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How good micro/macro ergonomics may improve resilience, but not necessarily safety

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ABSTRACT

Context: Professional sea fishing is among the world's most variable (non-standardized) and dangerous sectors of activity. Because of this, it provides a remarkable model to study the complex links existing between resilience and safety. Paradoxically, even if the huge risks being run cause many shipwrecks (low safety level), studies show that these sailors avoid an even greater number of accidents thanks to their exceptional skill and know-how (remarkable resilience level). This article examines several ways of improving safety in an activity of this type.

Method: Two intervention strategies are tested: (i) a micro-ergonomics strategy offering conduct assistance guidelines based on accident analyses of the most serious and frequent causes (collisions while fishing); (ii) a macro-ergonomics strategy comparing the safety level of large firms having committed to a Total Quality approach, to that of smaller companies, often privately owned.

Result: Neither of the two strategies works out as expected. The micro-ergonomics anti-collision assistance strategy is misused towards an increase of the fishing objective; the macro-ergonomics strategy is even more surprising: the largest firms suffer from a smaller number of shipwrecks, but a much greater number of work-related injuries; the strategy simply results in a minor shift of the sacrificial decision between performance and safety (loss of men vs. loss of vessels), while maintaining the same priority for financial performance.

Discussion: The article submits a simple modeling of the relationship between resilience and safety, and discusses the choice of strategies for safety-improving interventions, taking into account the system's financial performance and the legal pressure to which it is subjected.

1. Introduction

The maritime sector is generally known for its harsh professional conditions (state of the sea, state of the vessels, economic competition, etc.). Over 80% of accidents and injuries are attributable to the human factor (Hetherington et al., 2006). This observation is even more pronounced in the sea fishing sector, considered to be the most dangerous in the world (Wang et al., 2005; Kaplan and Kite-Powel, 2000; Marine Accident Investigation Branch [MAIB], 1995; International Labour Office, 1999). Subjected to great economic and competitive pressure, it encourages fishermen to take risks. Paradoxically, even if this excessive risk-taking causes too many shipwrecks, previous studies show that these sailors show exceptional resilience skills which enable them to avoid many accidents and injuries in hostile conditions (fishing in any weather, exhausted crews, difficult financial conditions) (Morel and Chauvin, 2006; Morel et al., in press).

Because of these factors, this human activity, professional fishing, is a remarkable model for the study of the relationship between resilience and safety. This report can be apprehended in two different ways, following the two visions of resilience described in the specialized literature. The first, quite general, is closest to Wreathall's definition (2006) in which he considers resilience to be an organization's ability to retain or recover rapidly a stable condition, enabling it to pursue its activities during and after a major accident, or in the presence of great and ongoing pressure (also see Hollnagel, 2006; Woods, 2006). The second vision focuses more on the question of arbitration between safety and production. Several authors define resilience as the ability to manage great pressure as well as conflicts between safety and production objectives (Flin, 2006; Hale and Heijer, 2006).

The professional fishing activity is also an excellent model to examine the safety-improving strategies which could be applied in such a domain, and to draw conclusions applicable to every professional sector which are the goals of this article.

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Along with a "prescription and regulation" strategy, which regulates safety by forbidding the areas of the domain considered dangerous (such as the speed limit for road safety), two "lines" of ergonomics intervention can be found in industry (Meshkati, 1989; Hendrick, 1997; Hendrick and Kleiner, 2002):

i a "micro-ergonomics" strategy, focused on the man-machine system, working on the improvement of workspace and interface design to prevent risk in the system's day-to-day running.[1] Micro-ergonomics rely on three fields: anthropometrics, physiology, and cognitive psychology.
ii a "macro-ergonomics"[2] strategy, aiming at optimizing the socio-technical system and studying the effect of organizational structures on human behavior and on safety. Macro-ergonomics are derived from the *Total Quality Management* principles (Carayon, 2003), which focus on the conditions required to improve a system as a whole, by acting mainly on (i) the number, training and satisfaction of staff members, (ii) equipment quality and equipment maintenance, (iii) improvement of the physical environment, (iv) quality of work processes, and (v) economic production that is sufficient in quantity and quality. This is not only an analysis method, but also an approach of the design of socio-technical systems (Carayon, 2006; Clegg, 2000), presenting the characteristic of being systemic (treating jointly the technical and organizational aspects), participative, and ongoing.

Obviously, a link will be made between these two strategies and the distinction introduced by Reason (1997) between strategies focused on the human person and strategies focused on the system.

To improve the safety of systems, Carayon (2006) proposes drawing on other organizational approaches, and particularly the HRO[3] approach (Perrow, 1984; Weick, 1993, 2001; Roberts, 1990...)

This article, based on the example of professional sea fishing, a risky domain, reports on the effects of two safety-improving interventions, one on the micro-ergonomics level, and the other on the macro-ergonomics level. In the first case, the analysis of sea fishing accidents and injuries performed by Morel and Chauvin (2006) shows that one of the greatest risks, both in frequency and in seriousness, is the risk of collision at sea. Causal analysis made it possible to identify two major causes: 1. mistaken diagnoses in an interaction situation with an antagonistic vessel; 2. a non-detection of signals: the antagonistic vessel was not detected by the man on watch before the accident. The ergonomic assistance offered here consists in giving the man on watch (usually the fishing skipper) high-performance electronic navigation assistance tools to detect antagonistic sea traffic. In the second case, the focus was on the organization mode of the fishing companies regarding observed safety (accident statistics). Two very different modes of organization were compared:

(i) Fishing firms: financially and technically sound (recent and well-maintained vessels), well structured regarding safety, and committed to a total quality approach,
(ii) independent fishing skippers, notable for a craft-type approach (in the management of both vessels and crews) working with a fleet of ageing vessels. These concerns are also more vulnerable economically than the fishing companies. They have more difficulties standing up to the very high economic pressures of the present day. As a result, many of these fishing concerns face chronic financial difficulties.

The article submitted here is divided into three parts. The first two present the results of the two assistance strategies tested. The last part is devoted to a discussion of the relationship between resilience and safety, and in a wider sense, to safety-improving strategies for risky systems.

2. Developing risk-reduction assistance

To help the man on watch detect antagonistic vessels more efficiently, and to make a better diagnosis of an interaction situation, the first assistance strategy to be tested is to equip the entire fishing fleet with state-of-the-art electronic assistance tools used for the prevention of collisions at sea. We propose the introduction of two tools, already widely used aboard merchant vessels: the ARPA (Automatic Radar Plotting Aid), and AIS (Automatic Identification System). Today, very few vessels in the fishing fleet carry this equipment, as it is costly and not compulsory.

The ARPA is a calculator linked to the navigation radar. It performs a follow-up of echoes (antagonistic vessels present in the water environment) to help the man on watch diagnose an interaction situation with other vessels. The main information elements supplied by the ARPA calculator are: the CPA[4] (Closest Point of Approach), the TCPA[5] (Time to Closest Point of Approach), the course and speed of the antagonistic vessel.

The AIS (Automatic Identification System) is an automated, vessel-to-vessel message system by VHF radio (Very High Frequency). This device enables all the vessels present in the same water environment to exchange a great deal of data in real time (their GPS position, course and speed, CPA and TCPA of antagonistic vessels).

A coupling of AIS and ARPA aboard fishing vessels could give a dual contribution: on one hand, it would help to improve the detection of signals by the man on watch (AIS), and on the other hand, it would facilitate the diagnosis in an interaction situation with (an) antagonistic vessel(s). Unlike the ARPA which runs independently, the AIS requires the cooperation of other vessels also equipped with AIS. The deficiency of this inter-vessel communication network is that the AIS can be voluntarily switched off, and/or the messages sent can include errors (Lasserre, 2002; Pasquay, 2004). As a result, it is necessary for these two devices to be coupled to make up for their respective failings: the vessels which do not come under the SOLAS convention are generally not equipped with AIS; the AIS can be voluntarily switched off; the ARPA radar is blind in rough weather.

To test this first assistance strategy, two axes were developed: 1. an experimental evaluation of the ARPA radar's contribution to the representation that fishermen have of collision risk; 2. a characterization of the use developed by fishing skippers, following the implementation of the ARPA and AIS on two deep-sea trawlers.[6]

2.1. Evaluation of the ARPAs contribution

2.1.1. Method

The method implemented consisted in comparing two modes of radar representation: (a) the "traditional" radar representation (see Fig. 1, left side); (b) the ARPA radar representation indicating the new data to be taken into account: the speed and speed vector of the antagonistic vessel, the CPA and TCPA (see Fig. 1, right side).

[1] Micro-ergonomics: an approach to ergonomics emphasizing a detailed examination of the man-machine interface as opposed to external factors.
[2] Macro-ergonomics: an approach to ergonomics emphasizing a broad system-wide view of design, examining organizational environments, culture, history, and work goals, very broadly defined.
[3] High Reliability Organizations.
[4] Estimation of the point where the trajectories of two vessels will cross, if these vessels maintain the same course and speed.
[5] Estimation of the time remaining before the two antagonistic vessels reach the CPA, if they maintain the same course and speed.
[6] Specialized in deep-sea fishing, with fishing tours of 96 h and more.

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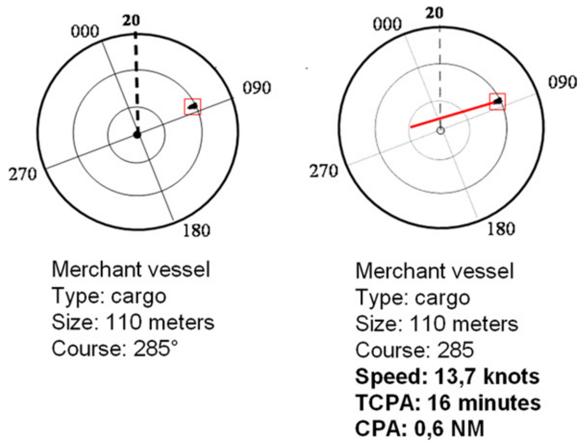

Fig. 1. The two radar representation modes.

2.1.2. Equipment

The representation of the collision risk by sea fishermen was tested through a questionnaire presented in two versions: [without ARPA vs. with ARPA]. The questionnaire included a series of questions relating to two interaction situations between a trawler and a merchant vessel: 1. trawler in fishing action; 2. trawler under way (see Table 1). Both situations presented a collision risk and were consequently very dangerous.

2.1.3. Participants

The 137 sea fishermen selected are all registered in the Le Guilvinec maritime quarter. They all practice deep-sea fishing in 15–24-m deep sea trawlers (average: 22.2; SD: 1.66). The selected sample was broken down into two groups (see Table 2). The participants of the first group ($N = 76$) filled in the "conventional radar" version of the questionnaire, and the members of the second ($N = 61$) the "ARPA radar" version of the questionnaire.

Two joint analyses were performed to characterize the ARPA's impact on the representation of the collision risk, the first by experienced fishermen and the second with junior seamen.

2.1.4. Procedure

The questionnaires were presented to the participants in their working environment, in the presence of the experimenter.

Table 1
Structure of the two questionnaires

Question number		Questions asked	Answer modalities	Nature of the questions
Vessel fishing	Vessel under way			
Q1.1	Q2.1	"This situation seems to you:"	– Very dangerous – Dangerous – Not very dangerous – Not at all dangerous	*Comprehension* Estimation of the dangerousness of the situation
Q1.2	Q2.2	"According to you, if no maneuver is performed, the merchant vessel will:"	– Cross ahead of your vessel – Cross astern of your vessel – Pass very close, there is a collision risk with your vessel – You don't know	*Diagnostic* Evaluation of the collision risk
Q1.3	Q2.3	"According to you, it is:"	– Very probable the merchant vessel will maneuver – Fairly probable the merchant vessel will maneuver – Not very probable that the merchant vessel will maneuver – Not at all probable that the merchant vessel will maneuver – You don't know	*Intention of the antagonistic vessel* Maneuvering intention of the merchant vessel
Q1.4	Q2.4	"According to you, your vessel is:"	– In a right-of-way situation – In a give-way situation – In a privileged situation – Not in a privileged situation	*Interpretation of regulations* "Privileged" vs. "right-of-way" situation
Q1.5	Q2.5	"You therefore decide to:"	– Hold to your course and speed without considering a maneuver – Maneuver to let the merchant vessel go by – Use some means (sound, light, VHF to show your presence so it will change course – Hold your course and speed and consider changing course if the situation becomes too dangerous	*Decision*

Table 2
Characteristics of the selected sample

Group 1 "Without ARPA" $N = 76$		Group 2 "With ARPA" $N = 61$	
N = 137 Participants			
Junior seamen[a]	Experienced seamen[b]	Junior seamen	Experienced seamen
$N = 38$	$N = 38$	$N = 28$	$N = 33$

[a] Sea fishermen who are not in command on board and hold the following degrees: Professional Aptitude Certificate (CAP), Professional Study Diploma (BEP), Nautical Initiation Certificate (CIN), Fishing Initiation Certificate (CIP), no training.
[b] Sea fishermen who are in command onboard and hold the following certificates: Fishing captain, Fishing skipper, Fishing Lieutenant, Qualified seaman.

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Table 3
Impacts of ARPA on anti-collision management activities by experienced and junior seamen

		Fishing				Under way			
		Junior Seamen		Experienced Seamen		Junior Seamen		Experienced Seamen	
		Without ARPA	With ARPA	Without ARPA	With ARPA	Without ARPA	With ARPA	Without ARPA	With ARPA
Q*.1	*Comprehension*								
	Estimation of the dangerousness of the situation	42%	71%	63%	91%	18%	68%	42%	82%
	Evolution of the % of correct answers[a]		+29 pts*		+28 pts**		+50 pts**		+40 pts**
Q*.2	*Diagnosis*								
	Evaluation of the collision risk	29%	75%	71%	91%	5%	61%	50%	88%
	Evolution of the % of correct answers[b]		+46 pts**		+20 pts*		+56 pts**		+38 pts**
Q*.3	*Intentions of the antagonistic vessel*								
	Maneuvering intention of the merchant vessel	39%	11%	29%	27%	89%	96%	97%	97%
	Evolution of the % of sailors who feel the merchant vessel will change course[c]		– 28 pts*		– 2 pts		+7 pts		–
Q*.4	*Interpretation of regulations*								
	"Privileged" vs. "right-of-way" situation	95%	93%	87%	91%	71%	96%	84%	88%
	Evolution of the % of correct answers[d]		– 2 pts		+5 pts		+25 pts**		+4 pts
Q*.5	*Decision*	58%	71%	66%	67%	58%	89%	71%	85%
	Evolution of the % of correct answers[e]		+13 pts		+1 pts		+31 pts**		+14 pts

* $p < 0.05$; ** $p < 0.01$.
[a] The situation involved a collision risk. To the question *"this situation seems to you:"*, the following responses were considered to be correct: *"Very dangerous"* or *"Dangerous"*.
[b] To the question "According to you, if no maneuver is performed, the merchant vessel...", the following responses were considered to be correct: 1. "will pass very close, there is a collision risk with your vessel"; "will cross ahead of your vessel" AND "will pass very close, there is a collision risk with your vessel".
[c] To the question relating to the merchant vessel's intention of changing course, the following responses were considered to be correct: "Very probable the merchant vessel will maneuver" or "Fairly probable the merchant vessel will maneuver".
[d & e] Concerning questions Q*.4 (Interpretation of regulations) and Q*.5 (Fishing Skippers' Decision) the responses considered to be correct were the ones which conformed to
Q5 the international regulation for preventing collisions at sea (Colreg, 1972).

2.1.5. Results

The results presented in Table 3 reveal three decisive points:

- The ARPA is a tool enabling sea fishermen to make a better estimation of the dangerousness of an interaction situation, and also a better evaluation of the collision risk with an antagonistic vessel. A marked increase of correct answers regarding these two points was found, even more marked in the second situation (trawler under way). The ARPA is consequently shown to be a very useful tool enabling sea fishermen to make a diagnosis that is well adapted to the characteristics of an interaction situation with an antagonistic vessel.
- The ARPA only has a minor impact on sea fishermen's representations of the intentions of the antagonistic vessel. However, while the trawler is fishing, the ARPA allows junior seamen to realize more clearly that the probability of the merchant vessel's changing course is small. In situations where the trawler is under way, sea fishermen (both experienced and junior) rely more on regulations (COLREG) than on the data provided by the ARPA.
- Overall, the junior seamen get the most benefit from the ARPA input. This is an important point, as they are often required to take night watch (Morel and Chauvin, 2006), i.e. in the most difficult conditions to manage situations with other vessels.

2.2. Characterization of use

2.2.1. Method

Working in collaboration with a Breton fishing company and a fishing equipment manufacturer, AIS and ARPA devices were integrated into the bridge equipment of two new trawlers ordered by this company. Two 14-day periods were spent aboard these trawlers. The objective of the first was to configure the AIS and ARPA and to train the crew how to use them; the second period took place a year later, and enabled us to assess what the devices were actually used for.

2.2.2. Results of the assessment

2.2.2.1. Observed use. Observation, and interviews[7] of the crews of the two vessels equipped with ARPA and AIS, show that the devices are put to two different uses according to whether the vessel is fishing or under way:

- *Fishing*: the AIS is switched off. The ARPA is used to track the fishing vessels operating close to the equipped vessel. The use in this case is a clear misuse, quite different from the device's original purpose (as a diagnosis tool designed for interaction situations with other vessels). This misuse is dedicated to the surveillance of competing activity performed by other fishing vessels. By recording the course of fishing vessels detected by the ARPA, the skipper is immediately made aware of the trawl hauls being made by these other vessels. Consequently, if the vessel being "watched" is making a good catch, the skipper tracking it can, if he wishes, exploit this information to his own profit.
- *Under way*: the ARPA and AIS are used according to their primary functions, i.e. as diagnosis tools enabling the fishing skipper and the crew to improve their anti-collision management activities. According to our findings, the ARPA and AIS are used more intensively near the Traffic Separation Zones (navigation zones with heavy merchant vessel traffic).

The misuse of both ARPA and AIS as surveillance tools has become a real problem. The feedback from the profession reveals a great deal of reticence on the issue of broadcasting a vessel's iden-

[7] We observed the activity of the man on watch on the bridge (fishing skipper during the day, crew member at night). These observations were focused on the use of APRA and AIS. The interviews were carried out directly in a working situation, through verbal exchanges between the observer and the man on watch. As a result, these interviews were not formally structured but led by a series of very open, very general questions bearing on the use (or non-use) of AIS and ARPA (ex: do you use the AIS while fishing ? What is it most useful for? Do you ever switch it off? And so on.).

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tity, its fishing activity (through a materialization of its trawl hauls), its course,... In short, all the information which was traditionally kept secret[8] is becoming available to competitors. Our observation turned up the following behavior: either the fishing skippers (or the companies):

- equip their vessel with AIS, but only in RECEPTION mode, with no broadcasts,
- equip their vessel with AIS, and use it in both RECEPTION and BROADCAST mode, but switch it off while fishing.

This selective misuse of AIS and ARPA can represent a serious accident-causing factor, due to the uncertainty it might generate in the fishing environment.

2.2.2.2. AIS: a very efficient tool in extreme situations. During the first period spent aboard, a collision with a merchant vessel was narrowly avoided thanks to the AIS. The weather conditions were very rough (storm: wind force 10–11, swells 6 m, visibility nil). The radar was blinded and the ARPA calculator unable to provide any data whatsoever. Only the AIS was operational, as it would have been in fine weather. Thanks to the AIS, the merchant vessel was able to detect and identify the trawler. As the trawler's skipper did not change course in spite of the demands of the captain of the merchant vessel, the latter applied COLREG rule 17 (maneuver of the privileged vessel), and changed course at the last moment (CPA = 0.1 NM; TCPA = 4 min). The collision was barely avoided, not through the fishing skipper's actions but because the merchant vessel was able, thanks to the AIS, to detect the presence of the fishing vessel in spite of the storm. This shows the importance of AIS use in BROADCAST and RECEPTION modes, and not only RECEPTION.

In assessing the results, our observation reveals a dual use of these two devices: a misuse, to benefit production, while the vessel is fishing (ARPA used to "watch" other fishing vessels; AIS switched off); a correct use when the vessel is under way (ARPA and AIS in operation). Knowing a fishing vessel spends an average of over 80% of its time in fishing action,[9] the AIS and ARPA are actually misused the greatest part of the time.

The use of AIS is highly prized by the fishing skippers for its high performance level in every type of situation. This device allows them to remain in a fishing zone in spite of very rough weather conditions. Very clearly, this possibility, being available to sea fisherman, may also lead to increased risk-taking.

3. Second assistance strategy: having an impact on the organization

The proposition for a second assistance strategy consists in having an impact on the system rather than on its components. This is the domain of macro-ergonomics. This approach was implemented in the sea fishing system through the integration of ergonomics in the design of fishing vessels; it was limited in part by the small size of the companies concerned (not easily compatible with the demands of a participative approach for ongoing improvement), and in part by the difficulty of determining the financial impact of the proposed improvement (Chauvin et al., in press). This initial failure led us to make a distinction between independent fishing skippers, and fishing companies. The study presented here is a preliminary study for a macro-ergonomics approach. Its purpose is to test the hypothesis according to which the more structured companies are more safety-conscious than crafts-type concerns. Our initial postulate is that it is possible to improve the fishing system's safety level by structuring the companies involved to resemble those presenting the following characteristics: (a) a strong company commitment to the issue of safety; (b) a satisfactory financial standing (possibility of investing, a good income and safe jobs for the crew); (c) sound vessels, much more recent than the national average (25 years).

To test this second assistance strategy, we propose to confront these benchmark firms to statistic data related to accidents.

3.1. Method

3.1.1. Identification of benchmark firms

The companies making up the fishing system can be put in two categories: (a) crafts-type (or individual) concerns, with a skipper-owner who runs his own vessel; (b) Non-crafts-type concerns (non-individual), either with a skipper paid to run a vessel belonging to a company, or crews on payroll aboard a fleet of vessels belonging to larger firms. It is in the larger firms that the characteristics described above are found. These firms' managers have a strong commitment to safety (Morel, 2007); their financial situation is satisfactory and their vessels are technically sound.

To be able to test the second assistance strategy, we selected as benchmark firms the largest deep-sea professional fisheries of South Brittany ($N = 7$). These seven firms have a fleet of 59 vessels altogether, 11 of which are less than 5 years old. These firms are considered to be the most up-to-date of the South Brittany fishing fleet regarding the three criteria defined above:

(i) A strong commitment to safety: they employ a Company Captain in charge of safety and the prevention of professional risks.
(ii) A satisfactory financial situation: they are the only firms today able to invest in new vessels and performing fishing equipment. These firms have high yearly turnovers of several million euros[10] (9.8 M€; SD 3.7 M€). In 2006, six of the seven firms (53 vessels[11]) had a global turnover of 58.7 M€, or 23.3% of the overall turnover of the entire South Brittany fishing fleet. Moreover, the pay scale of the fishermen working for these companies is said to be high, which is a good indicator of the firms' financial well-being.
(iii) Sound vessels, newer than the national average (25 years). These firms' vessels are technically sound (vessels over 60 feet, with an average age of 15 (SD: 7.5) with performing fishing equipment) and undergo regular and in-depth technical maintenance, coordinated by the Company Captains.

3.1.2. Comparative descriptive analyses

The seven benchmark firms were subjected to two comparative descriptive analyses related to:

- *Work-related injuries recorded in 2005:*[12] among the population of sea-fishermen in South Brittany.[13] The data was collected from

8 With limited success as the sea fishermen's turnover has resulted in a widespread broadcast of fishing plans between vessels, which has reduced the confidential aspect of the data!

9 Figure for a deep-sea trawler operating in the Southern Ireland waters.

10 Available data for six of the seven firms.

11 4.16% of the South Brittany fishing fleet.

12 The years before 2005 were not taken into account due to the lack of homogeneity of available data. No comparison between the years 2005, 2004 and 2003 was possible.

13 It was not technically feasible to extend the study to the French territory as a whole. The South Brittany area however is representative in terms of jobs and vessels, as it regroups 4531 seamen and 1271 vessels, or 30% of jobs and 31.9% of the fishing fleet for the North/Channel/Atlantic seafront. The type of fishing equipment is also fully represented: 28.4% of trawlers, 27.6% of netters, 37.2% of potter vessels, 24.6% of dragnet vessels, 47.5% pole and line vessels.

Table 4
Breakdown of collisions or groundings reported over the 1997–2004 period, according to company type

Type of company	Collisions (fishing/fishing)	Collisions (fishing/merchant)	Groundings
The seven benchmark professional firms	4 (1.8%)	7 (8.6%)	10 (5.7%)
Crafts-type companies	190 (88.4%)	61 (73.3%)	155[a] (88.6%)
Non-crafts-type companies	21 (9.8%)	13[b] (16.1 %)	10 (5.7%)
Total	215 (100%)	81 (100%)	175 (100 %)

[a] Five casualties.
[b] Seven casualties (Cistude: 4 casualties; Pépé Roro: 3 casualties).

the work-related injuries declaration forms available at the National Bureau of Disabled Maritime Personnel (ENIM).

- *Accidents to the vessels of the national fishing fleet* (shipwrecks, groundings or collisions): Three databases were used. The first was built up from data collected at the Marine Accident Investigation Bureau. This only includes an inventory of total losses in the fishing system over the 1998–2004 period. The other two databases were developed by Morel (2005) to study collisions and groundings involving fishing vessels over the 1997–2004 period.

3.2. Results

3.2.1. High-performance firms regarding vessel safety

Over the 1998–2004 period, 98 total losses of vessels were recorded nationwide in the sea fishing system, the total number of victims being established at 88. The craft-type concerns suffered the most losses, with 87.5% of accidents and 78.4% of the total number of victims recorded since 1998 ($N = 69$). Fishing vessels less than 12 m in length suffered 82.1% ($N = 69$) of these accidents with 85.6% ($N = 59$)[14] of the recorded victims. The main types of total losses are: shipwrecks (27 victims), hooking on the seabed (14 victims), capsizing (7 victims) and leaks in the hull (6 victims).

Non-craft-type concerns are notable for their low involvement in this type of event: 11.2% of accidents for 21.6% of the total number of recorded victims (19 victims due to the total loss of 4 trawlers and one netter). *Over the 1998–2004 period, no total loss was recorded among the seven benchmark firms.*

3.2.2. The specific case of collisions and groundings

Over the 1997–2004 period, the 59 vessels of the seven benchmark firms were very seldom involved in collisions and groundings (see Table 4):

- 1.8% of collisions between fishing vessels (4/215); the 59 vessels of the seven benchmark firms make up 1.5% of the fishing fleet exposed[15] to this type of risk. Even if the reported number of accidents remains very low (as an absolute value), the seven professional firms do not perform better than the other vessels of the exposed fishing fleet ($\chi^2(1, N = 3985) = 0.03, p > .05$) regarding this type of risk. These findings remain true ($\chi^2(1, N = 228) = 0.24, p > .05$) when these vessels are compared to the rest of Brittany's deep-sea fishing fleet[16] ($N = 228$ vessels for 21 collisions).
- 8.6% of collisions between fishing vessels and merchant vessels (7/81) for about 9.8% of the fishing fleet exposed[17] to this type of risk. As before, the seven professional fishing firms do not perform better than the other vessels of the fishing fleet (χ^2 (1, $N = 600) = 0.03, p > .05$) exposed to this type of risk. These findings also remain valid (χ^2 (1, $N = 228) = 0.17, p > .05$) when these vessels are compared to the rest of Brittany's deep-sea fishing fleet ($N = 228$ vessels for 22 collisions).
- 5.7% of groundings (10/180) for 1.5% of the fishing fleet exposed[18] to this type of risk. In spite of the low number of reported accidents, the vessels belonging to the seven professional firms are statistically more involved than the other vessels of the fleet exposed to this type of risk ($\chi^2(1, N = 3985) = 19.6, p < .01$). These findings are not surprising if one considers that these vessel's ports of registry are considered to be the most difficult of access, especially for large vessels. Nine of the ten reported groundings involved the largest-sized vessels (over 90 feet), and all took place while entering and/or leaving these ports.

In point of fact, the vessels belonging to the seven benchmark professional fishing firms are no different from the other vessels exposed to the same collision risks. They are more often involved in groundings because of their size and the difficulty of access to their respective ports of registry. However, the independent fishing skippers (craft-type companies) log up the greatest number of this type of accidents, with: 88.4% of collisions between two fishing vessels; 75.3% of collisions between a fishing vessel and a merchant vessel, and 88.6% of groundings.

3.2.3. Sea fishermen suffering from a great number of work-related injuries within the professional fishing companies

In the year 2005, 600 work-related injuries were recorded in South Brittany. In this area, 13.2% of fishing crewmen have suffered from a work-related injury, as opposed to 7.8% in the other coastal regions (827 work-related injuries for 10576 sea fishermen). Overall, it is the crew members aboard non-craft-type vessels (mainly trawlers)[19] who suffer the greatest number of injuries ($\chi^2(1, N = 4531) = 111.1, p < .01$) and most particularly the employees of the seven benchmark firms ($\chi^2(1, N = 4531) = 144.3, p < .001$) (see Table 5). They account for 26% of the total number of work-related injuries, though they only represent 4.6% of the South Brittany fishing fleet ($N = 59$) and 11.5% of seagoing personnel ($N = 522$). In 2005, 29.9% sailors were injured, of which only 9.8% belonged to craft-type concerns and 16.0% to non-craft-type concerns.

Table 5 also shows the accident rate for each of the seven professional fishing firms. Even if the difference between these rates is not significant ($\chi^2(6, N = 522) = 4.88, p > .05$), the findings show that firm no. 1 has the second highest accident rate, with 35% of crew members injured in 2005. And yet, this firm owns the most recent fishing fleet (with an average age of 10.6 – SD: 7.1); number of vessels under 5 years: 4/11). The sea fishermen belonging to this

[14] The sinking of the "Bugaled Breizh" (2004), of the "Perle de Jade" (2001) and the "l'Étoile de persévérance" (1999) account for the 10 additional fatalities counted in the craft-type concerns.
[15] Or the entire fishing fleet of the North, Channel and Atlantic coast: $N = 3985$.
[16] Fleet similar to that of the 59 vessels observed in terms of the collision risk.
[17] Exposure to a risk of collision with merchant vessels is subject to a fishing activity near or in areas crossed by merchant traffic roadways. Deep-sea trawlers are the most exposed to this risk, as well as a great majority of vessels registered in the North-Pas de Calais or Normandy sea quarters. Here, 600 fishing vessels are routinely exposed to a collision risk with merchant vessels. This is an estimation, as it is very difficult to give a precise figure because of the very heterogeneous nature of this system.
[18] Or the entire fishing fleet of the North, Channel and Atlantic coast: $N = 3985$.
[19] and more particularly those practicing offshore fishing ($\chi^2(1, N = 4531) = 85.6, p < .01$). Offshore fishing has a very high accident rate, with more than 46% ($N = 280$) of accidents which occurred in 2005 for only 206 vessels (out of the 1271 vessels registered in South Brittany).

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Table 5
Breakdown of work-related injuries incurred in sea fishing (South Brittany)

	A Number of vessels	B Number of sailors	C Number of injuries	C/B (%)
Craft-type concerns	**1114** (*87.7%*)	**3173** (*70.0%*)	**310** (*51.6%*)	**9.8%**
The seven selected firms	**59** (*4.6%*)	**522** (*11.5%*)	**156** (*26.0%*)	**29.9%**
Firm no. 1	11	66	23	34.8%
Firm no. 2	10	60	16	26.6%
Firm no. 3	10	117	36	30.7%
Firm no. 4	8	48	12	25.0%
Firm no. 5	8	102	30	29.4%
Firm no. 6	6	99	26	26.3%
Firm no. 7	6	30	13	43.3%
Non-craft-type concerns	**98** (*7.7%*)	**836** (*18.5%*)	**134** (*22.3%*)	**16.0%**
Total	1271 (100%)	4531 (100%)	600 (100%)	**13.2%**

Differentiation between the seven benchmark firms.

firm who work aboard the recent vessels have no fewer accidents than those working aboard the older vessels ($\chi^2(1, N = 66) = 0.04$, $p > .05$). The findings are identical for firm no. 6 ($\chi^2(1, N = 99) = 3.33$, $p > .05$) although it owns three vessels under five years old (i.e. half its fleet).

Of 600 work-related injuries recorded in 2005, 431 (71.8%) resulted in days of sick leave. Sea fishermen aboard non-craft-type vessels are more often involved in work-related injuries than those aboard craft-type vessels ($\chi^2(1, N = 4531) = 68.4$, $p < .01$); 15.2% of fishermen aboard non-craft-type vessels suffered from a work-related injury with sick leave in 2005, and only 7.8% of fishermen aboard craft-type vessels.

The injuries resulting in the greatest number of days of leave (more than three months) also tend to involve more fishermen aboard non-craft-type vessels (χ^2 $(1, N = 99) = 35.2$, $p < .01$), and particularly those involved in deep-sea fishing (χ^2 $(1, N = 4531) = 16.6$, $p < .01$). It is the accidents involving fishermen aboard the vessels belonging to the seven benchmark firms which caused the greatest number of days of sick leave per injury: $N = 81.7$. The craft-type concerns accounted for 48.4 days of sick leave, and the non-craft-type concerns: 58.5 days of sick leave.

Note: Article 79 of the working regulations regarding seagoing personnel sets the conditions in which work-related injuries are reimbursed. These laws tend to favor the craft-type concerns more than the professional firms: when a sea fisherman employed by an independent skipper suffers a work-related injury, the ENIM[20] pays all his costs starting from the crew member's first day ashore. For the professional firms, costs will only be reimbursed from the second month ashore. Compensation payment for work stoppage (duration < 1 month) remains an expense to be paid by the professional firms. As a result, even if the professional firms are better structured from the point of view of safety, the provisions of Article 79 penalize the professional firms, which could lead to a process or under-declaration or even non-declaration of work-related injuries when stoppage is shorter than one month. All in all, because of these compensation mechanisms, the professional companies' accident rate could in fact be higher than reported. In fact, the physicians who perform the on-the-job check-ups of seagoing personnel have noted this effect through the aggravation of the consequences of initially undeclared work-related injuries within these firms (Ex: amputations due to necroses caused by cuts that were neither declared or treated; aggravation of back pathologies following on work-related injuries that would have required work stoppage, ...).

The seven firms were selected because they were technically and financially sound, and practiced more advanced safety management than the craft-type concerns and most other companies. The two comparative analyses performed revealed very different results regarding safety: the seven professional fishing firms are very safe from the viewpoint of vessel safety (no total losses over the 1998–2004 period), but this result is relative since they also show the highest rates of work-related injuries. This situation clearly indicates an overexploitation of the fishing vessels; it has been demonstrated that injuries were linked, directly or indirectly, to bad weather conditions (Chauvin and Lebouar, 2007). In fact, by comparing the average yearly production[21] of firms nos. 1, 2 and 4 with similar vessels[22] aboard which there were no injuries in 2005, we found a performance level higher by 36% (firm no. 1), 28% (firm no. 2) and 26% (firm no. 4). In these conditions, it is obvious that while everything is done for the vessels to hold up to every type of pressure for ever-higher production results, the sea fishermen reach the limit of their endurance.

4. Discussion

The results presented above reveal that neither of the two assistance strategies is working out as planned. The micro-ergonomics strategy of anti-collision assistance is misused to increase the fishing activity (surveillance of other fishing vessels; assistance in maintaining a fishing activity in extreme situations); the result of the macro-ergonomics strategy is even more surprising: The seven benchmark firms have fewer shipwrecks and a higher production level, but hey also show the highest rates of work-related injuries. Giving sea fishermen safe and technically performing production tools encourages them to take even greater risks, as they expose themselves to more extreme situations in the name of better performance. In return, they develop the resilience skills which are necessary to their survival in these conditions. This is the end result: both assistance strategies improve safety, but this improvement seems limited because it goes hand in hand with increased risk-taking on the part of the sea fishermen.

The two assistance strategies tested were designed to make the fishing system safer by adding safety without changing the performance levels; the gains in safety seem marginal. This form of safety intervention is very different from the actions which consist in making a system safer by systematically lowering its performance level. In the more general context of arbitrations between safety and performance, these two forms of safety action result in two opposing models (see Fig. 2):

20 National Bureau of Disabled Maritime Personnel.

21 [The total yearly production of the firm's fleet] ÷ [the number of vessels in the fleet].

22 38 reference vessels for firm nos. 1 and 17 reference vessels for firms nos. 2 and 4.

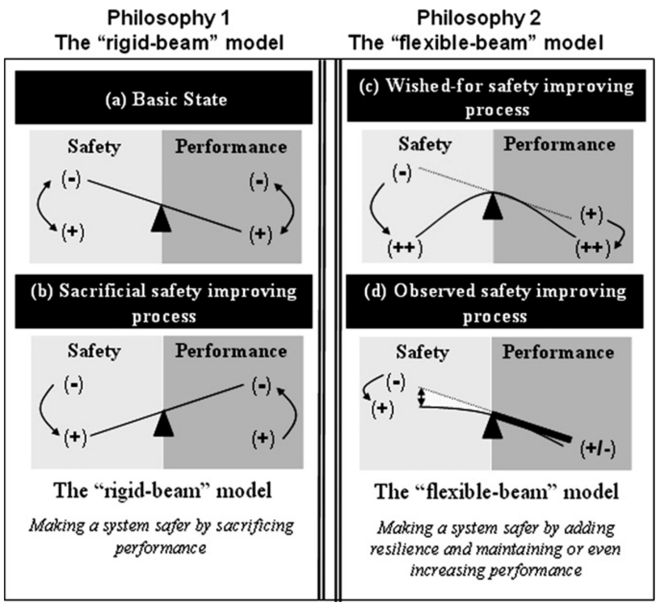

Fig. 2. Two opposing safety improvement models.

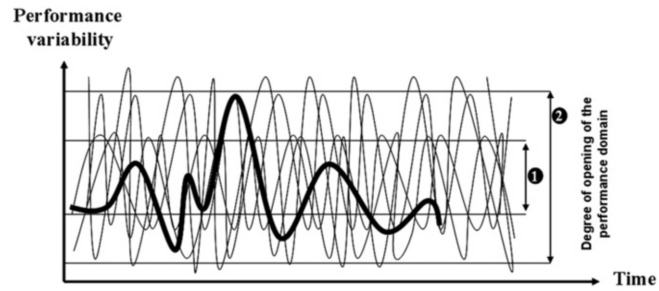

Fig. 3. Variability of performance and opening of the operating domain (adapted from Hollnagel, 2004). Q4

1. The "rigid-beam"[23] model. The basic principle (see Fig. 2a) is simple: any significant increase in safety gained is to the detriment of the system's performance and vice-versa (see Fig. 2b). The mechanisms of economic competition are such that this way of improving safety necessarily calls for sacrificial decisions (Woods, 2005, 2006). An industry often finds it difficult to make this type of decision. This model is spontaneously favorable to performance, but remains reactive to accidents. The beam's corrections toward safety are brutal, and tend to ease off slowly in favor of performance in long accident-free periods (models of normal drift and deviance, Vaughan, 1996, 2005; Amalberti et al., 2006). This spontaneous model is not very satisfactory for an industry, especially in a social context of safety audits by supervising bodies, and increasing legal pressure.
2. The "flexible-beam" model is typically the hoped-for and ideal "win-win" model, summing up an industry's requirements in the field of safety interventions. It protects performance while increasing safety. The principle consists in making a set performance situation safer by using the beam's flexibility, bringing in various tools and methods (assistance, organization and quality-level actions, training, particularly in non-technical skills). Fig. 6c[24] shows that while maintaining, or even improving the performance level (absence and/or insufficient use of sacrificial decisions), the safety gains are in direct relation to the flexibility of the beam. In this configuration, safety gains are possible, but they are limited to the beam's flexibility. This case in point brings us back to the issue of stoppage decisions and management strategies (Flin, 2006).

These two models refer implicitly to the fundamental notion of "open operating domain". This concept brings us back to the concept of resilience: "the ability of a system to adapt to greater or lesser variations in its performance domain" (Wreathall, 2006; Hollnagel, 2006). The greater and more controlled the open operating domain, the higher the resilience (see Fig. 3, situation 2). Conversely, the more restricted the open operating domain, the weaker the resilience (see Fig. 3, situation 1). This domain of operation can open out selectively, in exceptional situations, or else be the result of a gradual opening (which necessarily brings us back to the issue of safety/performance arbitrations). The question here is to choose how widely the operating domain is to be opened.

All these elements enable us to suggest a simple modeling of the relationship between safety and resilience, and the choices of safety-improving strategies, taking into account the system's performance and the open operating domain. Fig. 4 presents the two important ideas that follow upon this:

1. *To develop resilience actions*: the first curve (see Fig. 4) retraces the spontaneous evolution of the safety level when a system's operating domain opens out. The more the operating domain is opened (financial interests), the more safety breaks down, due to greater risk-taking. Resilience actions make it possible to bend this curve toward a second, higher level of safety (curve 2). In this context, the operational definition of resilience corresponds "to the safety gain obtained when the performance domain is opened out". It must be noted however that it is never possible, whatever the amount of resilience added to a system, to maintain safety at the rate belonging to a lower activity level, if economic interests are sacrificed: *the best way for fishermen to be safe is to remain in harbor, or at least not to go out in a heavy swell or with a badly-equipped vessel...*
2. *To position the useful work domain window*: The choice of this positioning is at the heart of the issue, knowing that the more the operating domain is opened to the right (whatever the resilience actions), the more the risks are increased. For any new resilience action, the useful work window is liable to shift to the right. The stakes are self-evident. Any shift to the right increases the performance level— and therefore the risk—and requires added resilience (case in Fig. 2d). Conversely, choosing a sacrificial decision or any voluntary constraint or regulating action can slide the same useful window to the left (case in Fig. 2b).

In view of this, it can be seen that the introduction of new active safety aids (assistance, optimized organization principles, etc.) leads to a valuable safety gain when the window is already to the right (wide open domain), and only a slight safety gain when the window is to the left (highly safety-conscious and restricted domain).

Conversely, any added constraint (regulations, interdictions of any type) shifts the window to the left, strongly increasing safety but closing the competitive domain.

To give an example, the introduction of individual quotas in Alaska (Hugues and Woodley, 2006) made it possible to improve and stabilize the sea fishing system by shutting down all but the soundest companies. The goal of this program was to improve safety while limiting the "race for fish". In concrete terms, it made it possible to improve the economic performance of the remaining companies, but it also enabled the company managers to have

[23] Beam: balancing arm supporting the pan of old-fashioned weighing scales.
[24] Scenario corresponding to what we tested as a means of improving the safety of the fishing system.

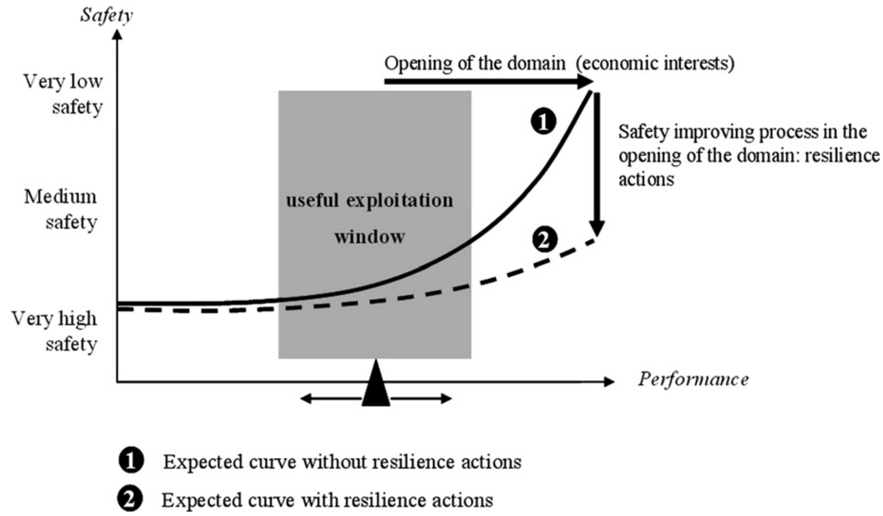

Fig. 4. Modeling the relationship between resilience and safety—concept of the useful work window.

better-maintained and better-fitted vessels (more stable, more professional crews). Today, the conditions needed to improve safety are all present. This improvement however does not follow automatically. The authors note that at this stage, safety improvement requires a significant and ongoing commitment from the companies and crews, so that financial factors do not take precedence over safety. It can be said that once the useful work window is fixed, it is necessary to implement an active safety-promoting approach. When, in a given organization, the rate of accidents or injuries remains stable, when it reaches a plateau, the structure's safety culture becomes, according to Reason (2000), a decisive vector of safety improvement. An organization's safety culture is the product of group or individual values. Their attitudes, perceptions, abilities and behavior patterns determine their commitment regarding health and safety management, as well as the style and ability of this management. Organizations with a positive safety culture are characterized by communication based on mutual trust, a shared perception of the importance of safety, and a trust in the efficiency of preventive measures (ACSNI, 1993, p. 23). This definition, coined in the nuclear energy sector, is the most widely recognized today (Guldenmund, 2000; Flin, 2007). The work of Westrum (1993) and Reason (1997) has led to the proposal of a model presenting five stages of a safety culture (pathological, reactive, calculated, proactive and generative). In the sea fishing system, the safety culture is, without doubt, at the reactive stage; safety mainly consists in investigations and measures taken after an accident. The goal is therefore to drive it to a higher level (creating risk management systems, then anticipating safety problems), by bearing down on the two major leverage points which are (Zohar, 1980; Mearns et al., 2003; Parker et al., 2006): involving the hierarchy in the issue of safety (in this case, the companies and the fishing skippers), and communicating (formal and informal communication between the company management, fishing skippers and crews on risks, incidents, accidents, injuries).

5. Conclusions

We have presented two conflicting safety-improving philosophies. The first, consisting in limiting the operating domain by regulatory constraints, is a maximal-safety philosophy which systematically shifts the useful work window toward a low performance level (to the left); the second philosophy is referred to as "optimization"; its objective is to increase resilience so as to maintain the system at higher performance levels (shifting of the useful work window to the right).

The choice between these philosophies is one of the recurring issues in the gradual safety improvement effort of risky systems (Amalberti, 2001; Amalberti et al., 2005), but it is also a recurring issue for the whole field of ergonomics and the sociology of intervention. The requirements of the heads of industry tend, almost systematically, to the second philosophy, which offers a better protection for their financial interests. In this context, the question becomes a near-ethical issue for the professionals of intervention: should industry leaders be helped to face increasing risks by an assistance enabling them to open out their commercial domain, knowing that *in fine* the accident risk will of course be decreased, but still remain higher than it would be with a solution setting authoritarian regulations and risk quotas? The ideal answer depends in part on the economic survivability of the systems in which the interventions take place; obviously, this answer requires an in-depth contextual analysis of the market economy. We would not even recommend the same intervention in a craft-type system, in which the legal and social pressure is slight in the event of an accident (the fishing system is a case in point), and in a public transportation sector, managed by large firms, and in which the legal and social pressure is considerable in the event of an accident (Amalberti, 2006).

Today, due to the current economic competition mechanisms, it is less and less conceivable to shift the useful work window systematically to the left. This would only be feasible if everyone obeyed the same rules (which was the case for the safety-improving action performed in the aeronautics sector). Today, resilience seems to be a strategic concept dealing with the improvement of safety in complex systems, since it could reconcile the notions of performance and safety rather than systematically oppose them. All in all, for safety specialists, resilience represents what lead represented for the alchemists.

Will the safety research effort succeed where the alchemists failed?

6. Uncited references

COLREG (1972) and Woodley (2006). **Q1**

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