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Exploring 'Canned Communication' for coordinating distributed mobile work activities

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Abstract

Communication between physically distributed people in industrial and safety-critical domains is often spoken and mediated through walkie-talkies, or closed-circuit intercoms. Because this kind of communication is hampered by noise, radio interference, lack of persistency, etc. vital information is sometimes lost. In response to this challenge, this paper discusses the use of 'canned' text-based messaging as a supplement for improving such communication. Based on data from ethnographic studies of work activities in an industrial domain, and grounded in a theoretical model of communication, we have designed and evaluated a mobile canned communication prototype system facilitating exchange of predefined text messages, a persistent graphical representation of the operation in progress, and a filtered list of completed tasks. Results from two evaluations show that in the domain considered, canned text-based communication has a potential to supplement voice and assist in overcoming some of the inherent problems of spoken communication. Yet using a textual and persistent mode of communication also raises new challenges such as choice of modality, speed, flexibility and handling situations deviating from standard procedures.

Keywords: Canned communication; Mobile device interface; Text-based communication

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1. Introduction

Industrial domains are potentially interesting areas of applications for mobile information and communication technologies. Work activities in industrial domains often involve a number of distributed collaborating actors who are mutually dependent on access to computer systems remote from their current location and on knowledge about the activities and strategies of their co-workers. Typically this is supported only by spoken communication mediated through mobile phones, walkie-talkies or closed-circuit intercoms. As spoken communication is highly sensitive to noise, radio interference, interruptions, lack of persistency, etc. vital information may be lost in the transmission or missed by the receiver(s). Previous research has to some degree dealt with the extent to which distributed mobile users in industrial and safety-critical domains can benefit from handheld computer systems in situations where actors are concerned with computerized information and processes of critical importance remote from their current location. Examples include the use of mobile multimedia communication for telemedicine and early diagnosing in emergency ambulance services (van den Anker and Lichtveld, 2000), distributed process control and error diagnosing in wastewater treatment plants (Nielsen and Søndergaard, 2000), and the use of remotely controlled service robots for aiding disabled or elderly people (Hüttenrauch and Norman, 2001). Also related to this, the limitations of voice-based communication by capturing spoken utterances and integrating it with other data for creating persistent graphical representations have been suggested within areas such as air traffic control (Fields et al., 1999), and fire-fighting services (Champ et al., 2000).

In response to this growing area of interest within HCI, this paper explores the supplementary use of text-based 'canned communication' in a prototype system for coordinating work activities on large container ships: the Handheld Maritime Communicator (see Fig. 1). The idea for the Handheld Maritime Communicator emerged from a multidisciplinary research project involving an ethnographic field study on work activities in the maritime domain involving computerized process control and information systems (Andersen, 2000; Nielsen, 2000). On the basis of this field study, we explored the usefulness of handheld computers for supporting communication by complementing existing spoken communication with the use of predefined (or 'canned') text-based messages similarly to the way SMS and e-mail applications on mobile devices complement people's voice-based communication.

In the study reported in this paper, we describe and discuss the lessons learned from a first step in the direction of 'canned' communication aids designed for overcoming some of the limitations of spoken communication in industrial domains by supplementing it with a textual and persistent channel. Hence, the aim of the study presented in this paper has not been to develop a final solution to a well-defined problem and deploy this solution in the domain studied, but to gain experience with and a deeper understanding of the use of canned textual communication as a supplement to spoken commands. This is done through experimental design and evaluation of a prototype system—using the prototype system as a sort of 'technology probe' (Hutchinson et al., 2003) to prompt and study new communicational behaviour. This aim has influenced our research in several ways. Firstly, we did not try to change the

Fig. 1. Canned communication on a mobile device for use on maritime bridges.

structure and content of what was being communicated but intentionally replicated this directly in the prototype system focusing solely on the changed modality of these utterances (from audio to text) and the use of pre-defined commands (communication canning). Secondly, we did not pursue research into issues such as the physical form factor of the mobile communication device facilitating use in a potentially harsh outdoor environment, and the technical implementation of a network infrastructure working robustly within a physical environment dominated by large amounts of metal. We acknowledge that these (and other) issues are highly relevant for the development of new communication device solutions for the industrial domain, and welcome further research into these specific areas complementing our own endeavours within the use of canned textual communication.

In Section 2, we introduce the industrial domain studied and the specific work activities supported by our prototype system. This includes highlighting findings from the field studies related to limitations in current means for communication and coordination. Section 3 presents our analysis of the field data. In Section 4, we present the details of the design of the Handheld Maritime Communicator prototype, and in Section 5 we present two evaluations involving usability experts and prospective users. The findings from these evaluations are discussed in Section 6. Finally, Section 7 concludes on our study and point out avenues for further research.

2. Field study: Work activities on board a large container vessel

Maersk Line operates some of the world's largest container vessels of sizes equivalent to the length of five Boeing 747–400 Jumbo-Jets (Fig. 2). The operation of such

Fig. 2. Sine Maersk (347 m long and 43 m wide) in Gothenburg Container Terminal, Sweden.

vessels requires workers to be highly mobile and physically distributed. At the same time, however, work activities are often related to the use of computer systems located centrally on the ship. Thus, a strong motivation exists for exploring the use of mobile computers for supporting distributed work activities in this domain. Designing useable mobile computer systems for the maritime domain is not trivial. Work activities on large container vessels are typically safety-critical and involve high risks in the case of errors. Especially when manoeuvring inside a harbour, erroneous actions may result in the vessel running aground, into the quay, or colliding with other ships. In either case, this would cause serious material damage, potentially severe injuries on personnel, and possible loss of human life.

Qualitative investigations into work activities on a Maersk Line container vessel were carried out (Andersen, 2000; Nielsen, 2000). This included ethnographic observations of the application domain and interviews in situ from several voyages along the coastline of Europe. The field studies were documented through written notes and video recordings capturing overall views of the captain, harbour pilot and officers on the bridge as well as close-up views of the interaction with key instruments. The audio channel captured interpersonal communication on the bridge and VHF radio communication with the distributed crewmembers. In order to facilitate systematic analysis, a person with detailed insight into the application domain transcribed a selection of the video recordings. A partial transcription of the recordings from one short voyage within Europe amounts to approximately 200 pages.

Apart from informing new interface design for existing maritime instruments (Andersen and May, 2001) a number of work activities were identified in which the use of mobile computer terminals could be desirable. These included diagnostic and maintenance work in the engine room, surveying the condition of reefers during voyages, locating personnel in case of accidents, and supporting various distributed collaborative work activities. Of particular interest to the interviewed crewmembers, our attention was brought to the processes of departing from and arriving at harbour including the operation of *letting go the mooring lines* before leaving the quay because this operation requires a high level of communication within a predefined pattern between actors that are physically distributed on the vessel. Currently, this communication is based on spoken commands being transmitted through handheld VHF radios. Through analysis of several video recordings and interviews with officers and captains, a series of limitations in the present means for communication and coordination were brought to our attention, some of which could potentially be overcome by the use of mobile computer technology. Project stakeholders from Maersk Line and the participating university researchers therefore agreed that supporting this particular operation would be a suitable starting point for experimenting with the use of canned text-based communication.

In the following sub-sections, the operation of letting go the lines as experienced through the field studies is described in detail. This description served as an overall context for the use of the envisioned Handheld Maritime Communicator and outlined a number of challenges, which had to be addressed in the design of the prototype.

2.1. The operation of letting go the lines

When a container vessel is ready for departure, the first step in leaving the quay is to let go of the mooring lines that are holding the ship in position fore and aft (Fig. 3). However, as physical space is restricted and means for precisely manoeuvring large vessels are limited, all lines cannot simply be released simultaneously.

When a line is let go, it will remain in the water for a period of time during, which no means of propulsion is available due to the risk of lines getting sucked in and wrapped around a propeller or thruster. During this time, the vessel can only be manoeuvred by means of the remaining lines. Consequently, lines are released sequentially in accordance to specific need for manoeuvring in a given situation.

Due to the huge size of the vessel, the work tasks involved when letting go the lines are distributed among a number of mobile actors located at strategic positions, as annotated on Fig. 2. On the bridge (1), the captain and other personnel control the rudder, propeller and thrusters. Fore (2) and aft (3), the first and second officers control the winches for heaving in the lines. Ashore, two teams of assistants lift the lines off the bollards. To insure the safety of the operation, individual work tasks are carefully coordinated and carried out under strict command of the captain in charge.

At present, communication between co-workers is spoken. While people on the bridge can see and hear each other directly, personnel on deck are, however, out of direct visual and audio contact and have to communicate with the captain via walkie-talkies. In order to carry out the operation of departure in a safe manner, the captain needs an overview and total control over the propulsion, direction and mooring of the ship. While information about the rudder, propeller and thrusters

Fig. 3. The aft mooring lines of Sally Maersk (sister ship of Sine Maersk).

are available on dedicated instruments on the bridge no information about mooring is available. At present this information only exists as a mental model in the head of the captain based on his perception of the ongoing communication between bridge and deck. As this mental model is highly sensitive to errors or misunderstandings in the ongoing communication between bridge and deck, and since disparity between the captain's mental model and the real world may cause wrong decisions to be made, considerable cognitive resources are spent on establishing and maintaining *common ground* (Clark and Schaefer, 1989) among the cooperating actors. By common ground, we refer to the principle of entering and maintaining a stage of mutual knowledge, beliefs, and assumptions among communicating participants through a collaborative process of *grounding*, during which common ground is updated in an orderly way, by each participant trying to establish that the others have understood their utterances well enough for the current purposes (McCarthy et al., 1991). While it has been pointed out that it is not necessary to fully ground all aspects of a conversation, it is essential that 'The contributor and the partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for the current purpose' (Clark and Schaefer, 1989:262). What constitutes this criterion, of course, depends on the context of the situation and will necessarily vary with the collaborators' goals. As a part of the process of grounding, communicating partners have different means of providing evidence of mutual understanding including displaying what has been understood, acknowledging utterances, continuing with the next expected step of a given process, as well as continued attention to the conversation.

Supporting reaching and maintaining common ground, established rules and formalized procedures exist for oral communication such as, for example, confirming status reports and commands by repeating them back to their sender. However, as the size of vessels and the use of technology increases so does the complexity of systems controlling the ship and the cognitive overhead and amount of parallel tracks of communication required for its operation.

2.2. Findings from field studies of 'letting go the lines'

Through analysis of video recordings, transcriptions, and interviews with officers and captains, a number of key limitations experienced in the use of spoken communication for coordinating collaborative work activities were brought to our attention:

1. sound quality is often poor;
2. communication is not persistent and
   a. cannot be automated,
   b. is time consuming,
   c. suffers from bottlenecks on the bridge (multiple parallel tracks),
   d. suffers from language barriers,
   e. lacks integration with other systems.

As walkie-talkies and VHF-radios often lack sound quality, workers reported that misperceptions and misunderstandings between the actors often occur due to incom-

prehensible messages. This leads to a need for repeating statements and meta-communicating. Due to the ephemeral nature of spoken communication, the workers also reported that messages were easily and frequently missed because they were only available during the limited period of time when they were 'in the air' and were not persistent. After an utterance had been communicated the information only existed in the memory of the actors taking part in the interaction and was not publicly available for others who had not received the utterance when first stated. In addition to this, workers reported that spoken coordination could not be automated but involved actors remembering sometimes highly complex workflow and continuously deciding for whom specific information may be relevant at which time. Workflows coordinated through spoken communication are hard to support and reducing the coordination workload was reportedly difficult. Workers also stated that spoken communication was very time consuming and that they tried to minimize time spent on communicating in order to maximize the time available for work tasks. As a part of this, workers reported that they would sometimes cut messages short and only communicate fragments of information and rely on implicit meaning in the given situation. While known for limiting the 'air time' of communication this approach was also known for sometimes leaving people confused about the meaning of utterances requiring explanations and meta-communication. The use of spoken coordination was also reported to suffer from different types of bottlenecks. One type of bottleneck reported by the workers consisted of multiple people talking on top of each other on the same channel resulting in communication being cut up, and information being missed. Another, and more complex, bottleneck reported by the workers consisted of multiple parallel tracks of communication across different communication channels (e.g. radio messages between bridge and deck disturbing communication between people on the bridge and vise versa) complicating the regulation of turn taking. Due to the international nature of the domain, communication on board container vessels is usually conducted in a language different from the language being used by the local harbour pilot to communicate with other pilots, the pilot boat, tugboats, vessel traffic service, etc. This results in the captain having limited immediate insight into the domain of the harbour pilot and vice versa and introduces a need for ongoing translations between the captain and the harbour pilot. Finally, workers raised the issue that information delivered through spoken communication cannot be integrated with the vast amount of other information sources in the ship's computerized systems. While the captain can, of course, take spoken information about, for example, distances, angles, etc. to objects in the vessels immediate surroundings into consideration when looking at other instruments, this kind of information cannot automatically be made part of the computations regarding the ship's movements performed by the systems on the bridge. As a result, it was reported that the spoken information is usually not utilized to its full extent because it demands too many cognitive resources.

While some of these observed limitations may be unique for the studied context (e.g. language barriers), others apply generally to spoken communication within industrial domains. Overcoming or reducing these limitations served as an overall motivation for the experimental design of the Handheld Maritime Communicator.

Inspired by, amongst others, chat applications, newsgroups and short messaging service (SMS) we speculated that a possible supplement to the present use of spoken communication could be the use of predefined, canned text messages on mobile devices. Hence, text offers some advantages over voice, it is a flexible communication channel requiring low cognitive overhead (Churchill and Bly, 1999; Popolov et al., 2000), and it is not subject to the ephemeral nature of spoken utterances but is persistent. Furthermore, text-based communication can be done asynchronously as it fits in with other tasks or threads of communication and is not influenced by, for example, noise. On the basis of this, it was our expectation that some of the identified limitations could be eliminated or reduced by means of exchanging canned text-based messages and as a result more cognitive resources would be available for the other operations.

3. Analysis of communication

Motivated by the initial findings from the field study described above, we revisited the video recordings to investigate more thoroughly the communication and coordination of work activities related to the operation of letting go the lines and identifying structures and properties, which could help us overcome the identified limitations. Guiding this analysis, we focused particularly on the overall challenge of achieving persistency in communication.

Achieving persistency in communication means capturing the utterances of a conversation for later access (Erickson and Herring, 2006). While audio or video recordings of spoken conversations can preserve a very rich picture, textual transcriptions capture the essence, are highly concentrated, and facilitate fast browsing. On the downside, raw transcriptions offer little support for linking related utterances and maintaining overview of present state or outcome of parallel tracks of conversations. This is similar to textual communication in chat-like applications where achieving common ground can be problematic as discussed in McCarthy et al. (1991). On mobile devices the usefulness of raw textual transcriptions is further limited by small screen sizes. By relatively simple means of formalization, however, some of these problems may be solved. Based on the analysis of our video recordings and guided by literature on the topic, we found that at least three properties of conversations exist, which may be used for improving the representation of textual communication on a mobile device: (1) the aspect and tense, (2) the object and (3) the structure of conversations.

3.1. Aspect and tense of conversations

On an overall level, a conversation can be categorized by aspect and tense (Andersen, 2000), hence, a conversation is either imminent (future tense) executing (present tense) or ended (past tense). While executing (present) conversations are still open for negotiation, ended conversations imply some kind of mutual agreement having been made among the communicating parties. Though the process by which this

agreement was reached may be of interest, the essential properties of ended conversations are typically their outcome. Imminent (future) conversations are characterized by potentially being initiated when and if appropriate in relation to preceding conversations (ended and executing). In relation to interface design for persistent communication, this categorization enables us to separate different conversations and differentiate priority. In some situations, ended conversations may be important, while in others only executing tracks are of interest.

3.2. Objects of conversations

Communication consisting of a number of interweaved tracks of conversations can be difficult to overview when sorted from the sequence of utterances. This can be illustrated with the following transcription extract of three conversational tracks taking place in parallel:

1	< Captain >	you can let go the bow line
2	< 1st officer >	let go bow line
3	< Captain >	and you can take the stern spring
4	< 2nd officer >	letting go stern spring
5	< 1st officer >	bow line let go
6	< Captain >	bow line let go
7	< 2nd officer >	and stern spring let go
8	< Captain >	stern spring let go
9	< Captain >	you just let go the stern line also
10	< 2nd officer >	let go line aft
11	< 1st officer >	and we have the bow line home
12	< Captain >	Ok
13	< 2nd officer >	and all let go aft
14	< Captain >	all let go aft

Sorting these utterances by the objects of communication rather than their sequence, the following structure appears.

1	< Captain >	you can let go the <u>bow line</u>
2	< 1st officer >	let go bow line
5	< 1st officer >	bow line let go
6	< Captain >	bow line let go
11	< 1st officer >	and we have the bow line home
12	< Captain >	ok
3	< Captain >	and you can take the <u>stern spring</u>
4	< 2nd officer >	letting go stern spring
7	< 2nd officer >	and stern spring let go
8	< Captain >	stern spring let go
9	< Captain >	you just let go the <u>line aft</u> also
10	< 2nd officer >	let go line aft
13	< 2nd officer >	and all let go aft
14	< Captain >	all let go aft

Grouping text in accordance to object rather than sequence thus enables the creation of a more comprehensible representation of communication threads as seen in, e.g. email and newsgroups (Popolov et al., 2000). Designing for the limited space of a mobile device interface this principle is valuable, as it requires little or no extra space compared to the raw transcription. For a richer representation of sequence, absolute timestamps or timers may be needed.

3.3. Structure of conversations

A number of computer systems for communication have been designed on the basis of speech-act theory (see, e.g. Winograd and Flores, 1986; Frisse, 1988; Alm et al., 1992; De Michelis and Grasso, 1994; Jayaweera et al., 2001; Akhus, 2001). The basic idea of these systems is that conversations follow an overall structure of recurrence. Formalizing and modelling this structure in a computer system, the state of a conversation and possible speech-acts at a given time can be identified. According to Winograd and Flores (1986:65), the basic course of a conversation for action can be described in a diagram with nine different states (Fig. 4).

The conversation for action model describes a generic pattern of communication, where one actor (A) makes a request to another actor (B). The model then describes how the conversation between A and B can develop over time through the performance of speech acts, resulting in a number of different intermediate states and end situations. As emphasized by Winograd and Flores (1986), the relevant regularities proposed by this model are not in the individual speech acts (exactly what is being said and how it is being said) but rather on the overall level of the conversation, in which successive speech acts are related to each other. For more detailed

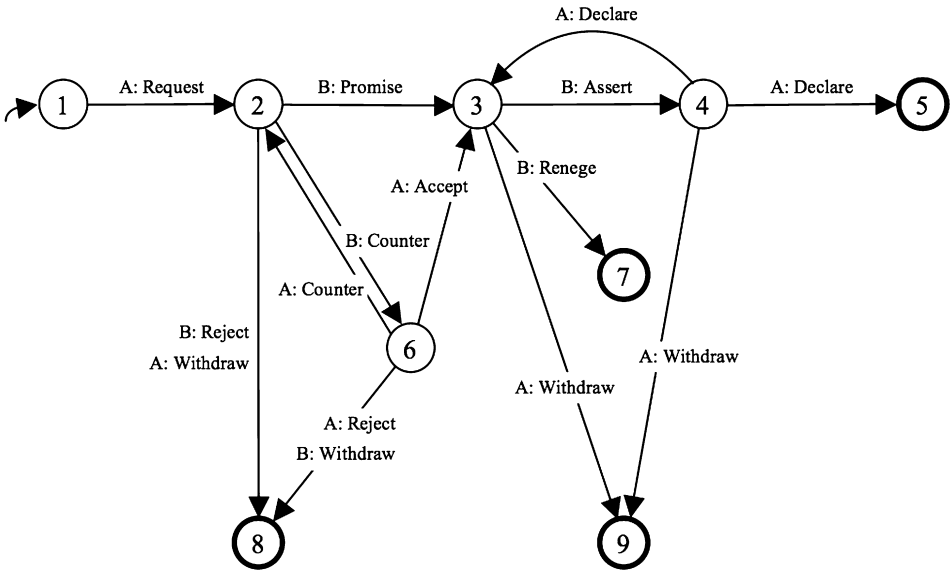

Fig. 4. Winograd and Flores' conversation for action (1986).

discussion of the speech-act theory approach to conversation modelling, see, for example, De Michelis and Grasso (1994), Winograd (1994), Suchman (1994), Denning (2003), or Goldkuhl (2003).

While we did not originally analyze our empirical data with the conversation for action model in mind, an object-oriented analysis (Mathiassen et al., 2000) of the problem and application domain produced, among others, a series of state-chart diagrams depicting structures in the tasks and communication patterns, which we quickly recognized from the work of Winograd and Flores (1986). Re-examining the video recordings in the light of the conversation for action model it became evident that the conversations taking place on the container vessel during the operation of, for example, letting go the lines, could indeed be mapped on to this structure. Hence, the conversation for action model was not enforced on the empirical data but emerged out of it. However, we also found that the recorded conversations between the distributed actors on the container ship did not involve rejection, withdrawal or counter orders. Thus, states 6–9 in Fig. 4 were not encountered in our field data. This was highly unexpected, but was confirmed by reviewing all transcripts of real-life casting-off operations (as well as other operations) and through interviews with domain experts. When asked about this issue, one of the captains stated that 'when I give an order, I mean it, and it is not up for negotiation'. Discarding the options of rejection, withdrawal or counter orders, we thus reduced Winograd and Flores' conversation for action model to a five state model corresponding to the formalized procedure for communication about 'execution of a direct command' observed in our field studies (Fig. 5).

The model of executing a direct command depicted in Fig. 5 applies to each track of conversation in the transcription from the field study above. Firstly, A requests the execution of a task (e.g. 'you can let go the bow line'), which B promises to fulfil ('let go bow line'), taking the conversation to state 3. Having fulfilled the request, B asserts to A that the execution of the task has been completed ('bow line let go'). Finally, A declares contentment ('bow line let go'), and terminates the conversation (state 5) or goes back to state 3, waiting for additional asserts from B ('and we have the bow line home'). Note that states 1 and 5 in this diagram correspond to the categories of imminent and ended conversations. States 2–4 correspond to executing conversations.

Formalizing a conversation in relation to a structure such as the general conversation for action model (Fig. 4) or the execution of a direct command model (Fig. 5) has a number of advantages in relation persistency and 'canning' of communication. First of all, knowing the state of executing conversations, this can be represented visually for persistent and fast access: has a request been met? has an agreement been

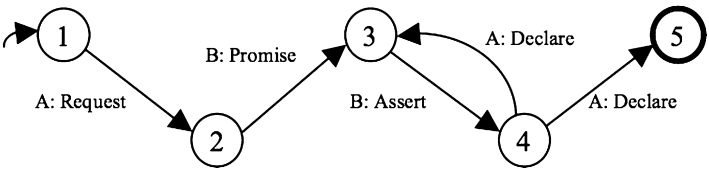

Fig. 5. Execution of a direct command.

made?, etc. This information can then be integrated with other data sources on the bridge. In relation to canning communication, possible future utterances may be deduced and prioritized over others in the form of predefined standard phrases as seen on some SMS-enabled mobile phones. Thus, demands for user-interaction may be simplified and reduced.

4. Canned communication prototype

Informed by the three principles described above, we designed and implemented a functional prototype, the Handheld Maritime Communicator, exploring the use of canned communication for supporting the operation of letting go the lines. This section describes the design of the prototype system.

The prototype was implemented in Microsoft eMbedded Visual Basic allowing it to work on any PDA running the Microsoft PocketPC operating system such as the Symbol PPT8800 industrial PDA series (Fig. 6). Apart from a touch screen, such industrial PDA's typically support interaction by means of large rubber buttons located below the display and suitable for one-handed interaction. Due to the potentially harsh conditions of the use domain, we decided that all interaction should be facilitated by the use of these buttons. On the Symbol 8800 this would mean that the two-way button would browse the list of possible commands and clicking on the large button below it would select the highlighted item. Though aware of the fact

Fig. 6. Canned communication prototype: the Handheld Maritime Communicator on a Symbol PPT8800.

that the final system would probably need to run on a custom-built, solid and weather resistant device and also have a built-in radio for voice-based communication in emergency situations, we decided that for a proof-of-concept prototype, experimenting with off-the-shelf hardware would be sufficient.

4.1. System architecture

The application running on the captain's device works as a server containing a formalized representation of the operation and patterns of communication. All other devices (for example, those on deck) log on to this server and identify their physical location following, which an appropriate interface is displayed on them. During the operation, function calls and unique command identifiers are exchanged in real time over the network. Thus, the problem of commands being missed in the air due to poor sound quality is eliminated. All network communication is broadcast to all devices on the network but processed and represented differently on each device in accordance with their physical location (bridge, fore or aft). While on the first prototype the devices all displayed the same representations (but different possible commands), this architecture would make it possible for us to change the representations and modality used on each individual device, in accordance with, for example, the location of the user, in future iterations without having to change the underlying code. Also, another feature of the exchange of unique command identifiers is that the desired language can be defined individually on each device, thus reducing potential language barriers between co-workers by commands being automatically translated. The desired language is specified in a simple text-file on each device and is thus easily extendable and modifiable.

4.2. Interface design

The Handheld Maritime Communicator prototype (Fig. 6) gives distributed workers on the container vessel access to a mobile text-based communication channel and provides a graphical representation of the ship and its mooring lines. Supporting bystanders 'listening in' on the communication, all communication is broadcast on the network as it unfolds. The overall design was based on two key ideas: (1) to supplement verbal communication with exchange of predefined, canned, text messages, and (2) to provide a simple representation of the work activities in progress in order to improve the distributed co-workers' reasoning about the ongoing operation as suggested by Rasmussen (1983). This supports human interaction rather than total system automation as discussed by Norman (1990). Meeting these suggestions, we designed an interface providing the user with access to a graphical representation of: the operation in progress; multi-threaded textual communication; a filtered list of completed tasks; and a selection of canned communication utterances.

The interface is divided into four sections resembling the tense of conversations:

1. pictogram of ship and mooring (present);
2. list of completed communication threads (past);

3. list of ongoing communication threads (present);
4. list of unexecuted commands (future).

The user interface for the bridge is illustrated in Fig. 6. At the bottom of the screen (immediately above the navigation button) unexecuted pre-defined standard commands and pending confirmations are displayed on a list. The order of the list corresponds to the standard sequence of the overall operation, and possible utterances only appear when appropriate in relation to the state of the task and the location of the specific device (bridge, fore or aft). By default, the most likely next step of the operation is highlighted. The list can be browsed with the navigation button and the highlighted utterance is executed (sent) when pressing the select button. When a command is executed, it is removed from the list and the most likely next step is highlighted (as illustrated in Fig. 7). Thus, the interaction required during standard procedures is limited to a minimum.

The list of ongoing tasks is perhaps the most important element of the interface. Here, inspired by newsgroups and multi-threaded chat applications, ongoing threads of communication are represented textually. As suggested in the discussion above, executing (present) conversations are grouped in accordance to the object to which they refer rather than by sequence (Fig. 6). Displaying parallel communication threads textually this way reduces the bottlenecks observed when multiple people speak simultaneously.

The representation of each thread of communication furthermore reflects the five stages of conversations for actions identified through the analysis. When a new command is executed (a request), it appears on the list of ongoing threads of communication representing uncompleted tasks. Next to it, a counter displays the time passed while waiting for confirmation (Fig. 8a). When a command is confirmed by repeating it back to the captain (a promise) the timer is substituted by the text '[ok]' followed by a description of the current activity (e.g. 'Singling up...'). A counter next to this displays the time passed since confirmation (Fig. 8b). When a task is reported com-

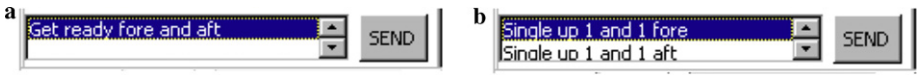

Fig. 7. Executed commands being removed from the command list and new commands appearing.

Fig. 8. Commands being executed (a), confirmed (b), completed (c) and confirmed (d).

pleted (an assert), a short statement (e.g. '1 and 1 fore') substitutes the description of activity and the captain is prompted for confirmation (Fig. 8c). When the completion of a task is confirmed by repeating it back to the deck (a declare) this is indicated by the text '[ok]' (Fig. 8d). As a feature of this design the list of ongoing tasks displays not only raw communication but also the present status of each command being executed.

When the captain confirms the completion of a task, the corresponding thread of communication is removed from the list of ongoing tasks and added at the bottom of the history list (Fig. 9). Hence, it changes from present to past tense. The history list automatically filters itself to contain only the initiating commands and subsequent outcomes by removing information such as timers and confirmations (promises and declarations), thus reducing the complexity of the user interface. When the history list is full, it automatically scrolls the oldest commands and statements out of immediate sight. The list can be scrolled using the navigation button together with a function button.

At the top of the screen a simple pictogram graphically represents the lines attached to the quay for quick reference. Additionally, the overall status of mooring is shown textually (Fig. 10). This representation is generated from the formalized outcome of past and present threads of communication and supports different levels of abstraction in the interaction with the system. In future design, this information could be integrated with other systems on the ship or made available to others (e.g.

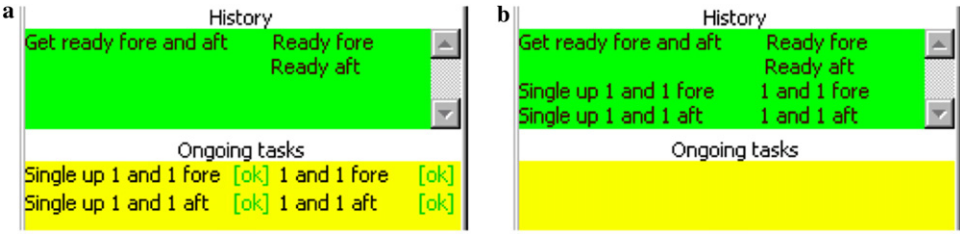

Fig. 9. Completed threads being added to history.

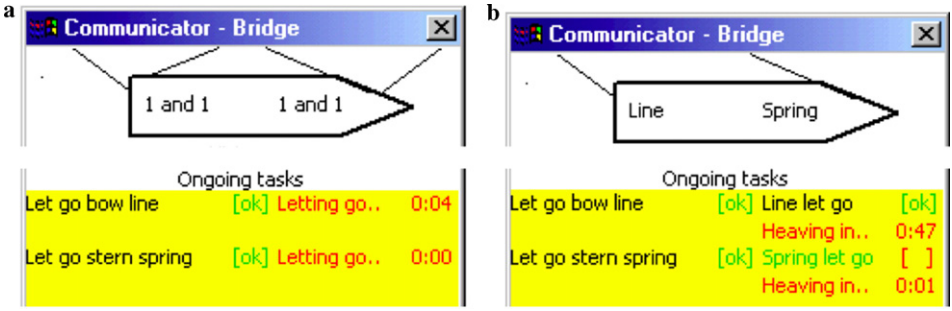

Fig. 10. Pictograms of current status of mooring.

harbour traffic control). While only containing redundant information that can also be deduced from the textual descriptions on the display, the graphical representation facilitates an overview of the present situation, which is not currently available on the vessel.

The interfaces on deck are very similar to that on the bridge thus providing the first and second officers with a view of the present status of the mooring and a list of all past and ongoing communication among the distributed actors. In the list of ongoing tasks, however, officers on deck are requested to confirm commands executed by the captain such as 'let go bow spring'. Correspondingly, the list of pre-defined commands only contains those appropriate at the specific location at given states of the operation—e.g. 'confirm: let go bow spring' for confirmation of the latter command or 'spring let go' for reporting the completion of this task.

5. Evaluation studies

Evaluating the use and usability of a mobile device for an industrial and potentially safety-critical domain is a major challenge. Firstly, field evaluations of an early stage prototype such as the one described here could cause a hazardous situation. Secondly, evaluating mobile systems in the field limits means of control and significantly complicates data collection (Kjeldskov and Stage, 2003; Kjeldskov et al., 2004). Because of these issues, Maersk-Line did not want to evaluate the prototype on board their container vessels at this stage of the project but preferred studying the use of the prototype in the safe and controlled settings of a high-fidelity ship simulator used in their training programs. In addition to this, it was decided to complement the study of use by real users in a highly realistic simulation using a heuristic expert evaluation focusing on potential usability issues of the prototype design.

5.1. Heuristic inspection

For the expert evaluation, we applied an established method for heuristic inspection developed by Nielsen and Molich (1990). The aim of this approach was to test the basic design of an interface using few resources and without involving users.

The heuristic inspection was conducted by a team of three usability experts holding master degrees in computer science with specialization in HCI. The team was given a 15-min introduction to the use domain covering basic maritime concepts, the operations to be supported, distribution of work, and present procedures of communication (Fig. 11, left and centre). They received no instructions on how to use the prototype. Aided by a standard heuristic for usability design (Dix et al., 1998), each person spent one hour checking for usability problems while using the prototype. Following the inspections, the team spent one hour producing a final list of problems.

5.1.1. Results

All three inspectors were able to use the prototype on their own and expressed that the interface design was intuitive and provided overview of ongoing activities

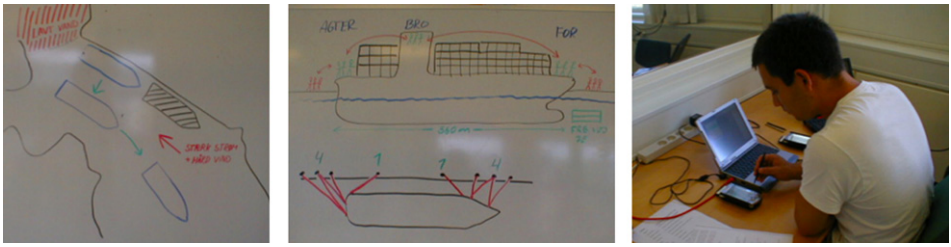

Fig. 11. Heuristic inspection: instructions on whiteboards and inspection set-up.

and the status of the ship. Twenty-seven usability problems were identified. These were primarily about the graphical design and dialogue between users. Firstly, the history list was criticized for fragmented information, unclear direction of sorting and absence of timestamps. Furthermore, the expert team found the depiction of the ship and mooring lines lacking detail regarding activities (e.g. a line being heaved in). Secondly, errors occurred because the system did not prohibit some commands from being issued before the necessary preceding operations had been completed. On the other hand, further flexibility for deviating from standard commands and sequence was also found desirable. Especially options for withdrawing or correcting commands were found missing (which was, of course, interesting in the light of the discussion of that particular issue with the domain experts during the ethnographic field study). Thirdly, the inspectors were uncertain whether the users would understand compressed statements, different technical terms describing the same objects, and requirements for implicit knowledge. Finally, the difference between confirming receipt of a command and reporting the completion of the related task was found to be unclear because of linguistic similarity.

5.2. Evaluation with captains and officers in ship simulator

While the heuristic inspection provided us with input about the usability of the screen design of the prototype valuable for further refinements, the most interesting and important evaluation study was, of course, the one carried out with real users in the ship simulator. For this study, we used a state-of-the-art ship simulator facilitating a fully equipped bridge and a high-fidelity interactive scenario of the operation of a large vessel to create a highly realistic yet controllable and safe environment thus combining strengths and benefits from both in situ and in vitro studies (Fig. 12). This approach is similar to other prototype evaluation studies of human–computer interaction design for industrial and potential safety-critical domains carried out in full-scope training simulators (for a recent example, see Norros and Nuutinen (2005) on the use of a nuclear power plant simulator for evaluating an experimental safety information and alarm system).

While we could not study the use of the prototype in the real world, we went to great lengths to ensure that the evaluation in the simulated use context was as realistic as possible. This was done by firstly, by developing a highly realistic and chal-

Fig. 12. Use in a ship simulator: the simulator and the video recording.

lenging scenario for the evaluation, simulating real world phenomena from the intended use context at a high level of fidelity. The scenario was developed in collaboration with Svendborg International Maritime Academy, which produces some of the most highly educated maritime officers in Denmark, and runs the simulator facility used for the evaluation. Secondly, the test subjects recruited were high-ranking real prospective users with several years of real life experience with the operation of very large commercial vessels as either captains or leading officers.

The ship simulator consisted of two separate rooms: a simulated bridge and a nearby control room. The bridge was fully equipped with controls for thrusters, propellers, rudder, etc. as well as instruments such as dobler log, echo sounder, electronic maps, radars, VHF radio, etc. From the control room, simulator operators could see the bridge on a closed circuit video surveillance system. The computer application driving the simulation made it possible to simulate the operation of any computer-modelled vessel at any modelled physical location. Also weather and dynamic traffic conditions could be included in the scenario.

The evaluation in the ship simulator involved six test subjects, divided into three teams of two experienced captains and maritime officers, given the task of departing from harbour using the prototype system for communication between bridge and deck. The captains were on the simulator bridge and the first officer was in a neighbouring room set-up to simulate the fore deck. As a part of the realistic scenario developed for the evaluation, the captain had to consider all aspects of manoeuvring the ship. This included controlling the rudder, propellers and thrusters as well as communicating with personnel on the ship, harbour traffic control, etc. and keeping clear of and taking into consideration the movements of other vessels. The first officer on deck had to orally forward commands executed by the captain via the mobile device prototype to the operator of the simulation (acting as the team of assistants carrying out the actual tasks) and report back to the captain. The operator would then enter the commands into the simulation (making the vessel respond differently to controls on the bridge as it would in the real world), and report to the first officer when the requested operations (such as letting go a line) had been carried out. For simplicity, commands targeted at the second officer were fed directly into the simulation with feedback given by the operator. The duration of the evaluation sessions corresponded to the length of the operation if it had taken place in the real world.

The simulator was set-up to imitate the operation of a large vessel in challenging weather and traffic conditions corresponding to a real world situation observed during the field studies (Nielsen, 2000) merged with scenarios used for training at the Maritime Academy. During the evaluations, the captains and officers were asked to think-aloud, explaining their actions and their use of the prototype. Two evaluators located on the bridge and deck, respectively, observed the captains and officers and asked questions for clarification. Total views of the bridge, deck, simulator control room as well as close-up views of the mobile devices were captured by four video cameras and merged into one video signal providing a synchronized view of the whole set-up (Fig. 12, right).

Following the evaluation sessions, a semi-structured group interview of 10–15 min was carried out reviewing the whole operation and discussing the use of canned communication as a supplement to spoken communication.

Data from the user-based evaluations was analyzed qualitatively and quantitatively by two researchers in collaboration producing a ranked list of usability problems as experienced by the captains and officers. Data from the interviews was analyzed qualitatively by (1) relating responses to associated usability problems and thus providing a more detailed account for them, and (2) extending the scope of the evaluation session findings (which traditionally tend to focus on problems rather than on potentials) with a set of themes related to user acceptance and ideas for extending and refining the design.

5.2.1. Results

Observing the use of the prototype by prospective users performing a realistic operation in the simulator provided rich data on the usability of canned communication for coordinating distributed work tasks. First of all, the user-based evaluation showed that it was possible to communicate primarily by means of canned text messages while doing a real-world operation. Secondly, the captains and officers expressed that the text-based channel of communication and the graphical representation of the ship gave them advantages compared to the walkie-talkies. Generally, the captains and officers learned to operate the prototype within the completion of one to two threads of communication. The differentiation between future and present commands appeared intuitive as well as the use of parallel threads of communication and technical notions. The pictogram was highly appreciated for providing a quick overview. The desire for more detail about, for example, what people were *doing* fore and aft was expressed both during the evaluations and in the post-evaluation interviews. At the same time, however, the threaded strings of conversations were found to be indispensable supplements to the pictogram for more details while the history list was rarely used and thus took up valuable screen space. In response to the automatic translation of commands between two languages (Danish and English), the officers and captains reported in both the evaluation and in the post-evaluation interviews that this appeared completely transparent to them.

The simulator evaluation revealed 22 usability problems experienced by more than one user. Firstly, we identified a need for correcting or withdrawing commands

(again, this was interesting in the light of the findings from the ethnographic field study). Also, we identified a need for requesting or reporting something out of the ordinary. Moreover, a number of standard commands were missing, for example, dismissing a team or requesting a status report. Thus, some captains and officers used the radio to retract a command or notify that a command could not be executed. Secondly, we observed that while all captains and officers executed commands or reports straightforwardly, the procedure for confirming having received a command or report was unclear in the current design of the prototype where those possible utterances appeared in the same list as possible commands. Most of the captains and officers did not immediately notice these new confirm options in the list of commands. One officer misinterpreted it until it was explained to him. One of the captains did not confirm reports from deck until four or five had piled up. On deck, this lack of feedback caused doubt as to whether or not reports had been successfully received. Finally, some officers on deck expressed that while textual communication supported overview and persistency, having to look at the device for reading an incoming command was not always ideal. In the post interview they expressed that they would like to be prompted by, for example, a synthetic voice in combination with the option of looking at the device to get a complete overview when it suited them.

6. Discussion

The two usability evaluations and discussions with prospective users and domain experts revealed several interesting results about the use of canned communication and provided substantial input for refining the prototype system. Canned communicating reduced many of the problems listed in Section 2.1. For example, it was obvious that the problems of poor sound quality and lack of persistence were eliminated and that partial automation by automatically suggesting commands proved possible. Furthermore, the graphical representation of the operation successfully supported maintenance of common ground. At the same time, however, interesting new challenges of canned communication also emerged. Below, we discuss some of these challenges and present some of our ideas for improving the use of canned communication.

6.1. Limitations of canned communication

Designing a text-based mobile messaging system for canned communication turned out to be an interesting challenge. As described above, the prototype is based on a reduced version of the conversation for action model. While this model provided a valuable foundation for structure and design, our evaluations also indicated a number of shortcomings, some of which have previously been discussed in the CSCW literature (Winograd, 1994; Suchman, 1994). The current design of the communicator did not support the handling of three types of non-standard situations. The first was retraction of a command. Even though our field study and interviews

found this to be unnecessary, the usability evaluations showed that this was not the case and that the captain may indeed want to modify or withdraw a command that had already been issued. A full implementation of the conversation for action (which would be technically trivial) would facilitate this. The second was error prevention. The change from continuous and open radio communication to discrete and closed text-based communication seemed to increase the risk of stating a wrong command (it is easier to select a wrong item on a list than to accidentally state a wrong command verbally). The third type was unanticipated communication. In an emergency situation, communication changes from asynchronous to immediate because the situation develops quickly. In this situation, the benefits of canned communication will be overshadowed by its limitations and communicating unconstrained from pre-defined messages will be necessary.

The evaluations also indicated some risk of task interference. When auditory communication is replaced with screen-based interaction some of the user's visual attention is diverted from the task being conducted to interacting with the mobile device. The captain and officers are already watching crewmembers, instruments, mooring lines, other ships, etc. In addition, they are watching their own physical actions. While relieving the highly busy auditory channel by introducing text messaging, having to look at a screen to handle communication puts additional burden on the users' vision, which in some situations may not be appropriate. In response, officers and captains suggested combining the two in a flexible manner.

6.2. Improving canned communication

The two evaluations and the post-evaluation interviews provided massive input for improving canned communication. Some of these are simple and closely related to the specific interface design of the prototype. Firstly, the history list may be hidden in a sub-menu thus freeing up valuable screen real estate. Secondly, the graphical representation could be extended to include more detail and, for example, reflect ongoing work activities. Thirdly, in order to bring attention to pending confirmations, these should be separated from commands, for example, by displaying them in two separate lists. Other problems are more general and complex, and require the development of new ideas and further evaluations.

6.2.1. Modifying and withdrawing commands

The lack of facilities for handling non-standard situations was found to be a key problem. Some of this problem would be solved trivially within the present overall design by implementing the full conversation for action model (Fig. 4) rather than the reduced execution of a direct command model (Fig. 5). A facility for modifying or withdrawing an issued command could then be included by introducing a special type of command that aborts an ongoing command and sends out a counter-order. If an error occurs frequently and is handled in a standardized manner, it can be integrated in a way that is similar to retraction. Otherwise, it must be handled as a case of unanticipated communication. The whole issue of modifying an issued command naturally raises the question of what happens if someone sends a wrong command?

This can take time to correct and result in wrong actions to be taken. Essentially the need to modify or withdraw commands is not a new challenge emerging from the use of textual communication but also applies to spoken communication. Hence, the use of canned communication does not introduce this challenge as such but merely inherits it. However, as canned communication based on selecting an utterance from a list rather than speaking it out may introduce a problem of commands being sent *by mistake*, a central challenge of building in the full flexibility of the communication for action model will be to produce a design that minimizes the risk of this happening, for example through a prompt for confirmation. What also needs to be considered in the design of communicator systems such as the one presented here is who has the overriding power to modify or withdraw a command? Does this privilege apply to everyone or just to the one issuing the order in the first place? In implementing the full conversation for action model, the ability to modify or withdraw a command would be distributed on all communicating actors through (potentially infinite) loops of negotiation.

6.2.2. Flexibility

Related to the need for modifying and withdrawing commands on a structural level, the use of canned communication also raises new challenges in relation to the flexibility of communication. Unanticipated communication, for example in emergency situations, seems to require flexibility and thus conflicts fundamentally with the motivation for using canned communication which takes advantage of the structures of standardized conversations to make it persistent, freeing up resources for other tasks. While new utterances may, of course, be 'canned' in the system over time, it is very likely that new exceptions will also continue to emerge, thus eventually making the complexity handling the number of possible canned utterances outweigh the reduction of complexity gained from using them. Thus, other means of supporting flexibility should be considered.

As suggested throughout the paper, canned communication in industrial domains such as the one explored here should not be seen as a replacement of spoken communication but as a supplement. Hence, one way of dealing with the flexibility issue is integrate facilities for radio communication *directly* in the mobile device and simply revert to this for communication out of the ordinary. In fact this was exactly what happened in the ship simulator. Combined with facilities for withdrawing a command, as discussed above, this would give the communicating partners full flexibility on top of a baseline persistent channel of communication. However, as human perception and action are to a large extent driven by expectation (Oatley, 1979), strong expectations about what channel to use in which situations is needed among the co-workers for such a multi-modal communication channel to work.

Another way of increasing the flexibility of canned communication is to look at the syntax of the individual speech-acts themselves. In the operation of letting go the lines, for example, commands typically consists of (1) *actions* (get ready, let go, etc.), (2) *objects* (spring, line, etc.) and (3) *locations* (fore, aft, etc.). Taking this differentiation into consideration, it would be possible to let the users create their own speech acts by combining a selection of actions, objects and locations rather

than canning *complete* similar speech acts (such as 'let go spring aft' and 'let go line aft') as separate instances. On the interface level, this could be done in a very simple manner by replacing the single menu of possible commands with three menus of possible actions, objects and locations.

6.2.3. Minimizing task interference

In order to reduce task interference, the use of alternative input and output devices could be considered. The requirement for visual attention towards a handheld device could be reduced by means of a wearable head-up displays or speech synthesis, and extending the device with a headset and voice recognition could support hands-free interaction while still maintaining the benefits of computerized persistent communication.

The discussion of alternative input and output media and modalities also raises an interesting question of whether all collaborating parties actually need the same representation of information, modalities and means of interaction or if differentiating between these in accordance to the context of each individual user would be preferable. Based on our findings from the evaluations, there are good reasons to explore solutions where, for example, officers on deck get commands delivered primarily through synthetic speech (allowing for the benefits of canned communication) while also having access to a secondary visual (and hence persistent) representation of the ongoing tracks of conversations in the form of text or a graphical representation of the vessel and mooring lines, or both. On the bridge, our field studies showed that during operations involving multiple physically distributed mobile collaborating actors the audio channel is the busiest one compared to the visual one. At the same time, it is the captain who has to keep track of most parallel tracks of communication. Hence the captains, not surprisingly, attached high value to the graphical representation of ongoing threads of communication and especially to the representation of the current status of the vessel. In relation to this, it would be interesting to investigate whether improving the graphical representation of the vessel could make the textual threads of utterances redundant. Also, as the bridge typically accommodates a physically co-located group of people (captain, harbour pilot, helmsmen, and sometimes machine engineers) clustered within a few meters, complementing their mobile devices with larger situated displays could provide a useful means for maintaining common ground and facilitating asynchronously 'listening in' to secondary tracks of communication and thus staying 'in the loop'. Because the utterances are already persistent and formalized within the computer system, translating between input and output media and modalities would not be difficult to implement (as described in Section 4.1).

6.3. Canned communication in industrial domains revisited

The presented mobile device was designed and evaluated for a specific industrial domain: the operation of large container vessels. This domain is characterized by activities proceeding at regular pace leaving time for the involved actors to read and comprehend written communication. Also, established procedures exist and

communication is formalized. In the case of emergencies and other non-standard events, this pattern is broken and workers should shift to spoken communication. Other industrial domains may have different characteristics. There may be more people involved, a much higher level of stress, and need for rapid concerted action. In such domains, the ephemeral nature of audio may sometimes be an advantage and actors may benefit more from sharing information by overhearing other people's communication than we observed in the maritime domain where multiple clearly separated channels of communication were used to contain communication to specific and delimited groups of co-workers. The auditory communication also provides the listener with an impression of emotional state, identity of the speaker, and ambient noise, which may or may not be important issues to consider. These aspects illustrate that the design of a mobile communication device for one industrial domain cannot simply be transferred to another without further consideration. Comprehensive studies and analysis of the domain in question must be carried out, designs must be tailored to the unique features of this domain, and substantial evaluation studies must be carried out to validate the quality of the design and inform further refinements.

7. Conclusions

Based on a thorough ethnographic study we have explored the use of 'canned communication' in an industrial and potentially safety-critical domain through the design and evaluation of a mobile prototype system. The prototype system supplements spoken communication with predefined, canned, text messages and provides a persistent graphical representation of an operation in progress and a filtered list of completed tasks. Two qualitative evaluations were conducted, a heuristic inspection and a user-based evaluation in a high-fidelity simulation of the use domain, providing rich and varied input on the potentials and limitations of canned communication for coordinating distributed and mobile work activities. Together, the two evaluations clearly indicate a series of advantages of canned text-based communication over spoken communication, but also bring attention to a number of challenges for canned communication regarding, for example, flexibility and task interference.

The mobile device was designed for a very specific and specialized domain but the concept of canned communication, as well as the central design ideas of the prototype system have value for the design of persistent mobile communication systems in general. In particular, the grouping of communication threads and the generation of a graphical representation, which integrated physical location, language, role and task proved to be highly useful. In order to increase the generality of our findings, additional studies of canned text-based communication on mobile devices should be conducted in both similar and different domains. The simulator-based usability evaluations should also be complemented with real-world evaluations over longer periods of time investigating the long-term use of canned communication. While requiring a very refined and stable prototype system, such evaluations might provide

a basis for assessing other relevant factors such cognitive workload and possible reductions in time spent on communication, as well as identifying further benefits and challenges of canned communication.

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