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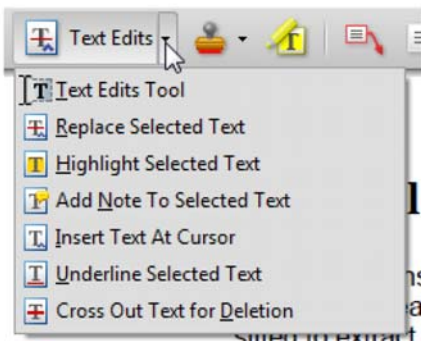
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Participatory safety barrier analysis: a case from the offshore maritime industry

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This paper argues that a participatory approach directly involving employees in safety barrier analysis can provide ‘added value’ to traditional barrier analyses. Employee participation (EP) could motivate employees to use their knowledge, suggest improvement measures and express their concerns. EP has not received much attention from safety researchers, although one may find several indirect arguments for EP informing the influential safety theoretical perspectives. An example of how participatory safety barrier analysis can be completed and what can be accomplished through such an approach is illustrated via a case study from an offshore logistics chain, and by an analysis of barriers that should prevent collisions between supply vessels and offshore installations. Such collisions could be the initiating event for a major accident. The empirical foundation for the paper is a hazard identification technique session, group and individual interviews, document studies and two search conferences involving approximately 150 participants. It is argued that a participatory approach to safety barrier analysis can reveal ‘holes’ in the defences that otherwise could have gone overlooked, and contribute to the generation of contextualized, definite measures that could strengthen a safety barrier system.

Keywords: barrier analysis; participation; maritime industry; action research

Introduction

Safety barrier analysis is generally regarded as an activity for competent experts, to be conducted as part of an integrated risk analysis. Fault tree analysis combined with the identification and scoring of risk-influencing factors are two methods used toward this end (e.g. Aven, Sklet, and Vinnem 2006; Johnson 1980). This ‘expert approach’ to safety barrier analysis provides valuable input, informing managers’ decisions regarding measures meant to be risk reducing and preventive.

The establishment, monitoring and maintenance of safety barriers are dependent, however, on concrete actions taken by all employees, representing all organizational levels and crossing different barrier types, including technical, organizational and operational safety barriers. Employees’ actions with regard to barriers rest on their awareness of the barriers existence, comprehension of their proper functioning and acknowledgement of the fact that they can exert influence over them.

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One important element in successful safety improvement interventions identified in previous research is the presence of constructive dialogue between sharp-end workers and management (Hale, Guldenmund, and Loenhout 2010). Employee participation (EP) and involvement in safety barrier analysis can serve as a vehicle for the development and maintenance of safety barriers, as it focuses employee attention and activates relevant knowledge. This paper will use a case study involving an offshore logistics chain to illustrate how a participatory safety barrier analysis can be conducted, and what can be accomplished through such an approach.

The case study contained in this paper examines the offshore logistics chain of petroleum company operating on the Norwegian Continental Shelf. A major accident scenario in this activity is collisions between supply vessels and installations. Such collisions could lead to extensive structural damage, capsizing and, in extreme cases, extensive loss of life.¹ Several layers of safety barriers have been established to avoid such collisions.

Using a hazard identification technique (HAZID) methodology, documentary analysis, interviews with 47 different actors in the logistics chain and search conferences involving 152 participants, collision prevention barriers have been identified and evaluated. These activities laid the foundation for the suggestion of several measures expected to improve the functioning of the barriers. The participating actors include onshore and offshore personnel from the petroleum company as well as crew members on the supply vessels. The study was conducted in the period from August to December 2011.

Theoretical background

Safety barriers

Safety barriers can be defined as ‘physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents’ (Sklet 2006, 496). They include physical devices, human actions and administrative procedures meant to protect vulnerable targets from harm. Functionally, safety barriers perform tasks, such as preventing vessels from colliding with offshore installations. Such functions are performed by different barrier elements which, in totality, constitute a barrier system (Rosness et al. 2010).

A ‘defence in depth’ strategy is commonly applied in the petroleum industry to prevent the occurrence of major accidents. According to Reason (1997, 12), major accidents occur as a result of failures in multiple layers of the defences separating potential hazards from people and assets. Accident trajectories pass through ‘holes’ in these defences, created by active failures – errors and violations – and/or latent conditions, such as design flaws and unworkable procedures.

We consider several barriers established to prevent collisions between vessels and offshore installations in the offshore logistics chain studied in this paper. For analytical reasons, these are divided into two groups: (1) *specialized* safety barriers, whose sole purpose is to avoid such collisions and (2) *generalized* safety barriers, which serve differentiated potential functions, including collision prevention.

Employee participation

EP² in decision-making is a core element of a healthy corporate democracy. Historically, EP has been regarded as a vehicle for societal change and crucial for the

development of democratic values in general, as employees spend so much of their time in work environments (Pateman 1970). It has also been regarded as a means of improving working conditions and counteracting feelings of alienation on the part of workers (Blauner 1964).

The initial use of EP in a political and emancipatory fashion has since been supplemented by an organizational approach. EP is claimed to have the potential to increase work quality and productivity, as well as job satisfaction. Incorporating EP could motivate employees to use their knowledge, suggest improvement measures and express their concerns, as it meets certain basic human needs, such as self-actualization, social belonging and meaning (Sashkin 1984).

The effectiveness of EP will vary with the circumstances of its implementation. When first adapted from a health-promotion context (Jacobs 2006; Pretty 1995), five different levels were identified with increased employee influence on the process and end result: (1) participation by information, where employees are informed of an impending safety intervention by the employer, and can ask questions; (2) participation by consultation, where employees' opinions on an intervention are solicited, but the employer makes the final decision as to the best course of action to pursue; (3) functional participation, where employees are involved in developing the intervention, but the employer retains control over the process; (4) interactive participation, where employees and employer are equal partners in defining problems and devising strategies to address them; and, (5) self-mobilization, where employees organize an intervention and employers support it if asked.

Regardless of the level of EP, research shows that it should not be regarded as a 'magic formula' capable of solving all problems in an organization, including issues related to health, safety and the environment (HSE). Remmen and Lorentzen (2000) found that, when implemented in an industrial context for pollution prevention, EP could lead to positive changes in work routines, behaviour and environmental consciousness, but that such effects varied considerably between enterprises, based on their traditions of cooperation, mutual respect and the level of importance given to HSE issues. As EP demands knowledge, experience and training, and a level of maturity on both the individual and organizational level (Pasmore and Fagans 1992), it seems that different structural, relational and social hindrances could limit the potential of EP in HSE work.

EP in the context of safety theories

Participation and involvement by employees in safety barrier analysis is a topic that has not received much attention from safety researchers. While reference to this specific issue is rare in the safety literature, several indirect arguments favouring such an approach inform many of the most influential theoretical perspectives. In the following, some of these arguments will be identified, in order to ground our approach in existing safety theories. We also articulate a common aspect of these different theories.

The logistics chain we present here may be considered a sociotechnical system,³ and one may think of different strategies for describing such systems and their safety barriers. They may be described structurally, i.e. by the way they are designed and by formal descriptions of technologies and work processes as theoretical representations. Alternatively, they may be described substantially, i.e. by the way they appear and are managed in practice. The structural description may be

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5 informed by governing documentation, technical descriptions and interviews with
managers and designers. In substantial descriptions such as those adopted in this
study, the methodology could include observation of the work actually being done
and interviews or workshops with the people involved and participating in the sys-
tem. The participation and involvement strategy characterizing the current study is
argued for by multiple theoretical perspectives.

Structures are merely resources for action

10 Suchman (1987, 130) has richly documented the significant difference between the
structure and substance of sociotechnical systems using the terminology of plans
and situated action. One of her main arguments is that plans – representing struc-
tures – do not determine action, they merely represent resources for action, since
15 action is always situated in a sociotechnical, dynamic system and must be con-
stantly adjusted to fit ever-changing conditions. When transferred to the context of
evaluating barriers against collisions between vessels and offshore installations, and
when adopting the term ‘living barriers’ (Rosness, personal communication; see also
Rosness et al. 2008), one might claim that it is not sufficient to consider only the
20 work process/flow chart descriptions of barriers; one must also consider the way the
barriers in the system are enacted. A focus on the enactment of technical, human
and organizational barriers is further indicative of a sociotechnical perspective in sit-
uations where even the most technical barrier exists in a social context – that is, in
relation to other technical, human or organizational factors – and the function of
that barrier is shaped by those larger relationships.

25 *Sociotechnical systems are reflexive*

According to Reason, a safe culture as an informed culture implies,

... one in which those who manage and operate the system have current knowledge
about the human, technical, organizational and environmental factors that determine
the safety of the system as a whole. (Reason 1998, 294)

30 Reason thus underscores the reflexive dimension of a sociotechnical system. A
consequence of this perspective is that a system may not be able to be objectively
described from the outside, since the knowledge of its operators influences its
performance, including the performance of its safety barriers. The argument is
35 closely connected to Suchman’s view in the sense that the system is not defined
solely by its structural description: the knowledge of those who manage and operate
the system makes a difference to the actual constitution – and thus the safety – of
the system, since they are themselves parts of the system. This knowledge is
seldom included in structural, external descriptions. To describe and evaluate this
knowledge, it is necessary to go to its source: the employees.

40 *Work is characterized by trade-offs between efficiency and thoroughness*

Although standards and guidelines informing the operation of a system are meant to
be reflected in the actual operation of a sociotechnical system, modifications to
instructions and rules violations are frequent even in highly constrained high-risk

environments such as nuclear power plants (Hollnagel 2009, 359; Leveson 2004, 369). Although such actions may be seen as deviations and human errors that may cause accidents, in whole or in part, such behaviour can also be interpreted as both rational (Leveson 2004, 369) and normal (Hollnagel 2009, 359). Hollnagel has coined the term ‘efficiency-thoroughness trade-off’ as a means of explaining the rationale for normal performance variability. The point is that, in order to manage a sociotechnical system and to accomplish the goals in a timely manner, it is often necessary to deviate from prescribed work practices. Such adaptations influence the system and, if the ambition is to produce an accurate and relevant description of a system and its barriers, this may be taken as an argument that the descriptions need to be informed by the operators.

High reliability may attributed as non-explicit, cultural traits

In the aftermath of the Three Mile Island nuclear accident in 1979, and Perrow’s subsequent development of Normal Accident Theory (Perrow 1984, 65), a group of researchers initiated a study on industries and organizations exhibiting a remarkably good safety record considering the high-risk nature of the involved processes (La Porte 1996, 371; La Porte and Consolini 1991, 395; Roberts 1990, 292; Rochlin, La Porte, and Roberts 1987, 163; Weick 1987, 243). Research into these organizations resulted in several characteristics seen as explanatory for the extraordinary safety performances of these organizations and industries. One set of such characteristics – labelled the five elements of mindfulness (Weick and Sutcliffe 2001), are: (1) a preoccupation with failure, (2) reluctance to simplify, (3) sensitivity to operations, (4) commitment to resilience and (5) deference to expertise. While Perrow explained safety conditions in terms of structural and technical characteristics; high-reliability organizations’ research has shown that a safe outcome cannot be explained by static, technical descriptions of the processes. The ways in which humans – whether individuals or groups – think, act and collaborate during both normal operations and in crisis situations are found to have a decisive effect on the outcome of operations. These properties may not be evident in formal descriptions of the organization, since they are cultural traits that may not even be explicitly known to the organization itself, and since they are not necessarily so stable as to be immune to change as a result of practical drift (Snook 2000, 148) or the normalization of deviance (Vaughan 1996, 174). The identification of these characteristics – and, in turn, of the safety condition of the system and its barriers – may thus benefit from in-depth studies, including interviews and observation of actual work.

Barriers are sociotechnical constructs

Barriers such as those preventing collisions between vessels and offshore installations may be categorized as either or both material or social.⁴ As indicated above, however, there is rich documentation of the fact that few phenomena in sociotechnical systems may be regarded as purely material/technical or purely human/social. A barrier will always exist in a context and its use will be situated, that is, its function depends on circumstances that are not static and that thus may not be statically described.

Rochlin’s (1999, 233) reference to safety as a social construct is, perhaps, an exaggeration of the significance of the social at cost of the material, as purely social

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5 phenomena are as rare as purely material phenomena (for an elaboration on this
perspective, see e.g. Latour 1992, 287). Rochlin's reference does, however, direct
attention toward the point made here – namely that, in order to map and evaluate
the function of barriers within a sociotechnical system, it is necessary to be
informed by those who actually operate or are in different ways involved with the
barriers in the actual, practical work. The existence, condition and function of these
10 barriers depend on the knowledge and actions of these people.

As a result, the durability of barrier analyses in sociotechnical systems can be
limited. Even if the technical systems and the written procedures remain unchanged,
the practices constituting the barriers may change due to practical drift, normaliza-
tion of deviance, changing efficiency requirements or deteriorating knowledge, to
15 mention just some of the points of concern noted in the relevant literature.

What we have aimed to illustrate in this theoretical section is that safety barriers
may be seen as sociotechnical entities that are constructed and reconstructed
through their daily exercising. This implies that an analysis of safety barriers based
on formal descriptions alone will be insufficient and misrepresentative. Through EP
20 and involvement, safety barrier analyses may take into account the context, the situ-
atedness, the enactment, the reflexivity, the trade-offs and the cultural influence on
the shaping, function and effectiveness of the barriers.

The case: Identification and evaluation of safety barriers

The offshore logistics chain

25 Offshore installations have continuous need for equipment and bulk products used
in petroleum production, supplies of food and water, as well as the off-loading of
waste and environmentally dangerous by-products to be relocated to onshore pro-
cessing facilities. The logistics chain established for these purposes includes multi-
ple actors (Figure 1).

30 The *supply bases*, located along the Norwegian coast line, are responsible for
preparing outgoing cargo and loading it onto supply vessels, as well as the handling
of return cargo. In cooperation with the vessels and installations, the supply bases
plan the placement of cargo and the route, to ensure efficient deliveries and reduce
the time spent loading and unloading alongside installations. The *supply vessels* are
35 contracted from different ship owners, and are responsible for the safe and timely
transportation of cargo to and from the locations. The *offshore installations* load
and unload cargo in close cooperation with the vessels. The operator's *Maritime
Traffic Control* (MTC) monitors vessel activities, and ensures they are not on a col-
lision course with the installation. The MTC also coordinates the activities, for
40 instance, re-routing vessels if special needs for equipment should arise on any given
installations. The *Maritime Administration Unit* is located onshore, and is responsi-
ble for the procurement and follow-up of the vessels and their ship owners – seeing
to, for instance, the satisfaction of technical and operational requirements, as well
as the overall safety and efficient functioning of the logistics chain.

The risk picture

45 The Petroleum Safety Authority in Norway (PSA) has defined two situations which
carry potential for major accidents involving vessels and offshore installations, and

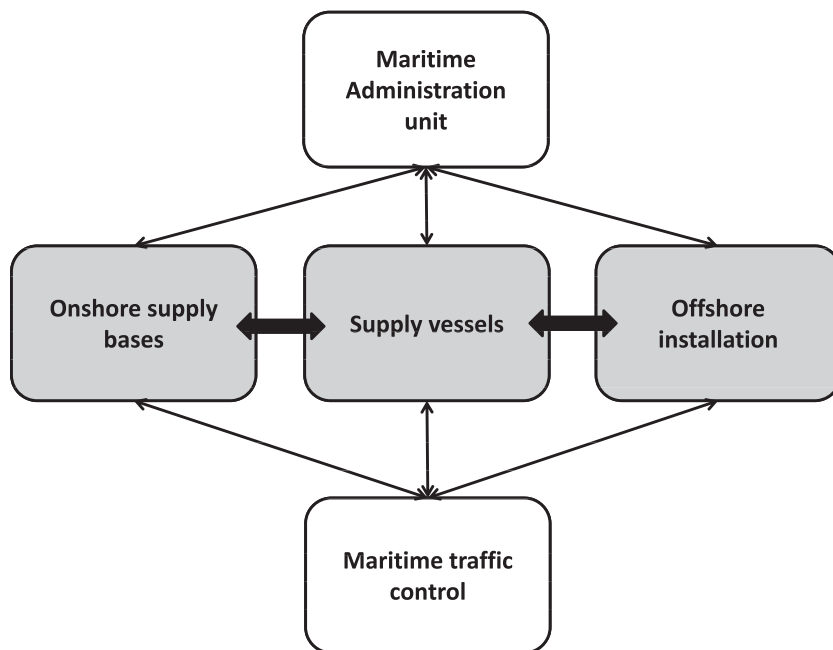


Figure 1. Actors in the offshore logistics chain.

require that petroleum companies have emergency preparedness plans in place to handle these situations, should they occur (PSA 2011):

- Vessel on collision course.
- Collision with field-related vessel/installation/shuttle tanker.

5

There have been 26 collisions between offshore service vessels and installations in the period from 2001 to 2010 on the Norwegian Continental Shelf. According to the PSA, six of these events had a very high major accident potential (PSA 2011). The PSA calls attention to the fact that supply vessels are getting larger, while offshore installations have not been redesigned to withstand the kind of energy a collision is now capable of releasing. Previous investigations revealed complex causes contributing to these collisions, including human error, organizational factors and failure of technical equipment. Responsibility for the incidents has been addressed to several actors in the logistics chain, including operating companies, ship owners and crews (PSA 2011).

10

15

Even though analyses of these collisions have been conducted, the PSA (ibid) still claims that: ‘Good collision analyses will not increase safety if they become only an academic exercise ... The analyses are rarely used as a basis for reducing risk. Here, we see a need for improvement’. This study can be seen as an answer to the PSA’s perceived need for better and more relevant information in order to reduce the risk for collisions between vessel and installation. By reviewing collision preventive barriers, and by evaluating the quality of them in interactions with actors throughout the logistics chain, it will be possible to reveal the potential for improvement.

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The participatory activities

The study was completed in four steps: (1) identification of collision preventive barriers, (2) evaluations of their functioning, (3) analysis and (4) identification of measures. The approach included three different participatory activities (Figure 2).

5 In addition to using participatory methods, relevant documents and statistics from the petroleum industry were studied in the initial phase, in order to gain a foundation of knowledge and a solid understanding of the phenomenon. Industry regulations, descriptions of work processes and steering documentation from the petroleum company and various statistical sources have been used for this purpose.

HAZID

10 The goal of the HAZID is to identify potential hazards connected to a specific situation, project, etc. A HAZID is usually organized as a workshop involving experienced personnel from different areas relevant to the topic at hand. Checklists of HSE issues are applied as aids in the discussion and identification of relevant topics and methods (Jansen et al. 2001).

15 A HAZID technique was used here to identify hazards relevant to vessel-installation collisions. Collision preventive barriers and their relative strengths and weaknesses were also discussed. Ten experienced representatives from the different parts of the logistics chain (see Figure 1) were present. The group worked together for one day, producing a list of potential hazards, collision preventive barriers and risk-influencing factors.

Qualitative interviews

20 Qualitative interviews are characterized by open-ended questions designed to elicit in-depth responses about people's experiences, perceptions, opinions, feelings and knowledge (Patton 2002). The most common qualitative interview is the



Figure 2. Participatory activities for the identification, evaluation and development of collision preventive safety barriers.

semi-structured interview, used when the researcher knows which themes are to be studied, but answers revealing unexpected perspectives are also of value (Kvale 2001). In most instances, an interview guide is used as an aid to ensure the capture of all themes of interest to the researcher or project.

Our intention with the interviews in this study was to evaluate the barriers identified by the document study and the HAZID. Our semi-structured interview guide consisted of themes we felt would provide insight into and knowledge of the collision preventive barriers. The structure was nearly identical for all interviews, with some variations in emphasizing the different barriers depending on what activities were most relevant to the informant.

A total of 47 persons were interviewed, both individually and in groups. Most respondents were interviewed face-to-face, except those working on offshore installations who were interviewed by phone. All interviews were recorded, partly transcribed and then categorized according to the activities and barriers discussed.

The interviews provided information on the functioning of the barriers identified in previous research activities, and gave us new insights into other aspects of the different actors' daily work. We also considered the quality of the barriers in a holistic way during the analysis; well-functioning barriers for one actor were not necessarily adequate in the eyes of other actors across the logistics chain.

Search conferences

A search conference is a method of collective problem-solving, generally involving a large group of people and planned by a facilitating research group. Depending on the topic, participants are invited based on their roles in current work processes and organizational belonging. The selection of participants should reflect a diversity of perspectives on the issues addressed. A search conference is based on a combination of discussions in smaller groups and plenary discussions organized by a staff of experienced facilitators. It starts with the presentation of different views on the problem at hand, and proceeds with creative problem-solving and the generation of a mutually agreed upon action plan (Greenwood and Levin 1998).

We arranged two search conferences on behalf of the operating company, each lasting two days and involving a total of 152 participants representing all parts of the logistics chain. The conferences were structured so that the first day was devoted to discussing collision preventive barriers and measures to strengthen them. The findings from the HAZID and the semi-structured interviews were presented to participants, followed by group discussions concerning the challenges and possible measures. This was followed by a plenary discussion on the second day, where the assembly reached a consensus on what measures that should be prioritized.

Results and suggested measures

The document review, the HAZID and the interviews provided an overview and assessment of the barriers. These were then used as a point of departure for the subsequent search conference.

Our primary impression prior to the search conference suggested the existence of a multitude of largely adequate collision preventive barriers. Many of these had been established in the last decade, and were associated with activities taking place at different parts of the logistics chain: procurement and follow-up of vessels,

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supply base activities, sailing, entrance into the installations' safety zone, loading and unloading and departure from the safety zone. Thirty-two specialized and generalized barriers were identified and evaluated, a majority of which were located at the 'sharp end' of operations, where collisions were most likely to occur. Examples of the barriers identified are presented in Table 1:

A review of earlier collisions conducted by authorities responsible for the Naval Control of Shipping showed that they were not associated with breakage of individual barriers or even a series of individual barriers, but rather the *concurrent* breakage of several independent barriers. We are thus reminded of Hollnagel's (2009) point that normal performance variations resulting from efficiency-thoroughness trade-offs may, under certain conditions, coincide with and give rise to a resonance effect that can contribute to accidents, as the FRAM model (Hollnagel et al. 2009) illustrates.

Predicting all possible combinations of barrier failures is clearly challenging. A more basic strategy capable of contributing to a reduction in the probability of collisions is to ensure the quality of the *individual* barriers. Various means of strengthening these barriers in relation to three specific aspects of the operations were suggested:

Competence in using the dynamic positioning system

The dynamic positioning system (DPS) as a technological system combines data on navigation, wind, currents and vessel movements, and computes the power needed for the propellers so that the vessel can remain stationary, for instance, while loading or unloading cargo at an offshore installation. Such systems have become increasingly automated, complex and reliable in recent years, paradoxically leading to navigators receiving less training in handling these situations in the case of DPS errors or malfunctions. More training under controlled conditions was thus a primary desire voiced by numerous stakeholders. Such training would address an important weakness of the otherwise largely reliable DPS barrier.

Table 1. Examples of identified collision preventive barriers.

Activity	Collision preventive barriers	Type of barrier
Loading/unloading at installation	The DPS	Specialized
	Manning with two navigators on bridge	Specialized
	Considerations of weather criteria (maximum wind, waves) during operations	Specialized
Entering the installations' safety zone	Reviewing checklists on bridge and in engine room	Specialized
	Risk assessment when operations are planned on windward side of installation	Specialized
Sailing to installation	Surveillance from the operators' MTC	Specialized
	Waypoint setting outside the installations' safety zone	Specialized
Supply base activities	Planning of sailing route and placement of cargo on vessel (reduce time spent alongside installation)	Generalized
Procurement and follow-up of supply vessels	Considerations of the vessel's technical conditions according to requirements (redundancy, design, etc.)	Generalized
	Considerations of the crews' qualifications relevant to requirements (certificates, etc.)	Generalized

A lack of redundancy in the DPS reference system

AQ4. The second aspect identified as having potential for improvement was the point that several installations lack redundancy in their DPS reference system, relying only on GPS receivers for positioning in the case of DPS malfunction. These signals are occasionally lost during loading and unloading, increasing the probability that a ship drifts into an installation. Redundancy may be achieved by setting up a RADius or FanBeam system⁵ on the installations, representing a relatively cheap and easy intervention.

Late requests to change loading and sailing plans

The third aspect identified as bearing potential for improvement was the need to be more restrictive in accepting late requests for changes to loading and sailing plans. Possibly a result of bad planning, installations occasionally would make such requests during or just after the loading of the vessels, while the vessels were already en route. Such changes introduced potential difficulties, as the vessels were loaded according to a specific unloading sequence and specific route between the different installations. Late changes increase the number of calls made by a ship, and often extend the time vessels spend alongside an installation, thus increasing the risk for collisions. Instead of simply being more restrictive in accepting late changes, all parties can adopt a progressive strategy by arranging for more involvement by all stakeholders, and especially the installations, in compiling shipping plans, as opposed to simply asking approval once the plans have been set.

Discussion

This paper has sought to illustrate that safety barrier analysis, usually an activity reserved for safety experts, could involve employees from the blunt to the sharp end in a sociotechnical system. With such an approach, ‘holes’ in the defences (Reason 1997) can be revealed that otherwise might have gone overlooked; fuller EP could also lead to the generation of definite measures that could strengthen a safety barrier system. A truly participatory approach could support safety motivation and ‘mindfulness’, too, as it satisfies certain basic human needs, such as self-actualization (Sashkin 1984; Weick 1987).

Participatory methods can be used both in assessing the current ‘state of the art’ and for the ‘promotion of change’ (Menckel 1993, 7). The participatory process may assume different forms, but the basic tenet is to involve all stakeholders in interpreting results (Ibid., 240). In doing so, we were able to gain insight into stakeholders’ differential experiences of existing barriers. This broad involvement can, on its own, increase awareness among participants as to the actual work methods and risk picture, thereby preventing collisions between vessels and installations. The PSA (2011) asks for supplements to traditional collision analyses as part of their efforts to reduce the numbers of collisions between offshore installations and vessels. The approach presented here is one possible direction to follow, a means of providing additional insight into barrier systems.

Two guiding principles can be identified in our interpretation of participatory barrier analyses: (1) meet complexity with broad involvement and (2) triangulate participatory methods.

Meeting complexity with broad involvement

As illustrated, an offshore logistics chain is a complex sociotechnical system involving different actors, including the operator and contactors who interact with each other and different technologies. A barrier system has been established in order to avoid collisions. This system includes a range of barrier elements placed at different parts of the logistics chain. The functioning of the safety barrier system is also dependent on people, whether directly – as in the surveillance of vessels on a collision course with an installation – or indirectly, as in the testing of technological systems. As a result, collisions will and do have complex causes, as the failure of an effective barrier system presupposes the concurrent breaking of several barriers. This is due in no small part to the sociotechnical processes involved in enacting these barrier systems.

One way to deal with this complexity and the interdependencies is to arrange for ‘requisite variety’ (Morgan 1998), i.e. broad involvement from the different stakeholders in efforts for strengthening the barrier system as a whole. Such stakeholder involvement would be expected to include and allow for considerations over how barriers are enacted (Suchman 1987), and their rationale for normal performance variability, such as that caused by efficiency-thoroughness trade-offs (Hollnagel 2009).

The involvement of key stakeholders can also provide a foundation for an informed culture (Reason 1998), where managers and operators are provided with insight into factors influencing the efficacy of the system. This could be particularly relevant considering the complexity of logistics chains, as such factors are often controlled or greatly influenced by outside actors, and thorough oversight in general is difficult to achieve. Such broad involvement could also provide input to and ensure the proper use of intelligent transportation system technologies, which give new opportunities for overview, coordination and user orientation (Ran et al. 2012).

Triangulation of participatory methods

The participatory methods used here, including HAZID, individual and group interviews, and search conferences (Figure 2), served different yet complementary purposes. The HAZID served as an aid in identifying hazards and situations where collisions could occur. This provided an important foundation for the subsequent identification and evaluation of collision preventive barriers, accomplished largely through qualitative interviews and document analyses. Lastly, the search conferences allowed the analysis of the empirical data collected by the researchers to be presented and discussed by in excess of 150 participants, facilitating the development of measures that will strengthen existing barrier systems.

Although several potentially appealing aspects of participatory safety barrier analyses can be identified, the project also raises certain uncertainties regarding the long-term positive effects such analyses will introduce. First, the level of participation is functional (Jacobs 2006), implying that the actual power to make the suggested improvements remains in the hands of the management. As the study was completed in December 2011, there is some uncertainty around whether the measures will be implemented. If no changes occur, one can envision this having a negative effect, de-motivating against further involvement and participation. Second,

although key stakeholders were involved in the analysis, the project could not include all employees throughout the logistics chain for practical reasons. Some were directly consulted, some were indirectly informed by others and still others likely remained wholly unaware of the project. While this might limit the value of this study, total involvement will seldom be possible, and the level of participation in this project was sufficient for us to assume that such a project can stimulate positive changes. 5

Further research is clearly needed to follow up on the consequences of participatory barrier analyses in terms of increased safety. One issue to consider is the significance of the level of participation. In this particular project, employees were consulted and involved in the development of measures, although the operator retained ultimate responsibility for the implementation and oversight of safety procedures. Participation could be considered functional, but it is unclear as to whether or not this level of involvement is sufficient to induce potent measures, awareness and appropriate actions, or if a more extensive, interactive participatory approach is required. It is also unclear if, and if so, to what extent a participatory approach strengthens the barriers and reduces the occurrence of incidents? Qualitative research methods could be used to explore such questions, possibly in combination with quantitative methods. 10
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Conclusion

We have illustrated how non-experts can be involved in safety barrier analysis by using an array of methods. A participatory approach allows for the collection of knowledge and experiences from different actors, which can then be applied in subsequent analyses. Although the methods by themselves are not unique, the combination creates a foundation for concrete, contextualised measures that can strengthen the efficacy of barriers and increase the safety level. This might also contribute to a general awareness of the barriers on the part of the different actors, and of how individuals can contribute to the proper functioning of those barrier systems. 25
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Notes

1. One example is the Mumbai High North accident in 2005, where 22 persons died and the platform was lost after a collision with a multi-purpose support vessel ignited a devastating fire (Mitra, Dileep, and Kumar 2008). 40
2. Participation can be defined as a process in which influence is shared among individuals who are otherwise hierarchically unequal (Wagner 1994, 312).
3. Sociotechnical systems, as used here, refers generally to any process or entity that consists of and relies on elements traditionally thought of as belonging to both the social and the technical, or material, domain. It does not refer to any programmatic definitions, such as the Tavistock programme, where sociotechnical system theory was focused on discerning 'the best match between the technological and social components' (Trist 1981). 45

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- 5 4. An alternative terminology may be physical, technical and human/operational.
5. These are commercial products that use reflected laser or radar signals as aids for measuring position relative to an offshore installation.

References

- 10 Aven, T., S. Sklet, and J.E. Vinnem. 2006. Barrier and operational risk analysis of hydrocarbon releases (BORA-Release): Part I. Method description. *Journal of Hazardous Materials* 137: 681–91.
- Blauner, Robert. 1964. *Alienation and freedom: The factory worker and his industry*. Chicago, IL: University of Chicago Press.
- 15 Greenwood, D.J., and M. Levin. 1998. *Introduction to action research: Social research for social change*. Thousand Oaks, CA: Sage.
- Hale, A.R., F.W. Guldenmund, P.L.C.H. Loenhout, and J.I.H. Oh. 2010. Evaluating safety management and culture interventions to improve safety: Effective intervention strategies. *Safety Science* 48: 1026–35.
- 20 Hollnagel, E. 2009. *The etto principle: Efficiency-thoroughness trade-off: why things that go right sometimes go wrong*. Aldershot: Ashgate.
- Jacobs, G. 2006. Imagining the flowers, but working the rich and heavy clay: Participation and empowerment in action research for health. *Educational Action Research* 14: 569–81.
- 25 Jansen, S., P. Brett, J. Kohnert, and R. Catchpole. 2001. Safety critical learnings in underbalanced well operations. Paper presented at SPE/IADC drilling conference, 27 February–1 March, in Amsterdam, Netherlands.
- Johnson, W.G. 1980. *MORT safety assurance systems*. New York, NY: M. Dekker.
- AQ5. Kvale, S. 2001. *Det kvalitative forskningsintervju*. Oslo: Gyldendal Akademiske.
- 30 La Porte, T.R. 1996. High reliability organizations: Unlikely, demanding and at risk. *Journal of Contingencies and Crisis Management* 4: 60–71.
- La Porte, T.R., and P.M. Consolini. 1991. Working in practice but not in theory: Theoretical challenges of ‘High Reliability Organizations’. *Journal of Public Administration Research and Theory* 1: 19–48.
- 35 Latour, B. 1992. Where are the missing masses? The sociology of a few mundane artifacts. In *Shaping technology/building society: Studies in sociotechnical change*, ed. W.E. Bijker and J. Law, 225–64, Cambridge, MA: MIT Press.
- Leveson, N. 2004. A new accident model for engineering safer systems. *Safety Science* 42: 237–70.
- AQ6. ~~Menckel, E. 1993. Evaluating and promoting change in occupational health services. Models and applications. Swedish work environment fund.~~
- 40 Mitra, N.K., P.K. Dileep, and A. Kumar. 2008. Revival of Mumbai High North – A case study. Paper presented at SPE Indian Oil and Gas Technical Conference and Exhibition, March 4–6, Mumbai, India.
- Morgan, G. 1998. *Images of organization*. Thousand Oaks, CA: Sage.
- 45 Pasmore, W.A., and M.R. Fagans. 1992. Participation, individual development and organizational change: A review and synthesis. *Journal of Management* 18: 375–97.
- Pateman, C. 1970. *Participation and democratic theory*. Cambridge: Cambridge University Press.
- Perrow, C. 1984. *Normal accidents: Living with high-risk technologies*. Princeton, NJ: Princeton University Press.
- 50 Pretty, J.N. 1995. *Regenerating agriculture: Policies and practice for sustainability and self-reliance*. London: Earthscan.
- PSA, 2011. Risk of collisions with visiting vessels. http://www.ptil.no/news/risk-of-collisions-with-visiting-vessels-article7524-79.html?lang=en_US (accessed January 5, 2012).
- 55 Ran, B., P.J. Jin, D. Boyce, T.Z. Qiu, and Y. Cheng. 2012. Perspectives on future transportation research: Impact of Intelligent Transportation System technologies on next-generation transportation modeling. *Journal of Intelligent Transportation Systems* 16: 226–42.
- Reason, J. 1997. *Managing the risks of organizational accidents*. Farnham: Ashgate.
- Reason, J. 1998. Achieving a safe culture: Theory and practice. *Work & Stress* 12: 293–306.

- Remmen, A., and B. Lorentzen. 2000. Employee participation and cleaner technology: Learning processes in environmental teams. *Journal of Cleaner Production* 8: 365–73. 5
- Roberts, K.H. 1990. Some characteristics of one type of high reliability organization. *Organization Science* 1, no. 2: 160–76.
- Rochlin, G.I. 1999. Safe operation as a social construct. *Ergonomics* 42: 1549–60.
- Rochlin, G.I., T.R. La Porte, and K.H. Roberts. 1987. The self-designing high-reliability organization: Aircraft carrier flight operations at sea. *Naval War College review* 40: 76–90. 10
- Rosness, R., T.O. Grøtan, G. Guttormsen, I.A. Herrera, T. Steiro, F. Størseth, R.K. Tinmannsvik, and I. Wærø. 2010. *Organisational accidents and resilient organisations: Six perspectives. Revision 2*. Trondheim: SINTEF Technology and Society. 15
- Rosness, R., S. Hauge, A.B. Skjerve, and K. Aase. 2008. Ti tommeltotter og null ulykker? Om feiltoleranse. In *Robust arbeidspraksis*, ed. R.K. Tinmannsvik, 95–104, Trondheim: Tapir.
- Sashkin, M. 1984. Participative management is an ethical imperative. *Organizational Dynamics* 12, no. 4: 5–22. 20
- Sklet, S. 2006. Safety barriers: Definition, classification, and performance. *Journal of Loss Prevention in the Process Industries* 19, no. 5: 494–506.
- Snook, S.A., 2000. *Friendly fire: The accidental shootdown of U.S. Black Hawks over northern Iraq*. Princeton, NJ: Princeton University Press.
- Suchman, L.A. 1987. *Plans and situated actions: The problem of human-machine communication*. Cambridge: Cambridge University Press. 25
- Trist, E. 1981. The evolution of socio-technical systems: A conceptual framework and an action research program. Paper presented at Conference on Organizational Design and Performance, April, in Philadelphia, PA.
- Vaughan, D. 1996. *The challenger launch decision: Risky technology, culture, and deviance at NASA*. Chicago, IL: University of Chicago Press. 30
- Wagner, A.J. 1994. Participation's effects on performance and satisfaction: A reconsideration of research evidence. *Academy of Management Review* 19: 312–30.
- Weick, K.E. 1987. Organizational culture as a source of high reliability. *California Management Review* 29: 112–27. 35