Articulating the Differences Between Safety and Resilience: The Decision-Making Process of Professional Sea-Fishing Skippers

Gaël Morel, University of South Brittany, Lorient, France, **René Amalberti,** Air Force Aerospace Medical Research Institute, Brétigny-sur-Orges, France, and **Christine Chauvin,** University of South Brittany, Lorient, France

Objective: As the world's most dangerous profession, sea fishing enables discussion of the concept of resilience and its articulation to the notion of safety in complex systems. **Background:** In the small, emerging community working on this concept, the prevailing idea to improve safety is that resilience must be reinjected into the know-how of complex systems. **Method:** Thirty-four male skippers, divided into two groups, took part in an interactive simulation of a fishing campaign. They had to make decisions in situations of trade-off between safety and production goals. **Results:** From the time they left the harbor, the fishermen never gave up on fishing, even in extreme conditions, and regardless of whether or not the catch was good. Not being suicidal, however, they used multiple expert strategies to reduce risk without giving up on their fishing activity. **Conclusion:** Systems run by craftspeople are very resilient because they rely on a high level of adaptability, based on the actors' expertise, linked to an exposure to frequent and considerable risk. Each actor is responsible for his or her own safety. The final discussion bears on the question of knowing whether or not it is possible to design a safe system while preserving its craftsmanship and therefore its native resilience. **Application:** The results of these studies suggest potential adverse effects of classic safety interventions in complex sociotechnical systems either in terms of professional reluctance to accept new recommendations or through the emergence of new sources of risk.

INTRODUCTION

Initially, the concept of resilience belonged to the physical sciences. Resilience is a body's ability to withstand pressure and recover its initial structure after an alteration of its shape. American psychiatrists specializing in the treatment of small children were the first to adapt the concept to describe an individual's ability to live, succeed, and develop in spite of adverse circumstances. From this point of view, resilience is "the art of navigating the rapids" (Cyrulnik, 2001, p. 223). Quite recently, the notion of resilience has been extended to research on the reliability and safety of complex systems (Hollnagel, Woods, & Leveson, 2006).

The present research is situated in this context. This paper is an interrogation on the articulation and the difference between the concepts of resilience and safety. It is divided into three parts. The first is an analysis of the theoretical framework linking the concepts of resilience and safety; the second, a study, through observation and experimental situations, of the relationship between resilience and safety in conditions of extreme risk using the example of professional sea fishing. The third is a discussion of the results of professional fishing and a general application of the concepts, through an understanding of the link between resilience and safety. The conclusion opens new avenues of research to refine the model and improve the safety of complex systems.

THE EMERGENCE OF THE CONCEPT OF RESILIENCE

Complex sociotechnical systems (e.g., transportation, energy, medicine) require safety measures. Over the past 30 years, cognitive ergonomics

Address correspondence to Gaël Morel, Study Group on Health, Work, Information and Cognition (GESTIC), University of South Brittany, Centre de Recherche, Rue Saint Maudé, Lorient 56325 France; gmorel@univ-ubs.fr. ***HUMAN FACTORS,*** Vol. 50, No. 1, February 2008, pp. 1–16. DOI 10.1518/001872008X250683.

has provided many description frameworks. The earliest efforts focused on the reliability of the human factor and the suppression of human error (e.g., the technique for human error rate prediction: Swain, 1964). The total eradication of human error was quickly abandoned as an objective (being unrealistic from a simple theoretical viewpoint), and safety naturally evolved toward a more systemic perspective (Rasmussen, 1986; Reason, 1990). In parallel, and in Rasmussen's (1986) footsteps, Hollnagel and Woods (1983) and Woods (1987) focused on the conditions of a better human-machine cooperation in which a system's risks would be perceived through its interaction dynamics, rather than through the risk of failure of single components within the system – the machine on one hand, the human on the other (the concept of joint cognitive systems).

Starting in the 1990s, a large community of researchers began working along these lines, in a trend notable for three strong points: an interest in complex dynamic situations (aeronautics, railways, nuclear plants, metallurgy, military situations); an interest in fieldwork and the safety decisions actually made by operators (naturalistic decision making: Klein & Zsambok, 1997; ecological safety: Amalberti, 2001a; Hoc & Amalberti, 2007); and an interest in limiting the traps or surprises that could arise from ill-designed automation (Billings, 1997; Woods, Johannsen, Cook, & Sarter, 1994).

The concept of resilience is a natural offspring of these original approaches, all focused on the control of safety in complex dynamic systems in the real world. The concept relates to relevant actions or strategies situated in three temporal horizons, of which the first is to imagine the catastrophe before it takes place. The example of Hurricane Katrina (New Orleans, August 29, 2005; Westrum, 2006) revealed that the potential for this catastrophe was known and even subjected to analysis through simulations of the events that could occur. Unfortunately this information was not acted upon – hence the poor response.

The second temporal horizon is to adapt to a critical situation and produce reasonable solutions in real time (Three Mile Island or Chernobyl in the nuclear industry, as examples of poor resilience, vs. instances of good resilience, such as the successful Israeli medical response to bus bombing; Cook & O'Connor, 2005). The third is to manage the fallout from the accident, to the point of deciding a company's success or failure – for example, the good resilience of the Concorde owners after the Paris crash of July 25, 2000 (Amalberti, 2006) versus the bad resilience of many companies for which one accident contributed to bankruptcy (TWA, Swissair).

Resilience provides full and adequate answers to these three levels because it allows operators to anticipate the unexpected so as to avoid it, to manage it when it does happen, and to survive the fallout after it has happened, in terms of reputation, image, and legal penalties (see, e.g., Wreathall's, 2006, definitions).

In other words, resilience could be described as a system's ability to resist a wide variety of demands from its whole domain of operation. The wider and better controlled the open performance domain is, the higher the level of resilience. This performance domain is continuously moving and expanding, either (a) occasionally, in reaction to an exceptional situation, or, more often, (b) as a result of a gradual opening associated with better personal and in-service experience. This last point brings the discussion back to the pivotal question of trade-off between safety and performance. Often, the advantages of increasing production are immediately perceived and the domain opens out, whereas the associated risk taking implies only drawbacks for safety at a later point in time. The proper resilience adjustment for a system caught in this voluntary or tacit increase in risk taking, with a view to immediate profits, has become a core topic for the study of resilience (Flin, 2006; Woods, 2006a).

Flin (2006) reported that earlier accounts of air or rail disasters revealed an erosion of managerial resilience. She considered the resilience of middle-level managers as a vital component of organizational safety. She also considered three kinds of skills that characterize managerial resilience in relation to safety: (a) diagnosis (the ability to detect the signs of an operational drift toward a safety boundary); (b) decision making (the ability to choose the appropriate action to reduce the diagnosed level of threat to personnel or equipment); and (c) assertiveness (the ability to persuade other members of staff that production has to be halted or costs sacrificed).

As can be seen, resilience is related to the capacity for recognizing the problem and making a safe decision in adverse conditions, possibly giving up the potential benefits. The problem is that the arbitration is often not that simple. The joint system made by humans and situations is also a matter of available cognitive capacities (whether they are natural or artificial). The feeling of danger fundamentally depends on these joint capacities and their reflexive perception by actors. Hence, another reading of resilience could consider the range of controllable situations as a matter of a natural expansion of expertise and thus determine that a more resilient system is a more knowledgeable system capable of maintaining safety and gains, neither of which excludes the other, in a larger range of situations.

Bad resilience could then be considered as the result of a triple force: poorly developed extended competencies, poor or incorrect reflexivity (metacognition), and last, but not least, difficulty in giving up when facing the boundaries of controllable area.

Woods (2005, 2006a) introduced the concept of "sacrificial decisions" to characterize this complex safety/performance conflict management and gave the *Colombia* accident as a most relevant example (Woods, 2005). The National Aeronautics and Space Agency had a culture of success, and its staff was used to performing in challenging conditions regarding both time frames and finances; for reasons of national pride and prestige, there was a great deal of pressure to turn in an immediate success. The trade-off thus naturally leaned toward risk taking, a risk which was moreover judged to be acceptable and controllable, considering the institution's know-how. The same ideas had already been clearly set out a few years earlier, in a study on risk taking in surgery, in the field of laparoscopy (Dominguez, Flach, McDermott, McKellar, & Dunn, 2004). Surgeons continually assess whether the patient's best interests might be served by converting a laparoscopic case to an open-incision one.

This trade-off is quite fundamental and has always plagued discussions of safety – the safest aircraft never flies, the safest anesthesia is never given – so that all operators in risky domains must find and adjust the balance between acute "faster-better-cheaper" goals (or the tactics that will help to achieve these goals) and chronic goals such as safety.

However, outside of the small circle of those who promote the concept, the questions (and perhaps the confusions) around the emerging notion of resilience are still widespread. It is not easy to grasp what it really represents.

For many professionals and scientists, the word *resilience* is only the fashionable "emperor's new clothes" of research on work-related safety, after the vogue in recent years of notions such as workload and situation awareness. In this line of thought, the notion of resilience is sometimes associated with any action designed to improve a system's safety: The safer the system, the more it is said to be resilient. Others imagine that the concept describes an "extra coat" paving the way to ultrasafety – a safety know-how that, once acquired, would complete, through specific new rules, a conventional safety plan that is already based on the usual restrictions, mandatory equipment, rules, and control protocols. The reality is probably more complex and also more of a paradox (Amalberti, 2001b, 2006).

If the notion of resilience refers to the ability to recognize, adapt to, and handle unanticipated perturbations (this would imply that resilience is concerned with monitoring the boundary conditions of the current model of competence; Woods, 2006a, p. 19), it can be postulated that the professions and practices most often exposed to such situations have acquired know-how in how to survive them and are, consequently, particularly resilient professions.

This opens the greatest paradox of all: The activities and professions most frequently exposed to unexpected, critical, unbalancing situations are those in which the greatest risks are taken. For instance, the best mountain climbers are known for their ability to survive in exceptional and perilous situations; each climb into the Himalayas is a source of surprises. However, mountain climbing in the Himalayas is the world's most dangerous sport, with a fatality rate close to 1 death out of 10 ascents.

This shows that the relationship between resilience and safety is much more complex than a simple, cumulative way of improving safety. To test this relationship even more explicitly, we will now analyze the behavior of a high-risk profession – sea fishing – and attempt to understand and model the safety management and resilience of this activity. Seafaring in general is a domain known for its harsh working conditions (conditions at sea, condition of the ships, economic competition, etc.). Eighty percent or more of major marine accidents are caused by human error or organizational error (Hetherington, Flin, & Mearns, 2006).

Perrow (1999) stressed the fact that the human factor has always been preeminent aboard ships, whatever their size and complexity, and that ship captains are faced, more than most deciders, with the problem of having to choose between safety and performance criteria. Perrow (1999) brought up the accident of the *Torrey Canyon* (the first of the big supertankers, capable of carrying a cargo of 120,000 tons of crude oil), which wrecked off the western coast of Cornwall in 1967 and caused an environmental disaster because the captain, for the sake of saving 6 hr, decided to take a direct route through the Isles of Scilly.

In seafaring, the trade-off between production and safety is all the more difficult because it occurs within a highly demanding context characterized by fatigue, extreme weather conditions, and stress. All these conditions are more extreme in the sea-fishing industry, which represents a genuine textbook case for the study of resilience, and of trade-offs between safety and performance.

THE SOCIOTECHNICAL SYSTEM OF THE SEA-FISHING INDUSTRY

Characteristics of the Sea-Fishing System

The model studied here is that of professional sea fishing. In this paper, we will focus on deep-sea fishing as practiced by 20- to 24-m trawlers (usually with a crew of five, for fishing tours of 4–14 days). This choice is justified by recent studies (Morel, 2005, 2007) showing that this fleet is highly accident prone. The main risk factors identified are intensive work rhythms, a hostile and changing environment, and the exposure of the crew to critical risks specifically linked to the trawling activity (handling the fishing equipment, hooking the fishing equipment onto the seabed, etc.).

A paradoxical system. The sea-fishing system, as is typical of craft-style activities, is characterized by a major paradox that has been pointed out by previous studies on the subject (Morel, 2006; Morel & Chauvin, 2006): This system is highly regulated and yet is unable to achieve a high safety level. Morel (2006) explained that this paradox is the consequence of regulations aimed at preserving the resource rather than ensuring the safety of the people exploiting it. Furthermore, the international conventions dealing with fishing safety are not applicable to vessels less than 24 m in length, and yet these make up 99% of the fishing fleet worldwide. Finally, the sailors' safety depends for the greatest part on the decisions made at sea, on board, by the fishing skippers.

A system that is objectively unsafe, economically fragile, and technically efficient. Sea fishing is a difficult profession, but the fishers' income has been maintained at a fairly high level, giving them (in France and the rest of Europe) an enviable social position in small ports, where employment in other fields is often precarious. In the deep-sea-fishing category, the vessels are often technologically sophisticated and equipped with advanced electronics; fishing over the season is aligned on the maximum authorized quotas.

In short, sea fishers live fairly well. However, their standard of living is critically dependent on the authorized fishing quotas, and their standard of safety is very low.

Sea fishing is the world's most dangerous occupation (International Labour Office, 1999; Kaplan & Kite-Powell, 2000; Marine Accidents Investigation Branch, 1995; Wang, Pillay, Kwon, Wall, & Loughran, 2005). The risks incurred by sea fishers include many different types of injury (falling overboard; being cut, burned, or crushed, etc.), which can cause major damage and even be fatal. In France, in the year 2000, the frequency of work-related injuries in "ordinary" professions was 44 per 1,000 workers; among sea fishers, the rate was 143 injuries per 1,000 workers (Chauvin & Le Bouar, 2007). Moreover, the rate of fatalities is much higher in this industry than in any other sector of activity. The figures for the year 2000 were 100 fatalities a year per 100,000 sailors, as opposed to 15 per 100,000 in the building trade industry (considered to be a high-risk sector) and 5 per 100,000 in other fields. These findings are not limited to France (Food and Agriculture Organization, 2001).

The few formal safety rules in this industry primarily involve steering and right-of-way regulations (with a privilege granted to vessels in the process of fishing), mandatory training, the presence of on-board technical devices, and technical rules applied to the vessels. Good practices and safety recommendations, brought up in interviews with professionals and insurers, are more numerous: the safety lines tying the fishermen to the vessel, the wearing of safety equipment, the safe positions of the crew on deck, the limits put on the fishing effort according to the state of the sea and the weather, the correct behavior over certain types of seabed (limiting or avoiding hooking onto the seabed with the fishing gear), the correct behavior of the man in the wheelhouse on watch (normally, a crew member is always on the bridge as a lookout and to manage anticollision activities), and so forth.

SIMULATION OBSERVATIONS

The objective of this experimental phase is to study the fishing skippers' decision-making process by placing them in (simulated) situations of conflict between production and safety. The study is based on a previous cognitive work analysis, which provides the basis for setting up the events of the simulated fishing campaign and for understanding the responses and judgments of the participating skippers. The scaled world study creates conditions for focused observations directly on the phenomena of interest. The study focuses on the phenomena through the addition of contrasting conditions of observation over the two scenarios. Thus the paper executes the now-classic methodology for a research program directed at naturalistic cognitive behavior (Woods & Hollnagel, 2006).

Method

Simulation of a fishing tour through scenarios. The method we developed consisted of simulating a fishing tour through written scenarios, to which we associated data (the determinants of the decision-making process on the bridge) that could be consulted on request by the fishing skippers as they went through the experimental situation. To study the decision-making process of military supervisors, Zohar and Luria (2004) also used scenarios in situations of conflict between safety and strategic objectives. Adie et al. (2005) used a forced choice decision paradigm with conjoint analysis to study the weighing of factors relating to accident risk perception by commercial deep-sea divers. The withheld information paradigm was previously used by Marshall, Duncan, and Baker (1981) to examine the problem-solving processes of nuclear plant operators.

We chose this method because it would have been extremely difficult and costly to study the decision-making process of fishing skippers directly on board, in real situations. The volume of the catch and weather conditions are not parameters that can be controlled. Simulations have two great advantages: they are easily implemented and easily accessible to fishermen.

Construction of the simulation. The fishing tour simulation was constructed from two sources. The first consisted of data gathered during a 14-day period spent aboard a 22-m deep-sea trawler. An analysis of the fishing skipper's activity on the bridge made it possible to extract the determinants of the decision-making process (see Table 1) and to show that sea fishers operate as a network (Chauvin, Morel, & Tirilly, in press). The information they exchange between themselves (quantities of catch at a particular fishing zone, location of vessels, characteristics of the latest fishing day) and the information they receive from the shore (weather conditions, current price of fish) are strong determinants of their decisions. Damage to the fishing gear is also an important determinant, as these incidents generally require a high level of involvement from the crew to undertake maintenance.

The second source was information gathered

TABLE 1: Determinants of the Decision-Making Process

Type of Information	Determinants
Information the skippers receive from the shore	The weather forecast for the next 24 hr; the current price of prawn (the day's selling price); the current price of fish (the day's selling price)
Information exchanged between the skippers	The geographical location of colleagues at sea; the quantities of catch over the last 5 hauls of the trawl (latest day of fishing); faxes received from colleagues at sea (information exchanged about the quantities caught by these colleagues)
Information directly linked to the fishing activity	The quantities of catch since the beginning of the fishing tour; breakdowns or damage to the fishing gear
Permanent information throughout the fishing tour	The price of diesel fuel; information related to the last fishing tour; fixed expenses (diesel fuel, supplies, ice, engine oil, employer contributions)

from expert fishing skippers. These exchanges made it possible to adjust the data extracted from the period spent aboard and to arrive at a formal design for a realistic simulation, recreating the professional context in which the fishing skippers are required to make decisions.

The simulation took the shape of a realistic scenario, reproducing the typical pattern of a 14-day fishing tour in three highly frequented fishing zones in the South Ireland waters: Jones Bank, Labadie, and Small (see Table 2).

Choice of two contrasted scenarios. To enable the participants to make decisions in situations when production (quantities of catch) and safety (weather conditions) are in conflict, two contrasted scenarios were developed: SC1 involved very satisfying production returns and steadily worsening weather conditions during the entire fishing tour, and SC2 involved production returns below the vessel's cost-effectiveness threshold (in which the crew's wages are not guaranteed) and steadily worsening weather conditions during the entire fishing tour (identical to SC1).

SC1 and SC2 were designed so that the participants would make four decisions at specific stages of the fishing tour:

D = 0: leaving harbor, with the vessel situated near the Ouessant sea lane (SC*.0);
D = 2: at the end of the 2nd day of fishing, with vessel situated on the Jones Bank (SC*.1);
D = 6: at the end of the 6th day of fishing, with the vessel in the Labadie zone (SC*.2); and
D = 10: at the end of the 10th day of fishing, with the vessel on the Small Bank (SC*.3).

At each of these four stages (SC*.0, SC*.1, SC*.2, and SC*.3) we assigned a given safety level directly linked to weather conditions. Both scenarios called for a similar, gradual worsening of weather conditions, reaching the limits of safety in SC*.3. The definitions of the different safety levels were made by expert fishing skippers, so as to avoid any floor effect (see Table 3).

At each stage of the scenario, the participants could choose from among the following actions: (a) continue operations in the same fishing zone, (b) leave the fishing zone for another, (c) temporarily suspend the fishing activity, (d) return to harbor, or (e) other. For each of the four decisions, the participants had to justify their choice by completing the phrase "you made this decision because" with (a) "you felt you could handle the situation," (b) "the situation was becoming too dangerous for the crew," (c) "the situation was becoming too dangerous for the fishing gear," (d) "you felt you must bring in more catch," (e) "you were satisfied with your catch," or (e) "other (define)."

Table 4 presents the structure of the scenarios.

The participants. Thirty-four fishing skippers (all males) aged 27 to 52 years (average = 37.8

TABLE 2: Characteristics of Fishing Zones

Main Species	Diversity[a]	Value/Ton of Catch[b]	Geographical Location	Characteristics of the Water Site
		Jones		
Large prawn, monkfish, cod, hake, dab	+++	+++++	Most southerly position; 3 hr from Labadie, 8 hr from Small,12 hr from Ouessant	Strong swell in bad weather. No prawn if the swell is too great.
		Labadie		
Large prawn, monkfish, dab	++	++++	Central position; 3 hr from Jones, 5 hr from Small, 15 hr from Ouessant	Same as Jones
		Small		
Small prawn, plaice, carrelet, small whiting, skate, monkfish, various	+++++	++	Most northerly position; 5 hr from Labadie, 8 hr from Jones, 20 hr from Ouessant	More sheltered than Jones and Labadie in bad weather. The swell is less strong.

[a]On a scale of + (*least diverse*) to +++++ (*most diverse*). [b]On a scale of + (*least value*) to +++++ (*most value*).

TABLE 3: Safety Levels Drawn Up by Expert Skippers

	Safety (1)	Safety (2)	Safety (3)	Safety (4)	Safety (5)
Wind force (bf)	<3	3 to 4	4 to 6	6 to 8	>8
Visibility (NM)	>10	>10	3 < V < 10	<3	0
Condition of the sea	Calm to slight	Slight	Slight to moderate	Moderate to rough	Rough to very rough
Height of swell (m)	0	Slight waves	2 to 3	3 to 4	>4
Actions recommended by expert fishing skippers	Fishing action	Fishing action	Fishing action	Momentary interruption or take shelter	Momentary interruption or return to harbor

Note. bf = Beaufort Scale. NM = nautical miles.

years, *SD* = 6.65 years) were selected. All of the participants were in command of 22-m deep-sea trawlers operating in the southern Ireland waters. The participants were equally divided between groups SC1 and SC2.

Procedure. The experiment took place in a Breton fishing company. The participants of both groups (SC1 and SC2) went through the simulation in turn, independently. In making their decisions, the participants could access the following information: (a) the data contained in the written instructions for each phase of the scenario (SC*.0, SC*.1, SC*.2, SC*.3): the quantities of catch since the beginning of the fishing tour, the geographical location of the vessel, and the stage of the fishing tour under consideration; and (b) data they could consult freely on a graphic interface developed in JAVA®. This interface was composed of interactive windows (see Figure 1), each corresponding to a determinant in the decision-making process (as identified during the time spent aboard a vessel and adjusted to the experiment's context with the assistance of expert fishing skippers; see Table 1).

By clicking on a heading, the participant opened a window containing the information. To look up other information, he could close the window and click on another heading. Every mouse click made by the participants was saved in a text file. At the end of the experiment, the file thus generated allowed us to trace all the participants' data requests as well as the order of these requests.

Each participant went through a training phase, in order to ensure optimal use of the graphic interface during the simulation. Moreover, to avoid an "apprenticeship effect" when information was requested through the graphic interface, we programmed a random presentation of the headings on the screen each time a sequence was opened (i.e., in SC*.0, SC*.1, SC*.2, and SC*.3).

Once the simulation was over, the participants were asked to give a hierarchy of the determinants of the decision-making process (the determinants presented on the graphic interface) by order of importance. We compared their answers with the information consulted on the graphic interface. Last, a debriefing period with the participants provided us with additional elements to define the safety model and type of resilience characterizing this system.

TABLE 4: Structure of the Scenarios

	SC1: High Production Level	SC2: Production Level Below Vessel's Cost Effectiveness Threshold	Safety Levels Applied (Weather Conditions)	
			At the Moment	Forecast for the Next 24 hr
SC*.0	Decision SC1.0	Decision SC2.0	Safety (1)	Safety (2)
SC*.1	Decision SC1.1	Decision SC2.1	Safety (2)	Safety (3)
SC*.2	Decision SC1.2	Decision SC2.2	Safety (3)	Safety (4)
SC*.3	Decision SC1.3	Decision SC2.3	Safety (5)	Safety (5)

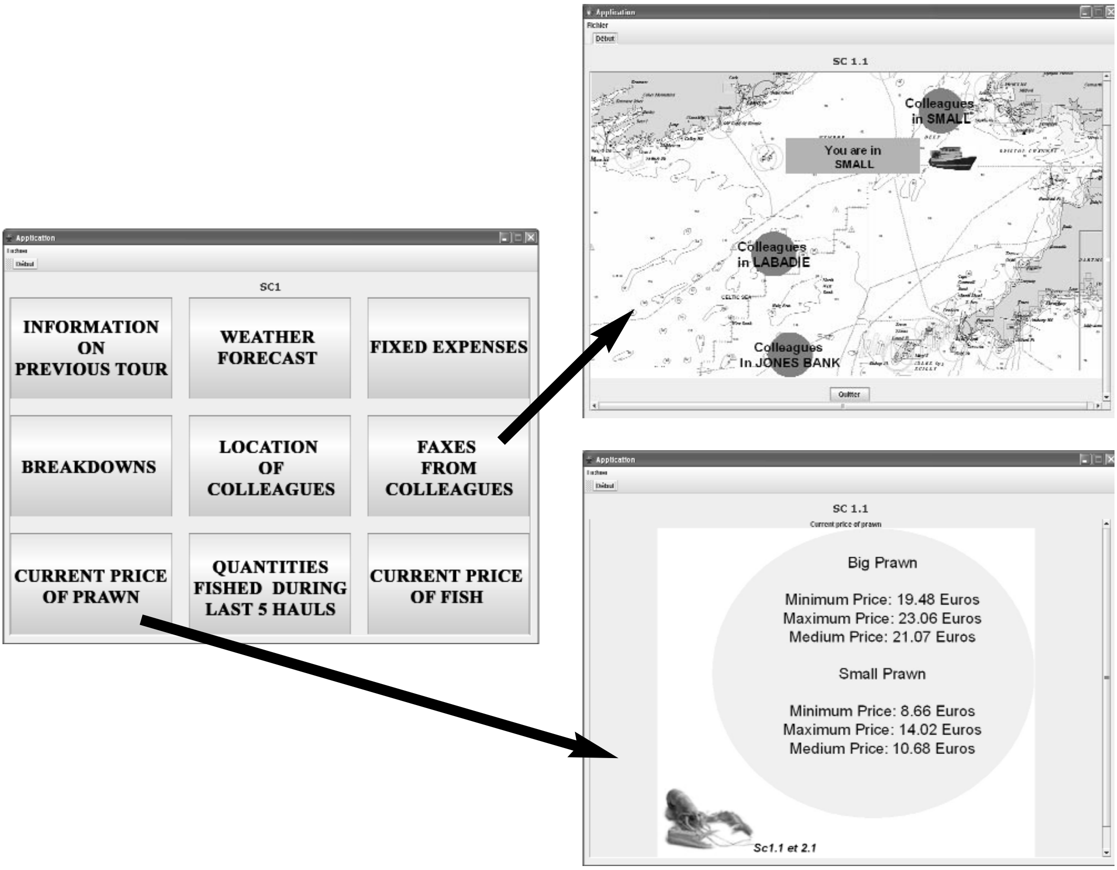

Figure 1. The graphic interface.

Results

Information consulted. The most important determinants of the decision-making process were faxes from colleagues, location of colleagues at sea, quantities of catch over the latest day of fishing, and weather reports. Table 5 shows that in SC*.0, 91% of participants made their decisions by combining only three determinants: faxes from colleagues and/or location of colleagues and/or weather reports. In SC*.1, 91% of participants made their decisions by combining the same three determinants and adding a fourth: quantities of catch over the latest day of fishing. However, 41% considered only the initial combination of determinants observed in SC*.0.

In SC*.2, 82% of participants were still considering only the combination of four determinants observed in SC*.1. In SC*.3, the participants called up new decision-making determinants (though still associated with the four previously defined): current price of prawn, current price of fish, fixed expenses, and damage to the fishing gear. At this point in the scenario, the fishing tour was drawing to a close. Overall, the participants took into consideration the new determinants that generally enabled them to optimize the upcoming sale of their catch.

Table 5 also shows data on the consultation of the weather report determinant. We found that this determinant was not systematically taken into account for the first three decisions, but it remained very frequently consulted in SC*.3 (during fishing in extreme conditions). Moreover, the hierarchy of determinants defined by the participants is very homogenous and reveals that the weather report occupied only the fifth place, after faxes from colleagues (first place), quantities of catch since the beginning of the tour (second place), location of colleagues (third place), and quantities of catch over the latest day of fishing (fourth place).

Decisions in favor of maximum performance.

TABLE 5: Information Consulted

Information Consulted on the Graphic Interface	SC*.0 SC1	SC*.0 SC2	SC*.1 SC1	SC*.1 SC2	SC*.2 SC1	SC*.2 SC2	SC*.3 SC1	SC*.3 SC2
Fax from colleagues	17 (100%)	16 (94%)	13 (76%)	16 (94%)	16 (94%)	16 (94%)	14 (82%)	16 (94%)
	97%		**85%**		**94%**		**88%**	
Location of colleagues	14 (82%)	9 (53%)	10 (59%)	12 (71%)	9 (53%)	10 (59%)	12 (71%)	9 (53%)
	68%		**65%**		**56%**		**62%**	
[Fax from colleagues] and [location of colleagues]	14 (82%)	8 (47%)	9 (53%)	11 (65%)	9 (53%)	10 (59%)	12 (71%)	8 (47%)
	65%		**59%**		**56%**		**59%**	
Weather report	7 (41%)	7 (41%)	10 (59%)	9 (53%)	12 (71%)	12 (71%)	15 (88%)	16 (94%)
	41%		**56%**		**71%**		**91%**	
[Fax from colleagues] and/or [location of colleagues] and/or [weather report]	15 (88%)	16 (94%)	6 (35%)	8 (47%)	4 (24%)	4 (24%)	5 (30%)	6 (35%)
	91%		**41%**		**24%**		**32%**	
[Fax from colleagues] and/or [location of colleagues] and/or [weather report] and/or [quantities of catch]	15 (88%)	16 (94%)	14 (82%)	17 (100%)	13 (76%)	15 (88%)	3 (18%)	5 (30%)
	91%		**91%**		**82%**		**24%**	
Others + [fax from colleagues] and/or [location of colleagues] and/or [weather report] and/or [quantities of catch]	2 (12%)	1 (6%)	3 (18%)	0 (0%)	5 (30%)	1 (6%)	14 (82%)	12 (71%)
	9%		**9%**		**18%**		**76%**	
Information on previous fishing tour	2 (12%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (12%)	1 (6%)
	9%		**0%**		**0%**		**9%**	
Damage to the fishing gear	0 (0%)	0 (0%)	3 (18%)	0 (0%)	4 (24%)	1 (6%)	4 (24%)	2 (12%)
	0%		**9%**		**15%**		**18%**	
Selling price of prawn	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (18%)	0 (0%)	8 (47%)	7 (41%)
	0%		**0%**		**9%**		**44%**	
Auction prices	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (6%)	0 (0%)	11 (65%)	10 (60%)
	0%		**0%**		**3%**		**62%**	
Fixed expenses	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (6%)	0 (0%)
	0%		**0%**		**0%**		**3%**	

Figure 2 presents the structure of decisions made at four key stages in the scenario: at Ouessant (SC*.0), Jones (SC*.1), Labadie (SC*.2), and Small (SC*.3). Each of these key stages represents a decision-making junction, characterized by the response modalities defined in the scenario. At each of these junctions, the expected gains and losses were estimated, enabling us to link the decision with the expected performance. Overall, it can be noted that the fishing skippers of the two groups (SC1 and SC2) tended to opt for the decision from which they expected the highest gains. The "suspend the fishing activity" and "return to harbor" modalities were never considered (except by a single fishing skipper in SC*.3).

Decisions made in extreme fishing conditions (SC.3).* Contrary to the results we expected, the fishing skippers in Group SC1 did not stop fishing but, rather, adopted a strategy aimed at maximum performance. Of the 34 skippers in both groups, 25 chose to leave a fishing zone because they hoped to increase their catch, and 8 decided to seek shelter, not so much because of rough weather as because of the risk of not catching anything more in Jones and Labadie (a heavy swell makes it difficult to catch species such as prawn). Their sheltering from bad weather was in fact a strategy designed to optimize production. Only 1 fishing skipper (in Group SC1) made the decision to return to port, not because of the weather but to optimize the sale of his catch (fewer vessels at an auction means a better price for the fish). Of the 25 fishing skippers who changed fishing zones, 23 went to Jones (52% in SC1, 48% in SC2) because they expected sizable profits from the move.

As in SC*.0 and SC*.2, both groups (SC1 and SC2) behaved in a similar manner concerning the decision to change or not change their fishing zone. Figure 3 reveals that a great majority of fishing skippers decided to change fishing zone rather than remain in the same zone, $\chi^2(1, N = 33) = 13.36$, $p < .01$. This decision was motivated by production objectives, as the reason given by 82% of fishing skippers was to fish more, $\chi^2(1, N = 34) = 14.24$, $p < .01$. Finally, within this simulation, the sea fishermen never gave up on fishing, even in conditions beyond the safety limits, whether or not they had had a good catch since the beginning of the tour.

Ecological validity of the simulation. Several studies (e.g., in the field of automobile driving; Godley, Triggs, & Fields, 2002; Hoyes, Dorn, Desmond, & Taylor, 1996; Törnros, 1998) have shown that participants tend to take more risks in simulated situations than in real life. To reduce this effect, we constructed the simulation according to on-site observations during fishing tours and with the assistance of expert skippers. As a result, the scenarios were very realistic. Moreover, the vessel activity log drawn up from elements from fisheries during the last year (the very low number of vessels coming back to port in very bad weather conditions) confirms the risk-taking level observed in the simulation.

DEBRIEFING PHASE

Method

Participants. Following the decision made in SC*.3, we debriefed 8 of the 34 participants; of these, 6 had decided to go to Jones, 1 decided to go to Small, and 1 decided to return to port. We did not go beyond the $N = 8$ participants interviewed because the information gathered was very homogenous.

Material. We used a questionnaire based on the theory of planned behavior (Ajzen, 1991, 2002) and which elaborated on the model of the one developed for vessel navigation by Chauvin, Letirand, and Delhomme (2007). This questionnaire included three types of questions:

- behavioral beliefs: Q1.1 "according to you, what are the advantages of (Option 1/Option 2)?"; Q1.2: "according to you, what are the disadvantages of (Option 1/Option 2)?";
- normative beliefs: Q2.1: "according to you, who would approve your decision to…?"; Q2.2: "according to you, who would disapprove your decision to…?"; Q2.3: "according to you, who would make the same decision?"; Q2.4: "according to you, who would not make the same decision?"; and
- control beliefs: Q3.1: "according to you, what led you to make this decision?"; Q3.2: "according to you, what could keep you from making this decision?"

The two options under consideration were the decision in SC*.3 (Option 1) and going back to port (Option 2).

Procedure. The questionnaire was successively filled out by the 8 participants in the presence of the experimenter. This face-to-face meeting opened the way for numerous open exchanges between the two parties.

Results

Implementing expert risk reduction strategies.

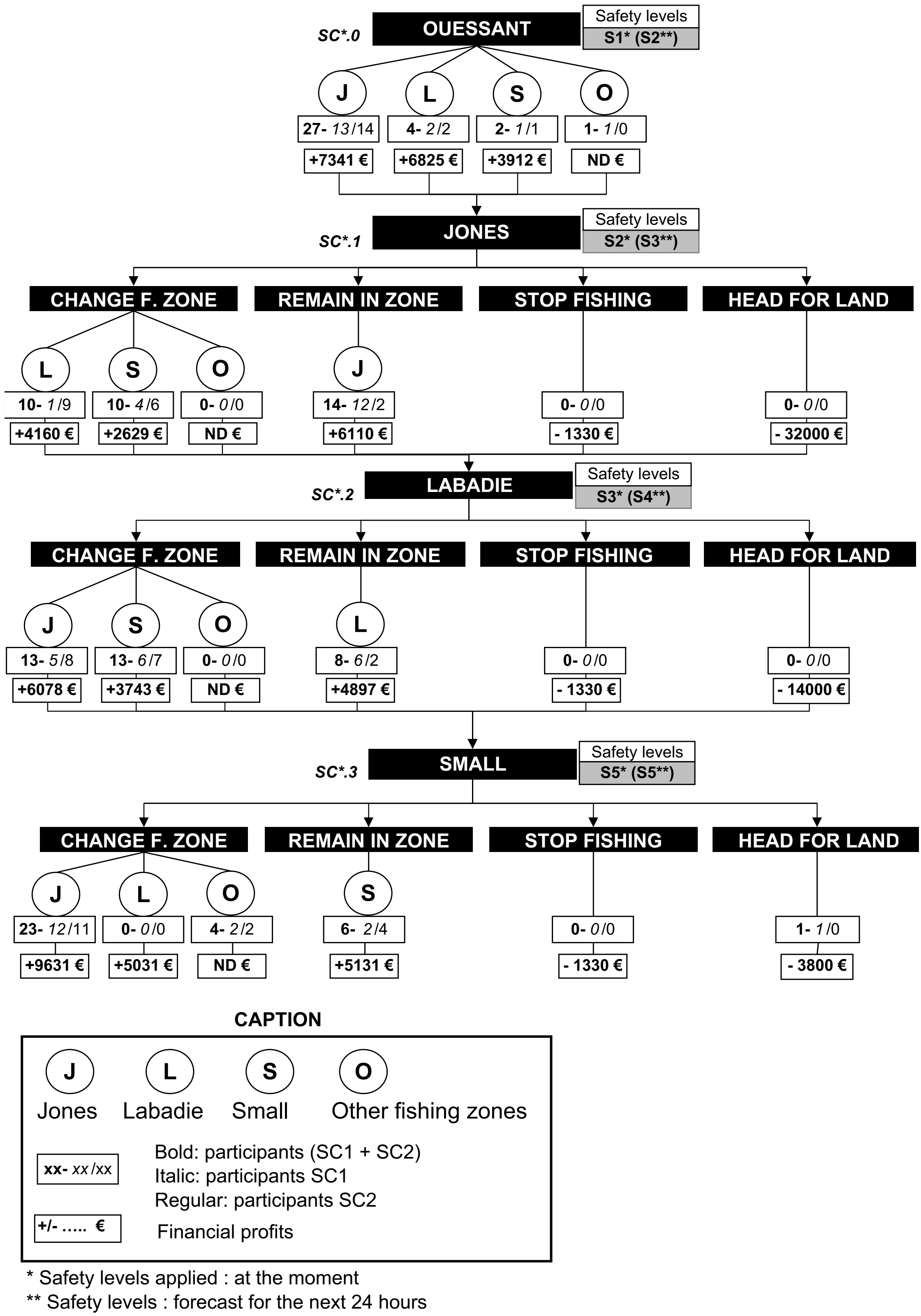

Figure 2. Structure of decisions at each of the four key points.

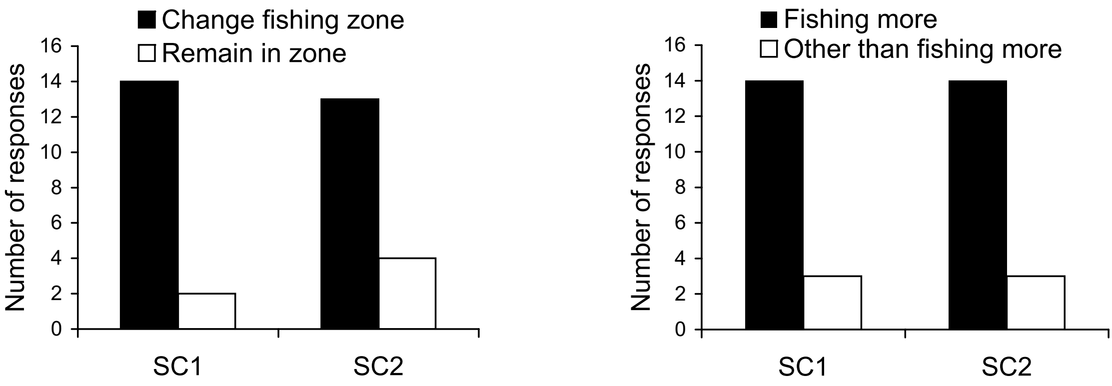

Figure 3. Choices and motivations of the decision in SC*.3.

Fishing skippers are assumed to be rational, nonsuicidal people. Consequently, if they continue fishing in conditions well beyond the safety limits, it is only possible through a high level of expertise on the part of the skipper, associated with the use of risk-reducing strategies. The most common of these consists in "heaving-to" the fishing vessel when the swell and wind force prevent the skippers from performing normal trawl hauls at their chosen course and speed. By fishing "hove-to," the skippers compromise with the storm by keeping the bow of their vessel in an optimal position in relation to the swell and the wind. The engine power of the vessels must also be adjusted to guarantee a speed allowing the crews to continue their work on deck in spite of extreme conditions.

The "heave-to" strategy is associated with another, consisting of choosing to fish over sandy sea bottoms in order to limit the risk of hooking the fishing gear on rocks or on other undersea elements. In extreme conditions, "hooking-on" can be enough to lose a vessel. This shows, more than anything else, how much the safety of the crew and vessel depends on the fishing skippers' ability to deal with the elements, however hostile. During the period spent aboard a trawler for the purposes of this study, the skipper made the decision to continue fishing during a full-blown storm (west wind force 11 on the Beaufort Scale – 56–63 knots), swell > 5 m). In spite of these extreme conditions, the skipper managed to continue his fishing effort and avoid accidents, though taking considerable risks.

When weather conditions no longer allow vessels to continue fishing, the skippers can adopt two other strategies. The first is to persist in their choice of a fishing zone. Some skippers prefer to "heave-to" and wait for an easing of weather conditions, so as to be more quickly in position to begin fishing again. The second consists in momentary changes in fishing zones. In this case, skippers choose to head for more sheltered fishing areas (closer to the shore or over shallower depths); they are willing to use up more diesel fuel to gamble for a bigger catch. When weather conditions become "acceptable" once more, they generally return to their original zone. One of the advantages of this strategy is to allow the crews to rest while the vessel is under way. (We also observed that in bad weather conditions, fishing skippers tend to lengthen the average time of a trawl haul, to give the crew longer rest periods.) All these strategies necessarily depend on the skippers' experience, skill, and know-how.

Fishing skippers: Sole deciders on board. When the skippers were asked "who would approve/disapprove your decision in SC*.3?" it clearly appeared that the skippers were the sole deciders on board. Consequently, the others actors (crew, company) could only approve them (except if their decision turned out to be counterproductive). The question "what could stop you from continuing fishing?" summarizes in itself all our findings, because all 7 skippers who decided to continue fishing answered, "no one." The same type of behavior can be found in small companies, in which the director is usually the sole decider.

Stop fishing: Only for a valid reason. Even if the decision to stop fishing could present advantages for the crews (reduction in fuel consumption, time lag between the vessels coming in to auction, decrease of damage from bad weather), the disadvantages were perceived as more important and of greater consequence. For 6 of the 8 skippers interviewed, a decision to stop in SC*.3 implied the sacrifice of 2 fishing days and, therefore, of an important percentage of their income. Weather conditions and/or breakdowns could represent valid reasons for skippers to stop fishing.

Decisions motivated by cost-effectiveness. The 7 fishing skippers who decided to continue their fishing action in Jones and Small were led to do so by the characteristics of the fishing zone and their desire to make a profit. The single skipper who decided to return to harbor (Group SC1) was motivated not by safety criteria but by the prospect of a better sale of his catch.

Metarules shared by every skipper of a fleet. To the question "who would do as you did?" the fishing skippers answered that all their colleagues working aboard the same type of vessel would have made the same decisions. In fact, the majority were unable to tell us who would have decided otherwise.

GENERAL DISCUSSION

Resilience: An Innate Quality of Risky, Reputedly Hazardous Systems

These results show that the deciders of the sea-fishing system are independent actors; they are alone in making decisions on board, and safety depends entirely on their decisions. Repeated exposure to risks creates in these sailors an adaptive know-how regarding safety, much closer to the definition of resilience than to a totally rational attitude. Although the best safety response would be to stop fishing in borderline conditions, the resilient response is to go on, and develop survival skills, according to the situation.

This willingness to take risks is actually based on genuine craft-style knowledge of resilience, centered on a familiarity with the environment and the ability to anticipate the changes both of this environment and of one's own skill, thus achieving permanent and favorable adequacy.

The present study is consistent with a series of other studies of high-risk activities. Amalberti and Deblon (1992) pointed out the exceptional skills to be found in fighter pilots, who constantly orient the situation in which they are about to place themselves as a function of the perception of their own ability to manage these situations (status of the context, previous results in comparable situations, flight fatigue, etc.).

Ranson et al. (1996) found that experienced practitioners (whitewater paddlers) were constantly seeking information (information-hungry behavior) to assess the changing hazards relating to their ability to manage and control upcoming hazards (e.g., whether the paddlers rested or tired; the ability to recover if a paddler spills; how the hazards of a particular run relate to the variation in skills among a team of paddlers). Anticipating the evolution of hazards is a key ingredient, and an accurate evaluation of one's own abilities in context is another. Both are difficult cognitive skills, and both can be enhanced even for an experienced operator – the second of the two being the most difficult to achieve and to assist.

It is obvious that professions in which risk taking is great and frequent encourage the acquisition of such skills, which in turn further increase the risk taking (metaknowledge effect). However, it is extremely difficult to help an operator to acquire these skills without exposing him or her to risks. This was one of the conclusions made of the failure of electronic copilot programs on fighter planes. Very good assistance equipment designed for controlled risk taking is mainly very good at helping pilots who are already experts and familiar with risk (Amalberti & Deblon, 1992).

The most frequently recurring requests of expert fishers are not for more regulations but the opposite: They want new means of staying at sea in unfavorable conditions (e.g., GPS equipment allowing more visibility of surrounding sea traffic, various electronic devices). It is a burning and even an ethical question in the field of ergonomics: Should a sector's request for help in optimizing production be satisfied, or should this request be denied because of the paradoxical consequences of added risk-taking, which would be the result of a successful joint assistance?

The fishing system is able to cope with unanticipated perturbations. In this way, this system is safer than average for these exceptional conditions, even if this result is relative and the system suffers more accidents overall as it exposes itself to more risks. To manage the risks, sea fishers rely almost exclusively on a specific form of safety: managed safety (S_M) or resilience. Going back to the definition of resilience suggested by Hollnagel and Woods (2006), "the ability to manage unexpected events" (p. 329) (before, during, and after), we find that this form of safety is very different from the form which has been, and is still, implemented to guarantee the safety of complex systems: safety through constraints (prohibitions and protections), or S_C. Consequently, a system's total (or observed) safety necessarily integrates both forms of safety, but definitely not on an equal footing. We postulate the following equation:

$$\text{Observed Safety} = [S_C + S_M].$$

Within the framework of the fishing system under scrutiny, constrained safety (S_C) is almost nonexistent. This first level of resilience constitutes a dynamic coupling between S_C and S_M, relying mainly on the autonomy of fishing skippers and, therefore, on S_M. Here, resilience constitutes an innate property of the basic craftsmanship system but is unable in itself to provide a high safety level (or observed safety; see Table 6).

$$\text{Observed Safety} = [s_c + \mathbf{S_M}], \text{ safety level: } 10^{-3}$$

Can the Fishing System be Made Safer Through Constrained Safety (S_C)?

The fishing system has reached an economic balance, but this balance is unstable because of the growing scarcity of the resource, added to increasing regulatory restrictions. These economic constraints force fishers to optimize their fishing activity if they wish to retain a high income, and they quickly reach the limits of authorized quotas. This strategy drives them to ever-greater risks. Inevitably, at this game, some win and some lose, and any one of them can sooner or later become "the loser." If their activity is to be rendered safer, the benchmark strategy in any industry would take the form of prohibiting risk taking (Amalberti, Auroy, Berwick, & Barach, 2005). This would cause considerable disturbance in the profession, which might not hold up under the strain (Amalberti, 2006). Moreover, the expertise that is gained with exposure to dangerous situations would gradually disappear, taking resilience with it.

Ultimately, the discussion on managed safety, overall safety, and local "resilience" brings us back to the most basic conceptual issue about resilience: often, the word *resilience* is used to refer to first-order adaptive capacity when it should more properly be reserved for second-order adaptive capacity: the way in which one can modulate adaptive capacity as the situations change beyond what one is normally able to handle (Csete & Doyle, 2002; Woods, 2006b; Woods, Wreathall, & Anders, 2006).

CONCLUSION

The process of making systems safer always leads to a considerable increase in constrained safety (S_C), to the detriment of self-managed safety (S_M).

$$\text{Observed Safety} = [\mathbf{S_C} + s_M].$$

Unfortunately, this increase is almost always to the detriment of the resilient, adaptive ability of the system. As it becomes safe, the system also becomes rigid.

One research question remains open: the compatibility of the two types of safety, constrained on one hand, self-managed on the other. Future research will have to define a method through which a complementary vision of these two approaches could be created.

Some avenues of research are already open: the adoption of a proactive point of view, training on simulators to cultivate resilience, proceeding within the limits of a well-regulated work domain where operators still retain some autonomy rather than by strict protocol-type guidelines (free flight), and rethinking the evaluation of risks by taking a

TABLE 6: Characteristics of Resilience in the Sea-Fishing System According to Amalberti (2006)

Safety Level	Model of Success	Model of Failure	Criteria for Resilience	Who Is in Charge of Organizing Resilience?
Sea-fishing industry = ultraperforming system	Quest of maximum performance depending on the skill of independent operational actors	Fatalism Low skill/know-how Uncontrollable outside factors	Skill/know-how Expertise Efficient tools and means of production "Grants"	Operational actors organized as a network Vessel owners Political structures

new look at improbable scenarios (which are currently left aside).

None of these has yet proven its status as a new approach regarding safety-improving actions for risky systems.

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Gaël Morel is an ergonomics researcher in the Study Group on Health, Work, Information and Cognition at the University of South Brittany, where he earned his Ph.D. in ergonomics in 2007.

René Amalberti is the codirector of the Air Force Aerospace Medical Research Institute in Brétigny-sur-Orges, France. He received his M.D. from the University of Marseille in 1977 and his Ph.D. in cognitive psychology from the University of Paris in 1992.

Christine Chauvin is a cognitive psychology and ergonomics researcher in the Study Group on Health, Work, Information and Cognition at the University of South Brittany. She earned her Ph.D. in cognitive psychology from the University of Paris V in 1996.

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