

# Guiding the thrust!

## Analytical concepts in the service of coordination support systems

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**Abstract.** The issue of analyzing and conceptualizing cooperative work and its coordination has gained considerable impetus over the last two decades. The Coordination Mechanism framework falls within that body of work by addressing the functioning of artifacts as means of supporting the coordination of complex cooperative work. The present paper takes the framework outside the world of artifacts and presents an initial investigation of the framework's applicability to the analysis of spoken coordination. The main focus is on investigating to what extent the analysis of spoken coordination can benefit from the conceptualizations of cooperation and coordination that have been established on the basis of empirical studies of artifact-based coordination. The investigation was undertaken within the work domain of maritime operations; a domain characterized by highly complex and time critical cooperation and coordination. The analysis of maritime operations illustrates that the basic analytical concepts underpinning the Coordination Mechanisms framework are also useful when addressing spoken coordination, and that central functional aspects of Coordination Mechanisms can also be identified in spoken coordination. The basic functional understanding of a coordination mechanism, as a means of stipulating and mediating coordination information, proved useful, whereas the restricted notion of physical artifacts as coordination means was, not surprisingly, too narrow for work settings mainly characterized by oral coordination.

### 1. Introduction

Work settings where the actors work in solitude are rare. Cooperation—the joint activities where several interdependent actors collaborate—is by far the dominant work structure in most domains. Yet for many years, when designing information systems for cooperative work settings, the design approaches remained sightless to the distinctiveness of cooperative work and did therefore not provide analytical concepts that aided the designer in developing a coherent understanding of cooperative work and its coordination. The natural first step – initiating the exploration of cooperative work in the context of computer systems design – was, of course, the recognition that computer systems running in cooperative environments quite often fell short of reaching their intended potential; they supported the actual work of the individual actor while ignoring the need for coordinative interaction

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between the actors in the cooperative work arrangement. The coordinative work functions were simply left out of the empirical formula.

The need for an explicit focus on coordination in the context of CSCW research has been anticipated for more than two decades now. Holt was among the first to address requirements for useful coordination technology [7]. Hereafter followed consequential work concerned with conceptualizations of cooperative work and coordination [see e.g., 8; 9; 16; 19], and numerous in-depth field studies of real world cooperation and coordination [see e.g., 1, 4, 5, 20]. However, in terms of analytical conceptions and coordination support systems only few instrumental accomplishments have been established, both with respect to technical and social issues. As pointed out by Heath & Luff [5] the major reason for the failure of both innovative and advanced cooperative technology has been not so much rooted in technological inadequacy as the general insensitivity towards the ways in which individuals interact and collaborate in the workplace.

The conceptual framework of Coordination Mechanisms [4; 16] and the underlying conceptual understanding of cooperative work have previously been used for analyzing and conceptualizing coordination activities and the function of coordinative artifacts [cf. e.g., 18; 4]. However, the analyses have so far all addressed work settings where much of the coordination and interaction between the cooperative actors was conducted over long periods of time, and where coordination relied heavily on artifacts like forms, boards, computers, etc. The objective of the empirical work providing input for the establishment of the framework has to date mainly been to investigate how artifacts are in fact being used as coordinative constructs. The conceptual framework of Coordination Mechanisms has furthermore been developed into a general computational notation for construction of computer-based coordination mechanisms [16].

The present paper will present initial result from an empirical study where the Coordination Mechanism framework is utilized in an analysis of spoken coordination as performed by the cooperative actors involved in maritime operations. The investigation will take into account the framework's founding understanding of cooperative work and coordination, as well as the analytical concepts dedicated to the characterization of coordination mechanisms.

## **2. Research approach**

The research documented in the paper is based on thorough ethnographically inspired investigations of real-world coordination and cooperation as performed by the actors involved in maritime operation. The aim of our empirically based effort is to analyze actions taken, information and information sources applied, the communication and coordination structures and means used, and roles taken in the cooperative work of navigating a ship. In addition to the observational studies a large number of informal interviews and talks with experienced Captains and Pilots have been carried out, all conducted as open-ended qualitative interviews [12].

The research approach used in collecting data on ship navigation can be characterized as qualitative research inspired by ethnographic approaches to studying complex work [e.g., 1] and, of course, by the conceptual framework of Coordination Mechanisms' underlying conceptual understanding of cooperative work [4; 16] introduced in the following chapter.

The empirical studies of maritime operations fall into two stages. Stage one—familiarization with the activities involved in navigating a large container carrier—was conducted in high-fidelity full-mission ship simulators at the Danish Maritime Institute. The first phase also served the formulation of a series of basic research issues and as a means of tuning the data collection that should facilitate discussion of these issues.

The second stage of the empirical work consisted of two in dept field studies carried out aboard two of the largest container carriers in the world. The on-board field studies were conducted by one of the authors (M. Nielsen) and was divided into two six weeks periods. The empirical material collected during phase two was collected during a period three months (full time) on board the container vessels Majestic Mærsk and Knud Mærsk respectively. The first journey was from Europe across the Atlantic Ocean through the Panama Canal, and up the west-coast to Oakland. The second journey was out of Rotterdam, through the Mediterranean and the Suez Canal, to the extremely busy harbor of Singapore and to Japan. During the two studies the vessels called on more than 30 of the busiest harbors in the world.

All stages of the empirical work have focused on the coordination of time critical co-operative activities. During the observations video recordings were widely used mainly to illustrate navigation and maneuvering in coastal waters, in and around harbors and canals. To understand the activities of the actors navigating the vessel the physical environment of the vessel has to be constantly and coherently represented in the data material collected.

Central parts of the video sequences have been transcribed, and the activities undertaken and ongoing communication among the actors has been related to the actual situation, both with respect to the vessel itself and the surroundings (weather conditions, other ships, etc.). The communication and interaction among the actors has been analyzed in order to identify the coordination activities.

From the description of the basic functions undertaken, and an identification of the mechanisms and means applied for coordinating the activities, the basic characteristics of coordination of maritime navigation have been described, i.e., some basic characteristics of coordination based upon oral modes of interaction has been identified.

We have elsewhere used the studies and findings for discussing computer based support of maritime navigation [e.g., 10] and for discussing the need for understanding the hidden functions in a work arrangement before considering a redesign [2].

Our aim in this paper is to discuss the applicability of the conceptual framework for understanding and conceptualizing oral modes of coordination. We shall do so based on a presentation of a small subset of our empirical data.

### **3. The concept of Coordination Mechanisms**

When several actors are involved in a cooperative work arrangement they become mutually interdependent in their work. In order to get the work done, they have to align, schedule, integrate, etc. their individual activities. In other words they have to coordinate their work along the salient dimensions of who, what, where, when, how, etc. [19]. Coordination activities cover aspects such as scheduling, meshing, and allocating resources, negotiating resource allocations, monitoring work activities, resolving inconsistencies, etc. Our understanding of coordination here is close to what Strauss, Schmidt, and others define as 'articulation work', although we do not include aspects like making sense of information [19].

Coordination Mechanisms is a conceptual framework for conceptualizing coordination activities and the mechanisms invented for supporting these. The aim has been to develop a set of concepts for analyzing and understanding coordination artifacts i real world work settings [4] and to develop a computational notation supporting construction of coordination mechanisms [16]. The framework addresses thus both analytical and constructive aspects i.e., it can be used as an analytical concept for understanding how procedures, forms, and other artifacts can be considered mechanisms supporting coordination, and it can be used to support design of computer-based coordination support.

In short, a coordination mechanism is defined as a construct containing a protocol that—by encompassing a set of explicit conventions and prescribed procedures—stipulates the coordination of distributed activities. The protocol is supported by a symbolic artifact with a standardized format that mediates coordination information; so as to reduce the complexity of coordinating the distributed activities of cooperative work settings [4; 16].

### 3.1 Basic conceptual structures and analytical distinctions

Prior to the establishment of the concept of coordination mechanisms some work was conducted on a framework supporting work analysis of complex work situations [cf. e.g., 15; 3]. The aim was to provide a more coherent and functional oriented approach to understanding a work system than the traditional procedural oriented approaches offered in software engineering. Focus was on understanding a work arrangement in terms of functions (services) the arrangement (system) provided to its purchasers. The work arrangement should be seen as a dynamic whole (system) requiring explicit focus on a) characteristics of the outer environment and the relations between the outer environment and the cooperative work arrangement (the functions), b) the field of work, and c) the characteristics of the actual cooperative work arrangement itself (i.e., the existing implementation of a socio-technical system). For further details see earlier work by Schmidt and Carstensen [e.g., 15; 13; 3].

The initial work on establishing an analytical framework identified the need for unraveling the cooperative aspect of the work arrangement in order to be able to design useful computer-based support systems, i.e., to change the division of functions handled by the actors and the computer-based systems.

**Field of work - Work arrangement:** In addition, the need for an analytical distinction between field of work and the work arrangement was recognized in relation to understanding the interaction between a work system and its environment, or ‘between the inner and outer environment’ as Simon has phrased it [17].

From the distinction between work arrangement and field of work, it was recognized that actors in a cooperative work arrangement are working within the same field of work. Thus, the actors are controlling, handling, transforming, etc. a number of interdependent objects, structures, processes, etc. To do this they have to interact in order maintain reciprocal awareness, direct attention to certain aspects of the field of work, assign task and obligations, etc. [14]. The interactional activities can have many different appearances, for example seeing, hearing, marking items, humming, pointing, nodding, doing activities in abnormal ways, or writing notes. Schmidt suggests to abstract these into three salient overall dimensions of “modes of interaction” [14]:

- Obtrusive versus non-obtrusive interactional activities. Some modes are disruptive. Others are conspicuous and do not require much further attention from the actors.
- Embedded in the field of work versus a symbolic representation embedded in an artifact representing the state of the field of work. The symbolic representation provides a higher degree of freedom in manipulating the intimations presented.
- Ephemeral versus persistent interactional activities. Some modes of interaction will disappear without leaving tracks. Others will leave a path to trace.

A fourth prominent characteristic of the modes of interaction is the allocation of the functionality between the actor and the artifact used. The degrees of freedom—or ‘local control’—of the coordination can be understood as a continuum from *ad hoc* coordination in the one end to coordination-based on rigidly prescribed protocols in the other.

**Work - Articulation work:** The interactional activities can be seen as a category of activities required to manage the fact that the cooperative work is distributed over several actors, in time, and/or in space. Coordination is required. It therefore becomes highly

relevant to make an analytical distinction between work and its coordination. When we relate this distinction to the distinction between work arrangement and field of work it appears that what is coordination for one work arrangement might be the field of work for another work arrangement. The work - articulation work (here coordination) distinction must thus be understood as recursive. "...management of an established arrangement of articulating a cooperative effort may itself be conducted as a cooperative effort which, in turn, may also need to be articulated" [16, p. 159].

### 3.2 Coordination Mechanisms

As mentioned earlier, work settings with a high degree of complexity of the activities or handling activities distributed in time and space often requires interaction based upon mechanisms embodied in an artifact containing a protocol that stipulate and mediate the coordination. Such mechanisms reduce the demands for coordination activities from the actors. Such mechanisms are what is called ‘coordination mechanisms’, and shortly defined as a protocol encompassing a set of explicit conventions and prescribed procedures, and supported by a symbolic artifact with a standardized format. The purpose of the mechanism is to stipulate and mediate the coordination of distributed activities. In the work of specifying the concept of coordination mechanisms certain specific characteristics were identified [cf. 4; 16]:

- (1) A coordination mechanism is essentially a *protocol*. It is a set of explicit procedures and conventions that *stipulate* the coordination of the distributed activities. The distributed activities are coordinated by executing the protocol.
- (2) The stipulations of the protocol are (partly) conveyed by a *symbolic artifact*, i.e., they are persistent and publicly available in some kind of ‘physical form’. Thus, a cognitive symbolic structure only existing in ‘the head of the actors’ is not considered a coordination mechanism. This is one of the aspects under test in this paper since we would like to understand coordination that is not supported through artifact based coordination mechanisms.
- (3) The symbolic artifact *mediates* the coordination of the distributed activities. The artifact is an intermediary between the actors.
- (4) The symbolic artifact has a *standardized format* that reflects pertinent features of the protocol. It thus provides affordances to and impose constraints on coordination.
- (5) The state of the protocol is *distinct* from the state of the field of work. Changes to the state of the field of work are not automatically reflected.

As it can be seen, this definition is very much established as a constructive contribution specifying characteristics of coordination mechanisms to be designed, typically computer-based. The concept of coordination mechanisms can, to some extent, be used to characterize mechanisms having a wide range of allocations of functionality between actor and artifact, from almost total reliance on human intervention to almost fully automated computer artifacts. However, all coordination mechanisms are fundamentally ‘social’, i.e., they are constituted within a set of socially agreed to procedures and conventions.

The explicit focus on artifacts implies that representation becomes important. Two aspects needs attention: The ‘surface representation’ and the ‘internal representation’ as Norman calls them [11]. Artifact with a surface representation are primarily “systems for making possible the display and maintenance of symbols: They implement the ‘physical’ part of the physical symbol system” (Ibid., p. 25). When analyzing coordination mechanisms and means supporting interaction both the surface and the internal representations

need to be addressed. The surface representation is usually immediately visible, whereas the internal representations can be ascribed to a protocol that is not incorporated in the artifact, for example forms or check lists used.

All the previous studies of coordination activities indicated that coordination is conducted with respect to conceptualizations (objects) pertaining structures in the actual field of work and the actual work arrangement, typically presented in the coordination mechanisms as 'pointers' to structures in field of work and the work arrangement (e.g., roles, actors, resources, tasks, etc.)

The aim of this paper is to apply the conceptual framework of Coordination Mechanisms in a work setting where the majority coordination means are not artifact based but oral. Hence aspects like for example types of representation mentioned above will have another meaning. Addressing this type of work setting is expected to have strong implications for the analysis. This is what is being evaluated in this paper.

#### 4. Maritime Navigation

Basically the movements of a sea-going ship are determined by the interaction between controllable and uncontrollable physical forces. From this perspective navigation is concerned with applying the controllable forces on the uncontrollable forces in ways that result in the desired movement of the ship; the objective being to transport the ship and its cargo between ports in safe and efficient ways.

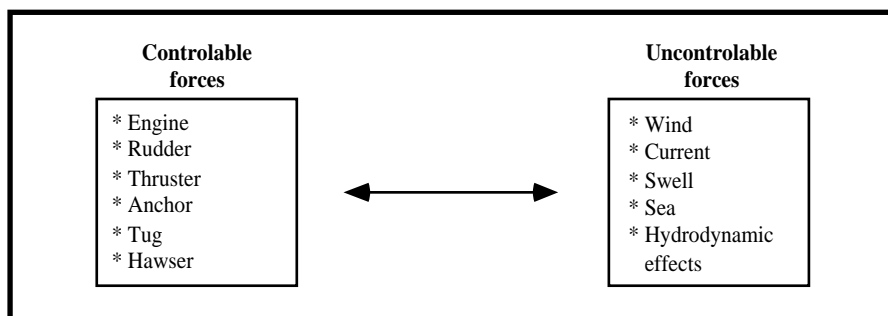


Figure 1: Controllable and uncontrollable forces determining the movements of the vessel.

Ships of the size and type of the container vessel Knud Mærsk have quite limited maneuverability. During the voyage it will often be the case that the uncontrollable forces work strongly against the desired navigation and at times they might even be the most powerful. But even leaving aside the influence of forces like wind and current the vessel still remains the victim of massive inertia due to her vast dimensions and tonnage: MS Knud Mærsk is a truly amazing vessel: She is 318 meters long, 42 meters wide, has a draught of 14 meters when fully loaded, and a corresponding dead-weight of 84900 tons. At a maximum load she carries the equivalent of 6000 20 foot containers. The vessel is fitted with a twelve cylinder main engine allowing for a maximum speed of 25 knots.

Measured from the bottom of the keel to the top she is 60, 65 meters high. The wheel house or command bridge is positioned at a height of about 35 meters above the water level when the vessel is fully loaded. When traveling fully loaded and at maximum speed it takes about 16 minutes and a distance of 6.1 kilometers to bring the vessel to a complete stop.

#### 4.1 Overall bridge layout

The wheel house or bridge of the vessel is the center of navigational activities. At all times there is one and only one actor in command of navigational decisions – the Officer of the watch or the Captain. The configuration of the bridge manning changes in response to the navigation at hand. The bridge combines two distinct locations. The central part of the bridge used for most navigation, and the bridge wings where navigation and maneuvering is conducted while in the harbor basin.

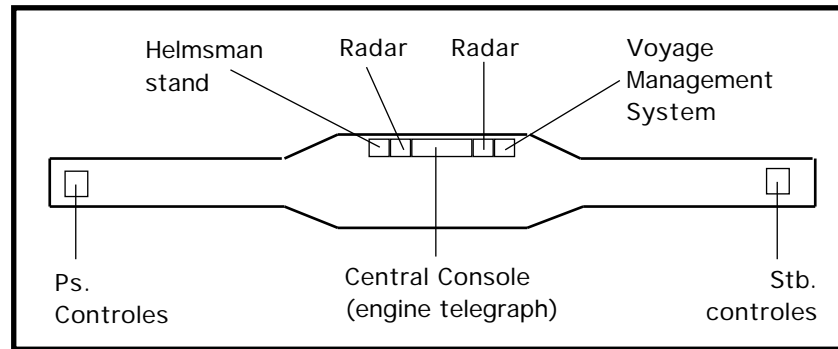


Figure 2: The overall layout of the bridge.

The host of instruments fitted on the central bridge can be divided into four overall classes. (a) Communication devices used for within-crew communication (walkie-talkies, closed circuit telephone network, and intercom); and communication devices used for ship-to-ship, ship-to-shore or shore-to-ship communication (primarily VHF radios). (b) instruments used for monitoring the vessels state (propulsion plant, steering gear, etc.). (c) instruments displaying the vessel position and performance relative to its external environment (radars, geographical positioning systems, conventional sea charts with the planned route and position plots, ECDIS systems combining digital sea charts and superimposed plots of ARPA targets from the radars with data on own ships heading and speed, etc.) Finally (d) the bridge holds a selection of navigational effector instruments used for changing system states (auto-pilot, helm stand, engine telegraph, thruster telegraphs, etc.). All instruments are available on the central part of the bridge, while only a selection of instruments are fitted in the bridge wings.

#### 4.3 Field of work and work arrangements

The boundary and character of the maritime field of work—as seen from the perspective of the navigating crew—is subject to drastic changes when the vessel moves from oceanic navigation to coastal waters and finally on to the waters in and around the harbor. As the vessel gets closer to land the degree of constraints and complexity gradually rise: the space available becomes less while traffic density increases.

The general level of complexity of the field of work changes continuously when the vessel moves from open sea to restricted coastal waters and harbor areas; yet, local peaks in level of complexity may occur with no prior warning and from moment to moment: for example as a result of changes in traffic patterns. The configuration of the work arrangement changes in response to the rising complexity involved in entering restricted waters. In open unrestricted waters the vessel is most often navigated by one Officer only. When entering restricted waters or trafficked water ways the Officer of the watch is joined on the bridge by the Captain who will either assist the Officer or take over control of the vessel. Most often,

the Captain does not formally take charge of the vessel until some time before the Pilot embarks to guide the vessel in and around the harbor area. As the Captain takes control – yet before the Pilot embarks – the steering will go from auto-pilot to manual steering. When manual steering is implemented the wheel is turned by a Helmsman.

Thus, at pilot embarkation the bridge is manned by three actors from the crew (Captain, Chief Officer, and the Helmsman, who has the rank of Ships Assistant), and the Pilot.

At about the same time as the Pilot boards the vessel another important change to the work arrangement is implemented: two teams of three and four actors respectively, led by the First- and the Second Officer, are allocated to look-out duty at the fore and aft mooring decks. The two look-out teams are important informants to the Captain as the view to objects close to the hull of the vessel is obstructed as seen from the bridge. The Officer of each look-out team is in contact with the captain via walkie-talkie and will relay information on the external environment to the captain at will or at request. While the vessel is close to and in the actual harbor basin one or more tug boats will assist the maneuvering of the vessel. The Pilot on board own vessel is in radio contact with the respective tugs. Finally, as the vessel gets close to the quay two hawser teams on the quay come into play. They pick up the lines, and the ganger of the two hawser teams also provides information on the exact position of the vessel relative to fix points on the quay via radio link to the vessel's bridge.

## **5. Coordination in maritime operations**

This chapter is structured as a mixture of descriptive presentations of maritime scenarios, analyses of the scenarios, and reflections on the applicability of the conceptual framework. First we present two situations of manual steering and use these as a point of departure for applying the Coordination Mechanisms framework. We will describe the overall abstract functions conducted by the navigational work arrangement and reflect on the basic analytical distinction between the field of work and the work arrangement suggested by the framework. We then discuss the information exchange going on among the cooperating actors and reflect on the analytical distinction between work and its coordination suggested in the conceptual framework. We conclude with some reflections on how the stipulation and mediation of coordination information is handled, and to what extent it makes sense to think of stipulation and mediation functions when no artifact based coordination mechanisms are involved.

### *5.1 Manual steering*

Most of the time, navigation on large oceanic container carriers, is performed by only one officer supported by a host of sophisticated navigational aids. Prior to initiation of any voyage a track plan is laid out in terms of courses to be followed for a certain distance, points of course change, and speed. These data are plotted in conventional paper-based sea charts and fed to the main computer-based navigational aid called the Voyage Management System which will automatically display the planned track (course lines and wheel over points) as superimpositions of lines and marks for course change on a digital sea chart. The Voyage Management System will alert the on-duty officer of an upcoming course change, while actual changes must be effectuated manually by setting the auto-pilot to follow the new course. Thus, the main duty of the officer during one person manning is to monitor the navigational aids, tune them and make appropriate changes to their settings, while keeping a constant look-out for traffic via radar and most importantly the view from the bridge.

The navigation goes through gradual yet significant changes as the vessel enters the trafficked and restricted sea lanes of coastal waters. A central shift is the change from auto-pilot to manual steering. In the manual steering mode, navigational decisions are made by the Captain supported by the Chief Officer. Decisions are based on the performance of the vessel relative to the state of affairs in the environment. The Captain is in hands-on control of the engine telegraph determining the revolutions per minute (RPM) of the main propeller, while the Helmsman performs the hands-on implementation of helm orders (bring the vessel to a specific course) and rudder commands (turn of rudder to specific angle) issued by the Captain. The Helmsman never acts at will and the oral communication between the Captain and the Helmsman proceeds in accordance with well specifies phraseology and structure. For example: The captain gives the helm order ‘Starboard one zero’ (read: starboard ten degrees); the helmsman responds ‘starboard one zero’ and turns the wheel to the ordered position. The rudder starts moving and when it has arrived at the desired angle the helmsman gives his final report to the navigator ‘helm is one zero starboard’.

In contrast to rudder commands, heading commands require the attention of the helmsman over a longer period of time. ‘Steady as she goes’ is a frequently used heading command meaning 'hold the ship on the current course until further notice'. Given the helm order 'steady', the helmsman has periodical command of the rudder and is expected to make adjustments of the rudder in response to deviations from the desired course.

<b>Navigator’s helm order</b>	<b>Helmsman’s reply</b>	<b>Helmsman’s action</b>	<b>Helmsman’s report</b>
Steady on 272	Steady 272	Makes necessary adjustments of the rudder to keep the ship on course 272	Notifies the navigator only in case of significant deviations from the current course
Steady at the tower	Steady at the light tower	Makes necessary adjustments of the rudder to keep the ship heading for the light tower	Notifies the navigator only in case of significant deviations from the current course
Steady rate 15 degrees	Steady rate 15 degrees	Makes necessary adjustments of the rudder to keep the ship turning at rate 15 degrees/minute	Notifies the navigator only in case of significant deviations from the current rate-of-turn

Table 1: Examples of heading commands and the associated replies, actions and reports.

The above tables represent the communicative structure and content in the interaction between the Captain and the Helmsman as it is observable during medium to high speed navigation with manual steering in restricted waters.

### 5.1.1 Manual steering at low speed

The Captain and the Helmsman are interdependent in their work due to the fact that there is a strong coupling between the speed of the vessel (controlled by the Captain) and the actual effect of the rudder (controlled by the Helmsman). The rudder is a non active maneuvering device. The rudder can only produce a transverse force to turn the vessel under influence of the water flow produced by the propeller.

When the rudder is at an angle a pressure zone will build on the side of the rudder blade facing the propeller and hereby produce a transverse force and a consequent turning moment. 1/3 of the total turning moment produced by the rudder is due to the push effect created by the water pressure on the blade, while the remaining 2/3 of the turning moment is a product of the suction effect created on the back side of the rudder blade. Consequently: the higher the RPM of the propeller the stronger the turning moment. This constitutes the basic

interdependence between the Captain and the Helmsman who have hands-on control of the propeller and the rudder respectively.

An important premise for successful cooperation between the Captain and the Helmsman is that the Captain's orders are doable, i.e., a command has to be in correspondence with the physical forces available. If maneuvering does not take these basic limitations into account performance will simply degenerate beyond recovery. Given meaningful and doable commands the interaction between the Captain and the Helmsman runs smoothly according to the general structure. The Helmsman relies on the Captain in regard to the quality of the commands, while the Captain relies on the Helmsman for qualified implementation of the commands. The Helmsman is told when and what to do, while he tells the Captain when it is done.

At low speed the interdependence between the Captain and the Helmsman changes as the Helmsman becomes increasingly involved in taking decisions on maneuvers. Decrease in speed means decrease in the effect of the rudder and below a certain speed the rudder has virtually no effect. It is the duty of the Helmsman to monitor the effect of rudder in order to detect if and when this critical state of no rudder effect is encountered. At some point the course change becomes unattainable by means of the rudder given the present speed. This is when the Helmsman is expected to report to the Captain that 'the rudder is losing effect', or if the critical point has been reached that 'the rudder has no effect'.

When the rudder loses its effect the Captain may choose to relieve the Helmsman from his duties and maneuver by means of tug boats and thrusters (secondary bow and stern propellers producing transverse force)—or he may choose to regain rudder effect by accelerating the RPM of the propeller. If speed was not a constraint to consider when maneuvering in and around harbor areas evidently the loss of rudder effect would never occur. It does however happen—mostly in an anticipated manner—in situations where the water ways only allow for very slow speed. In these situations the distributed nature of controlling the vessel becomes an evident issue.

If the Captain chooses to maintain the low RPM of the propeller after the rudder has lost its effect he is in fact in sole control of the maneuvering. If he chooses to maneuver by rudder, the goal is then to implement the course change while gaining an absolute minimum of speed: this means that the increase of RPM must only be maintained until the maneuver is made possible. While the rudder regains effect the Helmsman will monitor the movements of the vessel and report to the Captain the moment the vessel starts working up a turn rate. Then it is up to the Captain and the Helmsman to judge when the turn rate is strong enough; taking into account the massive inertia of the vessel. The Helmsman will continuously report changes to the turn rate while the Captain is expected to make his intentions known: maintain, decrease, or increase the RPM of the propeller.

### *5.1.3 The concept of the coordinative protocol and artifact*

The concept of a protocol holds a central position in the conceptual framework of coordination mechanisms. In the cooperative interaction between the Captain and the Helmsman there is no intermediary coordinative artifact present. We can, however, conceive of the well-defined phraseology as the vehicle of coordinative information.

The concept of the coordinative protocol – the structural specification of coordinative action – as provided by the coordination mechanisms framework, matches the structural coordinative patterns guiding the verbal interaction between the Captain and the Helmsman rather well—this being in opposition to the findings reported in [6]. Our understanding of the function of the phraseology and procedures was thus supported by the concepts in the conceptual framework; including the understanding of a protocol as "inexorably under-

specified" [16] so that the level of rigidity can differ as observed in the two scenarios presented in the above.

In the context of spoken coordination we can consider the utterances or language as the artifact mediating the coordination information between the two actors. Stipulation of the coordinative structure equals the communicative structure while the strict and well-understood phraseology accounts for a standardized communicative format. From this perspective then, there seems to be a good correspondence between the analytical concepts of artifact, stipulation, and mediation—which have all been put forward based on studies of artifacts like structured forms—and the coordinative functioning of spoken interaction. We shall return to this issue in section 5.4.

## 5.2 *The need for coordination*

An underlying concept for the conceptual framework of Coordination Mechanism is to approach work activities as means for conducting certain overall functions. Basically, the purposefulness and relevance of work activities performed by the work arrangement is defined by the activities' relative correspondence to the constraints and affordances of the field of work at any point in time. Thus, specific work functions will always have to be performed no matter whether the work is handled cooperatively or not, while the need for other functions (coordinative functions) arises exclusively due to the fact that interdependent tasks are being handled by an ensemble of actors rather than one actor [4].

The fundamental objective of merchant navigation is getting the vessel and its cargo in-between harbors while satisfying the overall constraints of safety, timeliness, and effectiveness. Voyage planning, re-planning, navigation, maneuvering, and implementation are probably the most basic work functions to be performed. The plan forms the point of reference during all stages of navigation; the ability to follow and execute it or change it in time if necessary are central functions and success criteria. Planning only serves its function if it matches the capabilities of the vessel to its external environment. Initial plans have to take stable and probable limitations into consideration, while the actual maneuvering (and execution of this) and re-planning involves the masterful interpretation of myriads of complexly dynamic and constantly changing interactions between the vessel and the environment into consideration. Thus, proficient navigation relies heavily on the actor's ability to *monitor* and *interpret* the continuous state changes locally within the vessel, in the vessel's environment, and in the interaction between the vessel and the environment.

### 5.2.1 *The field of work and work arrangement distinction*

A functional analysis of cooperative work will shed light on which coordinative functions are needed in order to handle the interdependencies present in the cooperative work being considered for computer support. The concept of 'function' serves as the most important immediate interface between analysis and design of coordination support systems. We have to understand the functions of the existing coordination means applied before we can consider re-design, otherwise we might end up providing more efficient communication channels for less important aspects of the work.

Coordinative functions are produced in the dialectic interaction between the field of work and the work arrangement; the cooperation and coordination between the Captain and the Helmsman is a stringent example of this matter. The need for coordination between the Captain and the Helmsman is a product of physical process interdependencies in the field of work. Thus, to understand the coordinative needs of cooperative ensembles we need to focus explicitly on the manifest and determinant work interdependencies that are to be handled by coordinative activities. Maritime operations correspond to the root objective of

bringing the vessel and its cargo in-between destinations in a safe, timely, and economical way. The objective can not be met by arbitrary work functions. Quite on the contrary: the work performed by the work arrangement needs to match the conditions that constrain and afford the general work objective. This is true for one actor working in solitude as well as for any cooperative work arrangement. In the analysis of cooperative work—the analysis of required tasks and the coordination of these—the analytical distinction between field of work and work arrangement is a valuable analytical construct.

### *5.3 Coordination in effect*

The Captain and the Helmsman need to coordinate the distributed activities involved in manual steering because they operate interdependent processes where changes made to one process will affect the other. Consequently the Captain will need information on changes made by the Helmsman and vice versa. As illustrated in the above the interdependencies becomes particularly evident in instants of steering at low speed where the standard pattern of communication and coordination can not be upheld.

Safe and efficient performance in navigation and maneuvering generally relies on the navigators ability to establish and maintain a detailed and coherent picture of the state of affairs of the field of work. Had there been only one navigator on the bridge the creation and maintenance of the picture would have demanded monitoring activities, but no coordination. In the case of manual steering however, the work going into the picture of the state of affairs in the field of work is distributed among the Captain and the Helmsman. Both actors continuously monitor the general state of affairs in the field of work yet due to the specialized division of labor their perspectives and respective interpretations of the field of work have to be combined.

During uneventful manual steering the standardized format of communication between the Captain and the Helmsman insures that appropriate information relative to the task at hand is exchanged between the two actors. The prerequisite premise for the functioning of the communicative protocol is, however, the specification and implementation of the well structured division of labor. That is, that both parties understand and respect that, the Captain is in supreme command of the vessel, he is in hands on control of the engine telegraph and that the Helmsman effectuated orders issued by the Captain.

Procedures and communicative structures play an important role in achieving effective coordination. Procedures allow the Helmsman to only implement changes if so ordered by the Captain. Consequently, the Captain does only have to monitor rudder settings when the implementation of a command is under way. Seen from the Helmsman's perspective decisions on when to act are most often quite simple. The stringent communicative structure of the interaction between the Captain and the Helmsman allow the work load involved in coordination to be reduced to a minimum while the error potential is reduced by the confirmations of all commands.

The setting of the engine telegraph is visible from the helm stand. Should the Captain however change the engine telegraph setting while the Helmsman has his attention elsewhere the horn that sounds for all changes made to the RPM will not be missed.

From the Captain's perspective it is not always possible to follow in detail the steering performed by the Helmsman. Consider the rudder command 'starboard 15 degrees'. In this case, basically, what the Captain needs to know is that the command has been correctly understood and that it is being initiated, that the wheel has been turned to the appropriate setting, and that the rudder has arrived at the designated angle. The Captain issued the command so his task is now primarily to evaluate the effect of the rudder command: does the maneuver bring the vessel to the desired position?

In case of course commands the Helmsman will have to make continuous adjustments to the rudder angle in order to counteract physical forces like wind and current. Seen from the Helmsman's perspective the coordinative procedure bears strong resemblance to the one used in the case of rudder commands: The Captain issues a command stating the desired course, the Helmsman confirms the command and initiates the turn, and when the desired course is reached the Helmsman acknowledges the Captain. If sufficient reactivity limits are not met, the Helmsman will notify the Captain of this. Yet he will only be expected to do so if the lack of responsiveness is important to the situation at hand. The coordination between the Captain and the Helmsman—in cases where the basic coordinative protocol does not fully apply—relies on the actors ability to judge the relevance of a communicative act as well as adhering to the general structure of the protocol in use during uneventful navigation.

### *5.3.1 Analytical discrimination between work and its coordination*

As mentioned previously a specific set of functions have to be performed in order to meet the work objective, no matter if the work is performed by one or several actors. The coordinative work functions are on the other hand a genuine product of the structure of the actual work arrangement. If only one actor is involved no "overhead" for coordination is needed. This is the phenomenon being addressed explicitly by the analytical distinction between work and coordination.

In the case of manual steering of a large container carrier some activities – like turning the rudder and controlling the RPM of the propeller – are needed no matter if steering is performed cooperatively. If performed cooperatively however, the turning of the rudder and the setting of the engine telegraph need coordination since the two activities are interdependent and performed by two individual yet interdependent actors. Explicit focus on these differences helped separating the interaction and communication between the actors into interaction with a coordinative purpose and interaction devoted to the fulfillment of the actual work activities required.

Coordination support systems should seek to support the general work performance by enhancing the cooperating actors ability to coordinate the interdependent work activities when needed. To do so we need explicit and dedicated focus on coordination as an issue in its own right. The discrimination is important when analyzing cooperative work with the purpose of establishing a basis for design of IT-support (i.e., redesign the functional allocation between actors and artifacts).

### *5.4 Coordination mechanisms: stipulation and mediation*

The basic assumption behind the ideas of coordination mechanisms is that a reduction of coordinative complexity can be achieved by means of a coordinative construct that stipulate the coordinative activities by means of a protocol and an artifact that functions as a communicative intermediary between the cooperating actors. How does this understanding of coordination match the coordination performed in maritime operations during manual steering of the vessel? To answer this question we will return to the role of the protocol and conceptualize the observed coordination in terms of stipulation and mediation.

Stipulation limits the needed coordinative reasoning by providing a predefined structure for the coordination to be achieved. The predefined and agreed-to structure guiding the verbal interaction between the Captain and the Helmsman can be considered a case of coordinative stipulation (a protocol). The communicative pattern stipulates coordination along the dimensions of structure and content of information exchanged. The initiation of the protocol – triggered by the need for a maneuver – is beyond the protocol; yet the

communicative protocol itself has been established to cover the exact communicative needs of this particular situation. The protocol reflects the anticipated need for communication during maneuvers – and in doing so, it limits the interaction between the Captain and Helmsman to a minimum. The protocol represents a predefined coordination flow that matches the required coordination. When the protocol is initiated during anything but very low speed it guides the actors in deciding who is to speak when – or rather, it provides the sequencing of coordinative utterances.

During manual steering at very low speed the communicative protocol is still engaged; yet it stipulates the communicative structure to a lesser extent. During this type of maneuvering the stipulation of coordination is to a large extent achieved by ways of the actors understanding of maneuvering itself and the mutual awareness in-between the cooperative actors. The issue of when to speak is still guided by the standard communicative protocol but at the same time the rigidity of the protocol is modified by the fact that a complicated assessment of the state of affairs in the field of work is ongoing. That is, the Helmsman will not speak up until the Captain has opportunity and capability to utilize the information. This will dependent on the state of affairs in the field of work as well as the state of affairs in the cooperative work arrangement.

The present level of analytical investigation suggests a functional correspondence between language- and artifact-based protocols; both can to some extent be characterized in terms of format, stipulation, and mediation. It is also clear however, that the expressiveness of the present analytical concepts will not suffice in a deeper analysis of the linguistic nature of the spoken protocol. The coordinative protocol stipulates the structural sequence of the interaction between the Captain and the Helmsman, yet it also provides a highly specialized and agreed-to phraseology that stipulates the communicative contents of the verbal coordination. The standardized phraseology reduces the complexity of coordination work for both the sender and receiver of the oral coordinative messages. The standard phraseology provides a relatively stable set of well understood statements that enables the sender to communicate in a very exact manner that at the same time reduces the potential of misinterpretations on the part of the receiver. This particular aspect of stipulation is not addressed explicitly within the existing Coordination Mechanism framework and it thus demands further attention in future work.

## **6. Conclusion**

The conceptual framework of Coordination Mechanisms is based on an understanding of a coordination mechanism as a protocol, encompassing a set of explicit conventions and prescribed procedures supported by a symbolic artifact with a standardized format. We have applied the concepts from the framework to situations from a field study of maritime navigation. The aim in this paper was to establish a basis for discussing the applicability of the framework as a means for analyzing oral coordination. The overall conclusion is that the framework proved useful for understanding several of the essential aspects of the coordination observed in the study. Our major lessons learned are summarized below:

It was fruitful to understand coordination needs by addressing the manifest and determinant work interdependencies that were to be coordinated, and by explicitly addressing the coordinative function (aim, basic constraints, etc.) of the procedures and the phraseology applied.

Actions in navigation are highly dependent on the state of affairs in the field of work. The analytical distinction between field of work and work arrangement supported the identification of relations between the work arrangement and the field of work, and thereby the interdependencies among the cooperating actors.

It also proved useful to analytically separate work and its coordination. By being aware of this distinction we were able to separate interaction having a coordinative purpose from interaction devoted to the fulfillment of the actual work activities required.

Understanding a coordination mechanism as a means that mediates coordinative information was somewhat problematic. As discussed in section 5.1.3 the standardized phraseology reduces the complexity of coordination by providing a stable set of well understood statements enabling the actors to communicate in a very exact manner, and this type of formalization of the interaction is highly important in work settings like navigation. The concepts supported understanding the general aspects of mediation and stipulation, but there are presently no means available for a deeper analytical understanding of the linguistic aspects of the phraseology.

Understanding a coordination mechanism as a protocol helped us to reason about the procedures and phraseology stipulating the interaction between the actors. We could thereby identify the different levels of rigidity obeyed depending on the situation.

Explicit focus on coordinative means is required in order to understand the anatomy of the oral means of coordination. These were not "visible" to the analysts (but audible). The means had to be extracted from the procedures and phraseology applied, i.e., one had to trace a communicative pattern through analyzing the actual content and purpose of the communication among the actors. The conceptual framework provided only little support for identification and characterization of the coordination means. The conceptual framework of Coordination Mechanisms has been developed to explicitly address the identification of artifact-based coordination mechanisms, whereas there is presently no notion of the 'oral coordination mechanism'. Henceforth, the identification of verbal mechanisms is, quite naturally, given less support. This is clearly an issue to be considered in further development.

Our initial findings indicate that the conceptual framework of Coordination Mechanisms provided good support for analyzing coordination activities based on spoken interaction. By refining and improving some of the concepts the conceptual framework can become a very useful analytical approach to characterizing spoken coordination interaction. Our findings need to be verified in other studies and other work settings before more clear-cut conclusions can be drawn. And it should, of course, be related to other approaches, e.g., theories and frameworks on verbal communication.

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