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Toward a resilient organization: The management of unexpected hazard on the polar traverse

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ABSTRACT

The aim of this research is to understand the organizational resilience through the safety management when unexpected events occurred, on an atypical transport environment, the polar traverse. Three polar traverses were studied, one of which being a detailed case study. Thus, ethnological observations over 3 year periods from 2012 to 2015 (to understand the traverse logic, functioning through unexpected event) and all-day interviews during a traverse (to understand actions and strategies of organizational resilience to cope unforeseen events) were collected. The main results, from quantitative and qualitative analysis, indicated (1) mechanical, organizational and both interventions allowed to face unexpected incidents on the traverse, (2) great possibilities to take actions on the convoy organization enabled to develop a pro-active management of the safety in alternation with reactive adjustments; (3) the importance was to preserve the machines functionality even if operators have to face environment hostility to repair; and (4) the variation of the convoy organization was permanent in its whole even if the incidents concerned only one road track. The strategies of organizational resilience building will be discussed in this article, around the proactive–reactive management, the organizational dynamic, the risk evaluation, and the risk taken to preserve the room manoeuver.

1. Introduction

The term « resilience » can sometimes, in certain cases, be reserved for the management of unexpected disturbances « which exceed the anticipated areas of adaptation » (Lundberg and Johansson, 2006, 2007; Woods, 2006, 2009). A system is resilient if workers adapt themselves by understanding the context in which adaptation takes place. Adjustments are thus constantly made by individuals and organization, even if they are more often approximate rather than exact (Hollnagel, 2012). Every organization is stretched to operate at its full capacity and, to be resilient, a system needs to be able to anticipate whatever may happen, monitor what is going on, respond effectively when something happens, and learn from past experiences (Hollnagel, 2009; Woods and Cook, 2002; Woods and Hollnagel, 2006). Consequently, the organizational resilience strategies are questioned to understand how a system could adjust itself to disturbances or unexpected hazard.

One of the main objective of researches focused on the strategies of organizational resilience is to understand the organizational preconditions conducive to a safe performance (Pidgeon and O'Leary, 2000). Some studies emphasized the need for proactive measures in safety management, while proactive manner invested in safety and resource allocations to safety improvement are key factors in ensuring a resilient organization (Dekker et al., 2008). Reactive adjustments are, by far, the most common ones. Short terms responses are not enough to guarantee a system's safety and survivability. One reason for this is that the system can only be prepared to respond to a limited set of events or conditions and over a limited period of time. The reactive approach quickly appears too restrictive (Daniellou et al., 2009; Hale and Heijer, 2006), as this new way of conceiving safety is of little interest if it only reacts to events and does not anticipate them (Dekker, 2006; Hollnagel and Woods, 2006; Westrum, 2006). Consequently, the proactive vision of resilience is therefore essential when aimed at the prevention and adaptation of a system to changing conditions prior to the occurrence of undesirable events (Hollnagel, 2006, 2008, 2009; Leveson et al., 2006; Morel et al., 2008; Westrum, 2006; Woods and Hollnagel, 2006). Proactive adjustments, however, mean that the system can change from a state of normal operation to a state of readiness before something

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happens. In this case, resources are allocated to match the requirements of the expected event and special functions may be activated. The Safety Management System (SMS) is interested in this problematic, considering the fact that organizational and management factors have to be taken into account to understand human contribution to major accidents (Hale and Hovden, 1998). SMS is the most efficient way of allocative resources for safety regarding which organization plays a major role. Supplementary resources are mobilized and local strategies are deployed to cope with disturbances. This is « opportunistic bricolage » which is a way to offset the disturbances and maintain the functioning of the system at the lowest possible level of risk. It is a safety measure deployed by human expertise, as well as the use of specific individual and collective skills in real time, as previous studies in polar context have already shown (Villemain and Lémonie, 2014; Villemain and Godon, 2015).

Studies focused on extreme situation at work are poor in the ergonomics approach, and even more so in polar context. Few researches in polar conditions have been led in a logistics thematic in arctic (Lièvre, 2007). At the present time, only our researches on working conditions in the Antarctic context working are being carried out with an ergonomics approach (Villemain and Lémonie, 2014; Villemain and Godon, 2015). To conduct research in such conditions requires a specific methodology to collect data because of the harsh conditions. Subsequently, the ethnographical method is the most appropriate to the ground constraints (Rix-Lièvre and Lièvre, 2010). These authors used this kind of method in order to study ski polar expeditions in arctic through ethnological observations and interviews.

The context and motivations of this research are particular and require to be specified. The French polar traverse, initiated in 1993, was followed by the creation of the scientific French–Italian station on the Antarctic continent called Concordia (situated to 1150 km from the French station Dumont D'Urville (DDU) and opened in 2005). At that time, the objective was to design a freight and material transport mode, in order to build the station, from DDU (carried by boat until this station) to Concordia. Thus, the issue then was a technical, material, technological, logistical and economical challenge. The traverse has been explored more from a technical point of view than a safety aspect, only guided by an experiential or empirical observation. In Antarctica, the environment hostility does not facilitate human activities, more particularly when those take place outside such as mechanical task to repair machines. During the traverse, temperatures can be below −50 °C in February. Thus, in this context, the smallest incident, if not managed immediately, can bear heavy consequences and become dramatic due to a limited medical assistance and the isolation. The vital prognostic is quickly engaged.

The polar traverse could be defined as a set of vehicles in movement in the polar continent, with a total autonomy. Eleven days are necessary to reach Concordia from DDU. Three return-trips DDU–Concordia are organized during the austral summer (between November and February). The convoy is composed with about ten persons, with a minimum of seven mechanics and one doctor, three (snow trains), seven machines, three levelling machines, and loads are consisting of fuel tanks and containers (see Diagram 1). The logistical traverse has to carry freight to Concordia with both quantitative and qualitative criteria, as quickly as possible and consuming as little fuel as possible. Today, twenty-two years after the first traverse, no human loss has been reported since the traverse was set up.

During about twenty-three days for a return trip, traversers will cross the white-ice desert living in a caravan and driving eleven hours per day. The traverse will be punctuated with mechanical incidents considered as unexpected events. All raiders know that incidents will happen during the traverse. Thus, in that way, we can consider that such situations are not unforeseen. It is however impossible to determine which kind of incident, when (in bad weather conditions), neither how and which consequence such situations will entail (pieces to repair or not? Know-how or experience to face the event?) nor where exactly in the convoy, which material, etc. In this regard, such events can be considered as unforeseen... Everybody knows that this will have incidents, but nobody knows exactly which ones. The real risk rests more in the incident conditions per se than concerning the unforeseen event in its current form.

Thus, in this context, the goal of the research deals with the system capabilities to withstand shocks or unexpected events, and to face harsh conditions every year, in order to answer the question regarding strategies of organizational resilience used to ensure the safety in a productive system. In the case of the traverse, "unforeseen" can be considered as a risky situation, jeopardizing the traverse group during a limited period of time, thus calling on the resilience abilities of this system. What is the nature of the unforeseen situations on the traverse? What solutions can be found? What strategies of organizational resilience can be deployed? To investigate these questions, we rely on the operative logic to manage risks during the traverses when unexpected events occurred. An explanatory study was conducted over three complete traverses (return trips) from which we gathered in situ data in real and dynamic situation to understand how the unforeseen events were managed, ensuring the organizational resilience of the system. Firstly, an analysis of the unforeseen events will be presented, as well as the solutions offered. Secondly, a single traverse will be used to present a case study to understand the role of the operators and the organization to act in the management of unexpected events and strategies deployed.

2. Method

2.1. Tools and procedure

The methodology used was, firstly, aimed at describing and characterizing the unforeseen events on the polar traverse and, secondly, at conducting ergonomic analysis of operators' activities when the unforeseen situation occurred in particular. The methodology chosen was to analyze immediately operators' activity in unforeseen and natural situation during the traverse and their interventions by means of observations in so far as, in such situations, the event is not necessarily known and neither are the technicians who are likely to intervene. As mentioned by De La Garza (2000), troubleshooting activities, by nature unannounced, make it impossible to define accurate observation conditions. Consequently, the ergonomic analysis of operators' interventions only concerned the three polar traverses studied. Nevertheless, particular attention was paid, whenever possible, to the potential transfer of this methodology to other risky environments.

Using both à quantitative and a qualitative approach, data were gathered over a 3-year period from 2012 to 2015. Participating ethnological observations were carried out from immersion work (note taking, films, photos). On board the outward and return trips of the convoys, the goal was to experience the traverse from the inside, (a) to understand exactly what unforeseen event referred to (the nature of unforeseen events), (b) to access proposed solutions without hindering the work in progress and (c) to understand the various actions undertaken during the traverse which could impact the management of unforeseen events and strategies of organizational resilience employed by operators. The methods used were the following: (1) firstly, objective and quantitative data relating to the unforeseen events encountered were identified, in order to proceed to a categorization of events (Amalberti, 1996).

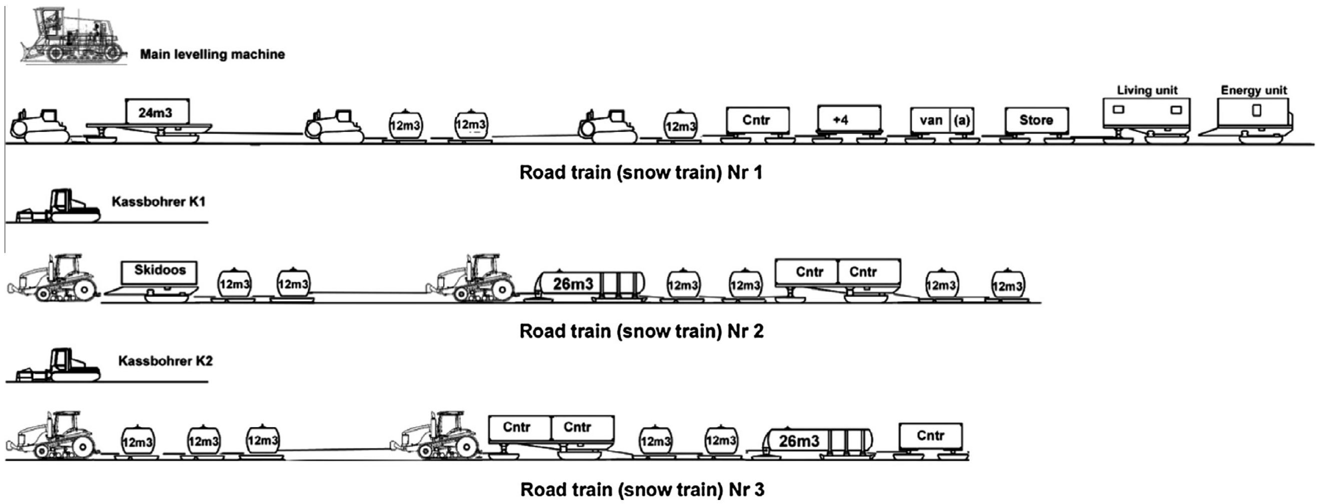

Diagram 1. Composition of convoy at the start of the traverse.

Considered as unforeseen events were those, which required a complete and unforeseen halt of the convoy or a delayed departure with regard to the starting point. It was studied as a stop sign of the normal process (Hollnagel, 2010). To begin with, ground data were collected when the unforeseen events occurred, such as the date and the time of the unforeseen events, the length of time the convoy was stopped, the GPS location, the nature of the unforeseen event, and the nature of the solutions put forward. The goal was to understand the conditions of the occurrence of the unforeseen events as well as the intervention logic of the traverse members in the management of the unforeseen events, but also to compared by experience the difference between "normal situations" and "unforeseen situations"; (2) secondly, equipped observations (by notes, audio–visual recordings) of the raiders' activities when an unforeseen events occurred to keep an update of the strategies deployed by the system and operators to deal with the disturbances; Monitoring these operators' activities would allow immediate interventions to be observed in real world setting; and (3) thirdly, interviews were collected in situ, each day throughout the traverses, with the leader of the convoy involved. Thus, the chronological order of events on the day (hour by hour) was respected during interviews in order to trigger the memory. The aim was to try to understand each action carried out and the strategic operational actions to respond to unexpected incidents.

2.2. Analysis

In a first time, all data from each traverse were transcribed and compiled so as to give meaning to the management of the unforeseen events in the form of matrices to document each unforeseen event produced and each action carried out during the traverse. In a second time, analyses of interventions on the three traverses were led from a temporal reconstruction of the raiders' course on the basis of all the data. This reconstruction combined a temporal structure (history of the intervention on the unforeseen event) and a functional structure (real work activities of the operators). Various elements contributing to this history were then investigated (in verbalizations and equipped observations) in order to better understand the global organizational logic. In a third time, verbatim and all usable data were categorized using a thematic analysis (Corbin and Strauss, 2008) with frequencies of categories for each unforeseen situation. Moreover, the position of the unforeseen events was converted and then transcribed onto a traverse route map (Diagram 1). The traces collected during the traverse were documented (Tables 1 and 2) highlighting the day, the observations, the interventions, and the length of the intervention.

2.3. Reliability

In this study, the data was validated in four steps: (1) the notes taken during the three traverses were transcribed, sorted and organized according to three ideas: all the actions carried out during the traverse commanded by the convoy leader, the unforeseen events per se, and the solutions applied. We therefore retained all the information consistent with these 3 preoccupations. Two investigators analyzed material following the procedures recommended by Miles and Huberman (1994). Each investigator read the transcripts and individually encoded them following this procedure; the reliability between judges was verified and the agreement rate was 100%; (2) the notes from the informal interviews (for the traverse 50, the case study) were transcribed, presented and discussed with the convoy leader of the traverse when there was disagreement until it was clarified; (3) the final results obtained, for the three traverses and including the traverse 50 and notably concerning the nature of the unforeseen events as well as the actions implemented, were presented to the designer of the traverse who validated them, according to his great experience; and (4) thematic units concerning operators' interventions to cope unforeseen events were categorized. The agreement rate was 95% and discrepancies were discussed until agreed upon.

3. Results

The results are presented in 2 parts. In the first part, objective and quantified dimension with figures and regrouping the data from all three traverses are presented in order to understand the organizational resilience with a global perspective. They aim to show all the interventions carried out on the traverse, consecutive or not to breakdowns. The objective of this approach is to understand the nature (a) of the unforeseen events; (b) the interventions proposed; (c) the actions carried out during the traverses linked to the management of the unforeseen events. In the second part, a single traverse will be presented as a case study in order to attempt to extract a strategic operational understanding from it with a specific point of view born of action and activity. For this, an explanation of the composition of the convoy during traverse 50 is described, as well as cartography of the unforeseen events. Each unforeseen incident, the intervention proposed as well as the

Table 1
Types of incidents, interventions and length of interventions of the traverse 50.

Days	Observations	Interventions	Length
Traverse outward journey			
1	Speed of ST1 too slow	Attachment of grading machine 8 to aid with traction	10 min
2	Hose (2)	Repair	1 h 15 min
	Alternator (2)	Repair	20 min
3	T°C high exhaust level (10)	Modification of convoy	20 min
	Broken tank hook	Abandon – modification of convoy	10 min
	Hydraulic motor (K1)	Repair	2 h 15 min
	Command ventilator (K4)	Repair	1 h
6	Off-track, tank stuck in snow	Fuel transfer – convoy modification	3 h
7	Broken tank hook	Dumping tank – convoy modification	20 min
8	Injectors (2)	Irreparable – machine loaded onto Sledge – convoy modification	2 h
9	Control blade (K4)	Repair	1 h
	Alternator belt (K1)	Repair	30 min
10	**Starter (10)**	**Repair**	**6 h**
	Torn sheet metal container	Convoy modification	30 min
	2 off-track incidents	Intervention (X2)	2 h
			Total: 20 h 40 min
Traverse return			
1	Valve blade (K2)	Repair	40 min
2	Headlights (K3)	Repair	20 min
	Broken caravan hook	Repair	1 h
	Leak in power generator	Repair	10 min
	Infiltration of exhaust fumes in cabin (6)	Repair	20 min
4	Headlights (11)	Convoy modification	20 min
	Hydraulic motor ventilation (K2)	Irreparable – machine loaded onto sledge – convoy modification	2 h
5	Leak of radiator cooling liquid (9)	Repair	20 min
	Starting (9)	Repair	10 min
6	Wheel unscrewed when Caterpillar leaving (9)	Irreparable – machine loaded onto sledge – convoy modification	1 h
	Lack of power ST1	Convoy modification	20 min
7	Door handle broken (10)	Repair	30 min
	Drawbar broken	Repair + convoy modification	2 h
8	Flexible + command blade (K1)	Repair (2) + convoy modification	1 h
	Lack of power (10)	Convoy modification	20 min
	Pistons (K1)	Repair + convoy modification	20 min
			Total: 10 h 50 min

Table 2
The convoy re-organization to repair and anticipate the future.

Observations ST1	Interventions
Speed too slow	– Hitching of grading machine 8 to tow (day)
Hose (2)	– Mechanical intervention
Alternator (2)	– Mechanical intervention
Off-track, tank stuck in snow	– Organizational intervention
Broken tank hook → reparable but not carried out	1. Abandon tank 2. Recuperation of a tank from ST2 → relief 3. Machine mounted on transport ski in ST2 4. Modification of convoy (8 tractor on ST1) 5. Recuperation of a tank from ST2
Injectors (2)	– Irreparable
Observations ST2	*Interventions*
T°C high exhaust level (10)	1. ST2 tank in ST1 following broken hook 2. Pumping of ST2 tank 3. Tank in RT1 following machine on ski
Tank hook broken (end of day) → reparable but not carried out	1. Pumping tank ST2 2. Abandon tank ST2
Command ventilator (K4)	– Mechanical intervention
Command blade (K4)	– Mechanical intervention
Starter (10)	1. Mechanical intervention (6h) 2. Pumping tank ST2 3. Abandon tank ST2
2 off-track incidents	– Organizational intervention
Observations ST3	*Interventions*
Hydraulic motor (K1)	– Hydraulic motor (K1)
Sheet metal container torn => irreparable	1. Modification of convoy in 4 trailers with the container hitched to 8 (ST4) 2. Modification of position of machines between STl and ST3 3. Modification of position of grading machines: all in front of ST1
Alternator belt (K1)	– Mechanical intervention
Observations ST4	*Interventions*
Off-track incident	– Organizational intervention

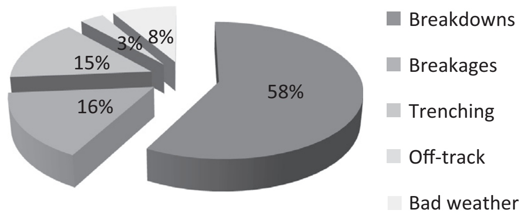

Fig. 1. Nature of unforeseen events on the traverses.

length of the latter, will be analyzed in order to better understand the strategies of organizational resilience developed.

3.1. Objective and quantified dimension to understand the resilience

On the three traverses carried out, we identified 95 unforeseen events, that is to say 95 regulatory actions following the occurrence of a hazard.

3.1.1. Five kinds of unforeseen events

The results indicate the existence of five types of unforeseen events provoking a temporary stop of the convoy or its delayed departure (Fig. 1):

- Stalling of the tractors (15%) arising either from increased tractive effort following the sinking in snow of the loads or because the loads stayed stuck to the ground at morning startup, or from a lack of grip of the tractor itself because of the surface being too icy.
- Breakdowns (58%), which concern mainly the machines, the generator set.
- Breakages (16%), which concern the hitches for items being towed.
- Bad weather (8%), which only allows reduced visibility in the best of cases and a circulation with special headlights to increase the contrast.
- Off-track incidents (3%), linked to inattention or to falling asleep at the wheel, following which the loads sink into the loose snow because the skis left the compacted track.

3.1.2. Mechanical, organizational solutions, or both

The results indicate that these unforeseen events can be regulated in three ways (Fig. 2): by means of a mechanical intervention (53%), by an intervention on the organization of the convoy (organizational) (40%), by a mechanical and an organizational or combined intervention (7%). Although mechanical interventions are in the majority, actions on the organization of the convoy are an undeniable lever in the management of the unforeseen events. Several interventions combine both to ensure the repair and also prevention to relieve trailer hitches. An action on the organization of the convoy is most of the time to act as a support for the repair, for the mechanical intervention performed. Modifications to the

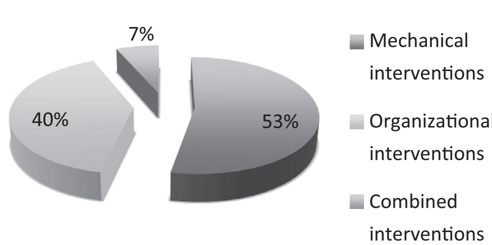

Fig. 2. Nature of interventions following the appearance of unforeseen events.

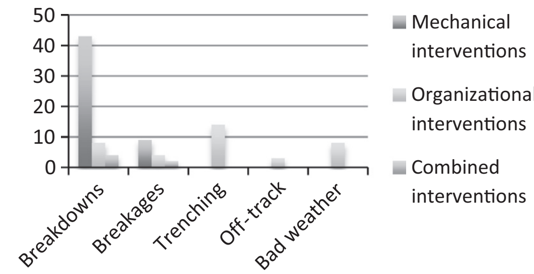

Fig. 3. Nature of intervention for each type of unforeseen event on all 3 traverses.

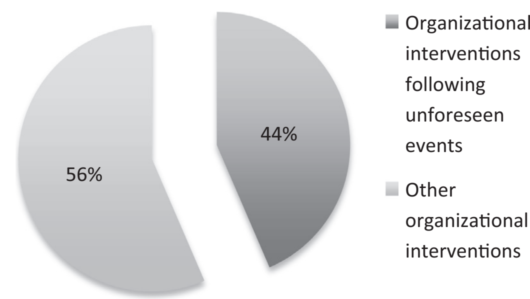

Fig. 4. Distribution of organizational interventions on the traverses.

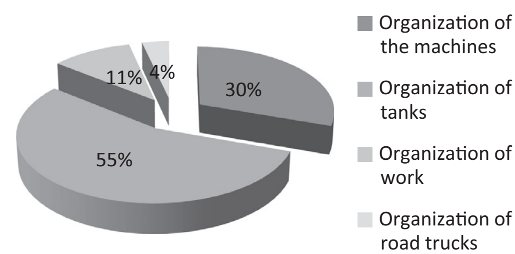

Fig. 5. Possible variations in the organization.

convoy can also be carried out instead of a repair, if the targeted part is irreparable and does not exist in the stock of spare parts.

When we look at the nature of the interventions according to the type of unforeseen events, it can be observed that the breakdowns and breakages are managed by three types of intervention (Fig. 3). Organizational interventions are carried out whatever the type of unforeseen event.

3.1.3. Other organizational actions carried out on the traverses to anticipate incidents

In total, we identified 143 actions performed during the three traverses for 95 unforeseen events. These results suggest that other actions were performed independently, or at least indirectly, to the occurrence of the unforeseen events. The actions identified correspond to the organizational interventions: if 44% of the actions were performed following the unforeseen events, 56% of these actions were not consecutive to the occurrence of the events (Fig. 4). It is very likely that these peripheral actions play a fundamental role in the management of unforeseen events.

3.1.4. The organizational game

The organizational modifications during the traverse and non-consecutive to the occurrence of an unforeseen event meet two objectives with regard to the lever of action chosen: first, an objective of breakdown prevention by acting on the position of the machines in the convoy (Fig. 5). It is possible to « play » with the location of the machines inside a train depending on the pathologies they present (30%, breakdown prevention according to the tractor symptoms). Next, an objective to improve production and output will lead to modifications in the positions of fuel tanks (55%, the best compromise between fuel consumption and the homogenization of the speed of movement of the trains in the convoy). To do this, a game of musical chairs will take place. In fact, the convoy leader calculates and decides which fuel tanks will be left on the road with the fuel of the return trip. In parallel he must also choose which tank will be pumped at the end of the day to to fill the reservoirs of the machines.

The work can also be organized otherwise depending notably on climatic conditions: filling the reservoirs tanks can be shifted to the morning of the next day to shorten the exposure to the low temperatures of the operators in charge of this task (it is colder at night than during the day). If the weather conditions are too deteriorated (white out), the driving time can be adapted: when it is darker, the landscape shows better with the headlights than during peak daytime hours (11%). Finally, actions on the disposition of the loads inside a train or on the position of the tractors can be implemented (4%). For example, if the conditions reduce visibility too much and it becomes necessary to move with headlights, the equipped tractors could change place in a train or in the convoy because not all the tractors are equipped. Finally, as some loads can also be associated with certain tractors, it will be necessary to reshuffle the sledge order of a train and sometimes the whole convoy.

3.2. Case study: the example of traverse 50

3.2.1. The convoy composition logic to anticipate incidents

The liaison by surface convoy must satisfy both technical and economic constraints. The freight must be delivered in good condition, on schedule and with a transport cost as low as possible. The final goal being to reduce the unitary tractive effort. Traverse 50 was a convoy composed of 3 snow trains that we will name ST1, ST2, and ST3. Snow train 1 carried the caravans dedicated to personnel, the one which produced electric energy (heating), the one with the dormitory, the refectory and the kitchen (life), the one with the food supplies and the one with the spare parts. The first train therefore determines the speed of the convoy. Between brackets is shown the number of involved machines. Seven Caterpillar tractor type machines to tow the loads (machines 2, 10, 11, 6, 9, 5, 3), 3 levelling machines to facilitate the passage of the convoy (K1, K2, K3). The fuel tanks with the fuel for the return will be left along the route on the outward journey to lighten the convoy (Diagram 1).

3.2.2. Repair at any cost…

The traverse took 19 days to make the 2300 km return trip. From observations and traces taken during the traverse, 32 incidents were identified (Fig. 6): 18 on the outward journey, 14 on the return (Table 1). The results show a total of 31.30 h of interventions out of 209 h of movement of the convoy.

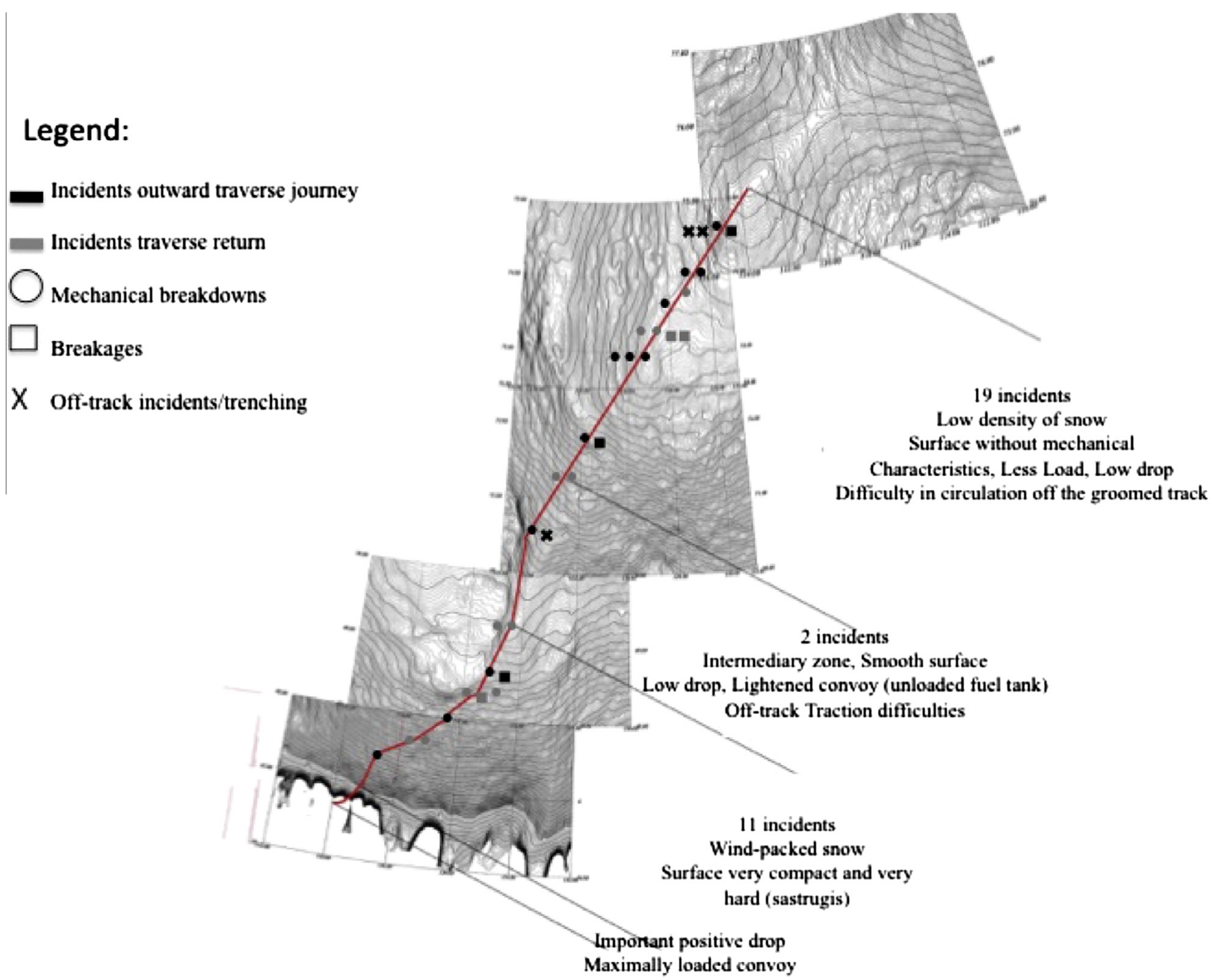

Fig. 6. Mapping of incidents during the traverse 50.

The results which follow were supported by the content of interviews carried out with the convoy leader in situ according to the time of the unforeseen events. The results of Table 1 show that the length of the mechanical intervention is not a criteria in the decision to repair or not. Only the availability of spare parts on board the traverse shop is decisive. As a result, we can observe a repair of 6 h (example of the starter, in bold in the Table 1), with cutting the bodywork using a grinder etc. The operators are therefore exposed to cold temperatures during this time. The importance seems to be to preserve the machine as long as possible despite the hostility of the environment and the hard conditions of the repair.

3.2.3. Modifications of the convoy during the traverse

The outward journey of the traverses has many more constraints than the return journey: there is a strong ascending elevation, the convoy is loaded to the maximum at departure, no load can be abandoned since the objective is to supply Concordia. There is also the question of dumping the tanks on the track to store fuel for the return trip. However there is the same number of incidents than during the return.

We have therefore only studied all the variations of the convoy in detail on the outward journey of the traverse (Table 2). The results of this case study highlight several things. First, with regard to mechanical interventions following breakdowns or breakages, two types of situation are possible: either it is reparable or it is not. On this outward trip, in 4 out of 11 situations of breakdown or breakage, repair was not possible. As a consequence, the results show an organizational intervention on several levels, having repercussions on other snow trains, each time on at least 2 snow trains (ST), with 2–3 parallel actions, and this, uniquely in the case of non-reparation. Thus organizational intervention is carried out on the whole of the convoy depending on the information of the moment. In certain cases (such as the breakages of the tank hooks), the breakage was irreparable. But the arrival of this unforeseen event at that particular moment (aided by the proximity of arrival in Concordia for example) was a decisive factor in the dumping of the tank to waste as little time as possible and to deliver the goods to the station as early as possible. Thus the option chosen can sometimes be to postpone the repair until the return trip, even to the return to base.

4. Discussion

4.1. Synthesis

Resilience focused not only on creating resilient system but also maintaining and managing system resilience. Framework contributions proposed by Rankin et al. (2014) is intended to support both perspective and prospective safety management activities. Prospective analysis is supported by the analysis of adaptation enablers, objectives and situational conditions and supports making prediction on how changes may affect the system. How practitioners and their management recognize, communicate and perceive work practice is critical for managing and maintaining system resilience (informal exchange between raiders during the fuel problem). The system should support and enable people to be adaptative to increase the system resilience potential thanks to a systematic analysis of strategies.

The results highlighted strategies of organizational resilience to cope unforeseen events which resided in reactive and proactive action alternation during the traverse, acting on (1) the dynamic convoy organization : the logic convoy composition to distribute loads (according to engines and their power and symptoms) and the organizational game with sledges and machines during the traverse before the unforeseen event; and (2) the competences and the risk evaluation: a specific work organization to repair at any coast in a hostile context, with mechanical and organizational competences.

4.1.1. A dynamic organization of the convoy to manage safety

The results emphasize that almost half the interventions on the traverse concern preventive actions or attempts to optimize output, notably with regard to the ratio between the consumption of fuel and the speed of the convoy. Even if the maintenance operations carried out each evening were preventive, this proactive perspective plays an essential role in the management of unforeseen events on safety (in accordance with Safety Management System) and on the appearance of future breakdowns.

4.1.1.1. Autonomy. Moreover, breakdowns or mechanical problems on the traverse created opportunities to build the proactive safety, thanks to precedent reactive mode and operators' autonomy. These opportunities from mechanical incidents allowed modifying the convoy organization to ensure the future safety. This logic is the same when traversers have to move tanks through the caravan's fuel station for example: it is a costly task in time, but also the opportunity to bring a new organization of the convoy in order to try to anticipate future incidents. The proactive management is representative of the autonomy allowed by the organization on the traverse, an observation made in previous studies (Villemain and Godon, 2015). Thus, proactive management is only possible on condition that the organization allows the operators enough freedom to be autonomous and due to reactive work. It is thanks to this autonomy that the system can be kept in perpetual movement. The possibility of acting so much on the organization of the snow trains, the position of the machines in the convoy, the positioning of the tanks, the choice of fuel tanks to be emptied or even the hours of work all represent the leader of the convoy's margin for maneuverability, allowed by the organization. Moreover, the objective is thus not so much to arrive in Concordia in the best time possible but to keep the machines functioning to the maximum, in short, to keep the margin of maneuver existing for as long as possible, opening the field of possibilities in order to have a supplementary option in the management of future breakdowns. This can be equated with a strategy of management of uncertainty and of the organizational resilience. This constitutes the main guarantee of organizational reliability and of safety. It is a question of permanent negotiation between advancing and preserving the equipment, the redefined goal finally being to advance with a convoy, which has the most possible functional resources to ensure future safety.

4.1.1.2. Perpetual modifications. In the field of resilience, performance variability is seen as essential to ensure an organizational resilience (Hollnagel et al., 2010). Dynamics is maintained by the perpetual modifications of the convoy, thus enabling the preservation of flexibility to half a day, thanks to operators' autonomy and mechanical/organizational competences. Proactive management therefore exists in the multiple efforts and attempts at changes to allow the system to keep in perpetual movement and not to become frozen. As if risk emanated more easily from a static position, equated with a non-control of the situation, with a risk suffered, with a rupture of rhythm. Furthermore, the results reveal a complexity in organizational activity: the organizational modifications are not limited only to a specific modification to the snow trains on which the unforeseen event occurs, but affect all the trains and therefore the convoy, with consequences in the form of ramifications, affecting several elements of action. Resilience is not immediate. It is not an organizational reflex but there is a temporal density necessary to its building.

4.1.2. Competences and risk evaluation

4.1.2.1. Specific work organization. Even when exposed to low temperatures, the objective is to repair the machine to preserve it for as long as possible despite the hostility of the environment and the extreme conditions of repair. This strategy seems to be a decisive factor in the construction of safety in this type of environment: future safety is ensured by being in danger temporarily. As much as possible, and whatever the length of time taken for the repair of the breakdown, the priority is to repair the machine; even if it breaks down repeatedly, the purpose is to keep it functional for as long as possible. These results demand attention, as it has been shown previously that the work on the traverse is mainly organized around reducing the time exposed to cold temperatures, a risk factor (Villemain and Godon, 2015).

4.1.2.2. Combined competences. And it is without doubt here that the skills of the operators specific to the polar environment come into play: beyond the mechanical know-how of the raiders, their understanding and knowledge of the polar environment and the constraints (especially for the convoy leader who is the decision maker on the traverse) enable modifications and transformations to be made to the convoy *a priori* of unforeseen events. Resilience lies in the end on the skills of the operators, the strategies and compromises developed on a daily basis so that the system works (Woods and Cook, 2002), even if mechanical skill is followed very closely by the development of organizational skills as well as a general understanding of the environment and of its constraints, adaptation skills. In addition, the results of the current study seemed to indicate the existence of an alternation between reactive and proactive modes in the traverse organization.

4.1.2.3. Risk evaluation and the risk acceptability. The expression safety-performance is perhaps only possible in such conditions, with a calculation of the acceptability of the risk taking. Previous researches on polar environment in Antarctica showed the work in extreme conditions (hostile) could develop new competences and know-how for operators, considering thus the polar environment as an enabling environment (Villemain and Lémonie, 2014), as the constructive ergonomics indicated it (Falzon, 2014). A recent research on the polar traverse indicated that the specific organization of the traverse was enabling, thus the traverse was an enabling organization (Villemain and Godon, 2015). According to these considerations, risky environments are favorable to the competences development, but in a certain limit: Because of the habitude, people minimized the risk evaluation, because of the acquisition of these competences in the time. Thus, the risk acceptability and the risk evaluation, depend on the operators' competences. And the danger appears when the operator used to be in hostile environment.

4.1.2.4. Opportunistic bricolage or inventive solutions. Furthermore, great lengths are taken to repair, with the implementation of daring intervention strategies. Cutting the bodywork of a tractor with a power-cutting tool because the mechanics could not access the starter is a good example of this: apart from war, these processes would not be used on another continent. The organizational reliability is based above all on having flexibility, notably in the cases of critical situations, where « do-it-yourself » improvisation is recognized as a source of resilience (Weick, 1993). While organizational resilience, in this case, certainly consists in the ability of the organization to resist shocks, it also consists in avoiding them (Roux-Dufort and Vidaillet, 2003). In the case of the traverse, safety does not lie in « set » formalisms, but on strategies, on showing initiative, on finding opportunistic solutions for breakdowns, bricolage, an improvisation and resourcefulness shown by the operators in real-life situations. It is thus built by human expertise and by putting into action in real time both individual and collective skills. All these things reinforce the dynamic vision of safety.

4.2. Limitations

These results have limitations that require further studying. Firstly, they are derived from a study of only 3 traverses, due to the difficulty to participate and to collect data on a large number of traverses. The data collections are costly because they are led in immersion. No studies have been done in this area. It is thus an explanatory study which needs to investigate the better way to understand the safety dimension as a whole. Finally, it would have been better to complete our analysis by gathering the collective activity analysis of the work and not only the task; that is to say focusing on the traversers behaviors (called "*the doing*") and on verbal communication exchanged within the team (called "*the understanding*") (Cuvelier and Falzon, 2015). This dimension did not appear in this article. But a reflexive and methodological work is necessary in order to grasp the system resilience through traversers' actions in a natural world setting, in a specific context such as the polar environment.

4.3. Implications

From these results, some key-lessons could be proposed regarding the traverse management. First, organizational actions will allow to be in a complexity reading of the situation (convoy as a whole) and not in an analytic reading in order to solve problems one by one on an isolated basis. Secondly, the know-how developed during the traverse does not only reside on mechanical competences but also organizational ones to negotiate the risk acceptability with regards to repairing and to ensuring the future safety. Thirdly, the organizational strategies development contributes to a permanent movement and prevents a set and static convoy composition. This movement also prevents being hindered by uncertainty which is difficult and impossible to manage as a whole.

The results of this study address high-risk environments, specific and confined, like in space; the analogy can particularly be made with long-duration space flights, like to Mars, where there will be a group of humans, left to their own resources, autonomous and without possible assistance, who will have to learn to cope with unforeseen events.

Finally, it is important to emphasize that the notion of an unforeseen event remains very vague and « is always relative to a concrete subject and to cognitive processes situated in a context of action, social relationships, a physical context and limited by the knowledge and know-how of the operator » (Perrenoud, 1999, p. 123). The question regarding unforeseen for whom remains to be seen. One has to take into account that the traversers, regulars on the traverse now for a good twenty years, are no longer surprised by anything. It is noted that working for long periods in polar conditions has led to habituation (Villemain and Godon, 2015). The situations met, even though remaining considered as undesirable events, are not really unforeseen. As a result, the situations chosen represent mainly what Hollnagel (2004) called possible situations, i.e., thought about unforeseen events. It is normal that on the traverse there should be a type of unforeseen events described throughout this article. Ultimately, it is a normal abnormality! It therefore becomes interesting to note what happens to the system as soon as this balance is broken by an unusual unforeseen event and to understand how the management of an unthought-of or unforeseen event is built (Hollnagel, 2004) on the traverse, like in 2013, when the fuel started to freeze on the return journey of the traverse.

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