Port Collaborative Decision Making –
Closing the Loop in Sea Traffic Management

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Abstract

The intermodal points of any transport chain are crucial for its overall efficiency. Sea Traffic Management (STM), and its sub-concept Port Collaborative Decision Making (PortCDM), can play a vital role in improving the overall efficiency of the maritime transport chain. Inspired by a similar concept applied for collaborative decision making within and between airports, PortCDM is a way of establishing not only a common view of all available information, but using this information as a tool to create a common situational awareness supporting the involved actors to make more efficient collective decisions. We show in detail how this would work for better planning of arrival and departure times, how the port would interact with vessels in order to optimize the port approach. As a consequence arriving vessels can adjust their speed and thus arrive just-in-time. Savings on fuel consumption and lower emissions are obvious benefits. For the vessels and the port, higher predictability will yield efficiency based on integrated performance. PortCDM not only makes the processes in one port more efficient but also how the information will help other ports on a vessel's voyage. By making the operations berth-to-berth as predictable as possible by multiple updates, ports will gain in efficiency on the inbound and outbound. By continuously sharing more accurate Estimated Time of Arrivals (ETAs), planners of shore transport are greatly supported.

1. Background

STM is concerned with increasing efficiency in operations within and between ports. This can can be achieved by maximizing the utilization of the facilities in ports and minimizing the use of energy to steam between two ports, constrained by safety considerations. It has been estimated that the bunker cost to steam between two port constitute between 35-70 % of a voyage's total cost, *Stopford (2009), Wigforss (2012)*. From a port gate-to-gate perspective, the actual sea voyage is estimated at 27% of the full cost, Fig. 1, *Anderson and Wincoop (2004)*.

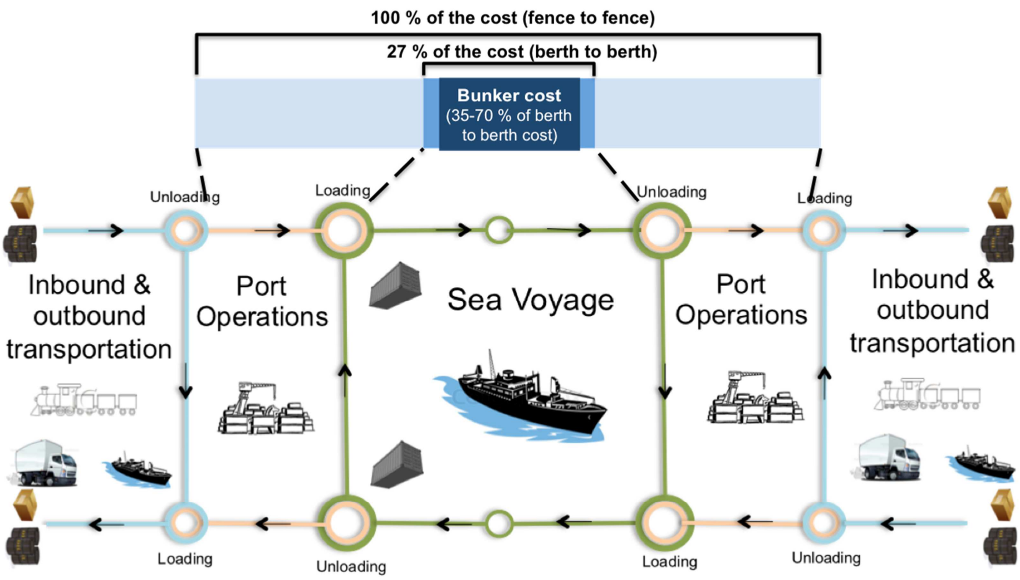

Fig. 1: Cost distribution of sea transport

Consequently, the main concerns of STM are four-fold:

- Provide a basis for right routing, resulting shorter voyages and thus optimize the use of energy.
- Synchronize the port approach between vessel arrival and port readiness enabling green steaming in the latter stage of a voyage.
- Enable a fast turn-around process by giving a port's various service providers the information to permit just-in-time operations.
- Synchronize the processes related to departing and arriving vessels and port readiness.

Overall, STM will contribute to environmental sustainability, operational efficiency, and high safety during sea transports. In order to ensure environmentally sustainable solutions, green steaming is preferred when appropriate. It requires a high degree of predictability in approaches to and departures from ports to enable just-in-time operations. In terms of operational efficiency, affected stakeholders, such as, shipping companies, vessel operators, towage companies, pilot organizations, terminals and the port, need to coordinate closely to execute each step of a sea voyage.

Coordination requires that the destination port communicates its resource availabilities to approaching vessels and matches this with the vessel's needs. Such an integrative approach would close the loop in STM, expanding and acknowledging the need to interact with the port of destination to enable efficient and sustainable sea operations. Due to the non-uniformity of ports operations, an unresolved quest is what to communicate and how digital collaboration could be established, inside the port, and in relation to other actors. STM enable ports to subscribe to information about upcoming port calls. A port call message should be initiated automatically as soon as the port of destination is decided by the shipping company and entered into the vessel's navigation system by the captain.

The ability to predict accurately times for when diverse operations should occur in port approaches is difficult due to numerous actors involved and the lack of situational awareness. It should also be emphasized that the willingness to share information to some parties is low due to the market characteristics of maritime transports. Sharing data might create a competitive disadvantage.

PortCDM enables the port to be efficient in its operations, and at the same time as shipping companies are given good basis for optimizing sea voyages by, as early as possible, coming to an agreement with the port of when to arrive. In the realization of STM, the integration with ports is vital. Thus each vessel needs to clearly communicate its intentions and needs as soon as feasible so the port as a complete picture of future resource demand and can plan accordingly.

Physically, a port approach is initiated by a vessel reaching the traffic area outside the port and concluded by a vessel's departure from the same after fulfilling the purpose of its visit. During a port approach, there are numerous actors engaged in enabling an efficient, seamless, and smooth approach. This requires providing sufficient data for potential and engaged actors to plan and optimize their operations. Given all these requirements, a port approach needs to be initiated long time before the vessel's physical approach to the port. An unresolved question is, however, how information about intentions, needs and changes, well in advance of the port approach, can be shared among engaged actors. Today there are numerous systems that partly enable such objectives, as e.g. Single Window, Port Control Systems, Port Community Systems. None of these, however, provides a common approach to real-time sharing of information and the building of situational awareness as the foundation for distributed coordination.

Even if the number of port approaches has decreased due to increased capacity of individual vessels, many approaches are performed without a reliable measure of when a vessel can leave the berth, and this often cause delays for new arrivals to the berth. This leads to escalated delays in the port planning operation. In order to increase the predictability of the estimated time to berth (all fast) for a certain port approach a special concern is, among other aspects, when the former vessel occupying the berth can leave and give room for the next approaching vessel. It has been acknowledged that the ETA (to the traffic area/port limits) for a vessel most times corresponds with the actual time of arrival. The problem many times centres on the inability to predict when the berth is available for the vessel to make berth.

One essential need is, therefore, that the diverse actors engaged in a port approach share information about different states (e.g., estimated time of arrival, desires of when a certain state is to be reached, commitments related to certain terms of condition, and the changes of the different states that has occurred). Inspired by the aviation industry (airport CDM), http://www.euro-cdm.org, this collaborative approach to information sharing and decision-making has been coined PortCDM (Port Collaborative Decision Making).

There are several similarities between airport and (sea) PortCDM, including:

- Airport and (Sea) Port Collaborative Decision Making (CDM) aim at improving Traffic Flow and Capacity Management by reducing delays, improving the predictability of events and optimizing the utilization of resources.
- Airport/PortCDM allows Airport/(Sea)PortCDM Partners to make the right decisions in collaboration with other Airport/(Sea)PortCDM Partners, knowing their preferences and constraints and the actual and predicted situation.
- The decision making by the Airport/(Sea)PortCDM Partners is facilitated by the sharing of accurate and timely information and by adapted procedures, mechanisms and tools.

Airport CDM concept upon collaboration between different airports with management by a centralized organizational body (Eurocontrol). This principle is however readily adaptable to the maritime sector because operations are more distributed and the presence of competing autonomous agents. (Sea)PortCDM does thus needs develop a distributed coordinating structure that recognizes and responds to market forces. It cannot apply Airport CDM's hierarchal approach.

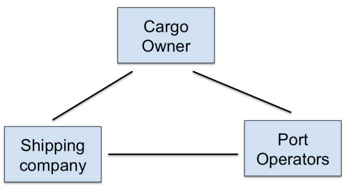

Fig. 2: The inseparable trinity in sea transports

Ports do not exist in isolation. Without any shipping companies ports and cargo owners (transport buyers) have no reason to exist. The same goes for shipping companies – they depend on cargo owners and port operators. For the purpose of defining Sea Traffic Management within MONALISA 2.0, this phenomenon of stakeholder/actor relationships has been coined an inseparable trinity, Fig. 2. The purpose with this paper is to elaborate on the goals and constituents of PortCDM.

2. Port operations of today

Deficiencies and new roles undertaken by ports clearly points highlights that port call processes need to be coordinated and operatively handled in a optimal way – both during planning and in the realization as well as the evaluation of conducted port calls. In this section, the different role and assignment a port can undertake are elaborated. We make the case for digitized solutions to enhance situational awareness and to provide a basis for the coordination functions that a port can facilitate.

In this paper, a port call is defined as the activities performed prior, during, and after the (physical) turn-around process, Fig. 3. A port call process is initiated when the port is informed for the first time, about a vessel steaming to the port. Thus, port calls are information-wise initiated well before the actual physical approach.

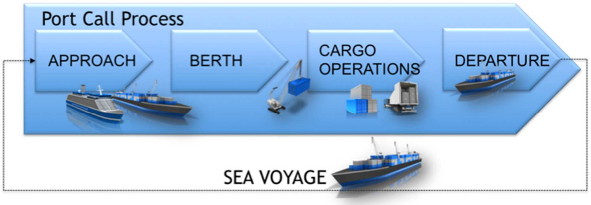

Fig. 3: The scope of the port call process

2.1 The current business situation

The coordination of port approaches is highly fragmented since involved port actors historically have tried to get access to and retain control of information that is of value to them for their optimization goals. This does mean that port approaches are uncoordinated; but as information about intentions, desires, commitment, and outcomes is not shared coordination is challenging.

For Europe, maritime transport has been a catalyst of economic development and prosperity throughout its history. Europe's ports are vital gateways, linking its transport corridors to the rest of the world. Some 74% of goods entering or leaving Europe go by sea, and Europe hosts some of the finest port facilities in the world. Ports also play a crucial role both in the exchange of goods within the internal market and in linking peripheral and island areas with the mainland (European Commission).

Nowadays different generations of ports can be identified depending on their modernization, specialization, and handling capacity levels. The United Nations Conference on Trade and Development (UNCTAD) identifies four different generations of ports according to these three parameters:

- First-generation ports offering basic port services to vessels by generic port terminals and generic handling means.
- Second-generation ports specializing in operations related to different type of cargo (containers, ro-ro, liquid bulk, solid bulk).
- Third-generation ports enlarging their service scope to transform into effective logistics platforms for trade beyond the port boundary.
- Fourth-generation ports characterized by diversification and internationalization of their activities, automation of operations, strong cooperation between the port community and complementary ports in view to increase its competitive advantages and to support transformation into a networked port, perfectly integrated in the logistics chain and in global supply chains where the handling and distribution of information is a cornerstone.

These divisions give rise to different kinds of organization regarding a port approach and different information flows, which mean that the functionality and features of associated information systems may differ significantly from port to port. To understand these differences and to optimally coordinate the port call, PortCDM must accommodate this diverse environment. .

2.2 The current institutional situation

The European Commission defines a Port Authority as, “the entity which, whether or not in conjunction with other activities, has as its objective under national law or regulation the administration and management of the port infrastructures, and the co-ordination and control of the activities of the different operators present in the port”, *SeaPorts (2010).*

However we can find different types of port authorities depending on their size, the kind of traffic they manage, their political, social and geographical environment, their main objective, the way they approach their functions, and the role and strategies they adopt. All these factors will influence directly the way port authorities approach ICT and e-maritime solutions. Port authorities traditionally have assumed three functions, *SeaPorts (2010)*: landlord, regulator and operator, but nowadays this concept has evolved in light of socioeconomic changes and strategic challenges.

- The landlord function consists on the management, maintenance and provision of infrastructure and facilities as well as the conception and implementation of policies and strategies. The landlord function can be considered as a fundamental function of contemporary port authorities. This role is subject to important changes due to important influencing factors such as competitive pressure for investments, financial pressure, and the competition for land-use.
- The regulator function mainly focusing on control, surveillance, and policy to ensure safe and secure cargo operations.
- The operator function provides different types of services such as the physical transfer of goods and passengers between sea and land, technical-nautical services (such as pilotage, towage and mooring), and ancillary services (provision of water, provision of electricity, waste disposal or warehousing and logistics services).

Thus, the former operator function has given way to landlord and regulatory functions that have gained a strong community focus leading ports to a new community manager function. This new function lies in coordinating private and public port community members to solve problems and develop efficient operations inside and outside the port with a global door-to-door corridor or supply chain perspective.

2.3 The current operational situation

A port call has many actors. Thus there is a need for coordination on a level beyond the single actor. Today, because of a lack of data sharing, it is hard to foresee when a port approach will occur. It is a great challenge to predict when a vessel might depart from a berth and thereby give space for a new approaching vessel. Data indicate that the expected departure time from a berth deviates highly among the different actors who provide a departure forecast. This could, for example, caused by very late assignments on additional services, such as a change of lubrication oil or bunker operations. The challenge is thus to overcome this low ability to predict state changes leading to poor coordination of port activities (arrival, activities at berth, and departure).

Besides some pre-defined interaction patterns, which information should be communicated to who and at what time is unclear. Actors do not share the same definition of measures to be used. For example, they might vary in their of definition of a vessel's state or change of state. Reasons for this lack of precision include:

- Diverse systems with closed and proprietary solutions for information management
- Operators' guesses based on multiple information sources on which, and when, approaches will be conducted
- The ability of each operator's to plan for needed capacity (short- and long-term) is low.

Consequently, there is a need to communicate accurate estimates on when a certain state will be reached, such as vessels' approach to the traffic area, and the transmission of another signal when the state is reached. Different actors have a need for an overview of current and coming events of the port and their status.

In the current situation there are numerous states that are reached during a port approach, Fig. 9. Many states are intermediary points for reaching a high accuracy on actual time of berth (ATB), i.e. ALL FAST, and Actual Time of Departure (ATD), ALL LOOSE. Fig. 4 shows some typical processes and some typical states for reaching the state of All Fast (ATB).

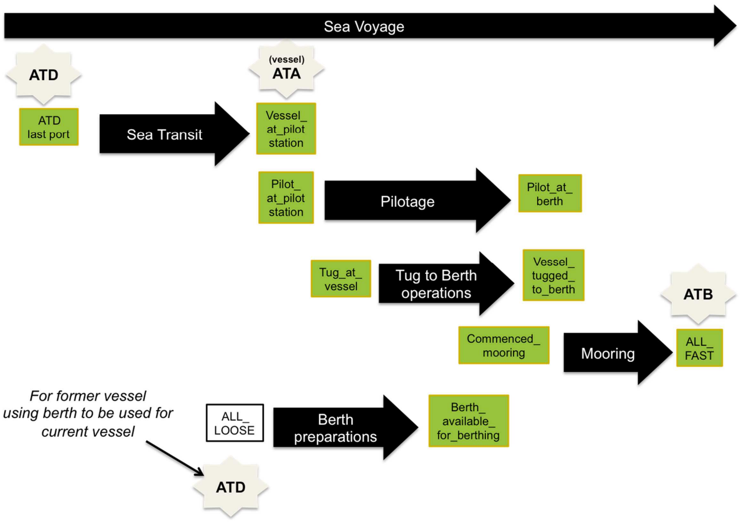

Fig. 4: Typical processes and states to reach during a port call with its basis in the port-to-port process

2. PortCDM as a key enabler for integrating Sea Transport in the inter-modal transport chain

2.1 Objectives and its scope with PortCDM

Ports are departure and arrival hubs for different means of transportation requiring a coordinated approach, addressing the goals of the transport system as a whole, with smooth and seamless operations at sea, at port (reaching the port, departing from port, performing loading and unloading operations (and sometimes other maintenance and extraordinary administrative tasks)) as well as connections to hinterland transportation. Seamless and sustainable transports enabled by STM require an efficient and collaborative port. PortCDM has been identified as a key enabler for reaching the full effects of STM. The purpose of PortCDM is to provide a basis (processes, content etc.) for the collaboration, enabling decisions that are based on, and have consequences for others, between key actors within the port and between the port and its surroundings.

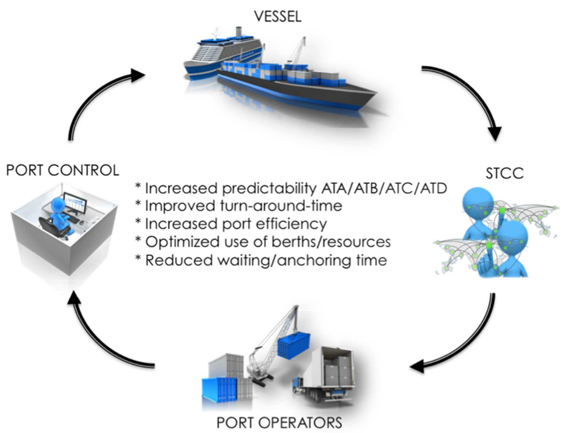

Fig. 5: Objectives on Port CDM - The efficient and collaborative port

The overall goal of PortCDM is to support just-in-time operations within ports and in relation to other actors being coordinated by the efficient and coordinated port, Fig. 5. PortCDM constitute the interface between sea operations and port operations within the STM concept. Essential boundary objects between sea and port, in the ship to shore interaction, are thus Estimated/Actual Time of Berth (ETB/ATB) and Estimated/Actual Time of Departure (ETD/ATD). ATB is defined as the time when the vessel is All Fast (at berth) and ATD as the time when the vessel is All Loose (from berth). Governance towards a high accuracy on ETB and ETD can support green or slow steaming as well as reducing unnecessary waiting times, which will reduce environmental impacts and increase financial returns. Examples of unnecessary waiting times are waiting for cargo operations and delays in leaving after cargo operations are completed. Enabling increased berth productivity should drive a port's decision making. A high predictability of ETB/ETD, optimal use of berths/resources, optimal turn-around time, and flexibility in the port approach planning are means for an high port efficiency and minimal waiting or anchoring times for shipping companies.

To summarize, the most important driver for PortCDM is high event timing accuracy, leading to, among other effects, optimal berth utilization. This would support increased berth productivity (by being ready to perform cargo operation as early as possible after ALL FAST and leaving from berth as soon as possible after the cargo operations and other actions that require the vessel at berth have been finished).

2.2. The Scope of PortCDM

PortCDM focuses on four collaborative arenas for enabling sustainable transports as a whole. These collaborative arenas are, Fig. 6:

1. Collaboration among actors operating within a port
2. Collaboration between port and actors on realizing sea voyages
3. Collaboration between port and actors realizing inbound & outbound transportation (besides sea voyages)
4. Collaboration among ports

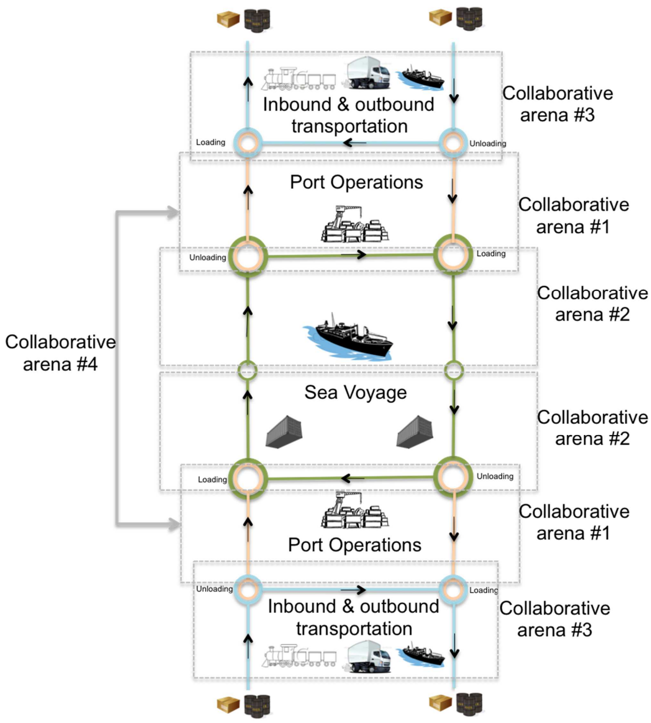

Fig. 6: Port CDM as enabler for integration in four collaborative arenas for inter-modal performance

Within each collaborative arena, PortCDM should support the development of efficient operations (e.g., integrating processes in the port (collaborative arena #1) so that the port is prepared for arriving vessels, creating conditions for efficient sea voyages (just-in-time arrival) (collaborative arena #2) etc.). PortCDM, as a common measurement, collaborative decision, and information sharing system would thus support the integration of different processes and permit each area of collaboration identified previously to operate highly efficiently, resulting in just-in-time operations within and between the collaborative arenas,. Such cooperation will advance efficiency in inter-modal transportation.

3. The basics components PortCDM

3.1 Common measures as coordination mechanisms and boundary objects

The overall aim is to reach agreement on the definition of key measures, Thus, ensuring that different actors are striving to reach a certain state (in time and place). This means that ports need to ensure that a port, and the actors involved in its activities, are prepared for incoming vessels and making port operations related to those vessels as efficient as possible (i.e. ensuring a fast and efficient turn-around process). The same goes for hinterland (inbound and outbound) transportation, which means that ports have dual, inter-linked, turn around processes. This requires coordination and planning the integration of the different operational processes within a port. Important coordination mechanisms for such planning, however, have their origins with actors operating outside the port, such as information about when the vessel is about to reach the port communicated well in advance of the physical approach.

3.2 Visualizing state of states for enabling coordination

PortCDM builds upon visualizing desired states to enable different operators to act in such a way that the port call (arrival, at berth and departure) can be performed as just-in-time as possible. The overall goal is that involved actors can trust the prediction of when a certain state will be reached and thereby can optimize their performance, in time (not too early, not too late) and by their optimal capacity. In PortCDM, so far, the interface to the port has been identified in relation to vessels' operations. This, among other effects, is to enable green and optimal steaming.

PortCDM builds upon the logic that communication about upcoming port approaches is made as soon as it is known and that changes are communicated as early as possible (both from the vessel's and from the port's point of view). The collaboration diagram, Fig. 7, points that as soon as an impending arrival is known by the receipt of a voyage order, it becomes possible for the port to initiate planning.

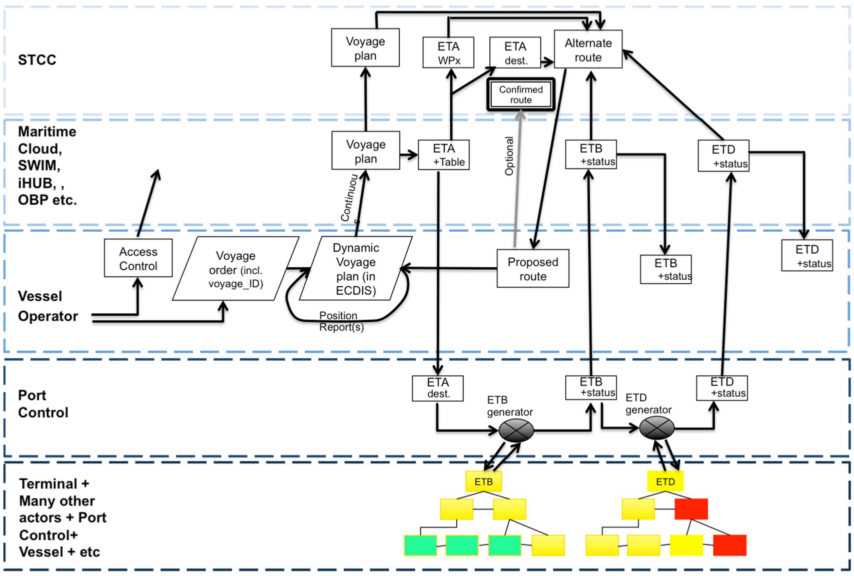

Fig. 7: Information exchanges during the port call

3.3 Matching estimates with actual times for an increased predictability

In order for a port to optimize its operations, it is essential to receive real time information of the status, together with updated estimates, of different operations/transports that are affecting the operations within the port. This means that the same measures functions both as coordination mechanism for optimizing port operations (and creating readiness for managing necessary loading/ unloading operations) and as boundary objects towards other actors outside the port for their optimization. These measures are at the core related to information being shared and the agreements being made within the collaborative arenas identified previously. The measures are used for giving estimates (such as ETB and ETD as two essential boundary objects), giving actual times of when certain states are reached, and as a basis for evaluation. Sharing information and supporting collaborative decision-making will require enabling technologies of different kinds, such as the maritime cloud, single window, SeaSWIM, e-navigational services, and various port community systems, *Lind et al. (2015)*.

The mean for reaching a high degree of predictability for a certain port approach is to strive towards a low deviation between the estimate (ETx) and the actual occurrence (ATx) (ETx – ATx should be as close to zero as possible). PortCDM is based on the actor's provision of estimates multiple times before the actual occurrence/state change. The resulting deviation represents the predictability (i.e., the ability for the port to predict) of the port as such, and represents a measure of how well the port performs in a synchronized transport chain (enabled by STM). This in turn would enable different actors to optimize their operations and the utilization of their physical infrastructure and variable resources (e.g. personnel).

3.4 State dependencies as the coordination mechanism for vessel and port operations

The design idea is built upon that, at the time of initiation of the sea voyage (by the voyage order and first tactical route planning), different ETAs (to waypoints and at the destination) are made available via SeaSWIM (as a representation of a common information sharing and service distribution environment), *Lind et al. (2015)*. The destination port subscribes to this information, puts this it into a port data cloud accessible for relevant actors, and sets up an instance of an ETB tree (with status objects that need to be green at the time of arrival to port) and an instance of an ETD tree for that voyage. A green status objects means that the necessary actions can be realized during the port approach. Preliminary ETB and ETD are generated by PortCDM information services forming the basis for other actors necessary to reach ETB and ETD to (potentially bid), agree, and plan for a successful realization. The status is continually fine-tuned based on the updates of a vessel's ETAs (via noon reports and arrival reports, or more frequently if appropriate) and other actors' desires and possibilities to perform operations related to a vessel's port approach. To ensure a minimal administrative burden in its introduction, a PortCDM system needs to be interfacing other existing systems to ensure one single point for reporting/providing intentions. This could be enabled by systematized structure of related principles of subscription between relevant systems, Fig. 8.

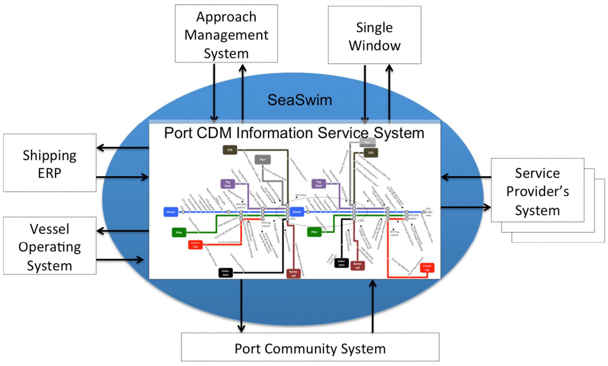

Fig. 8: Integration with Port information environment

Fig. 9 indicates that the different states are dependent on each other. Thus they should occur in parallel and in sequence for milestones to be reached smoothly. The different states depend also time-wise on each other, such as booking a pilot should be followed by the pilot's confirmation, or that a terminal needs to confirm when it is ready to receive a vessel at berth based on the vessels ETA.

Using states as coordination mechanisms for STM requires a commonality for the perception of and use of states as information exchanges. For this purpose a common nomenclature for the definition and the description of states has been developed.

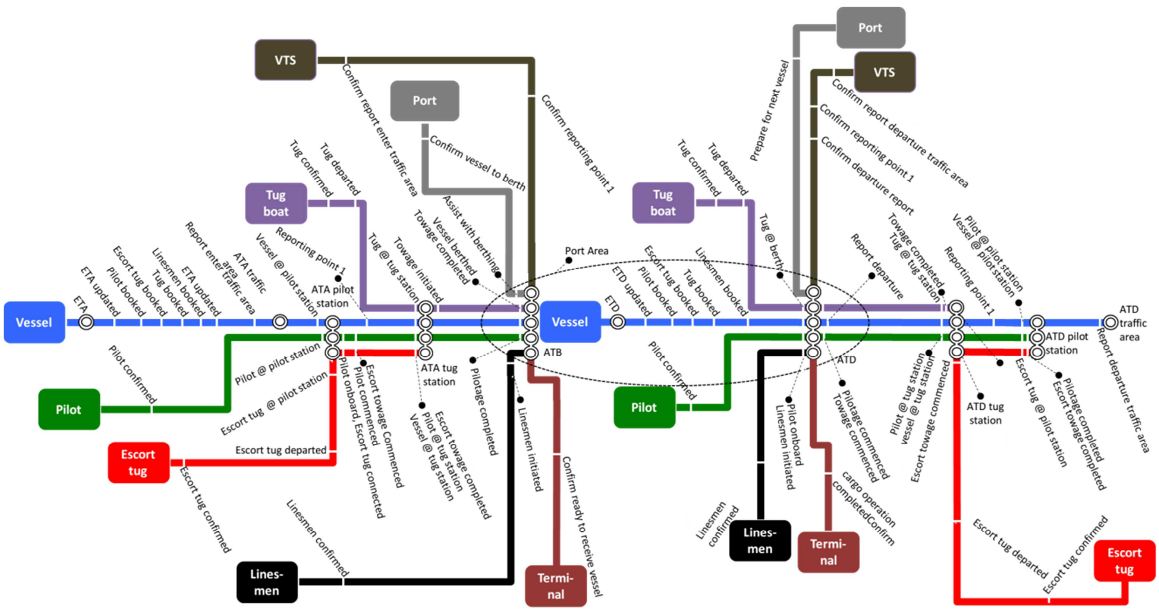

Fig. 9: States and milestones for the port call process

The construction is founded in Speech Act Theory, *Austin (1962)*, *Searle (1969)*, regarding the timestamp as a communicative act constituted by the following basic components: sender, recipient, communicative function and propositional content. In the nomenclature the communicative function corresponds to time type (i.e., Arrival, Departure, Start, Complete), the propositional content is translated into the combination of time sequence in relation to location/service/administrative process and reference object, the sender is labelled as the information provider and the recipient as the information consumer. In the nomenclature, states are expressed using timestamps to combine relevant information categories (*Time type*, *Time sequence*, *Reference object*, *Information provider* and *Information consumer*) to a certain *Location*, *Service or* administrative *Process* based on a particular *Data Source* being reported at a certain time (*Time Reported*). Therefore “timestamps” are the generic set of combined categories, Fig. 10, used to express a state based on the nomenclature, and “states” are the actual information communicated.

Time Type	Time Sequence	Location/ Service/ Adm	Ref. obj	Info Provider	Info Consumer	Data source	Time Reported
		Location				Manual	
ET [Estimated]	A [Arrival]	PS [Pilot Station]	Pilot	Vessel		System	
RT [Requested]	D [Departure]	TA [Traffic Area]	Vessel	Ship agent			
CT [Committed]		AA [Anchor Area]	Tug	Pilot			
AT [Actual]		TU [Tug Area]	Linesmen	Terminal			
		PA [Port Area]	Stevedore	Port Authority			
		Service	Terminal	Port Control			
	S [Start]	Pilotage	Service Provider	Tug Operator			
	C [Complete]	Towage	Quay	Linesmen			
		Mooring		Maritime Administration			
		Cargo Op.		Governmental body			
		Service Op.					
		Adm Process					
		Report/clear./Notif.					

Fig. 10: Nomenclature for timestamps (i.e. States) (instances derived so far)

To exemplify how a certain state can be classified according to the nomenclature, we use the following state: “Estimated Time to Arrival at Berth”, communicated from the Vessel to the Terminal at the arriving port. The following categories can be derived [*Time Type:* **Estimated** Time], to [*Time sequence:* **Arrival**] at [*Location*: **Berth**], for [*Reference object*: **Vessel**], from [*Information Provider*: **Vessel**] to [*Information Consumer*: **Terminal**] communicated at [*Time_Reported*]. This basic classification can be used to express all possible variants of states.

The nomenclature categories are defined as follows:

- Time types
  - Estimated times: Estimations of Time sequences (i.e. *Arrival* and *Departure* to/from a specific location and *Start* and *Completion* of Services/processes), to be regarded as a communication of intentions, continuously updated, used for capacity planning.
  - Requested times: Requested times for service operations, to be used as a basis for negotiation (request, recommendation and confirmation) between actors, such as vessel and terminal, to be updated due to changes (changes in request, availability, traffic etc.) leading to new negotiations and committed times. An estimated time for arrival to a port area can be used as a requested time for services operations. Although, it is important to distinguish between the communicative function of an estimation, as a communicated intention of a certain occurrence, and a request for a service at a specific time.
  - Committed times: Committed times correspond to agreed (between two or more actors) times based on a negotiation following an interaction of communicated requested times, recommended times and confirmed times. An obsolete committed time requires a new negotiation initiated by an updated estimated or requested time (complemented with root cause notification). Committed times can be used as a basis for actors to plan and fine-tune a realization (i.e. reserve capacity, adjust speed, initiate services, etc.). Committed times should continuously be confirmed by involved parties to ensure a high reliability of time stamps communicated.
  - Actual times: Actual times is realized times for time sequences, used for evaluation based on the actual occurrence related to estimated, requested and/or committed times. Actual times can also be used for billing, logbooks and/or statement of facts.

- Time Sequence
  Two sets of time sequences have been identified due to if the subsequent category is a certain location, or a service/process. The first set of time sequence is used to define the events for a certain location, using Arrival or Departure. The latter set defines services and/or administrative processes as started and/or completed.

- Location/ Service/ Process
  To reach a higher precision in the communication of states a distinction between geographical location, services and administrative processes has been made. The services are the set of port related operational services available.

- Reference object
  What the communication is about (e.g., vessel arrival to a certain location or pilot arrival to that same location).

- Information Provider
  The actor that communicates or makes a certain information component (e.g., state) available for other actors to consume.

- Information Consumer
  The information consumer category defines which actor is using the information from a certain provider.

- Data Source
  The data source from which the information is collected.

- Time reported
  The time of which the message was created.

3.5 PortCDM as an enabler for sustainable (sea) transportation processes

To reach the full effects of STM and thereby enable sustainable sea transport processes, high accuracy (based on solid estimations) related to berthing, unloading, loading, and departure, becomes necessary. Solid conditions for the ultimate sea voyage can be established by enabling high accuracy on the arrival, port operations, and the departure. Different planning horizons are associated with different levels of tolerance for deviation between the estimated and actually reached state (the outcome), Fig. 11. The deviation should be diminishing with time; the closer to the Execution Phase the smaller the tolerance for deviation should be, until the actual moment of occurrence is reached for a certain state. This allows a planning process, performed by the different actors, with different time horizons (i.e. long-term, mid-term, and short-term planning) to be performed optimally, based on the information about the interval of the outcome (e.g. a time span of the reaching of a certain state). Sea transportation is a multi-organizational business with numerous actors positioning and coordinating their performance in relation to different control points. Related to STM, PortCDM closes the loop in the transport chain by establishing conditions for the realization of the sustainable sea voyage. STM will be realized by sharing information about status and values related to identified control points (e.g. states) for the particular voyage.

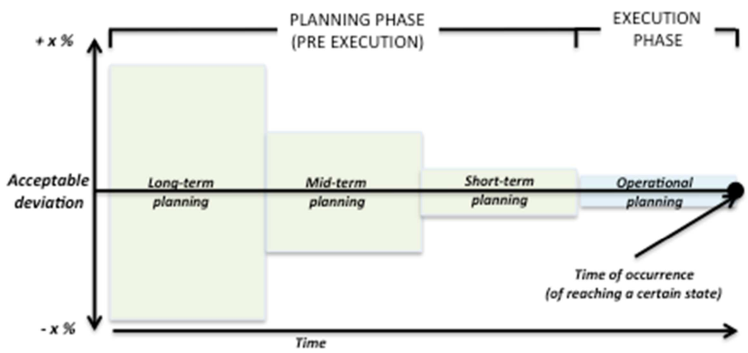

Fig. 11: Acceptable deviation between estimate and actual occurrence (in different time slots), *Haraldson and Lind (2005)*

3.5.1 State management and performance metrics for PortCDM

Estimates and actual times are the key parameters in PortCDM. The backbone is the vessel arriving in a port, performing berth operations, and departing from a berth and consequently from the traffic area/port limits. These times are used as basic parameters for the calculation of other metrics. Besides the necessity to capture the times for the estimates (e.g., ETA, ETB, ETD) and real occurrences (e.g., ATA, ATB, ATD), the updates of the estimates are crucial in order to calculate key performance measures. Consequently different updates on actual state changes become important for performing evaluation of how well the port functions.

There are two ways for ensuring that different states are reached according to desires:

- To communicate about desires and possibilities for actions well in time
- To include intermediary states to govern towards and as a basis for evaluating the probability to reach latter states.

The ambition is to identify relevant (intermediary) states to use for ensuring that certain states with higher degree of coordination force (expressed as milestones) are reached in time. Two examples illustrate this idea:

- One actor might want to have information about estimated times to different waypoints of the sea voyage in order to judge the probability of that the vessel reaches the traffic area/port limits according to the estimated time of arrival.
- Another actor might want to include a state when the pilot vessel is departing from its berth in order to judge whether the pilot will be at the pilot station according to the estimate.

By adopting principles of state management and identifying root causes for non-successful performances the idea is to enable the inclusion of additional states to govern towards. The goal is to have a list of possible states to increase the ability to predict the occurrences of important milestones and to share experiences among different ports.

The governance towards states is the basis for making calculations for the following measures:

- Predictability - an essential coordination mechanism for increased punctuality and hence just-in-time operations. Predictability means the ability to estimate the time of a specified state. Hence predictability can be used to determine how well one actor or a group of actors succeeds in estimating one or several occurrences. There exist several predictability measures that can be used separately or as aggregates, Fig. 12. In order to measure the effects of PortCDM the following predictability measures are recommended to be included in the baseline (as the reference point): Predictability in relation to xTA, xTB, xTC and xTD (x = **E**stimated or **A**ctual). The measure should reveal the predictability for the key states identified (e.g., milestones) for a specific approach and certain actor. Then predictability as compound measure can be calculated by aggregating the performance measures. The PortCDM solution contributes to synchronized and coordinated port approaches. By increasing the predictability of when different states are about to occur, other actors can optimally plan for their contribution to the ecosystem. One basic start is to identify data sources for different estimates made for different accurate states. It is the sum of all data sources from several port related system that should contribute to situational awareness of the port approach. One assumption is that multiple estimates for the same state, Fig. 11, should allow for an increased degree of precision about the estimates for a particular occurrence.

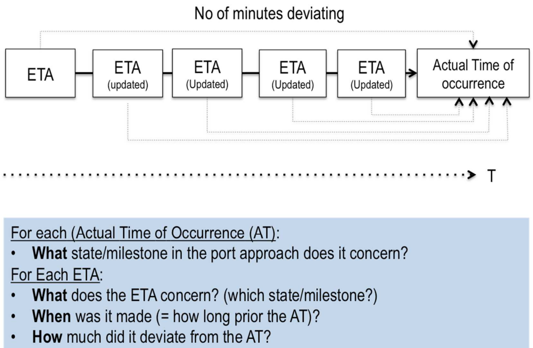

Fig. 12: Basis for the ability to predict

- Punctuality - a measure of how well in time different actors performed their actions. Similar to Predictability, Punctuality can be calculated for single or group of actors, for particular milestones or for a certain or a sum of approaches, Fig. 9. In order to measure the effects of PortCDM the following punctuality measures are recommended to be included in the analysis: punctuality in relation to xTA, xTB, xTC and xTD. The measure should reveal the punctuality for the key states identified (e.g., milestones), for a specific approach and actor. Then punctuality as compound measure can be calculated by aggregating the performance measures.

- Berth Productivity - an international measure used to compare different ports in relation to each other. When it comes to container traffic, the berth productivity measure is defined as: "[…] the number of total container moves (on-load, off-load, and re-positioning) divided by the number of hours during which the vessel is at berth (time between berth arrival, or 'lines down (all fast)' and berth departure, or "lines up"), without adjustments for equipment and labor down time," *Piers (2013)*. This means that there is an interest to govern port approaches towards xTB and xTD and enabling just-in-time operations to as a high degree as possible. By actors sharing intentions of when different contributions are meant to take place, they could optimize the coordination/planning of their operations. It is not obvious that the berth productivity will be changed due to the introduction of PortCDM, but it is necessary to show that the berth productivity will stay on the same level or increase. Increased predictability and punctuality related to the milestones for more just-in-time operations, will affect the berth productivity, such as reduced waiting time at the berth due to the need for waiting for linesmen, tugs, documents, or pilots.

- Waiting times/Anchoring times - an overall goal of PortCDM is to enable optimal planning for operations. One measure that expresses the ability to optimally plan, and to respond to the commitments being made, is waiting times/anchoring times. Waiting/anchoring times can be derived in two ways; either the actor accumulate waiting times related to each milestone or that waiting times are derived from when singular state changes occur in relation to compound state changes at a particular milestone (e.g., the difference between the time when the pilot is at pilot station (e.g., agreed meeting point) and the time when the vessel is at the pilot station).

- Capacity utilization - PortCDM should also form the basis for enabling involved actors to plan for utilization of the infrastructure they govern/utilize in an optimal way. A strong desire is to achieve information about intended actions as early as possible. This is made possible through PortCDM by sharing intentions, desires, requests, and commitments as early as possible (such as a port subscribes to information about upcoming port approaches via the SeaSWIM-layer). Measures for capacity utilization are based on the time the infrastructure is used, divided by the availability of the infrastructure.

3.5.2 Thresholds for built-in inertia – the logic behind the PortCallManager

In order to avoid multiple re-planning due to small changes by updates on estimates of when a certain state is to occur PortCDM provide a built-in inertia by using thresholds for when counter-actions (i.e., updated commitments) are needed. The thresholds to be applied have their bases in time frames of when different actors can perform their operations. Analytically, the different time frames of when a particular actor can perform its operations should overlap and as long as it is still possible to perform the operations due to changes in estimates (e.g., an earlier or delayed approach to the traffic area/port limits).

3.6 Core services in PortCDM

The PortCDM concept is defined by the PortCDM services. These are both of operational and informational characteristics. These services are based on design criteria founded in an approach for service-oriented architecture, and distributed and federated service development.

3.6.1 Operational services in PortCDM

At its core, four operational services define the PortCDM concept:

Port Call Synchronization Service	
Objective:	Coordinate the vessels approach with a port's readiness. Enable the vessel to set an accurate speed for a just-in-time approach to the "service meeting point," such as traffic area/ pilot station. Enable each involved Port Call Service Provider to plan in advance enabling optimized turn-around times and resource utilization.
Description:	Synchronization is enabled by coordinating service planning and realization (requested needs and available capacity) for involved actors, using information about service realization (time, spatial and infrastructure) as the basis.
Service provider:	Port Authority or Company/ Private Service Provider
Area of operation:	Berth to Berth
Port Call Optimization Service	
Objective:	To coordinate and adjust actions related to other actors shared intentions and performances, based on the set of states for a particular port call
Description:	An optimization service for planning and on-going activities for actors involved in a port call, based on an instantiated generic port call process
Service provider:	Port authority or company/private service provider
Area of operation:	The turn-around from arriving to the traffic area / pilot station, to departure from the traffic area / pilot station.
Port Call Monitoring Service	
Objective:	To provide situational awareness for upcoming and on-going port calls and actors performance, to enable involved actors to monitor particular (and/or parts of) port calls (based on each actors accessibility to provided information).
Description:	This service provides real-time images of the status (desired, committed, fulfilled actions by different actors) of upcoming and on-going Port Calls. Provide basis for monitoring, coordination, and optimization.
Service provider:	Port authority or company/private service provider
Area of operation:	The turn-around from arriving to the traffic area / pilot station to leaving from the traffic area / pilot station after loading/unloading
Port Call Improvement Service	
Objective:	To evaluate and propose means for optimizing future port calls.
Description:	This service uses conducted port calls as a basis for evaluation to establish means for optimizing future port calls. Generic process definitions of a port call are up-dated and then used as the basis for future port call instances.
Service provider:	Port authority or company/private service provider
Area of operation:	The turn-around from arriving to traffic area / pilot station, to leaving from traffic area / pilot station after loading/unloading and information exchanges related to port call.

3.6.2 Information services in PortCDM

Three types of information sharing services are distinguished; Commitment/expectation management services, Capacity planning services, and Port Approach Optimization services, Fig. 11.

Service	Description
Planning services	
ETA_Planning service	Based on the vessel's desired ETA to the traffic area/port limits, a response is given of when the port operators have the capacity of taking the vessel to berth.
PortCall_Managing service	To establish/update a network/tree of related desires/intentions/ outcomes/ capacities for a certain port approach, where involved actors inform each other about their status.
Capacity_Planning service	To provide operators with plans for how available capacity could be utilized optimally in respect to upcoming port approaches (short-term, and

	long-term) expected efforts
State_Indicator service	To provide service consumers with the current state, and planned state changes, of a certain object
PortCall_Status service	To provide service consumers with a status report of how the port approach is planned for/is being realized
Noon_Reports_Sniffer service	To provide service consumer with noon reports (of updates about states and forthcoming ETAs) by searching multiple entry points
Port_Service_Planning service	To match the vessel operator's needs of services and service providers' capability (and/or capacity) to provide needed services and expected realization.
Execution services	
State_Updates service	To provide information about changed states related to the ETx-Manager and ETA_Planner for one voyage or several voyages)
Commitment_Mgmt service	To provide real-time information about changed states, and patterns of behaviour related to commitments as a basis to manage actor relations and real-time evaluation in relation to commitments and established SLAs.
Evaluation services	
ETAT_Evaluator service	To provide an evaluation of the capability to predict the actual time for a particular state change.
Root_Cause_Analyser	To provide root causes for, and solutions to, why a certain port approach (arrival, berth, departure) did not fully correspond to the expectations.
Waiting_Time_Statistics service	To provide information about waiting time per operator for a particular port approach and/or accumulated waiting time for a certain operator and/or sum of waiting time per voyage.
Commitment_ Monitoring service	To provide information of broken commitments during planning and/or realization. This information (sometimes combined with the Root_Cause_ Analyser) can function as a basis to manage commitments per actor and/or per voyage to improve future estimates and realization patterns.
Other services	
Port_Maturity service	To provide a judgement of a port's maturity level and what requirements there are for moving to the next level based on the result from several port approaches
Berth_Productivity service	To provide a measure of the berth productivity for a certain time period for a certain terminal
Port_Approach_Analyse service	A Port_Approach_Analyser allows simulating and re-planning approaches based on a range of estimated and real time based input parameters (e.g., number of voyages, type of vessels, port operators' capacity) for optimal realization and capacity utilization for a specific approach.

4. Stakeholder benefits

One of the benefits of PortCDM is the ability to predict and provide conditions for enabling "green-steaming" to port. Potentially, there are great savings in energy and bunker consumption, if waiting times in pre-cargo operations and anchoring could be eliminated. This, of course requires changes in business contracts and industry practices (such as virtual ETA, Virtual Laycan). This would mean that a port with good predictability, would enable a shipping company to earn more by green-steaming, than going to another port, all other things being equal It would become a competitive parameter for the port and all its actors. A reliable and collaborative port is a profitable port for a vessel.

Terminal operators can also benefit from an increased ability to predict the port approach. A terminal would be able to better align its resources to the requirements and planned operations. The principles of the commitment tree, could also be applied internally for the terminal, using the same logic and giving the same benefits as for the approach. Capacity management for other actors, such as pilots, tug operators, linesmen, and stevedores, would also yield benefits.

Other port service providers could also gain better efficiency and planning capabilities from an implemented PortCDM, when their contribution to the approach and port call were better planned and predicted. This does however require a high degree of willingness to share information for the benefit of getting more back.

5. Final remarks

In this paper we have elaborated on PortCDM as the mean for closing the loop in STM. Ports are arrival and departure hubs that create requirements on fast turn-around processes and actions. Due to the existence of multiple actors there is a need for (distributed) coordination. In such an environment, such cooperation relies on information sharing between involved actors. In this paper, we have elaborated on the constituents of such interaction to enable high predictability and thereby high punctuality, reduced waiting and anchoring times, high capacity utilization creating means for governing towards high berth productivity. Such performance metrics would enable green and optimal steaming and thereby closing the loop in the transport chain. Digitizing port operations with CDM can enhance the efficiency and sustainability of shipping.

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