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Enabling multimodal intelligent transport systems: It is time for surf-n-turf

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Abstract

Fuelled by the *Internet of Things* concept, *Industry 4.0* adds AI-enabled automation, robotics, and 5G telecommunications. *Shipping 4.0* and *Logistics 4.0* have emerged as part of Smart Shipping and related multimodal supply chain initiatives. Roughly 90% of global trade involves port-to-port maritime transport, but the need for supply chain agility has led to a recent focus on creating efficient, integrated, multimodal *door-to-door* supply chains. National and regional service-oriented Intelligent Transport System (ITS) frameworks have been used with success for road and rail applications, but the maritime component has largely been missing. Extending these *practical* ITS frameworks with a Maritime ITS (MITS) component could cover *smart* inland and transoceanic shipping, support the specification of Multimodal ITS (MMITS) supply chains with ports as central hubs, enable interoperability, and include mechanisms to better integrate standards-based data models.

Keywords: system engineering and architecture • IoT • Maritime ITS • Multimodal supply chain

Introduction

Inspired by Industry 4.0, smart shipping or Shipping 4.0 is closely related to Logistics 4.0 that incorporates artificial intelligence, extreme connectivity, robotics, and automation technologies to help create highly efficient and agile multimodal supply chains (MSC) [1,2]. Smart Shipping has four principal objectives: 1) increase maritime transport efficiency, 2) improve maritime safety and security, 3) protect the environment, and 4) enable cost-effective, highly efficient MSC. Over the last three decades, Intelligent Transport Systems (ITS) for on-road networks have been developed and deployed worldwide using ITS Reference Architectures (ITS-RA) as architecture frameworks. To date, a similar approach using an ITS-RA for Maritime ITS (MITS) has been relatively unexplored.

Background

In North America, the United States (US) Department of Transportation (USDOT) Architecture Reference for Cooperative and Intelligent Transportation [1] (ARC-IT), and the National ITS Architecture for Canada[2] have been developed conjointly and provide a set of tools for describing business processes and value chains at different levels of abstraction including functionality,

[1] https://local.iteris.com/arc-it/html/architecture/architecture.html

[2] https://www.tac-atc.ca/en/itsarchitecture

system-level physical objects, service packages, information flows, and data communication interfaces. They have been used to derive regional ITS concepts such as the City of Saskatoon ITS Strategic Plan [3] as well as in various USDOT Connected Vehicle (CV) pilot projects[3]. They have also been used to help develop comprehensive regional ITS architectures such as the Spokane Washington Region ITS Architecture that includes Concept of Operations (CONOPS) with detailed functional requirements specifications [4].

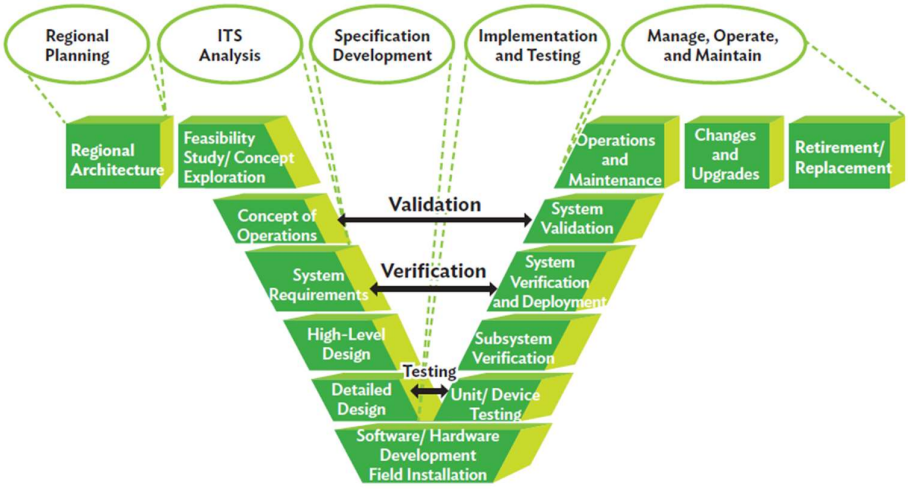

Figure 1: Systems Engineering Vee Diagram for Intelligent Transport Systems, from [7]

ITS Reference versus Regional Architectures

ITS architectures can be described on different levels of abstraction [5] with the main purpose of ensuring interoperability across a system of systems, including information exchange agreements among stakeholders. ITS-RA vary in scope (municipal to multinational), in mode coverage (single or multiple), and in level of abstraction (concept exploration or detailed analysis). The high level of abstraction of the European FRAME architecture [6] is well-suited for specifying implementation approaches, and deployment strategies, but does not focus on detailed system requirements. Conversely, ARC-IT is low-level and can produce detailed system requirements specifications. ITS analysis activities are explicitly defined in the Systems Engineering v-model in the USDOT Systems Engineering for ITS (SE-ITS) Guide[4], shown in Figure 1, as depicted by Jaffe [7].

ITS Interoperability

Intramodal versus Intermodal Interoperability

Intramodal interoperability: Typically, the focus of most ITS initiatives like connected ITS (C-ITS) [8] is on communication between vehicles, and between vehicles with roadside infrastructure, to achieve a more integrated and cooperative traffic system.

Intermodal interoperability: Focus is on interoperability between modes (e.g., efficient intermodal transfer of cargo and/or passengers). For cargo transport, *multimodal* typically implies intermodal

[3] https://www.its.dot.gov/presentations/trb_2020/CVP_TRB2020.pdf
[4] https://ops.fhwa.dot.gov/publications/seitsguide/

transport under a single contract of carriage. In general, this is a relatively complicated legal matter, often including cross-border clearances. In the maritime sector, there is a need for both an intramodal and intermodal transport. Intermodal transport is important for the competitiveness of maritime transport: Transhipment costs, hinterland connectivity and cross-border clearance are all major cost and complexity factors for ships [9].

Levels of Interoperability

There are three basic levels of interoperability: organizational interoperability at the enterprise level, syntactic and semantic interoperability at the system level, and technical interoperability at the network and transport level [10]. For complex safety-critical systems of systems, a political context at the government level, as specified by the US SE-ITS, is deemed a fundamental need for an overarching transport strategy [6]. Interoperability strategies for MSC should at least cover the basic three levels but focus on system interoperability.

ITS Services

The ARC-IT and ITS Architecture for Canada are ITS-RA that propose an extensive set of standards-based service packages[5], including commercial vehicle operations, data management, maintenance and construction, parking management, public safety, public transportation, support, sustainable travel, traffic management, traveller information, vehicle safety, and weather. Each service package includes descriptions of the business processes goals and objectives, associated systems or "physical objects", system requirements, information flows, data interfaces, security concerns, and applicable standards[6]. The ARC-IT[7] framework, which are also used by the ITS Architecture for Canada and FRAME, defines four service-oriented views:

- Enterprise view - Describes the relationships between organizations and the roles those organizations play.
- Functional view - Describes abstract functional elements (processes) and their logical interactions (data flows) that satisfy the system requirements.
- Physical view - Describes physical objects (systems and devices) and their functional objects and interfaces.
- Communications view - Describes the layered sets of communications protocols among the physical objects.

Interoperability, modularity, and reference models

Interoperability, at the system level, is the capability of multiple systems to successfully interact to achieve a common goal or objective. Modularity is a decomposition of system functionality into components so that they can be easily modified or replaced. Modularity is an enabler for interoperability during the design phase and during system updates. Common reference data models

[5] See, for example: https://www.itscanada.ca/it/architecture/itsarchv3/servicepackages/index.html
[6] See, for example: https://local.iteris.com/arc-it/html/servicepackages/sp168.html#tab-5
[7] https://local.iteris.com/arc-it/html/viewpoints/viewpoints.html

for specific domains are also interoperability enablers that can direct component design. However, universal, monolithic reference models should be avoided for use in complex systems of systems. These systems involve a large and diverse group of stakeholders and diverging information exchange requirements can lead to problems such as incompatibilities and misalignments. It is preferable to use a modular, federated reference model approach [11].

Several international regulatory bodies and standardization organizations including United Nations commissions, international trade and commerce organizations, and the International Maritime Organization (IMO) have advocated for increased digitalization of the maritime sector to increase the efficiency and resilience of the maritime supply chain. Central in this is the development of the IMO Reference Data Model that includes definitions for ship-to-ship communications, fairways and port approaches, ship services, ship operations, clearances, port operations and port services [12].

Maritime and Multimodal Transport Domain

Road versus Maritime

Maritime transport is cost-effective and has little competition in the long-distance hauling of heavy and bulk goods. For shorter distances, ships are losing market share to road transport. The EU Transport White Paper target from 2011 [13] was that 30% of road freight over 300 km should shift to rail or waterborne transport by 2030. So far, this goal seems to be failing, as from 1995 to 2016, the share of road transport in intra-EU ton-km increased from 45% to 49%, whereas the share of short sea shipping dropped from 33% to 32% (see Figure 2) and inland from 4.3% to 4.2%. In the same period, total freight increased with 29% (ton-km) [14].

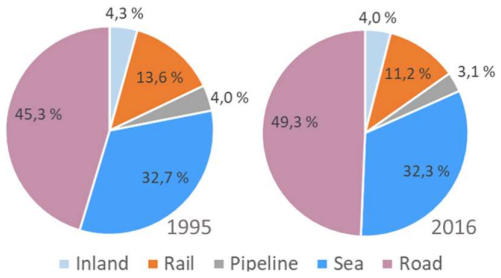

Figure 2: Share of transport work in EU

Public/Private Transport Systems – Who pays for infrastructure?

Transport systems can be both public and private endeavours. This varies by mode and by region. Road networks tend to be public, although there has been a trend toward privatization of road networks in North America and Europe [125]. In North American rail networks, freight traffic systems are owned and operated by private freight operators and tends to be separate from passenger operations. In Europe, freight and passenger traffic share the same public rail network resulting in lower operating costs compared to North America [16]. Another problem is lower investments in infrastructure for waterborne than for roads. For example, in Norway, 47% ton-miles of cargo transport is by sea, but planned public investments in sea transport infrastructure is only 3.5% of the total [17]. This may be explained by the population's higher demand for good roads. This often results in "hidden" subsidies for commercial on-road transport. Maritime transport systems are largely privately owned and operated. In North American, port authorities are primarily public or quasi-government. In Europe, 87% of port authorities are essentially landlords under public ownership with about 50% operating as commercial entities [18]. In contrast, private sector terminal operators are

key actors in maritime shipping. In summary, maritime transport operations involves more private sector actors than road transport.

Transport Policy and Planning

The public or private nature of the different transport modes influences transport policy and planning decisions. Transport policy, such as Transport Canada's Strategic Gateways and Trade Corridors initiative[8], is defined by governments, and considers economic growth initiatives, environmental protection plans, regulatory frameworks, and other priorities. Transport planning tends to deal with the implementation of actions to solve specific problems and is performed by public and/or private sector actors. Although there are geographic variations, generally national governments provide maritime infrastructure and the regulatory framework while the private sector assumes the provisions and operates the terminals and vessels [19]. The private and international aspects of maritime transport create a challenge for national policy makers since private firms serving global markets will quite naturally set their own policy agenda. As described below, this situation has led to an *interoperability void* across a diverse body of stakeholders, representing a major challenge for global smart shipping initiatives.

Transport Efficiency

Maritime transport is international in nature, accounting for about 90% of global trade and has the lowest relative cost of all the modes (see Table 1). However, port-to-port transport is often not sufficient to move goods from source to destination. As a result, additional legs using other modes are required. Generally, the last leg of the supply chain is the least efficient and can account for up to 28% of the total cost of delivery [20]. Last-mile logistics mainly use road transport and often targets urban areas. The transfer of goods during intermodal maritime-to-road transports has a significant impact on overall efficiency. Improving the planning and coordination of transfers is an area where ITS frameworks may be particularly useful.

Table 1: Performance by mode

Mode	Rel. cost	Emissions
Airplane	83	560
Modern truck	35	45
Modern train	3	18
Modern ship	3	3

Environmental concerns and ecological impact

The transport sector worldwide accounts for about 27% of total greenhouse gas (GHG) emissions in Europe in 2017, with 5% attributed to international shipping [21]. As shown in Table 1 (grammes CO_2 emitted per ton-km transport), large ships emit 6 times less CO_2 than rail, 15 times less than trucks, and nearly 200 times less than planes. IMO has targeted CO_2 emission reductions of 40% by 2030 and 50% by 2050, compared to 2008 levels [21]. In addition to new fuel types and improved ship designs, one way to achieve significant reductions in ship emissions, also for existing ships, is to improve the operational efficiency of shipping activities. This can be done by increasing vessel capacity utilization,

[8] https://tc.canada.ca/en/corporate-services/policies/gateways-corridors

reducing port access delays and idle times, and streamlining intermodal transfer of goods. The latter is highly dependent on better ship-to-shore connectivity and integration as well as increased digitalization onboard vessels. These are key areas of MITS. They potentially offer additional gains by improving the coordination of last-mile logistics. These aspects could all be supported and promoted by using a standardized Maritime ITS-RA.

Maritime Safety and Security

International maritime trade is a critical part of our modern society, as evidenced by the COVID-19 pandemic during which ships continued to supply vital cargo, food and raw materials across the globe. The well-being of seafarers, and the safety and security of ships and port are increasingly dependent on an international and interoperable digital infrastructure. Although this is not the main subject of this paper, it is a compelling argument for a further attention in future MITS extensions to ITS-RA.

Ports: The Core of MITS and MSC

Ships transport cargo from port to port, but ports are generally not the place of production or consumption. Ships are dependent on ports, transhipment, and hinterland transport from source to destination. But additional transport adds delays, costs, and paperwork. Improved connectivity and increased digitalization of information across transport modes can reduce the impact of these drawbacks.

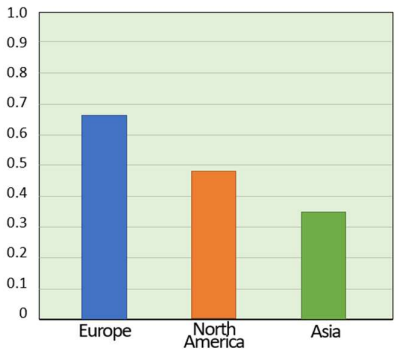

Figure 3: Smart port index, derived from [22]

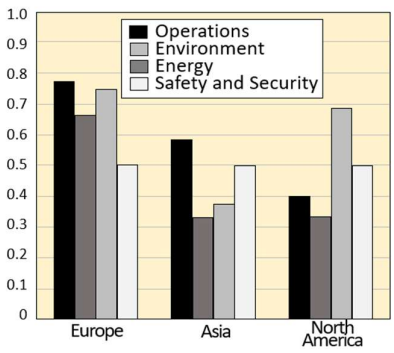

Figure 4: Smart port sub-index, derived from [22]

Smart Ports

The efficiency of port operations not only contributes to maximizing throughput and minimizing turnaround times, but also has environmental impacts when energy use is decreased. These are the key motivations behind Smart Port initiatives. Molavi et al. propose a Smart Port based on data from 14 ports: 7 from Asian (including 2 from the Middle East), 3 from Europe, and 4 from North America [22]. They devised an overall index and sub-indexes for operations efficiency, environment impact, energy consumption and safety and security. Figure 3 shows that North America is behind Europe but ahead of Asia in terms of the overall smart port index, but Figure 4 shows North America being behind both Europe and Asia in terms of efficiency of operations. North America is only slightly behind Europe in terms of environmental impact. Europe is leading most sub-indexes except for safety and security which were reported as equal by the study. Asia accounts for about 2/3 of world container port

throughput. Europe accounts for 4 times less with 1/6 of the world throughput, while North America accounts for 1/12 of the world throughput.

Inland ports

In Europe, inland ports are losing market share to road-based transport. In North America, the inland ports represent an essential part of the economy. The Saint-Lawrence Seaway and Great Lakes System is a key supply chain and accounted for 30% of the combined Canadian and US economic activity and employment in 2017[9]. Schilk et al. suggested the use of ITS technologies for establishing River Information Services to improve the efficiency of inland operations through better information-sharing [243]. One challenge sited is that of expanding the ITS services to benefit a wider user base including more private sector entities from the logistics and MSC industries. This highlights the importance of also including inland ship operations in the MSC frameworks.

ITS for Enabling Multimodal Supply Chains

Intermodal and multimodal transport is associated with a door-to-door distribution of goods and can be broken down into three segments: pre-haul, long-haul and post-haul. Ships are normally used for long-haul transport. Pre- and post-haul are often done by road, and accounts for between 25-40% of the total transport cost [Error! Reference source not found.4]. Thus, effective interfaces between MITS and road ITS are needed. The ARC-IT framework includes a module for port operations and has started to address requirements for an MITS extension[10]. The European FRAME ITS-RA has added a set of service packages for freight and fleet management and has identified the need for multimodal transport interfaces. Regardless of whether ITS-RA are used to specify emerging MSC ecosystems, it has become clear that national interoperability strategies are required to define information sharing approaches that ensure the smooth flow of cargo and goods. In June 2021, ITS Canada kicked-off a Technical Committee on Maritime Shipping and Multimodal Supply Chains (MMSC)[11] to facilitate the development of a national MMSC interoperability strategy and define requirements for digital information sharing architectures and infrastructure. Likewise in Norway, a new project will start in August 2021, led by ITS Norway, to develop a MITS extension to Norway's ITS architecture[12].

Preparing for Maritime Autonomous Surface Ships and Connected Vehicles

As there are currently several connected vehicles pilot projects in the US, and as the level of autonomy of maritime autonomous surface ships (MASS) increases in the coming years, it will be necessary to establish a seamless transfer of freight from MASS to autonomous CV networks. Today this may seem like a lofty goal, but it is a reminder of how much work remains in connecting the maritime and ground transport modes.

[9] https://greatlakes-seaway.com/en/the-seaway/
[10] https://www.pcb.its.dot.gov/t3/s190502/s190502_ITS_ePrimer_Port_Operations_presentation.pdf
[11] https://www.itscanada.ca/about/technical_committees/maritime-multimodal-supply-chain-tc/index.html
[12] https://its-norway.no/en/arrangementer/maritime-its-and-mobility-is-there-a-nordic-way/

Conclusions

Improving the efficiency and resilience of global MSC has become a priority for many nations. This presents several challenges within the maritime shipping ecosystem, at the intermodal connection points (i.e., the ports), and in the coordination across a streamlined MSC. One of the biggest challenges so far seems to be that of reuniting a large group of public and private sector stakeholders that represent the interests of the different transport and logistic sectors, regulatory agencies, and service providers.

ITS-RA are frameworks that were developed with this problem in mind and could be useful in guiding the definition of interoperability strategies and/or specifying regional and national digital information sharing infrastructures. Up to now, most ITS-RA have been developed and used to plan and specify road infrastructure and applications. In general, ITS for maritime transport has not been a major consideration even though maritime transport is vital in international and many regional trades. There is an opportunity to explore the development of ITS-RA extensions for the maritime domain, i.e., MITS, to support both intercontinental, short-sea, and inland shipping, and to specify intermodal transfer and MSC ecosystems. Port operations are at the core of both maritime and multimodal transport. Work is also required to engage with maritime transport stakeholders such as port authorities, terminal and vessel operators, and captains and pilots to collect the needed international and regional requirements for these MITS and MMITS extensions. This process also helps inform stakeholder of the potential benefits of adapting and using the ITS-RA to help flush out the ITS requirements, plan for smart shipping infrastructure deployment, establish new and/or enhanced standardized information exchange mechanisms, and achieve GHG emissions reduction targets through green vessel propulsion technologies. Additional reductions are also possible using ITS to shorten port times, maximize container loading / off-loading, and more efficient cargo transitioning from ship to ground-based transport modes.

Considering the possibility that the maritime shipping and logistics communities may not wish to adapt ITS-RA to specify their business processes and interoperability strategies, there is also a possibility to develop MITS and MSC extensions to existing ITS-RA that specify well-defined services and interfaces that other communities can include for use in their own frameworks or system architectures.

It is recommended that MITS extensions to the ITS-RA focus on ship-to-shore information exchanges with consideration for the emerging IMO Reference Data Model. The goal is to enable the ports as hubs for multimodal transport. A single reference model may not be sufficient and a modular, federated approach using multiple reference models that promotes interoperability may prove the best approach. Finally, the ITS-RA development process can be used to facilitate feasibility studies, for developing CONOPS and for specifying requirements.

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