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Assessing organizational resilience: an interactionist approach

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This article addresses the issue of organizational resilience in a structural context marked by complexity, change and distribution of activities between interdependent occupational groups. We adopt an interactionist approach, relying mostly on the works of E.C. Hughes and A. Strauss to show how articulation within and between groups can affect the achievement of organizational goals (safety and production) in the face of unexpected events. The paper is based on an empirical study of teams involved in major modernization projects of the rail transport system and facing critical, risky and very constrained work situations. Our empirical results describe in depth the nature of arrangements and negotiations made within and between occupational groups to articulate the work. We show how organizational conditions affect these arrangements and finally the resilience of the project organization and groups within it. We then discuss our results in four main points, aiming to give a more general scope to our results. Our first two points demonstrate how professional rivalries and asymmetric relations lead to a displacement in organizational goals and affect resilience. Our third point assesses the role and the limits of both informal and formal arrangements in articulation and resilience. We finally show how adopting an interactionist perspective questions the notion of resilience for an organization as a whole.

Keywords: organizational resilience, reliability, structural interactionism, work, division of labor, articulation, occupational groups, modernization project, signaling.

INTRODUCTION

The concept of "organizational resilience" stirs real interest amongst risk-management researchers. It is derived from the generalization of the concept of resilience in psychology, referring to "a fundamental quality of individuals, groups, organizations and systems as a whole to respond productively to a significant change that disrupts the expected pattern of events without engaging in an extended period of regressive behavior" (Horne & Orr, 1998: 31).

The emergence of the concept of resilience is linked to a change of paradigm for safety management. Indeed, safety used to be seen as a static concept: it was assumed "that safety, once established, could be maintained by requiring that human performance stayed within prescribed boundaries or norms" (Woods & Hollnagel, 2006: 4). Safety relied on predicting dangers and preventing them from happening, by implementing barriers and new safety rules. In this view, humans were considered as sources of unreliability, since their behavior was not totally predictable and they could therefore make errors. Since the 1980s, researchers, by studying successes or failures in complex organizations, have shown the positive contribution of humans and groups to safety (recovery from critical situations, improvization in the face of non-prescribed situations, adaptation to a modification of the environment...). In this view, safety is a dynamic concept which recognizes the positive role of changes, adaptation, adjustments and fluctuation management made by humans and groups to cope with complexity and unexpected events. The variability of work situations is not seen as something that should be eliminated, but as something ordinary and intrinsic. The challenge for safety management is to be able to cope with this variability, i.e. with unanticipated, unexpected events. According to Hale (2006: 40), resilience becomes a useful concept when it is defined as "the ability in difficult conditions to stay within the safe envelope and avoid accidents".

The concept of "organizational resilience" recognizes that risk control depends on the capacity of an organization to take account of "irregular variations, disruptions and degradation of expected working conditions" (Hollnagel, Leveson & Woods, 2006: 347), or the organization's skills in Managing the unexpected (Weick & Sutcliff, 2001). Thus, "a high reliability organization is one that exhibits resilience, among other qualities, in the face of unanticipated occurrences" (Kendra & Wachtendorf, 2003: 14). The "resilient organization" works a bit like a reed in bad weather: it bends but does not break under pressure, whilst a tree, which is more rigid, would have broken. In the literature, the nature of "unexpected occurrences" or "disturbances" of the workflow which are studied can vary from unforeseen aspects of the activity (Hollnagel, Leveson & Woods, 2006), continuous stress, or major incidents (Hollnagel, 2006), to a crisis affecting the organization, including an element of trauma (Kendra & Wachtendorf, 2003). In this paper, we will define resilience as the ability to manage disturbances of the normal workflow and to regain a dynamically stable state which allows the organization's goals of production and safety to be achieved.

Researchers have identified several abilities on which resilience depends: forward planning, perception and reaction to variations (Hollnagel, Leveson & Woods, 2006), the ability to interpret events and manage complexities, improvisation (Rerup, 2001), the redefinition of roles, and the ability immediately to correct errors and learn from them (Weick & Sutcliff, 2001). The literature particularly emphasizes the fact that a resilient system must be flexible and adaptive (Hollnagel & Woods, 2006). Organizational forms which allow flexibility are characterized by the presence of informal work practices, local autonomy of action, management systems for feedback, learning and continual improvement (McDonald, 2006). According to Weick & Sutcliffe (2001), High Reliability Organizations (HROs) are those able to preserve flexibility in the face of disturbances: they respond to disturbances with new learning rather than new rules or procedures. We see, then, a clear link between resilience and flexibility or adaptation: to regain a dynamically stable state, and thus to be resilient, an organization needs to be flexible and adaptive.

Since researchers who work on resilience adopt a systemic approach, coordination between groups or teams is recognized as an important issue for an organization's resilience. Researches emphasize the fact that accidents are non-linear phenomena (Perrow, 1984), which means that "the safety of an organization can not be derived from a linear combination of the parts, but rather depends on the way in which they are coupled and how coordination across these parts is fragmented or synchronized" (Hollnagel & Woods, 2006 : 354). However, few studies really concentrate on the concrete forms of coordination within and between teams, and on their impact on organizational goals and survival. We either find works that focus on macro-level issues, such as cross-scale interactions or conflict goals inside an organization (Woods, 2006), or works that study interactions and adjustments inside a team coping with an unexpected event, i.e. micro-level analysis (Weick, 1993).

The sociology of work, especially interactionism, offers a theoretical framework through which to study the coordination process within and between groups in a dynamic way. In this paper, we rely mostly on Strauss's work and on his concept of "articulation work". Strauss defines his approach as "structural or pragmatist interactionism" (Clarke, 1991). Strauss (1985, 1988, 1999), relying mostly on Hughes's conception of work and occupations, proposes a framework through which to analyze interactions between occupational groups within a division of labor. Its roots lie deep within traditional Chicago concerns with the interactional processes by which tasks are shared, distributed and negotiated between groups, and thus by which boundaries between groups are constructed. In this view, boundaries are places of cooperation or potential conflict. The unit of analysis is the work itself, and behind that, all the actions and interactions necessary to perform a given piece of work. To study the work, the analysis is not limited to the observation of communication, symbolism, universe of discourses or linguistic interactions, but also investigates more tangible facts, such as activities, the workplace, technologies, artefacts (plans, machines, etc) or organizations (including the division of labor and rules) [1].

Hughes (1951) emphasizes the interdependence of occupational groups resulting from the division of labor which leads to a distribution of tasks within the organization. The coordination of tasks and team members is subject to permanent readjustments "because the numerous interconnected and sequential tasks […] will not automatically organize themselves into appropriate action and time sequences"

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[1] This approach noticeably differs from symbolic interactionism, grounded in Mead's work, and from the work of Weick (deeply inspired by Mead) and Goffman. For these authors, the unit of analysis is the situation. Both adopt rather a micro level of analysis, and analyze how individuals select pertinent cues in a situation and interpret them to make sense of it. Goffman studies mostly interpersonal relations and everyday interactions by focusing on face to face interactions, communication and linguistic exchanges. Weick focuses on the nature and the quality of interactions between individuals within a group. However, the organizational and structural conditions are not really taken into account.
The importance of the symbolic dimension in interactions (developed by Mead) is present in the work of Strauss. However, by focusing on actions and interactions needed to perform the work, he also questions and analyzes the role of non-human actors, organizational context and historical or biographical elements.

(Strauss, 1985). Since there are different groups in charge of different types of work, “there must be arrangements in place [...] in order for articulation to occur” (Corbin & Strauss, 1993: 74). Articulation is always questioned, threatened by the contingencies of the workflow: it is the work that “gets things back on track in the face of the unexpected, and modifies action to accommodate unanticipated contingencies” (Star & Strauss, 1999: 10).

Articulation is grounded in a division of labor which has “social-psychological nuances in it” (Hughes, 1951): to each occupational group are associated identities, statuses and boundaries resulting from competition for control of task areas. It pertains to the perception that the different groups have of their tasks (which tasks are considered noble and reputable, or, conversely, have little respect or are without interest). The arrangements which are worked out within and between occupation groups will depend on these perceptions, on the distribution of power within the organization and on work situations.

To articulate their work the different actors negotiate, persuade and make more or less “tacit understandings” in order to rank priorities, resolve time-related conflicts and finally construct a “negotiated order” (Strauss, 1988). Negotiations will encompass the statuses (Abbott, 1988; Bechky, 2003), the meanings of actors, their tasks, responsibilities, obligations, commitments, conceptual structures and time-related issues (Hampson & Junor, 2005). Even if these negotiations or arrangements can be institutionalized in formal procedures, they will have to be permanently reworked in order to adapt to work contingencies and because not all the structural and organizational conditions that will affect the work performance can be anticipated. Corbin & Strauss (1993) indicate that articulation is only possible thanks to a complex, multi-level network of arrangements within and between occupational groups. Within an occupational group, these arrangements pertain to questions such as: what type of work, by whom, where, for how long, with which goals? Between occupational groups, besides the questions listed above, the arrangements will have something to do with: what resources, technologies, suppliers, delays?

In this article we intend to show how the sociology of occupational groups can shed new light on the concept of resilience in socio-technical complex systems, characterized by activities distributed among numerous occupational groups and major safety issues. If we consider that resilience “is concerned with understanding how well the system adapts and to what range or sources of variation” (Woods & Cook, 2006: 69), assessing the resilience of an organization (and teams within it) involves identifying the forms taken by the adaptations to disturbances of the workflow, through the arrangements reworking process within and between occupational groups. Adopting an interactionist perspective will allow us to question the notion of resilience by highlighting the limits of organizational arrangements in the face of an accumulation of disturbances of the workflow. It emphasizes particularly how occupational rivalries, asymmetrical positions and power struggles within and between occupational groups affect the arrangement-making process and the definition of organizational goals. It re-establishes the protective role of formal procedures which enable weakened occupational groups to reaffirm their professional identity and to defend their integrity in the face of constant disturbances. It underlines the importance of informal boundaries and the difficulty of assessing the resilience of an organization as a whole when work is distributed among numerous occupational groups.

This paper is based on an empirical study of critical work situations in which work is distributed between numerous occupational groups dealing with complex activities (linked either to old technologies requiring modification or new technologies being designed). Our study focuses on teams (implementation and project ones) involved in major modernization projects of the rail transport system. These renewal projects aim at adding a new automation system to the existing and currently operating system. These projects involve designing a new, automated system to replace partially the existing one; although some of the older technologies will be conserved, they will require substantial modification in order to work with the automated system. Strauss emphasizes two major issues linked to project unfolding. Firstly, lots of unexpected outcomes disrupt the workflow, thus "contingencies and outcomes of responses to contingencies are central" (Strauss, 1988, Atkinson et al., 2006). Secondly, as projects involve various but interdependent occupational groups, they require strong coordination mechanisms between tasks and project members. Since those projects also entail technological changes, they lead to a redistribution of tasks, statuses and territories amongst occupational groups.

To build our demonstration, we focused on adjustments across occupational groups within the project organization, in reaction to disturbances of the normal (or planned) workflow. We carried out an in-depth analysis of several major incidents linked to implementation operations on signaling equipment. An ethnographical study at the heart of this project organization allowed us to consolidate our analysis of organizational factors which degrade reliability. We questioned the resilience of a given professional group and of the project organization as a whole in the face of two types of disturbances: continual stress linked to non-negotiable project contingencies and major mishaps. We aim at identifying more precisely the nature of adjustments and negotiations made according to the types of unexpected events and the category of individuals or groups affected, and the effects of those adjustments on the different occupational groups.

The paper is built as follows: we begin by exposing in detail the research setting and our methodology. We then present our main results. We first focus on the interactions and adjustments within a given occupational group, i.e. the signaling implementation team, to identify under which conditions this team can be called resilient or not. We show that the resilience of a team is increased when unexpected events are managed within a strong "community of practice". Secondly, we observe interactions and negotiations between two occupational groups: the signaling implementation team and the automation project team. We aim at showing how the organizational and structural conditions influence the negotiations between these occupational groups, and vice versa, and finally affect the resilience of the implementation team and of the whole project. Thirdly, we come back to the incidents we studied to understand how the different occupational groups react to major incidents and to assess the resilience of the system when coping with major mishaps. Finally, we show the ways in which the notions of occupational groups and articulation work are a pertinent analytical model to evaluate resilience in organizations in which work is distributed between various interdependent teams.

RESEARCH CONTEXT AND METHODOLOGY

Research setting

This research took place in a rail transport company currently undergoing a major equipment-renewal phase in order to provide a safer but also more efficient transport system (whilst reducing the intervals between trains to increase transport capacity). This gave rise to the concomitant launch of several major projects affecting more than half of the network's lines, the aim of which was to automate the existing rail transport system.

The occupational groups upon which this research focuses are involved in these automation projects. The projects primarily involve the automation of train-driving systems. This means adding new, computerized automation systems. In order to ensure effective, safe operation, these computerized systems are interfaced with large amounts of older equipment, such as electro-mechanical signaling devices (detection of trains and information from the control room and from other drivers, etc). This older equipment also needs to be modified in order to be adapted to the computerized train-driving systems. The work situations are particularly critical because the modernization projects concern infrastructures which are used for passenger transport on a daily basis. Modifications are progressively introduced during operational downtime, in other words at night. The conditions under which these modifications are implemented increase the risks associated with those operations. In this case, work is undertaken on existing installations which are in operation. The phasing of operations is, therefore, very important: throughout the period of the project (several years), partial modifications are made almost nightly, to very tight deadlines (between 3 and 4 hours), tested and checked before services start up again at 5 o'clock in the morning. After the work is completed, the system must, therefore, be perfectly safe, but also ready for operating. Several technical configurations (old and new) coexist during relatively long periods and that must not impact operations: the trains continue to carry passengers.

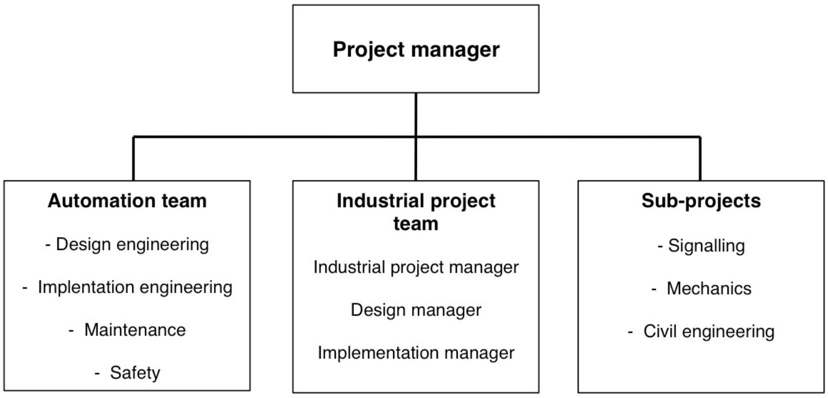
The distributed nature of the project.

Project organizations are a classic example of work situations marked by change, instability and dispersal. In the particular case which we study, the distributed nature of work in the modernization projects depends on several factors.

The concomitant launch of several major projects leads to structural reorganizations (creation of project organization, gathering of engineering activities, etc). The introduction of computerized systems within the rail transport system leads to a redistribution of competences and power relations within the organization between occupational groups in charge of old and new technologies. These projects involve a very large number of participants divided in various technical specialties. Each technical specialty requires highly specific knowledge and competences. In these projects, activities are also distributed in time and space. Firstly, different temporalities are juxtaposed. The projects last from 5 to 10 years, formal important steps are defined in the project (functional specifications, design, implementation, validation, etc), and work is planned a year in advance and then readjusted monthly and weekly. Moreover, the modifications are implemented during the night: implementation teams have only about three hours to work. This requires very precise description and planning of tasks and each unexpected event can have severe consequence in the shortterm (operating disruption and delay), but also in the longterm (it can induce planning modification, and affect the work of several occupational groups which will have to be readjusted).

Finally, the activities are distributed in space: for each technical specialty, some tasks are carried out at the office (specifications, design, verifications, etc) while others (implementation and validation tasks) are carried out during the night, close to the installations. This spatial division of work requires effective communication between night and day teams.

Figure 1: Main occupational groups within the project organization



The complex nature of the project

Besides the distribution of the activities and the technical heterogeneity of the project, the different teams involved in the automation project are faced with many challenges. (1) The different sub-systems, in particular the automation and the electro-mechanical ones, are closely interdependent and might interact in unforeseen ways (Perrow, 1984). Thus, there is a risk of technical incompatibility between signaling and automation or between signaling engineering and contractors on account of the technical interfaces involved. It is important to ensure that the modifications are interoperable and that a modification to one part of the system will not compromise the operation of another. (2) The modernization projects engage new technologies which have not yet been designed and have never previously been in operation. The project team cannot really depend on any real past experience, and some aspects cannot be defined or planned beforehand, which makes scheduling very difficult. (3) The different sub-systems are developed concurrently: if the requirements of one sub-system evolve, this might imply a resumption of the design activities in another sub-system. (4) These different teams face many uncertainties and the unanticipated events are more likely to happen and to propagate from teams to teams (from sub-systems to sub-systems) in an unexpected manner. (5) Operations are not interrupted during the implementation phase even though the rail transport system is constantly changing as new systems are introduced and old ones are modified. For all these reasons, the projects which we study are significantly more complex than previous projects undertaken by this company.

Table 1. Preparation and responsibilities of signaling technicians, automation engineers and project managers

	Professional training	**Formal roles and responsibilities**	**Major issue (discourse)**
Signaling technicians, engineers	Two-year professional training diploma in electro-mechanics to engineering degree	3 main roles: **Project managers:** Following the design and the implementation for their sub-system, organizing (by planning) implementation operations, managing the subcontracts. **Work supervisors:** organizing and supervising implementation operations during works nights. **Verifiers:** verifying electro-mechanical diagrams and test logs made by designers, supervising validation tests of new signaling systems.	**Ensuring industrial safety under pressure (tight deadlines, numerous modifications to specifications or work planning)**
Signaling sub-contractors	Maximum two-year professional training diploma in electro-mechanics	Designing signaling diagrams, carrying out the implementation operations (mostly cabling) and validation tests.	**Ensuring the reliability of the implementation operations**
Industrial Project Team - IPT (automation engineers)	Engineering degree	3 main roles: **Design manager:** Reformulating the client's needs in terms of technical constraints and performance objectives Ensuring the coherence between the system's interfaces Coordinating safety activities Carrying out design, verification and validation activities Examining functional modifications **Implementation manager:** Carrying out detailed industrial design and implementation activities Coordinating implementation activities and organizing operations Examining technical modifications **Industrial project manager:** Representing the IPT towards the project manager and managing the IPT **Technical coordination** of the project	**Controlling the design and the implementation of the computerized sub-system within the agreed deadline/budget**
Project managers	Engineering degree	Managing the project globally Global coordination of the project (the technical coordination is delegated to the industrial project manager) Resolving any disputes between the client and subcontractors	**Managing the whole project within the agreed deadline/budget**

Research approach

This article is based on a three-year study of how actors manage to deal with unexpected events (and then to control risks) in a work context characterized by distributed and complex activities. To carry out this research, we were integrated into the "risk control" department of the rail transport company. This department was concerned about the company's ability to control risks in the current organizational context.

Two major incidents concerning the "signaling" team actually occurred in the framework of automation projects. These two incidents were particularly serious and occurred just several months apart. The signaling engineering team was shaken by the sequence of events and questioned its capacity to control the risks linked to modifications being carried out on a very large number of points on the network. The fallout went beyond this occupational community: the directors of the technical and operating units demanded explanations. They also came to confirm the worries of the "risk control" department, which asked us to carry out an analysis of the incidents in question. Formal enquiries were launched, workers held responsible and possible sanctions mooted.

These incidents attracted our attention for a number of reasons. They were all linked to work intended to modify signaling equipment. The first incident showed a lack of vigilance and a certain weariness on the part of designers-checkers. The second incident related to design and was typical of a complex system: the modification carried out had unexpected effects on other systems.

Once we gained access to the signaling engineering department, we had the possibility to interview people, and to observe work situations. Thanks to the signaling technicians, we were able to contact the automation project team members and to interview them. Our aim was to pinpoint the organizational, structural and occupational factors that could explain these incidents. We adopted a qualitative and systemic approach and had the opportunity to gather data from different sources (interviews, observations and documents) and from various points of view: the signaling technicians directly involved in the incidents, their peers, their superiors, the project members, i.e. automation engineers with whom the signaling technicians are in interaction.

We adopt a pragmatic approach to generate rather than test theory. Our sampling was first open, as questioning, to allow the concepts (especially the unforeseen ones) to emerge from the data. The sampling became more selective as research progressed: we later chose people to interview or sites to observe in order to make pertinent comparisons and to develop and link core categories which emerged from the data (Corbin & Strauss, 1998). Throughout this research, we paid special attention to unexpected events (incidents, technical or organizational lapses, etc). Focusing on interruptions to the workflow is a useful way of understanding both reliability and coordination issues, since articulation work is mostly invisible during normal workflow and through rationalized models of work; it is brought to light when the planned workflow is disturbed. Our approach was then to focus on these unexpected events (especially near-misses) in order to understand how people reacted to them according to their occupation and position within the organization.

Data collection

We collected three main types of data, namely semi-structured interviews, meeting and field work observations, and documents (plans, schemes, incident reports, etc), from people involved in the automation projects (signaling technicians and engineers, automation project engineers and project managers). The interviews and observations constituted our major data sets. The archival data were used to gain an initial insight into the incidents and to understand the rationalized models of work; they enabled us to validate our findings further and to identify structural indicators.

We collected and analyzed the data over a period of two and a half years, as shown in **Table 2**, which indicates the type, amount and timing of data collection.

Interviews

We interviewed signaling team members, project team members and safety engineers involved in the automation projects or in less strategic projects. The people we asked for an interview were free to refuse and, when they agreed to meet us, their anonymity was guaranteed. We conducted 49 interviews, as detailed in **Table 2**. All of the people involved were part of the engineering department, which is a large, multi-level, multi-functional and hierarchical unit. We began by interviewing the signaling technicians directly involved in the incidents. Then, to ensure that our sample was representative, we interviewed workers of different statuses and functions and with differing levels of experience in the field.

We asked the relevant individuals about the activities involved in their daily work, the different tasks that they had to accomplish and the way in which they went about doing so. We paid special attention to the kind of disturbances to the normal workflow which they were facing, and to how and with whom they were interacting to organize and plan their work and rearticulate it when disturbances occurred. It soon became evident to us that the project organization they were in and their interactions (interdependence) with the project managers were a source of difficulty, since many disturbances were linked to the development of the automation system. Thus, to have a more systemic and objective view, we interviewed the project team members: automation engineers and project managers. Here, our questions primarily concerned the existing organization, the formally defined roles of the different individuals, the documents which accompany their work activities and how the different teams involved in the project coordinated with one another. We closed the interviews when we achieved data saturation, i.e. when no new issues were emerging.

Interviews were face-to-face and conducted in the workplace, usually in the interviewee's office. All the interviewees were very busy individuals, dealing with unexpected events modifying their planned work, so interviews were often rescheduled or even in some cases cancelled. However, participants were generally very cooperative and even willing to talk about their work. Our interviews lasted on average two and a half hours.

Observations

Even though interviews provide a great deal of information, they are insufficient to give access to concrete work practices and articulation work. Thus, we wanted to observe technicians during the implementation phase to assess the complexity of the technical devices, the work conditions and environment at night and the difficulties and risks they had to deal with, and to see the work practices and coordination mechanisms "on the ground". We adopted an opportunist approach, consisting of asking the interviewees (especially the signaling engineers in charge of implementation) if it was possible to accompany a team during modification work. We thus gained permission to observe implementation teams for five nights and three days. This provided us with more "situated" details about the importance and the characteristics of the physical installation and of the drawings, the division of labor between individuals and the way workers were reacting to unexpected events. Indeed, each night we observed, workers had to deal with unforeseen contingencies which disrupted the planned workflow. We also had the opportunity (thanks to our position in the risk management department) to observe the inter-departmental meeting, in which major incidents were collectively analyzed. It helped us to understand the negotiating processes by which causes were found and responsibilities assigned. Each time we found out about the occurrence of a major incident in the framework of a modifications project, we asked the risk department head if we could attend the meeting. We were thus authorized to observe seven inter-departmental meetings. For both the works and the meetings, we recorded as much of the conversation as possible.

Documents

We collected two major types of archival documents in order to understand better the formal project organization, formal definition of roles and incident analysis. On the one hand, we collected job descriptions, project management plans, procedures and safety rules, organizational charts and signaling and automation schemes and drawings. This helped us to compare the way in which the work was prescribed and divided with how interviewees described their tasks and what we had observed. On the other hand, we obtained the incident reports for six major incidents occurring during modification works, including four in signaling. These enabled us to compare the causes and responsibilities pointed out in these reports with the ones we identified during our study.

Table 2. Data collection and analysis

	Amount of data	Time of collection	Analysis and use in theory development
Interviews Preliminary interviews with signaling technicians involved in incidents. Individual recorded interviews with signaling technicians, engineers and subcontractors, and with project managers and members of the automation project.	49 interviews: 26 signaling technicians, 22 project team members or managers, the engineering department head **1500 pages**	Middle of year 1 through to middle of year 3	Transcribed interviews coded (first manually then with NVivo tool): close examination of qualitative data to name and categorize phenomena. Continual review of data to identify the core categories and concepts and the relations between them in order to explain organizational limits to the capacity of resilience.
Observations In-depth observations of works during both night and day, and observations from post-incident meetings	Field observations (6 nights and three days) 7 meetings **130 pages**	End of year 1 through to middle of year 3	Transcription of field notes. Observing and understanding work practices and contingencies which disrupt the workflow. Identifying tacit knowledge, negotiations and arrangements, especially when unanticipated events occur during workflow. Understanding how individuals or groups analyze and explain incidents and negotiate to identify causes and to allocate responsibilities.
Documents Internal documents from signaling team and automation project team (job description, procedures, safety rules, project management plans, signaling and automation schemes, Incident reports)	**250 pages**	Middle of year 1 through to end of year 3	Understanding structural context. Identifying formal roles and responsibilities. Analyzing formal causes and responsibilities identified in the incident reports.
All	**1880 pages**		

Data analysis

Our analysis is based on procedures and techniques used to develop "grounded theory" (Corbin & Strauss, 1998).

All our data were subject to in-depth analysis, based mostly on a comparison process: we were looking to identify the themes cited from within the different technical specialties, identify similarities and differences in the way in which these themes were addressed and, finally, associate the two. We tried to articulate two levels of analysis (the organizational level and the group level) in order to gain a global understanding of the phenomenon we wanted to explain.

To analyze each interview, we paid special attention to the vocabulary and the linguistic register used by the interviewee. We distinguished during the analysis process between what referred to tangible facts (work documents, formal organization, incidents…) and what reflected the interviewee's point of view.

We read the recorded and transcribed interviews attentively to divide them up into sequences. To each sequence corresponded a sub-theme. We then grouped together the different sub-themes under general themes, i.e. categories (Corbin & Strauss, 1998). Field notes and documents came to enrich the analysis model we had built, as well as the interviews made throughout the research. Regarding the observations, we adopted two complementary positions: on the one hand, we focused on the "work activity" which means that we followed a given actor in different workplaces, temporalities, circumstances and observed the way he was interacting with other workers; on the other hand, we observed "work situations", which enabled us to analyze interactions,

actions, negotiations between several actors individuals during a sequence of a given activity, geographically and temporally situated (it was the point of view we chose to study in inter-department meetings). Throughout our research we made several formal feedbacks (to the signaling team head and to project managers during a formal meeting) and we encouraged some of the interviewees to read drafts of our work: their feedbacks, both formal and more informal, have helped us to refine our results by showing them to the people concerned.

We then identified the core categories (Corbin & Strauss, 1998) resulting from our analysis and we formulate our hypothesis by linking these categories.

RESULTS[2]

When the arrangements break down: the signaling team confronted with two major incidents

The incidents

In the night of February 14th to 15th 2006 [3], modification works to signaling equipment were carried out at station “X” on the red line, in order to be adapted to the forthcoming automation of this line. The objective was to run installation tests on a new switching system, involving a change in the signaling logic: it meant checking that the signals matched with the position of the switch (left or right), i.e. that they pointed the train in the right direction. During the whole night, the workers had to deal with different unexpected dysfunctions (breakdown of equipment, problems of communication with the operating agents...) which they managed to solve. At 4.35am the trials were completed. At 4.55am the equipment and workers returned to the station: no-one was now on the tracks. At 5.10am, the final tests were carried out remotely, from the station: the situation was considered normal. At 5.45am, the workers, who were still in the station, were informed of a problem with the switch signal: the signal was green and, therefore, the driver was authorized to go through it, even though he would be going in the wrong direction. The workers returned immediately to the signal and observed an oversight in the reopening of the electrical supply controlling the signal, i.e. the system was still in project configuration. After corrective work, a further test was carried out: the situation was now normal and the workers left the station. The green signal had temporarily authorized the driver to go onto a track where another train was stationary. A train collision was narrowly avoided!

In the night of April 17th to 18th, works and tests were carried out at station “Y” on the red line. Only sub-contractors were present since the modifications carried out were considered minor and without any operational incidences. This work was completed during the night of April 18th to 19th. At 6am, after the test passage of two trains (to ensure that no anomalies occurred), as required by the regulations, the sub-contractors called the company to inform them of the post-work situation. The conclusion was clear: “nothing to report”. At 11.16am,

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[2] **2.** Empirical and general results (discussion) are presented in a synthetic way at the end of the ‘discussion’ part (TABLE 3).

[3] **3.** For confidentiality reasons, the dates of the incidents as well as their locations have been modified. However, the intervals between these incidents have been respected.

the signaling engineering group was informed of a signaling anomaly at station "Y", which suggested an "absence": the train at the station virtually disappeared: it was no longer electrically detected and, therefore, the signals intended to protect it stayed green and the central control tower did not see them. There was nothing to stop a train positioned behind it from moving forward […] and hitting the "ghost train". The seriousness of the situation was assessed immediately and all traffic was stopped. The work carried out on the previous nights was thought to be the root cause. The signaling project manager responsible for this operation went to the area in which the dysfunction had occurred and informed the sub-contractor of the situation, who also attended the site. Together, they checked all the plans concerning the modification carried out during the previous nights; they then realized that this modification had a functional impact on signaling logics which was not identified at the time of the design and verification process. They therefore made modifications to the equipment to secure the zone temporarily. At 3.25pm, the situation was back to normal: traffic could re-start. The signaling workers had to review all the designs in order to secure this zone on a permanent basis. Once again, a train collision was only just averted and traffic was stopped for 4 hours.

The accidental uncovering of the problems

By comparing these incidents, we see that the signalmen were not able to detect the problems, in spite of all the tests they carried out. Problems were always discovered by an operating agent (a driver or rail-traffic controller), by chance. In the first case, it was the conductor who could physically see what was happening and raised the alarm. Neither the signaling technicians nor the rail-traffic controller detected the problem. In the second case, thanks to an agent who had to go on the tracks, the rail-traffic controller paid special attention to the traffic and finally discovered the "absence" by chance. We can deduce from this, firstly, that the verification of all diagrams does not always guarantee that they are error-free; secondly, that tests carried out "in the field" do not always enable the workers to detect errors; and, thirdly, that the defective operations can go unnoticed.

The time of process solving: a collective process

As soon as a problem is discovered, the signalmen in charge of modification are informed and have to attend the scene of the incident. Several cases are possible: either the incident is discovered during the night before the operating restart (first incident), or the incident is discovered after the operating restart (second incident). In the first case, the signalmen are allowed and encouraged to fix the problem themselves. In the second case, the maintenance team is called and is responsible for fixing the problem. In any event, the signaling technicians and engineers (both from the company and from the subcontractors) are always called to help them solve the problem. The process of problem solving is always collective. We observe, in particular, a strong cohesion between the technician responsible for the modification and the subcontractor. They analyze the problem and find the solution together. In other words, thanks to their shared skills, experience and representations, they collectively make sense of the unforeseen critical situations. The new drawings are made immediately on test, and the double checking is carried out between them.

Once the incidents are solved: the time of reappraisal and doubts

These two incidents were particularly serious and occurred just several months apart. The signaling implementation team was shaken by the sequence of events and questioned its capacity to control the risks linked to modifications being carried out at a very large number of points on the network. This led to many debates (and to more formal inquiries) within the occupational community, including the sub-contractors, in order to make sense of what had just happened. This crises revealed how the roles and the responsibilities were allocated by those involved and which tasks were considered complex and "“noble” within this community, but also the boundaries of this occupational group, that is to say which signalmen included or rejected from this community. This showed that the boundaries of this occupational group were not those defined by the company. The sub-contractors were clearly part of the community, whereas youth and works supervisors were not seen as signalmen, and therefore not treated “on an equal basis”. As we will demonstrate later, this leads us to reconsider the formal work control process and the independence between the firm and the sub-contractor.

An initial causal analysis quickly brought to light the fact that the incidents occurred in a high-pressure production context, particularly due to the deadlines of the different projects.

“This operation has been subject to successive modifications (studies completely reworked) at the request of the project. Respecting an evolving, tight schedule means slicing up interventions and increasing risks”. (Incident report)

“Successive delays in functional specifications at the system level (automations) generate multiple phasings which require successive and partial reworks on studies that have already been done globally, to carry out trials in a context where pressure is on in terms of schedule”. (Incident report)

The formal validation processes for the design and implementation plans, based on dual controls (i.e. organizational redundancy), would appear not to have ensured the reliability of the operations carried out on the nights in question.

“These trials are based on the competencies of the agents. After every operation, the workers wait for the first two trains to come through in each direction (in compliance with prevailing regulations)”. (Incident report).

“The trial log described the test for modifications on one circuit, but not modifications to the other circuits. The impact on the other circuits was not shown either during the trial log draft, or during verifications, or during field trials”. (Incident report).

However, the workers involved in these incidents were mostly experienced and considered highly competent within their own occupational community. This dramatically increased the malaise of the whole signaling community. The dominant feelings amongst senior as well as junior members were the lack of recognition from their hierarchy and retrospective fear.

“Personally, that’s what really got to me... retrospective fear. Because there, we focus on this incident, but we fiddle with the whole of the line and when we

make modifications, it's like that all the way down the railway line! You should see some work situations. It's amazing what's going on. So things like that… we've got dozens and dozens all the time… is what shocks people, retrospective fear, fear that one day, we'll miss something which has some nasty consequences" (signaling engineer directly involved in the incident).

The incident reports and the interviews with the signalmen directly involved in the incidents show two distinct types of causes: internal (competencies, formal control process, redundancies, etc) and external (production pressure, design modifications due to the automation part, etc). This clearly reveals a number of problems with coordination and calls into question the roles of adjustments within and between occupational communities to achieve both safety and production goals in a very tense context where the planned workflow is disturbed by many unforeseen contingencies.

Formal procedure and informal arrangements within an occupational group

In this section, we will examine how the different tasks are distributed and coordinated within the signaling team, which concrete practices form the basis of the modification of existing signaling installations, and how the signalmen adapt to the contingencies of the workflow, especially unexpected ones.

Rail signaling is as old as the rail transport system. It has always played a crucial role in rail safety, since it is the role of signaling to prevent the two major rail transport risks: collision and derailment. The occupational community in charge of rail signaling is thus an old community which has acquired routine practices and specific skills over the years, especially in order to achieve their production goals and to control risks. Some of these practices have progressively been rationalized and formalized.

Formal rules as a resource for an occupational group

Within the signaling team, there is a division of work between functions, mostly according to the phase of a particular project (specifications, design, implementation). In terms of implementation, activities are divided up between workers from the company and sub-contractors: some of the work is indeed sub-contracted, although a representative of the company will be present in a supervisory capacity.

In theory, error-free, reliable signaling modification operations require a formal control process called "dual verification". This means that any document (drawing, plan, specification and test logs) will be checked twice: once by a person from the group having created the document and a second time by a person from the group working downstream on the modification chain. Thus, the design plan will be verified by a person from the implementation group, and the implementation plan prepared by a sub-contractor will be checked by a person from the implementation group. Checks are documented in "opinion forms" in which any errors and modifications to be made to the document are entered. At the end of this process, the document is validated. As defined formally, the two checks are supposedly independent, i.e. the actors are not supposed to have any exchange outside the opinion forms. Once all the necessary documents have been validated, the works phase begins, during which the equipment is modified, followed by the test phase where checks are carried out to ensure the modifications allow the installations to function properly and safely.

This formal process also aims at articulating formally and at ensuring the sequence of tasks to modify a signaling installation.

A complex activity which requires practical and experiential knowledge

Signaling engineering requires very specific and sophisticated skills. Apart from technical knowledge of signaling logic (electro-mechanical technology), it is very important to have a clear understanding of existing equipment and its specificities. The task also requires a high capacity for concentration and vigilance (Vaughan, 1997) throughout the modification management process: verification of plans, cabling of equipment installed and technical tests. Moreover, formal documents (procedures, rail regulations) supply very little information on the precise nature of the tasks to be carried out on account of their very general nature. This is also explained by the fact that signaling equipment is not generic and, therefore, it is impossible to prescribe precise operating procedures. For each area of the network there is different equipment, depending on the network's age, the equipment used, etc. Competence is based on a keen knowledge of different installations and the capacity to adapt to the associated specificities and risks. Thus, the most experienced members have learnt to be sceptical of dual verification and test logs: it is not because there is dual verification that the design work is flawless. On account of this, nothing totally guarantees that the test log, which is created from implementation plans, contains no errors or covers absolutely every angle.

The occupational community as a resource to cope with hazard and complexity

Teamwork plays a crucial role in the development of "mindfulness" (Weick and Sutcliffe, 2001) throughout the modification management process.

"We need to have a different perspective because it is true that when we are involved in a project over many months, our objectivity is affected. Therefore, the fact of having an outsider taking a different perspective gives rise to auto-criticism. Finally, more or less all of us tend to end up putting objectivity back on the rails. It gets us to check with each other. For big projects, it's crucial." (Signalman)

In spite of the formal processes and division of work, we observe a certain level of flexibility, but also a relatively shared and coherent vision of the work to be done and methods to be used. On top of the formal double-check procedures, there are less formal forms of doubling-up or redundancies: each person involved, if they have the necessary skills, will, when they carry out their part of the task, re-check whether the previous task has been done correctly.

"This is unquestionably a relatively complicated area and, when we are working alone, it is not easy. We need to be able to sound out those around us. There are areas like that where being alone is not a good thing. You need to be able to ask questions around you on areas which seem a little complex to us, where we may have difficulties… It's good to be able to go and knock on

someone's door and get a different perspective". (Signalman)

Whilst certain individuals are formally entrusted with coordinating specific aspects of a project, they are far from being the only ones to play this coordination role. Everyone, more or less discretely, seeks to inter-connect the work and "hold together" its different aspects (Strauss, 1988). More than the formal dual verification procedure, risk control is primarily dependent upon adjustments, understandings and informal arrangements between signaling engineers, and especially with subcontractors doing signaling works. The designers will talk about plans face-to-face, or go onto the night shift with partially modified documents, with the intention of checking certain points directly when they get to the site.

These adjustments also allow the construction of collective competencies. It is a fact that informal regulation encourages workers to exchange and talk about their problems and difficulties (within the occupational community) and divide out the tasks, depending on competencies, with each technician not necessarily having the same experience of the technology, or the same knowledge of the sections of track affected by the modification Faced with dead-ends, the technicians will talk to each other.

"When we have a problem, we go and see whether someone else has come across it or whether someone has an answer. Even if it's someone who is not working on it, we can ask all the same. We manage our own activity, but we can ask questions if we have such-and-such a concern. (…) our offices are all close to each other and so, very often, when we come across a problem in our work, something which seems odd, somebody will say to us "yes…I've seen that, that happened to me". (Signalman)

Problems can therefore "migrate" within the team, from the requester to the most experienced and the most competent member. We observe what Weick and Sutcliffe (2001) call "deference to expertise", typical of Highly Reliable Organizations: this is the most competent person faced with the given problem at the local level who is allowed to take a decision. This not only enables a solution to the problem to be found easily, but also strengthens occupational group cohesion and improves knowledge and practical know-how within the signaling team.

An occupational community weakened by rationalization of work and youth arrival

However, signaling engineering has undergone major changes in the make-up of its teams. With the arrival of young, less experienced technicians, a new division of work and competencies has arisen. Whilst before, the designers also piloted works, today this task is the responsibility of the project manager who sub-contracts implementation. The young engineers who have become the main interfaces between design and work do not have the same level of technical competencies and cannot understand and check the work of the designer-verifiers.

"People come and work here with their BTS (two-year professional training diploma in electro-mechanics) and we let them loose on these projects; you have to believe me, it's complicated! It's said that it takes between 5 and 10 years to understand signaling. And even after 20 years, we don't know everything, and we can all make mistakes". (Signalman)

"Training in the past was based on apprenticeship, and we had much more

time; we could double people up and take them to the work sites during the day, during the night. (…) but all that has gone and it's a real pity, because that's where we learnt the most". (Signalman)

For major projects, the type of training favored in the past (i.e. apprenticeship) has largely been abandoned on account of limited resources. Young people only receive theoretical training and are assigned to projects as soon as possible. Finally, design and verification operations for plans are increasingly the domain of a handful of the most experienced people. Thus, informal redundancy based on the overlapping of competencies between all workers no longer really exists. It is more a one-way counselling relationship from the "old hands" to the new arrivals. The more experienced members have few people to whom they can turn.

"Before, what made the robustness of the signaling, not to say the robustness of everything? It's simple: for a given work, you had always a guy there, asking: "why did you do this? Why did you do that?", that's what made the robustness, the fact that x guys were there, having nothing to do, at least it kept them busy, it was good, as you say: there is no stupid questions. That's why it went well everywhere. There were redundancies, apprenticeship, etc... Today, we realize that with the economical system and "the whole bit", what happens? It's a chain now, and to go from the step A to the step B, there is only one guy, there is no more this doubling up, the difficulty's there! And with the pressure, the problem is that the guy explodes and this leads to difficulties." (Signalman)

Experienced workers are also assigned to the biggest and most complex projects. The danger is that they become swamped in the number of tasks to be carried out and lost under a pile of documents connected to the project. Indeed, with the projects, a certain "bureaucratic accountability" is developing (Vaughan, 1999): everything has to be written, tracked and signed, which sometimes leads the older workers to neglect technical tasks (such as the second, informal opinion that they expressed on all plans in the past).

This also leads to a change in the way in which regulations are obeyed. The more experienced workers, whilst recognizing the importance of these rules and traceability in particular, do not have total confidence in them. They know how to get around them and make the most of their "practical" and "experienced-based" know-how (Vaughan, 1997), in particular given unexpected occurrences where formal documents do not serve much purpose. On the other hand, the younger workers place great faith in regulations. Their philosophy is as follows: "if I respect the rules, I will have done my utmost to avoid an incident". The same applies to test logs: the younger workers are incapable of referring to the electro-mechanical plans from which the test logs originate, and, therefore, are unarmed if mistakes slip into the trial logs.

"The flip-side of this formalization is that people tend to hide behind documents. I don't want to seem like an old warrior, but not so long ago, we worked mostly on the plans and people perhaps visualized the diagrams better." (Signalman).

Informal checking is, therefore, less systematic or less effective. The very element that makes the team flexible and highly reliable is being challenged by the progressive diminishing of occupational competencies and all forms of redundancy. The team's resilience is progressively declining. It would probably take just one major unexpected occurrence or exceptional workload for the team to start making mistakes and not be able to detect them.

Finally, we see that the management of unexpected events is facilitated/made easier in an occupational community with overlapping competencies, transfer of know-how, mutual aid and mutual control. Thanks to inter-understandings, trust and a shared perception of "a job well done", arrangements in this community are in place and working well, such as informal forms of redundancies or doubling up: they allow them to be flexible and reactive when faced with unexpected events. However, changes in organizational and structural conditions affect arrangements within an occupational community and necessitate a reworking of arrangements.

Articulation between different occupational groups

Since the activities are distributed and inter-dependent within the project organization, they require strong coordination processes to align the different tasks and make them fit together. The special work that enables this is the "articulation work" (Strauss, 1988). This involves paying attention to negotiations, more or less tacit understandings and adjustments between teams within the project organization.

The redistribution of competencies and positions between occupational groups

The introduction of new automation technology has led to a repositioning of the different occupations. Indeed, in the previous technical system used to direct trains, signaling (electro-mechanical technology) was primarily responsible for averting major risks. With the onset of computerized systems, the automation engineers are now at the heart of the system and the signalmen have somehow lost their central position within the overall system. In particular, until now, signaling technologies were at the heart of collision prevention. With automation, the computer system is progressively taking responsibility for collision prevention. The computer system is tagged onto existing signaling equipment, which provides information on train positions. In other words, in order to be perfectly reliable, the system must now combine three checks to ascertain whether (i) the signaling equipment already in place, (ii) the interface between signaling equipment and automation and (iii) the automation system itself are all functioning properly. We have moved from a situation where the signaling engineers were the main contributors to risk prevention to a situation where the responsibility is shared between automation engineers and signaling engineers. With automation, a new form of risk has arisen: that of technical incoherence, particularly in the interfaces between the automatic system and existing signaling equipment. These new risks are the subject of real concern, both for automation engineers and signaling engineers.

Moreover, project management has been entrusted mainly to the automation engineers and teams in charge of older technologies are considered as service providers working at their behest, according to needs generated through the development of automation systems, and without too much concern for the availability of resources.

Difficult inter-understandings between the two occupational groups

Our study first shows that these two occupational groups have divergent representations concerning the nature of occupations and on the appropriate risk control practices.

"Today, one of the difficulties is that the system engineers don't speak signaling, and the signalmen don't speak system." (Signalman)

Contrary to automation systems, a new and innovative technology that will evolve over time, signaling is considered traditional technology. Behind the "traditional" label, automation engineers implicitly mean that the technology and the associated practices have been fully tried and tested and are, therefore, controlled whatever the context. Signalmen reject the "traditional technology" label that the automation engineers give them: the environment in which signaling operates has become so complex that their operations cannot be qualified as "traditional" and "controlled". The signaling engineers now have to deal with technologies and work situations that they do not understand.

"We are taking new computerized systems on board…and we say, well signaling…we know that, so it's not a problem. Except that signaling is understood in a given environment, but that environment is changing. And these environments… when we are reasoning no longer in signaling sub-systems but in overall systems, these other sub-systems have a direct impact on signaling and its functioning and there we have no experience…" (Signaling designer)

"Currently, we are creating new stuff in signaling which has never been tried and tested which means we have no absolute guarantee on functional and safety aspects. But our bosses continue to consider that signaling is something that is known and controlled and that the guys know how it works. No, I'm sorry, we have changed environment and we are in the process of reinventing elements of signaling…and there, there is a real risk. And what's sure is that they don't understand that today. They just don't understand". (Signaling designer)

The automation engineers, on the other hand, criticize the signaling engineers for not taking an interest in new system risks, but focusing only on risks that are inherent to signaling and, by extension, their risk-prevention methods.

"When they (the signaling engineers) validate their diagrams and all that, they're not worried at all about system safety, they're worried about obeying the rules listed in the signaling instructions and that's all. And so the safety of the whole is based on the analyses of these instructions upstream. It is upstream that we need to take a hold of it because after, it is too late, and it takes time". (Automation engineer)

These criticisms crystallize divergences on practices upon which risk prevention should be based, but also on the position of safety issues in the occupational group's identity.

On the signaling engineers' side, risk control is first based on the rigorous application of formalized design rules but there is no real prior risk analysis (in the FMECA [4] or operational safety sense of the term). The risks are then identified on the ground, near to the equipment and in a very practical way. Designers, developers and checkers must adapt to the variable nature of situations and equipment in place (their ageing, etc). The "subject matter", the "technical object" in its "resistance" to human logic, played a vital role here and many problems are solved on

[4] Failure Modes, Effects and Criticality Analysis

the ground and working with cables.

On the automation system side, all safety analyses and tests are carried out upstream, before they are actually installed on-site and, more often than not, using formal methods and simulator tests. On-site, the testing of the automation elements is monitored by supervisors. If the tests are not compliant with their test logs, they must attempt nothing on-site; in fact, they are not asked to think about the causes of these non-conformities. They just look at their results:; it is up to the engineers to analyze them and to decide on any corrective action relating to the software.

The field phase during which the equipment is physically installed is, therefore, much less critical in automation systems than in signaling. On the software side, the tests carried out upstream during design ensure that the system is reliable; it is at this moment that the reliability of the software has to be checked. Once installed, improper cabling cannot lead to safety issues. In signaling engineering, on the other hand, the field phase is really critical: a single bad connection can trigger a safety incident.

"In signaling, it's very delicate, because you have only got yourself to blame. There is no system above. We are in a signal box and it's completely autonomous. If you get it wrong, there's no system above us which will necessarily pick up the mistake. Whilst, on the software part, with all the loops and redundancies built in, safety is more diffuse." (Automation engineer)

The different interpretations of risk control partly explain the conflicts or at least the separation between these occupational groups. Signaling engineers' practice is not understood by the automation engineers, who criticize their deadlines and verification procedures.

"The problem with signaling engineering is that you have a specifier, a specification verifier, a designer, a design verifier, an implementer, an implementation verifier… So, to make a modification, it takes more or less a year. So, imagine the case of [this project] where there are several hundred modifications! We know it's the sinews of war." (Automation engineer)

In fact, these different interpretations of risk control reflect tensions between these "occupational groups" (Bechky, 2003). In the medium term, the signaling engineers are in danger of losing the "noble" part of their profession. As a project manager confided to us, "the signaling engineers remind me of the Gauls in the Roman Empire". This metaphor perfectly illustrates what is going on between the two groups: the Gauls are indeed seen as an archaic community which is using old, or even obsolete, tools. The Romans represent modernity, but also the invaders coming to conquer the Gauls' land. In keeping with the metaphor, the signaling engineers are there to resist the automation system "invaders".

If risk control practices are questioned to such a degree on both sides, it is because it is not only safety which is at stake, but also (and above all) performance in developing the projects. Since not everything can be planned in advance, performance can only be achieved through flexibility and reactivity to cope with unexpected events. These abilities have to be shared and balanced to cope with complexity and interdependencies.

We will, however, show that the division of work, which induces competition between occupational groups, and the fact that there is not a shared representation of work and risk control practices, have important consequences for negotiations between groups.

How structural and organizational conditions affect "structuring articulation" [5]

We will first focus on the way in which the division of labor limits or at least frames negotiations between occupational groups. We will call "structuring articulation" the global level of articulation which aims to organize work between occupational communities. This includes formal coordination mechanisms as well as routines and common representations of work.

If we observe the many adjustments within the signaling engineering team, the same does not apply when we cross the "community of practice" border. Thus, between signaling engineering and the project team, negotiations, understandings (informal ones in particular) seem no longer to exist. There is a fault line between signaling and the project which compromises cooperation between the two.

There is no regulation governing the number of requests, no negotiation over workload and no collective discussion about the best way of organizing requests between signaling technicians and the project team. The automation engineers perceive the other groups as the main causes of project delays and exert permanent pressure to ensure that their modification requests are processed.

(Concerning signaling engineering verification practices) "It's very slow, very slow. We go quicker than they do, they get us behind and that's why the dates I'm giving you keep getting postponed." (Automation engineer)

Signaling engineers cannot make the project teams understand the difficulties that they have in completing their tasks, and the risks that they have to take. Their occupational ethic is profoundly linked to controlling railway safety. But in the organizational context described, they say that they can no longer guarantee safety.

"What is getting really hard is this sort of political speak. In meetings, we say that safety is the department's number one priority, but if you don't put the staff there to supervise the contractors, it just doesn't add up." (Signalman)

Between the different occupational groups there is "structural secrecy", a concept that Vaughan (1988) uses to understand why organizational deviance in a given group is not perceived by anyone outside the group: errors or difficulties encountered are rarely fed back or discussed. Secrecy is induced by the very structure of the organization: division of work, hierarchy, physical distance and power struggles segmentalize knowledge about objectives and tasks and make the actions of one part invisible to the other. Like the Gauls, the signaling engineers go off into their occupational corner and exchange less and less information with those from outside the group, while continuing to pursue their own objectives (Metiu, 2004).

This is also explained by the rivalries between occupational groups and, more precisely, between the group which delegates risk (here, the automation engineers) and that which actually takes that risk (the signaling engineering). He who delegates risk will also be quick to ac-

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[5] We borrow the terms "structuring articulation" and "trajectory articulation" from Grosjean and Lacoste (1999).

cuse the other group if mistakes are made. An informal standard within the colleague group will then come into being for fear that errors may be used by the others: errors are only discussed in your own occupational group because "the colleague group would consider that it alone fully understands the technical contingencies and that it should, therefore, be given the sole right to say when a mistake has been made" (Hughes, 1951). Of course, this creates opacity, which is primarily based on "the feeling that outsiders will never understand the full context of risk and contingency that makes colleagues so tight-lipped".

The modernization of equipment thus leads to a wholly paradoxical situation: occupational rivalry, exacerbated by different risk-assessment practices, does not help us to understand new risks induced by technological hybridization. There is no "collective state of awareness" (Weick & Sutcliffe, 2001), which limits "continuous adjustments that prevent errors from accumulating and enlarging". Each part has its own interpretation of risks, and the most appropriate means to control them, and ignores the particular situation of others involved in the project. Concerns are not shared between teams, each of which focuses on its own turf.

How the lack of negotiation between occupational groups affects "trajectory articulation"

We will call "trajectory articulation" the articulation work performed to align the different tasks needed to carry out a modification. In our case, we observe the trajectory of a modification in signaling.

In principle, signaling engineering intervenes after automation engineering on the basis of its specifications. However, on account of time constraints, operations cannot be carried out sequentially: the signaling engineers have to anticipate and launch their studies with information and specifications which are often very approximate. They might make hypotheses as to the way in which signaling will interface with new automation systems. However, these hypotheses are often called into question during the project, when knowledge of the automation part improves and the system evolves. This leads to constant recourse to the design plans. Once launched, however, the signaling operations are very difficult to modify because, each time, the whole dual verification process has to be re-done.

"What I'm saying is that generally what happens is that the project team know what they want, but they don't understand the constraints, so all these preliminary meetings, which last over several years before we get any financing, are intended to finalize the project in the finest detail… During this time, we have to work, but we still have no definitive solutions, let's say. It sure gets very complicated." (Signalman)

Furthermore, for the signaling engineers, the accumulation of modification requests raises questions. It is a fact that the difficulties encountered by the automation engineers in developing their new system and interfacing it with existing equipment leads to unjustified emergencies or repetitive modifications which are perceived as incoherent by the signaling engineers.

"And sometimes we do stuff in a mad rush, but it turns out to be for nothing. Well, I say for nothing… We are asked to do it quickly and, therefore, we do it quickly and, at the end of the day, it's used or it's not used, but later….they've squeezed us and if we hadn't done it so quickly, it would have been better." (Signalman)

"To tell you the truth, I've already had cases where you have had to speed things up… We were getting the test logs a bit late, normally I think it's 15 days minimum before the work begins, and sometimes we get them less than a week before. It's very commonplace, especially with small projects". (Signalman)

The pressure exerted by the project managers on the signaling engineers, and the many and incoherent requests, bring about a sort of weariness and a feeling that the safety issue is not really shared within the organization, and with that comes a degree of demotivation. This demotivation makes people less vigilant, both individually and collectively. Everybody goes into their corner and experience-sharing and problem-sharing, previously the real strength of the signaling team, become difficult.

As we saw previously, risk-prevention practice, based on various formal and informal redundancies, is very sensitive to workload. The signaling engineers have to accept a work overload which will quickly erode the redundancies which, until now, guaranteed a high level of reliability (Woods, 2005).

"The guys that manage the schedules sometimes try to put pressure on us by saying, "When are you going to check it? When are you going to check it?" and then, "Go on then….when are you going to get down to it?" but what they mean is "So….the IT people are waiting for them, contractually we need to do it," and the guys….I think they just feel great pressure… A bit of pressure is put on and that causes problems, because they want to shorten the schedules, and we don't have the input documents and we've got all these procedures which mean that…. It's just heavy going". (Signalman)

The signaling team then has to take unreasonable risks, for example by doing only partial dual verifications. Informal redundancy does not allow compensating the one for the other, since each actor is focused on his part and does not have the time to worry about what his colleague is doing.

"No, but it all adds up, and it means we can't work calmly and it just doesn't help; the atmosphere is deteriorating. That's clear. And then you've got pressure and stress and there's no way around it… someone who's working so many hours at night, who doesn't have much time to recuperate, at some point in time, if he's working all alone, there's a chance he is going to cock up. Even for the schematic diagrams, we get to the crunch and we have to get documents together as quickly as we can and we do them as quickly as we can and they get handed in with loads of mistakes… that's just not right!" (Signalman)

Little by little, the doubling-up practices are abandoned, whereas previously it was these that helped control risk, leading to a form of "organizational deviance" or "routine non-conformity" (Vaughan, 1999). This organizational deviance is produced or even encouraged by the organization and the structural conditions (comprising relationships between groups and representations). The risks are perceived by the signaling engineers individually but they are not subject to a collective initiative.

Formal rules as a professional reaction to deviance

Our study shows that the incidents were perceived very differently by the signaling team and the project team. If the emotion was high within the signaling community, the project team members showed very little concern for these events: either they had never heard of them, or they had interpreted them as having no relationship with the project, except in a sense that they might delay it. In other words, the feedback which was limited to the signaling engineers' team did not lead to their questioning project management more globally. However, these incidents were seen as a strong indication for signaling engineers, showing that time pressure and shifting constraints led to dangerous situations. And this signal (Vaughan, 1997) was not heard or taken into account by the project teams which made no modification to their working methods.

Faced with this situation, the signaling engineering management team saw no other alternative to attempt to maintain safety and get the project teams to take their constraints into account than making their organization more rigid through formalization.

The signaling team thus chose to monitor their internal control and redundancy rules more strictly so as to avoid potentially being held responsible again. New procedures, such as impact analyses, were even created, which sought to analyze all the risks associated with a new modification and tracking them.

The workers, therefore, did not deviate from the formal dual verification process. Further to the incidents, they collectively decided to abandon informal night verification and no longer work under emergency conditions. They would no longer compromise to guarantee the delays at any cost.

"We don't work last minute in this area, or…. I should say, now I refuse to. I have always tried to get stuff out in time. Given what happened recently, I'm taking my time. It was a real wake-up call!" (Signalman)

They cite respect for the dual verification procedure (and the associated regulatory verification times) to justify any delays and, through this, try to reduce the number of modifications which progressively add to their workload. Recourse to strict application of procedures leads to rigidification. Rigidity reduces the system's capacity to face up to unplanned events and to bounce back when under pressure.

Rigidification of design and verification practices thus exerts an impact on the project: longer deadlines, worsening of the conflict between the project team and the signaling team, no in-depth dialogue on the risks of the new socio-technical system, etc. Negotiations with the project teams, in particular on resources, has not got any better. The question of deadlines is even thornier and more inclined to worsen the conflicts than help to resolve them. Also, this strict respect for procedures leads to isolation of the different people involved; there is less sharing of experience and the workers increasingly face problems alone. However, the signalmen use the formal procedure to reassert their professionalism: it allows them to regain trust in their occupational groups and in their interactional and technical competencies. Finally, this allows them to rework new arrangements with which they can perform their work under the structural and organizational conditions.

DISCUSSION

By approaching organizational resilience from the issue of articulation between occupational groups, we shifted the attention to look not only at interactions between individuals within a given group nor purely at organizational or structural aspects, but also at the articulation between occupational groups, characterized by symbolic and identity issues. Our research highlights the fact that resilience can be qualified more precisely when you focus on informal arrangements thanks to which tasks are articulated and negotiated within the organization and on the inter-group dynamics which affect these arrangements. Addressing the notion of resilience in this specific perspective sheds light on the question of trade-offs between goals so as to show how informal articulation can lead to a displacement of both occupational and organizational goals. In continuation of this thinking process, our research questions the effects of formal and informal coordination mechanisms on resilience: whereas informal arrangements are required to cope with unexpected disturbances, formal rules can have a structuring and protective role and help to rebalance asymmetric arrangements.

Organizational resilience is affected by professional rivalries and asymmetric relations

Understanding articulation involves taking a special look at the types of negotiations (proposed, imposed, non-existent, etc) which are allowed by the structural context (division of labor, rules, etc) and the characteristics of each occupational group (tacit and contextual knowledge, meanings, tasks, obligations, etc). The division of labor positions the occupational groups in relation to one another by distributing tasks as well as statuses, roles, identities and meanings. Each occupational group has its own territory, and thus we observe discontinuities between occupational groups. As Mork et al (2008) emphasize, the analysis of "discontinuities between occupational communities" and their impact on workflow still has a lot to teach us. The question is to identify where the discontinuities are and how those involved manage to transcend them. Workplace studies (Star, 1989; Wenger, 1998; Strauss, 1988) have clearly shown the extent to which cooperation between members belonging to different occupational groups, "social worlds" or "communities of practice" can be difficult and will substantially influence work performance. Several of the origins of these tensions and "misunderstandings" have been identified: a high degree of bureaucratic partitioning; highly specialized knowledge which is difficult to transfer (Carlile, 2004); spatial difference (Metiu, 2004); the existence of divergent interests (Metiu, 2004); identity-related issues (Wenger, 2003; Mork et al 2008) and the lack of shared objectives and meanings (Star, 1989).

The division of labor also affects the ways in which the different actors perceive what is possible or not to negotiate for them and the others (Strauss, 2002). Further, as Strauss emphasizes (2002), the forms taken by the negotiations encompass the occupational groups' features, i.e. the representations of their tasks, their obligations and interests, their expertise, the competencies to which they attach value, their identity and their autonomy. Individuals negotiate as members and even representatives of their occupational group; the interests of their community (as the protection of their occupational territory) can prevail upon the global interests of the whole organization.

In the case studied, the technological changes have led to a redistribution of competencies within the organization, and especially to the emergence of a new occupational group. Technological innovation projects can lead to the redefinition of occupational territories (Abbott, 1988; Mork et al, 2008; Bechky, 2002), questioning the roles, identities and statuses of certain groups within the organization (Metiu, 2004), leading to deliberate obstacles to cooperation (development of opacity, intra-organizational competition), obstacles in the management of unforeseen outcomes and the absence of formal and informal regulation between the different teams. Coordination can be severely affected by the division of work, the tendency to depersonalize relationships as well as physical distance or competition between occupational groups. Within the project organization, the occupational group in charge of new technologies seems to be more powerful than the one in charge of old technologies. The latter is thus unable to negotiate the constraints and the additional workload resulting from the project's unanticipated contingencies. Finally, professional rivalries and asymmetric relations reduce the resilience of the weakest group, and, as we showed, the resilience of the whole organization.

Asymmetric articulation between the different occupational groups leads to a displacement in performance and safety goals

The researchers that study the resilience of an organization, such as NASA (Woods, 2005), emphasize trade-offs between safety and production goals or between long-term and short-term goals. As they define the organization as a whole, they have little consideration for the different parts (occupational groups) which all contribute to production and safety goals in a different manner. The issue of divergences regarding the definition of goals between occupational groups is not really addressed.

Yet, the fact that the different occupational groups which compose the organization define goals in the same way is nothing obvious. Indeed, in spite of common formal organizational goals, each occupational group has different main objectives and defines production and safety in a specific way. On one side, the emphasis is on production regarding the project development, i.e. staying within the agreed deadline or budget. Safety is viewed in a systemic way, regarding the interface between the different sub-systems: the safety of the system is said to depend on formal methods of proving and on the testing of simulators. On the other hand, the main goal is to perform the work without degrading the safety of daily operations. Of course, the signalmen are concerned about deadlines and budgets, but this merely constitutes more constraints they have to deal with to perform their work safely rather than goals that they will defend. Our study shows the extent to which two inter-dependent occupational groups which contribute to the same organizational project and are part of the same organization can have different views of the work objectives. These views are competing, but are not really expressed beyond the boundaries of a given occupational group. The definition of goals is linked to the division of labor and the characteristics of each occupational group. It pertains to the perception that the different groups have of their tasks, their roles and of what constitutes a job well done.

In our study, automation engineers benefit from a privileged position which allows them to impose their goals to weakened groups. To achieve these goals, the others groups have to rework arrangements permanently within their occupational community. These arrangements are mostly tacit, and thus invisible to the rest of the organization, and even to their peers and their hierarchy. They seem to enable the weakest group to manage the unexpected events coming from the project and to achieve production goals. This therefore gives an illusion of resilience. But these arrangements in a tense context lead to deviations which disarticulate the formal procedure of verification and lead to a shift in formal boundaries: the members of the weakest group abandon some formal coordination and control mechanisms to the advantage of tacit understandings. Thus, the arrangements conversely impact the division of labor by strengthening the link between individuals belonging to the same occupational group and facing similar work situations (regardless of the organization to which they belong). At the same time, this reinforces the opacity of their work and isolates them even more. The negotiations between these two groups are even more difficult. As a consequence, safety is compromised; production goals (imposed by the high-ground group [6]) prevail over safety goals.

Formal procedures as a resource for the weakest occupational group to shape interactions with inter-dependent groups

To face unexpected events and work disruption, and thus to be resilient, flexibility and adaptation are said to be needed (Weick & Sutcliffe, 2007; Hollnagel, 2006). Weick & Sutcliffe (2007) emphasize the fact that a resilient and highly reliable organization is one that is able to learn from errors rather than increasing rigidity by focusing on rules. However, researchers, such as Rasmussen or Reason, also stress the importance of procedures and standardization to control risks. Our study, by focusing on cross-occupational interactions, enables going past the apparent contradiction between formal and informal practices (McDonald, 2006). It reveals that individuals in a given occupational group will use informal arrangements as well as formal procedures to cope with various types of disruptions of the workflow: accumulation of modification requests, workload increase, lack of resources or supplies, major incidents, etc. Both formal and informal practices express the workers' professionalism. Moreover, both formal and informal practices play an important role in articulating the work.

The distinction we have established between "structuring" and "trajectory"

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[6] By "high-ground group", we design the group which benefits from a privileged position within the organization, i.e. the group which has most power within the organization.

articulation enables us to study the conditions of resilience in detail.

Firstly, our results underline the limits of "trajectory articulation" in a context of professional rivalries and asymmetric relations, since the accumulation of informal adjustments can lead to deviance. We show that, in distributed organization, each individual can be seen as an "articulation agent" (Strauss, 2002) which takes charge of a part of the articulation work. This role is officious and the articulation work, given the forms it takes (negotiations, tacit understandings, coercion), stay largely invisible. It allows flexibility and a certain fluidity in the sequence of tasks, but represents a very high cost for those involved. When no satisfactory arrangements and negotiations are reached between interdependent groups, the weakest group has to bear all of the extra work necessary to rearticulate the trajectory of a modification if disruptions to the normal work-flow occur. With all the unexpected events which disarticulate the work, the articulation of the tasks ends up representing an important workload which is not formalized anywhere in explicit rules. The adjustments which allow flexibility and production become uncontrollable and lead to deviations. The extra work performed by each actor individual to fit the different segments of work together cannot be controlled or evaluated by the organization. In this case, deviations cannot be detected by the organization and so they lead to safety problems.

Secondly, due to the unclear and unstable nature of the distribution of tasks between occupational groups and the lack of mutual understanding between old and new groups, there are no collective and shared arrangements for "structuring articulation" (neither common work routines nor formal coordination mechanisms). Resorting to formal procedures can be the only interactional strategy for the weakest group which has difficulties in negotiating with inter-dependent parties to create "structuring articulation". We can distinguish at least three purposes for this strategy: it makes the positioning of the weakest group in the organization and its difficulties more visible, it restores cohesion and trust among peers and it allows them to exercise some control over the size of their workload, which is not otherwise negotiated.

With excessive adjustments, a breaking point is reached when arrangements lead to deviations and mishaps: major incidents occur. The relations of power and the lack of inter-understandings which have been progressively constructed can explain the fact that, even in extreme situations, the division of labor and the power relationships within it, which constrain the work of the high-ground group, are not questioned. The only solution that the organizationally weakest group can find is to focus on formal rules and reinforce them, which makes the whole organization more rigid. This enables them to regulate the workload.

For this reason, in post-incident situations, the occupational groups and their hierarchy focus more frequently on rules. In a context of tension, this reaction increases the conflicts between occupational groups. This situation is particularly unbearable in a project context. In the studied case, a punctual solution is applied to a more global problem. The lack of negotiations and the competition between occupational groups prevent the organization from learning from errors and from constructing satisfactory arrangements for both the project and the occupational groups within it. There is no real thinking about the redistribution of constraints within the organization and thus no improvement in the management of unexpected events.

The interactionist perspective questions the notion of resilience for an organization as a whole

Our study shows that the resilience of a given occupational group does not implicate the resilience of the whole organization and vice versa. Depending on the group and the situation being observed in the organization, the diagnosis will be different. Within the organization, every occupational group is able to define what resilience means for it. Moreover, these different definitions will not necessarily be shared: it depends both on structural and organizational conditions and on the internal functioning and informal rules of occupational groups. It is possible to point out the durability of an institution, or to identify whether the objectives of a given project are achieved or not, but assessing resilience implies defining the cost it represents for the different occupational groups involved to do so. When confronted with a crisis or an important change that shatters its expertise, an occupational group seems more likely to focus back on its own priorities and to defend its community and occupational territory and thus to manifest some rigidity and resistance as a way to regain their professional bearings. A dynamic approach shows that these diagnoses can also vary depending on the organizational context. In the course of organizational life, permanent rearrangements modify compromises between groups and the balances between objectives: the organization is always evolving. Who will finally have the legitimacy to judge if the new equilibrium is acceptable or if the organization has been able to recover stability?

Table 3. Assessing resilience by considering intra- and inter-group dynamics: results obtained using an interactionist analytical framework

Empirical results	General results
Articulation within an occupational group (OG)	
Formal procedure as a resource for an OG to control the reliability of operations and to articulate the sequence of tasks	**Resilience of a team is increased when unexpected events are managed within a strong "community of practice"**
Practical and experiential knowledge as a resource to adapt to work contingencies and to compensate for the incomplete nature of the formal rules and procedures	
The occupational community as a means of remaining mindful and to cope with hazard and complexity	
Changes in organizational and structural conditions (arrival of young, inexperienced technicians, fewer apprenticeships) diminish the occupational competencies and all forms of redundancy.	
These changes affect arrangements within an occupational community => the team's resilience is progressively declining	
Articulation between OGs	
The launch of major projects leads to a new division of labor, thus to a redistribution of tasks, competencies and position between OGs	**Organizational resilience is affected by professional rivalries and asymmetric relations**
Difficult inter-understandings between the two occupational groups	
Structural and organizational conditions affect "structuring articulation" => no regulation governing the number of requests, no negotiation on workload and no collective discussion on the best way of organizing requests between them	**Asymmetric articulation between the different occupational groups leads to a displacement in performance and safety goals**
The lack of negotiation between occupational groups affects "trajectory articulation" => formal and informal doubling-up practices are abandoned => organizational deviance	
Reaction of interdependent OGs to a major mishaps in the weakest OG	
High emotion within the weakest group Very little concern showed by the project team	**Formal procedures as a resource for the weakest occupational group to shape interactions with inter-dependent groups.**
Interactional strategy of the weakest group in the face of major mishaps = recourse to strict application of procedures, rigidification of the work processes and organization	

CONCLUSION

To conclude, even though the occupational dynamics reported in this study would not be reproduced identically in other settings, the findings illustrate that the intra and inter-groups dynamics should be taking into account to assess the resilience of an organization in which activities are distributed between different occupational groups. From a methodological point of view, this involves taking a special look at workplace interactions between occupational groups within a division of labor. Power and position of the different inter-dependent occupational groups are influential regarding organizational resilience: the actors improvise, adapt and redefine roles as members of an occupational group to defend their occupational territory and their expertise. Moreover, the trade-offs between safety and production goals can be explained in the light of relations of power and identities, since the more powerful occupational group can impose its goals without negotiations on workload and resource allocation. Thus, our study shows that the question of goals is problematic, since the fact that the different occupational groups within a division of labor have the same goals and the same definition of what is production and what is safety is nothing obvious. This should be carefully studied and could perhaps enable more to be learnt about what enhances resilience than only taking trade-offs between production and safety into account. Even if the link between the failure to balance safety risks with intense production pressures and accidents has been shown (Woods, 2003), it seems to us that it is an interesting result to show the importance of occupational groups' identities and relations of power on resilience.

Furthermore, talking about the arrangements made to cope with unexpected events questions the boundaries between occupational groups and the extent to which arrangements made within an occupational group enhances the resilience of the organization. Moreover, arrangements (especially within an occupational group) can be very opaque and thus make it difficult for those involved to detect the limits beyond which these arrangements become deviant. We showed that resilience is situated in the sense that it is dependent on the situation and the point of view considered. We thus believe we shed new light on resilience by paying special attention to arrangements' networks (including formal and informal practices) amongst all the interdependent occupational groups within the division of labor, and not only within a given occupational group.

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