp shipping compared to regular liner traffic. Following this analysis, **a pilot** was conducted at one Finnish port in 2020. Four individuals piloted a simple SMS-message service providing ETA data for two weeks. **Additional validation** was conducted in meetings with the port authority and the stevedoring company in 2021. Background **interviews** were conducted with maritime actors including icebreakers, pilots, and traffic coordinators to establish expected impacts (Pitkänen et al., 2021).

After successful piloting, VTS proceeded to **a public tendering** phase in 2021. An international tendering was conducted in two rounds, with eight competing offers in the final round. The ETA and timestamp data was to be redistributed by VTS at no additional cost to Finnish public authorities and the National Maritime Single Window (MSW) environment, as well as to port operators and their partners, who rely on ETA data for scheduling and coordination. While certain technical and service requirements were mandatory and established the minimum eligibility threshold, the final selection was primarily driven by price competitiveness (70%). Qualitative criteria - such as proposed added functionalities, implementation approach, and service continuity - accounted for the remaining 30%.

The contract was awarded to a company, that had participated in the working group and had already worked several years on a machine learning based ETA predictions. They delivered the service within one month of being selected. This service aggregates data from multiple sources to provide improved estimates of vessel arrival and departure times. Data sources include AIS (Automatic Identification System), port call predictions and realization, meteorological predictions and observations, and other maritime information on environment, cargo and traffic patterns. It is designed to be accessed either through an API interface (to be integrated with current port call and logistics systems) or as a Port Activity service, also available on mobile. The service adheres to relevant standards including the Port Call Optimization Task Force's Port Information Manual, the IALA S-211 Port Call standard, and The International PortCDM Council recommendations.

4.2 Costs and Investments

The costs associated with Aikatieto fell into three distinct categories: a) *Out-of-pocket costs:* Direct investment by VTS plus ongoing operation and maintenance costs (approximately 45% of initial per annum) b) *Project management costs:* Transaction costs of managing change across the stakeholder network, estimated at approximately €70,000 including staff time, travel, and preparation costs. c) *Connected investments:* The most significant category, representing vested investments made by stakeholders to fully leverage the service. These varied widely across ports (from €70,000 to €462,000) and were approximately ten times the direct investment in the service itself. This substantial ratio highlights the networked nature of benefits and

the need for complementary investments across the stakeholder ecosystem to fully realize the potential of such services.

4.3 Impacts of Aikatieto in ports

In Finland, there are approximately 50 ports, with 16 handling freight volumes exceeding 1 million tons. Based on feedback gathered by VTS in the spring of 2023, 12 of these major ports responded, and all of them were using Aikatieto and considered the service either useful or very useful.

However, our in-depth interviews revealed variations in how ports use the service highlighting the importance of flexibility in digital infrastructure design to accommodate different organizational needs and technical environments. It also demonstrates that the value of such services is perceived differently across organizations, influencing their willingness to invest in full integration. Table 2 shows the usage patterns, and an example of benefit charts can be found in the Appendix.

Table 2: Aikatieto Usage in Interviewed Ports

Port	Access	Integration Level	ETA Source	Improved by ETA data
Ha	API interface	High - Fully integrated into port's own system	System-generated dead reckoning ETA	Berth planning, operations scheduling, personnel alerts.
Uu	Port app (web & mobile)	Medium - alongside existing systems	Dead reckoning ETA, pilotage estimated	Berth planning, automated invoicing, transport scheduling, personnel alerts, geofencing.
Ko	Port app (web & mobile)	High - Used actively in existing systems	Dead reckoning ETA	Berth planning, Port-wide coordination, Staff coordination, real-time updates, optimized arrival times
He	Not using Aikatieto	None.	Port net system	Trucking companies complain that they don't get good enough ETA.
HK	Not using Aikatieto	A port activity system being developed	Marine Traffic AIS	Seeks a system to recommend optimized arrival times, not just ETA tracking

The two largest interviewed ports did not use Aikatieto, as it is not included in their current port activity systems. However, these systems are now outdated, and they are investing in new ones. For the others, the benefits of Aikatieto clustered around three primary areas: improved coordination, enhanced timestamp data quality, and system integration benefits.

Improved Coordination: Direct beneficiaries include ports, ground transport operators, vessels, and service providers. Ports gain advantages in better berth utilization planning and avoiding operational failures by sharing information: *"There is less confusion than before, which is why I do not get urgent phone calls as I used to before."* Ground transport operators benefit from real-time coordination of their activities with the needs of arriving cargo and types of vessels. Ship operators, (i.e., vessels) can improve their route planning and coordination with smoother operations at harbour entry. Service providers such as bunkering and waste management companies have better situational awareness and improved planning capabilities. As one port noted: *"We see problems earlier, so we can solve them before they happen. If certain types of vessels arrive at the same time, we can warn them that 'this is not a good time to come' and suggest alternatives."*

Indirect beneficiaries including pilots, icebreakers, tugboats, and linesmen can have significant improvements as well. Pilots gain from enhanced route planning and coordination capabilities. Icebreakers gain better situational awareness for their assistance operations. Tugboats benefit from improved service prioritization. Linesmen can have better work-life balance due to the improved predictability of vessel movements.

Improved Timestamp Data: The more precise timestamp information provides substantial benefits across stakeholder groups. Ports mentioned improved billing accuracy, better berth planning, enhanced vessel monitoring, and more optimized operations. They can also cut costs: "*with reliable ETA data, we can avoid calling in extra crew unnecessarily*". Vessels benefit from smoother operations and reduced fuel consumption due to better planning capabilities. Agents' situational awareness improves, and costs are optimised through reduced unnecessary waiting times. Linesmen gain better planning and resource allocation tools: "*We created an alert system so that when the vessel enters a specific area, personnel get a notification 1–2 hours before they need to be at the port.*"

System Integration: The integration of Aikatieto with existing systems provides several technological and operational benefits. Organizations reported more efficient billing processes through automation: *"Before, invoicing required a lot of manual labour. We had to check shipping information manually and input it into our invoicing system. Now, it's automatically there."* Berth planning becomes more data-driven and responsive. Information sharing across platforms improves significantly, leading to reduced manual data entry and fewer communication errors. The automated information exchange reduces the workload associated with monitoring vessel movements and updating stakeholders' situational awareness.

4.4 Beneficiaries and their changing relationships

An important finding from our study was the complex network of beneficiaries and their relationships in the Aikatieto ecosystem. Figure 1 illustrates the key stakeholder groups and their connections, highlighting how Aikatieto has changed the relationships between parties by disintermediating some connections while concentrating or reinforcing others. Orange ovals illustrate that the new entrant Aikatieto and improved connection with the vessels was controversial among stakeholders despite the benefits, and while green ovals show that the ports and pilots were perceived positively thanks to more precise estimates and integration to the overall service network.

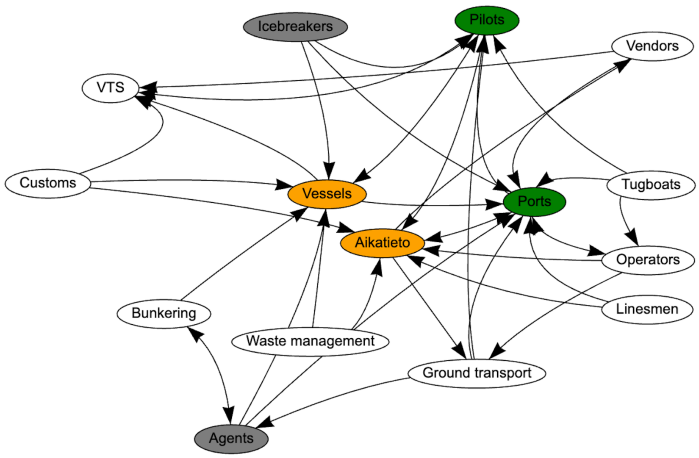

Figure 1: Beneficiaries Sociogram

The sociogram evidences the centrality of cooperation between vessels, pilots, ports, and the Aikatieto service. However, the agents' connection with other parties has become less critical and their relative position weakened (grey oval) when compared to the other parties. Ice-breaking services are still called for aid in the traditional manner – they were not part of Aikatieto design, which illustrates some planning integration problems in the operations.

5 Limitations of Current Public Investment and Procurement Approaches in Networked Digital Infrastructure

Our analysis identified several significant weaknesses in current public investment methods and procurement processes when applied to digital infrastructure projects in networked environments such as maritime logistics: The prioritization of digitalization projects is often based on *vague, quasi-economic criteria* that fail to capture the full range of benefits and costs across the stakeholder network. Comparison of alternatives becomes particularly difficult because typical methods cannot adequately identify *interdependencies* between necessary projects and investments. Investment models should explicitly account for complementary investments required by various stakeholders, not just the direct investment. Our finding that connected investments were approximately ten times the direct investment underscores the importance of this networked perspective.

Another limitation is the failure to consider *diffusion patterns* in benefit accrual. Current methods often assume immediate deployment and benefit realization, whereas in reality, benefits accrue gradually as adoption spreads across the network. This over-optimism can distort investment calculations. Additionally, *architectural priorities* such as compliance with initiatives like the European Maritime Single Window (MSW) and various interoperability requirements should be given sufficient weight in the prioritization process.

The current investment methods also inadequately account for different *development methodologies*. The increasing use of mixed development approaches - combining component-based, continuous integration and continuous delivery (CI/CD), agile, and waterfall systems development life cycles - requires different evaluation frameworks, yet these approaches are often treated uniformly in investment decisions. Furthermore, developing *open interfaces* for future uses is demanding and

requires cooperation between partners, stakeholders, and vendors, along with vested investments that may not be properly accounted for in initial evaluations, emphasizing the need for previous remedies.

Software procurement models add yet another layer of complexity. Whether the software is acquired as turnkey, Software as a Service (SaaS), or Platform as a Service (PaaS) requires different approaches to data governance and intellectual property agreements, as well as different ex-ante and ex-post risk management strategies and incentives between vendors and public agencies. These distinctions are rarely addressed adequately in current investment methods – even though they may make fundamental differences in intellectual property, updates and maintenance of the service.

Despite these challenges, our findings emphasize the growing importance of public investment in digital infrastructure for maritime logistics. Three factors illustrate this:

1. Capacity Preservation: Digitalization enables better utilization of existing capacity, preserving the status quo without requiring substantial physical infrastructure investment. As one port noted: *"With reliable ETA data we have been able to squeeze in more vessels in our schedule"*
2. Technology Affordability: Public investment has effectively utilized IT vendors' product development, maintaining affordable price levels that individual stakeholders might not have been able to achieve independently.
3. Coordination Benefits: The ability to leverage benefits in coordinating, planning, and operating ports across a network provides substantial value that would be difficult to achieve through uncoordinated individual investments.

The Aikatieto case also demonstrates how such digital infrastructure can catalyse broader shifts in business and operational models, extending value beyond the initial implementation context.

6 Conclusions

The Aikatieto case demonstrates both the potential and challenges of public investments in digital infrastructure for maritime logistics. While the direct investment was modest, the total investment across the stakeholder network was substantially higher -ten times the direct investment - demonstrating the networked nature of costs and benefits, and how traditional cost-benefit analyses fundamentally underestimate the true economic impact of such initiatives. This finding has significant implications for how such investments should be evaluated and managed. Second, the implementation reconfigured the maritime ecosystem's power dynamics and information flows—strengthening relationships between vessels, ports, and pilots while diminishing agents' centrality—highlighting how digital infrastructure can reshape industry structures beyond its intended operational improvements. Finally, it seems that conventional evaluation methods fail to adequately capture interdependencies, diffusion patterns, and architectural considerations that are essential for successful deployment in complex stakeholder networks.

These findings contribute to both transaction cost economics and incomplete contracts theory by demonstrating how digital infrastructure investments can reduce coordination costs across organizational boundaries while requiring flexible governance frameworks that accommodate evolving stakeholder needs. For policymakers and practitioners, our results suggest that evaluation models for digital maritime infrastructure should explicitly account for complementary investments, stakeholder network effects, and long-term architectural implications.

This study is not without limitations. It is based on a single case within the Finnish maritime logistics sector, which may limit generalizability. The qualitative nature of our data, while rich in detail, constrains the scope for quantitative validation. Furthermore, our analysis focused on one phase of implementation; future research could investigate the evolution of benefits and stakeholder dynamics over time. Comparative studies across different countries would help identify contextual factors that that influence the results.

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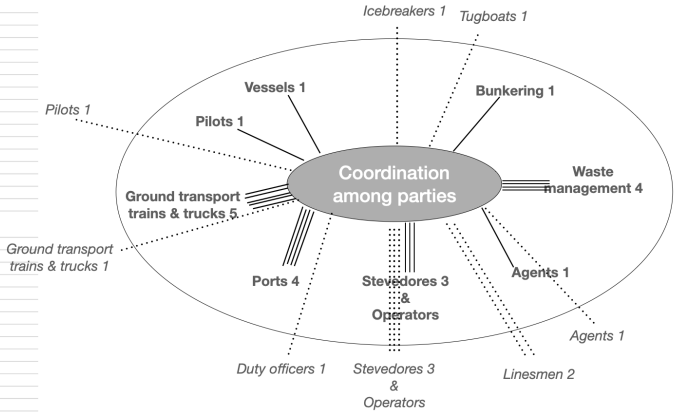
Appendix 1:

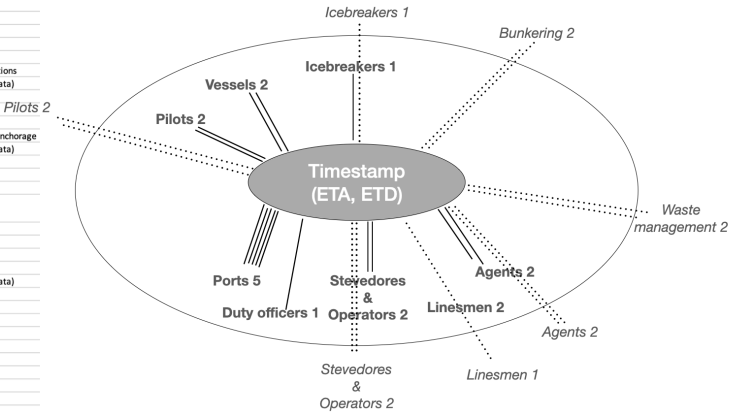
Direct and *indirect* beneficiaries of better coordination

Direct beneficiaries of Coordination	
Ports	MRO in tool ports
	Berth planning
	Avoiding messes
Ground transport Trai	Just-In-Time -coordination
	Fleet management
Vessels	Route planning and coordination
	Smooth operations
	Optimizing fuel and harbour costs
	Better information on available berths
Bunkering	Security and safety
Waste management	Timing, organisation of work
	Planning
Agents	Situational awareness
	Exception handling
	Optimizing costs
Stevedores and Operators	Better Service
	Optimising the resources
	Time management
	Just-In-Time -coordination
Indirect beneficiaries of Coordination	
Transportation	Time and traffic management
Pilots	Planning
	Exception handling
Icebreakers	Situational awareness
	Route planning and coordination
Tugboats	Planning and management
Agents	Real-time information
	Resource handling and management
	Better service on time
Linesmen	Better worklife
Stevedores & Operators	Better service
	Resource handling and management
Duty Officers	Planning
	Human resources management
	Resources and time management



Direct and *indirect* beneficiaries of improved timestamp data

Direct beneficiaries of improved timestamp data	
Ports	Billing
	MRO in tool ports
	Berth planning
	Avoiding messes
	Operational planning, optimized operations
	Saving time (no need to search other data)
Vessels	Smoother operations
	Optimizing fuel and harbour costs
Linesmen	Balance working and free-time
	Managing and preparing the tools for anchorage
	Saving time (no need to search other data)
Agents	Situational awareness
	Exception handling
	Optimizing costs
Stevedores and Operators	Just-In-Time -coordination
Icebreakers	Route planning and coordination
Tugboats	Requests for service on time
Duty Officers	Planning and managing
	Organising and implementing
Linesmen	Saving time (no need to search other data)
Indirect beneficiaries of improved timestamp data	
Waste management	Capacity planning and contracting
Pilots	Planning
	Exception handling
Icebreakers	Planning and route management
Bunkering	Better service
	Resouce planning and management
Agents	Real-time information
	Resource handling and management
	Better service on time
Linesmen	Just-in-time on duty
	Better worklife
Stevedores and Operators	Better service
	Resource handling and management



Direct and *indirect* beneficiaries of increasing systems integration

Direct beneficiaries of System Integration	
Ports	Billing
	MRO in tool ports
	Berth planning
	Operational Planning
	Information sharing
	Avoiding messes
Vessels	Smoother operations
	Optimizing fuel and harbour costs
Icebreaking	Route planning and coordination
	Information sharing
Tugboats	Requests for service on time
Waste management	Timing
	Planning
Agents	Situational awareness
	Exception handling
Stevedors & Operators	Planning and resource management
	Energy Saving
Linesmen	Better worklife
Indirect beneficiaries of System Integration	
Pilots	Planning
	Exception handling
Tugboats	Planning
Customs	Correct ETA
Waste management	Capacity planning and contracting
Bunkering	Better service
	Resource planning and management
Agents	Information sharing
	Correct ETA