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Safety as a network, digital and global reality

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Summary

This article is a contribution to the special issue on safety science research in the new age of work. It aims to promotes an interdisciplinary and broad (multilevel) approach of safety, recognising the interplay of technology, tasks, culture, structure, power, strategy, regulation, society and markets At the conceptual level, the article promotes a multilevel approach to change which connects mega-macro (global) trends with meso-micro realities with the help of an analytical (integrative) framework. It argues that safety has become a networked, digital and global reality during the last decades. At the methodological level, ethnographic research is presented as one suitable approach to studying safety in this context. Its relevance is based on prolonged periods of time spent in safety-critical systems observing work combined with interviews concerning daily operations and incidents. At the empirical level, a study of a plant in the chemical industry is used as an illustration of the argument. A narrative of the case is developed, exploring the implications of changes in automation and computerisation, externalisation of activities and organisational structure following a new corporate strategy. Change in plant boundaries, in the level of standardisation, in the amount of

bureaucratic work, and in group (and regulatory) control and oversight are discussed along with their implications in terms of the nature of tasks and activities, professional identities, patterns of social interactions and distribution of power (decision making). Through the narrative, the increasingly networked, digital and global reality of the plant is revealed in full, with its multiple implications. The article then discusses the findings and reflects on the current flurry of changes which expose safety-critical systems to new challenges.

1. Introduction

The argument of the article is that the new age of work (e.g., globalisation, automation, artificial intelligence, working from home) is likely to operate as a multilevel phenomenon affecting several dimensions of organisations. To substantiate this assertion, the article illustrates empirically, in the chemical industry, how change can be a broad, multilevel phenomenon which affects simultaneously several aspects of safety-critical systems.

One of the profound changes occurring in company environments, which drives the evolution of the configurations in organisations can be attributed to the intensified level of globalisation that has been taking place since the 1980s. If a chemical plant can be characterised by a description of energy, data, gas and chemical flows throughout its processes, then globalisation can also be defined in terms of the flows or an increase of flows across continents (even if unequal).

Flows of capital, of goods, of people, of images, of data, of money have increased in proportion and speed in the past centuries and decades (Lemert, 2015, Martell, 2017, Ritzer, 2022). Technological possibilities in transport (aviation, maritime) or in communication through digital infrastructures (internet, satellites) combined with the economic policies of powerful states and regions (e.g., Europe) towards free markets (liberalisation of trade and finance, deregulation and privatisation) in relation to the growth and expansion of such markets (e.g., Asia, South America) explain much of the intensification of such flows.

Companies have thus participated in the advent of global production networks (or global value chains) which connect them to their suppliers, customers and markets across different geographic areas in the world (Dicken, 2015, Goldwin, 2016, Gereffi et

al., 2019). The financial crisis of 2008, or Covid-19 in 2020 has reminded us, if necessary, of what globalisation means regarding the interconnectedness of businesses, states and societies (thereby also prompting discussions on de-globalisation) and how this entails global risks (Le Coze, 2022).

As many other industries, the chemical industry has been shaped by these evolutions (Avenas, 2015). Another approach beyond describing flows in order to characterise globalisation and its effects on businesses, is to relate it to trends. These trends include digitalisation, externalisation, standardisation, financialisation and self-regulation which are combined, for research purposes, into an analytical (integrated) framework (Le Coze 2017, 2020, figure 1). Their origins can be found in the drivers associated with the wave of globalisation of the 1980s (transport and IT revolution, liberalisation of trade and finance, deregulation and privatisation). These trends are presented in the following.

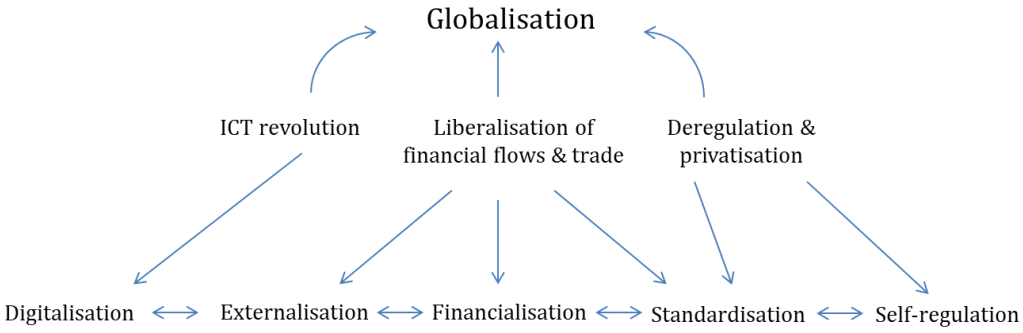


Figure 1. Analytical (integrated) framework (Le Coze, 2017, 2020)

Digitalisation corresponds, at one level, to the capability of instant communication across long distances, which has been characterised as a sort of space-time compression, the experience of higher connectivity brought by the information infrastructure, and the ability to exchange data instantaneously across long distances. At another level, it is the capability of organising work through computerised systems based on workflows which can structure activities in alternative ways (with or without big data and artificial intelligence). These new capabilities have been thoroughly exploited by companies to design new business configurations described as “networked configurations” because of the opportunities they create to externalise activities (Veltz, 2017).

One aspect of globalisation, and financial capitalism (Kocka, 2016), is indeed the widespread strategy of sub-contracting or offshoring activities in order to focus on the core business of companies or finding cheaper ways of producing abroad - something

which has become a possibility with the advent of transport, instant communication, and free market economies with open borders. This goes hand in hand with the **standardisation** trend (Busch, 2011). The proliferation of standards issued by organisations such as ISO (International Organisation for Standardisation), is a result of companies transforming their business models into networked ones and relying on third party certifiers to make sure that standards are applied by their contractors.

Focusing on core business is one outcome of the **financialisation** trend, which has re-oriented strategic decision-making of companies by granting higher importance to principles such as "return on investment" (ROI) for shareholders (Kay, 2015). Companies' responses to the expectations of financial analysts and shareholders gives more power to financial markets, and many companies have followed their expectations, beyond mergers and acquisitions (M&A), for greater visibility of their core business, coupled with high level ROI expectations (Weil, 2014). Finally, **self-regulation** corresponds to the strategy of states to move away from a prescriptive, command and control style of regulation to a more supervisory role - which implies a different relationship with the regulated companies.

Detailed prescriptive regulations can be difficult to enact in a context of fast-paced technological change; companies will struggle to make regulations keep pace. A command-and-control style can also be burdensome, with issues of the relevance of prescriptive rules in relations to specific businesses. Self-regulation is therefore a regulatory strategy which requires that risk be explicitly identified and managed by companies, and which requires that their internal controls be available for inspection by authorities. This leads to process-oriented or management-oriented type of regulation, with varying degrees of command-and-control and self-regulation across the world, and sectors (Ansell, 2020).

But **self-regulation** is also the result of companies expanding internationally, compelling them to develop standards which are relevant worldwide, since multinationals operate in several continents. It is also one aspect of a neoliberal agenda which promotes less state intervention in the economy, even if, in practice, states have not necessarily stepped aside but rather changed their ways of regulating businesses, including process safety. However, these diverse self-regulation schemes can replace, compete with, or complement state-centred regulations, and the relationship between

state and infra or supra-state sources of regulation is a key issue in the context of globalisation (Graz, 2012).

Such trends (digitalisation, standardisation, externalisation, financialisation, self-regulation, figure 1) are global in the sense that they are felt in many sectors and countries around the world, and the heuristic value of this analytical (integrated) framework is to offer a way to connect mega-macro realities with micro-meso ones when applied to case studies as shown in this article. They correspond to an increasingly networked, digital, and global reality which shapes a continuously evolving operating landscape for safety-critical systems. However, they do not imply a convergence in the way they affect sectors, and companies within sectors. The chemical industry is very heterogeneous. Countries have for instance differing legal, labour, education, demographic, social, business, cultural, economic, state and political systems and traditions which therefore adopt these trends in different ways. Great care should therefore be granted when addressing these trends, something for which ethnographic research is particularly relevant.

In safety science research, these trends have been studied for at least over a decade, exploring their consequences as a new operating landscape of safety-critical systems (Le Coze, 2019). Standardisation has been shown to modify, for instance, the context of work when it is implemented by external consultants (contracted out to implement their audit safety management system for certification), and this can delegitimise the practice-based safety of workers and increase bureaucratisation (Almklov et al., 2014). Digitalisation transforms the nature of tasks by creating an increasingly informational infrastructure (Haavik, 2017, 2019) and goes hand in hand with standardisation, changing the way work is performed, and professions experienced, and changing the way safety-critical systems operate (Almklov, Antonsen, 2019, Kongsvik et al., 2020, Haavik et al., 2020).

Consultants contracted out for certification purposes are only one aspect of the externalisation trend (i.e., offshoring, subcontracting, joint venturing) which creates new organisational configurations with safety implications for workers and the conditions in which work is carried out (Quinlan et al., 2013, McDermott, Hayes, 2017, Walter, Wadsworth, 2021). Self-regulation alters the principles of inspections, making them rely more on management standards at the expense of the engineering-oriented approach

(Johnson, 2014), thereby also reinforcing the role of non-state actors (Engen, Lindøe, 2019). Financialisation creates a decision-making context at the highest levels which might favour short term investments strategies at the expense of long-term ones more favourable to safety-critical systems (Hopkins, Maslen, 2015) - a course of action shown retrospectively to be at the heart of disasters (Saes, Muradian, 2021).

This article adds to these studies another empirical case of change engendered by the trends identified and connected with the analytical (integrated) framework (figure 1). It illustrates the clear evolution spanning a decade, of the operating landscape of a chemical plant including production technology and work design, organisational boundaries, level of standardisation through a matrix structure, bureaucratic work, corporate and regulatory control, and oversight. These changes have strong implications for the nature of the tasks and activities, professional identities, patterns of social interactions and distribution of power (decision-making) of the organisation in question.

The next section discusses the ethnographic method that was followed, explaining how data was collected, mixing observations of daily operations, interviews with different categories of employees, and analysis of incidents. The third section develops the description of transformations taking place over a decade, using the analytical (integrated) framework as a conceptual background to elaborate on it. The last section is a discussion of the case study, based on the analytical (integrated) framework.

2. Methodology

2.1. Ethnographic research: principles

An ethnographic study of safety in relation to change in the chemical industry consists in spending prolonged periods of time as observers in chemical plants, with access to people and activities in different areas. In safety science research, qualitative and ethnographic methodologies have a rich history going back to foundational works produced at the end of the 20th century in the analysis of disasters by Turner (1978), Perrow (1984), Vaughan (1996) or Hopkins (1999), and also to studies of daily operations by Roberts (1993), Westrum (1997) or Bourrier (1999). These research strategies have been praised for the insights they produce, their generative value for a

fruitful understanding of the complexities involved in operating safety-critical systems (Pettersen-Gould, Mcrae, 2021, Le Coze, 2021, Dupré, Le Coze 2021a).

The method applied for this case study follows this ethnographic path, which is consistent with the development of a similar approach in other fields investigating organisations through an ethnographic methodological agenda (e.g., Yberna et al., 2009, Pedersen, Humle, 2018). Getting close to the contexts of actions; understanding people's views expressed in relation to various situations; entering the material, practical, symbolic, and patterned social experiences of people are some of the unique perspectives gained through ethnography. In comparison to other methodologies (e.g., survey, questionnaires, interviews), it provides an incomparably rich background against which to explore the significance, meaning and quality of the data collected.

Building knowledge out of such a methodological approach implies going back and forth between data and theory through a process of refinement which depends on the purpose of the research, on the questions asked. This topic has been at the heart of many important discussions regarding the conditions for the production of reliable knowledge concerning real-life situations in multiple social contexts (in comparison to quantitative methods), an example of which is the debate between the promoters of grounded theory and the promoters of the extended case method (Tavory, Immermans, 2009). It triggers deep and complex epistemological interrogations which are not developed here. In the present study, the relationship between data and theory is mediated by the analytical (integrated) framework (figure 1) which serves as a sensitising device to elaborate on change as a multilevel phenomenon (see Le Coze, 2021b).

2.2. Empirical investigation

The case study presented in this article is based on several weeks of observations and analysis of documents, combined with forty interviews of a relatively small chemical plant in France staffed by 100 people (plus 10 to 20 contractors). We used notebooks, writing our observations, interviews, ideas, but we also drew (e.g., people at work, control room, chemical reactors). This study took place during seven periods lasting 3 to 4 days, over seven months, between October 2011 and May 2012. The plant belongs to a foreign group, a multinational company of around 3500 employees. As an initial approach, we conducted a risk analysis led by a process safety engineer with several

plant experts (i.e., maintenance; health, safety, quality and environment - hsqe; production; process improvement), to get to know the technological, engineering, and chemical risks.

This first step, which lasted two days, allowed us to familiarise ourselves with the plant. We needed to understand the number, nature, and use of dangerous chemicals in the plant, the engineering aspects regarding their loading/unloading, storing, circulating, mixing, reacting, and packaging, and the associated risks. This first phase was quite cognitively demanding considering the complexity of most chemical plants. Many chemical plants have long histories, this one being more than 60 years old, and acronyms naming different parts of the plant, from reactors to administrative buildings through products and storage areas, are commonly used - which makes it demanding for external observers to orient themselves at first. This is one obstacle to obtaining a good grasp of process safety from a sociotechnical perspective in the chemical industry when enough time is not available.

Following this first step, two sessions of four days of observations and informal discussions were planned, from 8 am to 6 pm, over a period of two weeks, plus two weekends in order to study the different production steps. The aim was to understand how people work in shift production teams, but also their interactions with people from other departments such as maintenance, process improvement, etc. The aim was also to spend time in the control room with operators and around the chemical reactors and machines, understanding their work, their practices, paying attention and investigating their use of interfaces, visiting the plant with the different team supervisors (e.g., shadowing) to have them show us and explain to us their practices, their views of the plant, but also of the organisation, of the members of their team, of other teams, of the management. This type of data obtained through informal discussions, was gathered (when possible) when team members were available to show us around or to comment on their work. We therefore alternated phases of discussions with phases of observations (e.g., practices, documents, communications), very much based on opportunities offered by production rhythms, and moments.

Sometimes they explained their tasks to us first then showed us how they performed them in practice, sometimes it was the reverse: we observed their activities then asked them about what we observed, paying attention to the material and informational

dimension of the work. We extended this approach to other areas, such as loading and unloading of hazardous chemicals in the storage areas of the plant. These storage areas are connected via pipelines to the tanks and reactors where reactions take place, and we followed the flows of chemicals to piece the whole process together. We were indeed informed by supervisors or operators about the different parts of the plants, the flows of chemical, gas, and fluids which we linked to the risk analysis step we started with. Going back and forth between our knowledge of the different risks and their material reality proved to be an important step towards a greater understanding of some of the key issues from a safety point of view.

Through these observations, we also discovered how production teams interact with people from other departments such as maintenance, process improvement, and HSEq: with which frequency, when, how, and on which occasion. We for instance witnessed a problem-solving situation during a chemical experiment with several engineers in the control room together with the production team operators, trying to figure out what was going on.

We were interested in people's educational background, their work history and how they felt about their jobs, their colleagues, the plant, the managers. We were of course probing their views regarding safety, how they learned what they know, how they developed their expertise, how long it took them to be in their current positions. Some showed us how they memorise key information, including chemical formulae, and proportions of products to be mixed - which they write down on little notebooks in their pocket, etc.

We also spent our lunch times with the operators, who have a dedicated room (outside the production area, about 80 meters away and close to the administrative offices) equipped with a fridge, a microwave oven and a sink where they wash the dishes after meals. Working in shifts (6 am - 2 pm, 2 am - 10 pm, 10 pm - 6 am) without stopping on weekends, they take in turn and in teams of 7 people, a moment to eat. Production teams of 7 people (including the team leader) are divided in level of seniority and expertise, with temporary workers hired when needed for carrying out the easiest tasks which can be replaced without long training. Supervision of chemical reactions through computers in the control room is the highest level of expertise and rank, performed by 3 people in

each shift, the 3 others have other more manual roles, and do not need to be as knowledgeable about the reactions and the chemical processes.

These days of discovery of the plant, its processes, risks, and its daily life were followed by our participation at different meetings and formal interviews with all the production department team supervisors (four of them), then by a selection of personnel: engineers, and different department managers, including the plant manager, and one corporate manager physically present in the plant. These interviews, which were organised after several days were spent in the plant, allowed us to situate their work in relation to the daily operations that we observed.

We also met department managers for: maintenance and new projects (including the IT engineer), production, HSEq, process improvement, research and development, customer satisfaction. During our interviews, we asked similar questions to all, starting with their work experience, their role and activities, what they do during the day/week, who they work with mostly, and their views on safety, environment, health. We did not, however, follow a prescribed set of questions, and we left much space for topics which appeared relevant as a result of our knowledge of the plant, thus creating more of a context for conversation than a formal interview.

During our exchanges, we also introduced a historical approach, asking them about changes in the plant from technology to organisation and management, but also to contrast or compare the past with the present. This historical angle revolved around the evolution of safety, of course, but was not restricted to it. When their work experience in the plant was rather limited, we also asked them to contrast their work experience at the plant with their previous work experience.

We tried to remain neutral and not judgmental but also asked normative questions at times. These interviews were planned over three periods of four days. Finally, we followed another qualitative research approach consisting in choosing interesting process safety events which happened recently, and we investigated how they investigated it - a kind of "*analysis of the analysis*". We selected two to three events, and we interviewed people about them, and we saw again in this different context many of the same people we interviewed before. This last sequence lasted four days.

This sequence was a very important methodological step. When studying daily operations, one follows mostly the everyday successes, the collective ability to produce the quantity, the quality, in safe conditions, of products to deliver to customers. Solutions are found to problems, and it generates the impression of a seamless flow. Studying an event which triggered a formal analysis creates a new perspective, which challenges this impression. It reveals another facet of operations, in which problems are not sorted, were sometimes not identified, and thus escaped collective scrutiny. It exposes the complexity of the sociotechnical reality behind success, the expected imperfections which people failed collectively to prevent.

Each interviewing period was also a moment of further observations, during which we walked through the plant between two interviews, met people, discussed their activities, discovered more of the daily life of the plant in different areas, saw live interactions between different experts of different departments. This ethnographic study that took place over several months (including data analysis) was followed by feedback sessions of two to three hours. Several groups, starting with the management committee, then department managers, supervisors, and a selection of operators available were invited to these sessions.

Our safety analysis was presented to, then debated with the participants. In this case, the plant investigated had suffered no major events over several decades, except one employee who died in the 1990s in an incident involving the moving mechanical part of a machine. Process safety events or occupational incident do occur frequently, however, but not more or less than in any other chemical plant that we knew of, and without any serious consequences or injuries.

3. Results: the evolution of a chemical plant

One very interesting aspect of the story of this plant is the occurrence of many changes within a decade (2000-2010), a period that our study of 2011 and 2012 brought up because the plant personnel was experiencing the consequences of these changes and was explicitly addressing them during our discussions, and spontaneously referring to them in the conversations. Because of the rapid and cumulative changes in technology, organisation, management, strategy, regulation, and markets over the past decade, people with long work experience could contrast and formulate quite clearly some of the

differences with the past. This transition was at the heart of our conversations, our observations and interviews with the plant personnel because it explained many of the problems they face.

More recent recruits with less work experience at the plant who incarnated some of these changes offered many insights too. The main topics which reflected these important changes were expressed in recurring terms used by various employees during our study - expressions such as '*matrix structure*', '*CCMS*' (for computerised maintenance management system), '*Ross*' (the name of a software developed for corporate purposes by an IT company) '*minimum requirements*, '*MOC* (for management of change), '*Fox*' (i.e. a contraction of '*Foxboro*', the name of a control room software implemented by an IT company) but also *"WaterT"*[1] or *'regulation'*. Based on these vocabularies and with the help of the analytical (integrated) framework (figure 1), we can build a narrative around them to capture this multi-facetted evolution. We divide the narrative in three parts, capturing some of the core changes in the plant:

1. "*The advent of informational infrastructures"* which corresponds to the digitalisation trend
2. "*Into the matrix"* which relates to the trends of standardisation, self-regulation and financialisation
3. "*WaterT & Co"* which illustrates to the externalisation trend

3.1. The advent of informational infrastructures

3.1.1. Increase of automation, change in work, practices and teams

From 2000 onwards, a much higher level of automation was introduced in the plant to replace what were almost exclusively manually operated reactors. This transition modified the composition of the production teams because less people were needed to operate the plants' chemical reactors. From manually operating to cognitively supervising the reactions through computers, the production teams lost 5 people, dropping from 12 to 7 members in less than 10 years. Some tasks which were highly physical (carrying heavy bags of chemicals, breaking with a hammer the solid product of

[1] Company name of the externalised management of the water treatment station, changed for confidentiality reason.

some chemical reactions) were no longer executed, greatly improving working conditions, health, and safety. One consequence, commented by some with longtime experience, was the loss of what used to be a higher degree of solidarity between team members, who used to help each other out more because of the physical activities involved. Their relationships were now different. Patterns of interactions were altered, also modified by the slow replacement of workers from a past generation, with many of the senior operators recruited in the 1970s and 1980s retiring, or about to retire.

By automating much of what used to be performed manually, such as loading products in tanks and reactors or opening or shutting valves, operator work became slightly more of a solitary job, without a colleague to directly share physical work with. As a result, these workers spend less time at the reactors, freeing extra time to be devoted to a new task. Quality testing of the products by the team chemists during production was now carried out by control room operators. This additional work required that they learn new skills, using new kinds of laboratory machines, and to progress a step further in their knowledge of the composition and nature of chemical products. It was also another change in the way they used to work: more generally from physical and demanding (sometimes exhausting) manual activities to more supervisory and laboratory-related type of activities.

The number of production team members also diminished with the departure of the electro-technicians too. These experts used to assist them in maintenance trouble shooting. But with the externalisation of the heating machinery and the water treatment station, these members of the teams moved to a day job, from 8 am to 5 pm, and thus out of the shift system. A consequence was, according to one team supervisor, a loss of opportunity for operators to learn from their interactions with them. As they worked together during shifts, they had many opportunities to solve problems together, learning from each other about the different machines, automations, valves, pumps, and products which contributed to a greater ability to handle problems collectively, and also to their interest in the job.

This considerable change in the nature of the work went along with a concern expressed quite unanimously by team supervisors about the need to maintain the ability to follow plant processes during production phases. One issue was to supervise the chemical reactions away from the equipment, trusting the computer screens despite their known

imperfections. The computers' views of the plant were indeed not thorough or complete. Some valves which were still manually operated, were not systematically depicted, for instance. The views were not always updated according to the modifications made to the chemical processes, something which took place from time to time. We discovered, for example, that some recently added sensors required by the regulator for hazardous chemicals were not visible on the screens. Data from the sensors was physically present in the control room (in the screens and via sound and visual alarms) but were not shown on the screens themselves.

There was also information about the reactions which couldn't be gathered from computer screens - such as visual events, noises, and haptic clues about what was going on inside the tanks, reactors or pipelines. Only physical presence around the reactors, tanks, pipelines especially in exothermic phases, was considered a good practice, strongly recommended by the supervisors, and endorsed by the plant manager. They saw in their incident investigation that troubles often came from a discrepancy between the material, physical world of the plant and the world of interfaces, screens. Closing the gaps between the two in real time by operators was an important aspect of their expertise.

This familiar aspect of problems raised in any automated environments among safety-critical industries must however be supplemented by another relational and organisational change introduced by this more computerised working environment. The first change was about how safety was engineered in the system, and the second is about the new balance of power that it introduced. First, what used to be mostly based on practices, on written instructions in procedures and paper traces of product quality and process safety, was now programmed in software sequences.

3.1.2. A new expert: the IT engineer

To program these recipes, a new function, the IT engineer, became central to the daily operations. Only he could enter the computer, in particular the *Fox* software environment, when a new recipe had to be programmed or when problems needed to be fixed. Previously, there was a direct relationship between process improvement people and the production team; now, a new cooperation, a new step in the development of a recipe from testing to production was required. This added layer certainly achieved a

higher level of process safety, as sequences were programmed and automatically executed; sequences executed in the past relied on the manual intervention of operators who could make mistakes. Yet, because of the imperfections already discussed, the presence of the operators' expertise was still highly relevant, and impossible at this stage to eliminate, even though it was quite reduced, or transformed. Indeed, programming recipes was not immediately successful, and some corrections were sometimes needed: a temperature threshold, a quantity of a product or a discrepancy between screens and sensors indications, for instance.

Therefore, the way operators expressed their autonomy and expertise was not the same as before. They could only modify certain parameters while the access to others was restricted by the program. They also had to figure out how to handle changes to be made to recipes when they couldn't be immediately reprogrammed. It is now possible for process improvement engineers to request modifications for improving the product, while the process is still in the hands of operators who may, for instance, be executing manual sequences still allowed by the program because it does not control certain equipment. Some modifications are therefore left unprogrammed in the *Fox*. This introduces the second point of this new relationship.

This increasing reliance on the new programming expertise led to a problem in updating, and correcting the flaws, imperfections and holes, in recipe sequences. Due to the frequent unavailability and workload of the IT engineer, who only works part time at the plant, many of these problems were left unsolved. Most of the time they were minor problems, which were recorded by operators in a folder on a table in the control room but were not being treated immediately. Again, while most of them remained minor, they contributed to this lack of trust, and illustrated the need for a sustained knowledge of what the screens meant in the physical, chemical and material world. An example of an unsolved problem was that alarm sounds were turned off because they were not properly filtered by the software. There were too many of them, and so were ignored by the operators, who knew their meaning. They were then hidden from the main screens once they were validated, a practice taught to newcomers, but not easily mastered. The designers of the interface did not anticipate that the number of alarms programmed would be a nuisance to operators.

3.1.3. More IT: maintenance and supply

This reality of software systems mediating the coordination and cooperation between artefacts and people in the plant extended beyond the classic case of automation of control room. It also concerned other domains such as maintenance or logistics and supply. Although widespread in the industry, a computer maintenance management systems (ccms) was never implemented in this plant. A recently recruited maintenance manager with experience in the implementation of a ccms in the automotive industry led the project. He saw this as an opportunity **first** to standardise equipment (e.g., pumps, valves) which exhibit a large degree of heterogeneity (a problem for maintenance), **second**, to further coordinate activities of two separate departments: maintenance and new projects. Now coordinating the two departments which were previously distinct, the ccms became an important tool in combining their operations.

In the supply department, an Excel spreadsheet replaced the old paper-based systems used by the previous manager. This program shared by his counterpart in the supply department from another plant of the group in another country became the basis for the easier handling of the multiple products to be bought (for which the various quantities needed to be anticipated). More than 60 recipes exist in production, although 20% of them cover 80% of the amount of production. Yet, there is a need to anticipate the type and quantities of chemicals in relation to their consumptions for the various reactions, and according to sales. Commenting on his use of the program, the new supply manager, an ex-production team supervisor with twenty-five years' experience in the plant, wondered how his predecessor could work without it, in spite of the program's imperfections (which he indicated). Sometimes, anticipation of products to be purchased failed for reasons that he was unaware of but that he noticed because of his knowledge of production. He combined his participation to production meetings with regular visits to the control room to find out about tanks' levels. This way, he tried to be aware of any lack of anticipation by the software.

When *Fox*, the name of the control room software is often mentioned during our observation of work and our conversations with production teams, another name for another software system is often heard in our discussions with maintenance and supply managers, engineers and operators. This is *Ross*, a software system implemented by the company headquarters, and it is a data management system which connects the activities of these departments with the computers of the multinational branches

abroad. They often referred to the gap between *Ross* and their own local computerised support tools.

One problem for the supply manager was the difference between product quantities shown in *Ross* and those of his Excel spreadsheet. Another was the problem of the slowness of *Ross* during the days when its slowness created problems with the maintenance logs used by operators and department supervisors. One reason given for this was the time difference between the plant and headquarters abroad. Note that CCMS and the Excel spreadsheet were local software used within the perimeter of the plant. Ross, by contrast, is a newly implemented software management system with a broad scope: it connects the plant to the regional group, a new system directly linked to the corporate strategy, to which we now turn.

3.2. Into the matrix

3.2.1. A change of organisational structure

With the introduction of *Ross*, this new information infrastructure demonstrated one aspect of change in the organisation structure, where the change went from higher autonomy for plants to a matrix-based structure with less autonomy for plants. Family owned, the company took a new direction in 2008 with the recruitment of senior managers from competing multinationals to oversee the design and implementation of a new strategy. In a fast-evolving market with increasing regulatory expectations - a change was needed. According to one corporate manager, improved performance was expected, but also improved health, safety and environment (HSE) management, hence the recruitment of executives from other multinationals. One key element of this strategy introduced by the new senior managers was a change in the organisational structure of the group. Before, countries were more independent. A plant (or two) in a country (e.g. UK, China, Mexico, France, Japan, Korea, Switzerland, India) was ran by a national top management team with services enjoying a fair degree of autonomy at the country level in terms of human resources, environment, health and safety, product development, customer acquisition, and also supply.

With the new organisational structure, this degree of autonomy was reduced. First, plants were grouped by geographic areas or regions at a higher level than countries.

Four regions were created: North America, South America, Europe/India, and Pacific Asia. Second, plants were managed at this higher level of aggregation. Top management in a country disappeared, plant managers remained but reported now directly to a top management situated at the region level. At the highest corporate level, there were four vice presidents for the four regions, then four VPs in hr, finance, HSE and sourcing, plus the corporation CEO. Above that, there was the Board. This new structure reduced only to three the number of levels from CEO to plant managers: CEO, region VPs and plant managers. Third, new functions were created at the region level with a corporate manager for each: HSE, finance/hr, sourcing, process improvement, research and development, and commercial/marketing.

These were the core elements of the new strategy, translated into a matrix structure which amplified the degree of centralisation through tighter corporate control and oversight. What used to consist of self-contained businesses at the country level, with their own top management was therefore radically modified. This change was of course not without consequences. One of them was the recruitment of new people for the plants. Indeed, to operate in this context, the plant in France needed to modify its own internal structure by positioning capable managers in the matrix at the interface with the corporate level. They needed to speak English; they needed to able to respond to both plant needs and matrix (corporate) needs. This is a new role that the current managers of some services, who climbed up the ladder internally, were not considered to be able to fulfil. The plant manager recruited four new and relatively young managers with stronger educational backgrounds (with ten years professional experience in their domains, sometimes outside the chemical industry) in production, process improvement, hsqe and maintenance. Once in place, the organisational structure of the plant and the patterns of interactions inside the plant were, as one could expect, radically modified. A new class of employees was indeed created, with a crucial managing role in the plant combined with a strong role in the matrix as well, in order to satisfy corporate demands.

One manager of the plant with long experience and a new role in the matrix, commented that the previous organisation with more independence granted to countries worked well but the new structures was designed to offer new career opportunities to employees, so as to create synergies, to improve productivity in a declining market, to

introduce some competition between plants, but also to bring more transparency to shareholders. The matrix was indeed designed to improve performance by creating more problem-solving capabilities through the sharing of practices across countries, plants and expertise, but it also served to standardise further HSE requirements. This new ambition unavoidably put new constraints on people's activities. It reduced the autonomy of plant and service managers, something which some employees resented. It modified managers' workload and more broadly, it shaped new patterns of interaction within and outside the plants. Many also wondered if this move towards a matrix structure as found in big multinationals was "*copied and pasted*" into their organisation, thus taking them out of their depth, in view of their level of resources.

3.2.2. Standardising HSE

The evolution of HSE illustrated this situation well and served as a good example of what the move to a matrix structure meant. Before, HSE carried on somewhat independently from the group in the plant. Corporate initiatives were limited on matters of HSE, were close to none and were left to be dealt with at the country level. The HSE manager at the time, in the 1990s, followed the quality approach applied to safety. He produced a safety management system made of procedures, as much as quality proceeded. The philosophy was one of compliance, with sanctions being imposed in the event of incidents. The business of HSE was perceived and expressed by managers of this era as an exercise in procedural discipline. There was initially only one person who also dealt with quality and safety, and then in the early 2000s, a new internal recruit with a strong administrative/legal background joined the group. After that, an external recruit with a primarily operational background joined the HSE department in 2006. So, an HSEQ service grew from one to three people in the 2000s. Then the manager retired and a recruit with an educational HSE background arrived in 2011.

For this new HSE manager, work consisted in playing out his role in the matrix while responding to local demands of the plant. These local demands were first, the operational requests of the plant manager regarding concrete daily safety problems and second, compliance with the law (supervised by local authorities) in process and environmental safety, but also occupational safety. On this front, a major accident in 2001 in France (ammonium nitrate explosion in a chemical plant, several deaths, and destruction in a major city, Toulouse), led to a modification of the law (based on a

European Directive transposed to French law) thus raising the level of the requirements imposed on the risk assessment of chemical sites. Higher expectations were also turned into inspectors' number of visits (four to five times a year), in terms of process safety management system, and by addressing topics such as learning from experience and management of change. To these requirements one needs to add the new headquarter expectations translated into procedures such as of management of change (MOC), process hazard analysis (PHA), "minimum safety requirements" and also learning from incidents (reporting). To all of this, one needs to add the environmental dimension, and the new European regulation on the assessment of chemicals (Reach).

In other words, within the decade stretching between 2000 and 2010, the level of requirements on HSE was dramatically increased both at the local (national, through control authorities' regulation) and group (corporate, through safety standards) levels. Concretely, this led to a much higher level of bureaucratic activity carried out by the new manager, who never spent time in the plant as a result. He was simply absorbed by the regulatory and corporate requirements which demanded full time dedication. He summarised his critical views on this problem introduced by the matrix construction in two points: **first**, the level of requirements had become much higher without necessarily the resources or support to comply with it. **Second**, there were priorities at the group level which were not necessarily priorities at site level, thus creating a discrepancy and unnecessary additional activities or burden (this is consistent with comments made by other managers already indicated).

Despite these problems, all involved - including the HSE manager - admitted that the intention behind this change was good. A higher level of requirements translated to group standards made sense as a strategy for improving practices, including process safety. One example was the management of change (MOC), both targeted by local authorities and corporate as lacking, or insufficient. In a chemical plant in which changes occur regularly, one way of anticipating safety risks consists in making sure that such changes do not lead to unexpected consequences. To do so, one needs to analyse the nature of changes, then invoke the right expertise to determine their potential consequences. A question in this regard is when to trigger a MOC: for what kind of change, who oversees it, and is it one or several persons. In this particular instance, the new process improvement manager was chosen to coordinate MOC. Her role is to

centralise any changes to ensure there are no undesirable outcomes from an HSE point of view (the HSE manager must therefore be included in this loop). The approach adopted consists in discussing changes requiring an MOC, during each production meeting taking place every morning.

From the group perspective, this strengthened process safety management, even if, again, from the perspective of the plant, it led to more bureaucratic activities that make demands on scarce resources. Process safety analysis (PHA) evolved in a similar fashion. PHA required training relevant employees across the company in the LOPA method (layers of protection analysis). A consulting company was contracted for this training and multiple sessions were organised to make sure that this approach is used across company sites throughout the world. Previously, chemical reactions in the French plant were informally treated from a safety perspective by the process improvement technician. Now, the new process improvement manager and the new HSE manager were henceforth both in charge of updating all of the risk assessment of the chemical reactions, in the years to follow. These initiatives were redundant with the “safety case" required by the law and contracted out to a consulting company …

3.3. WaterT & Co

Subcontracting was indeed another facet of the changes occurring over the years at this plant. Water station treatment, maintenance, inspection (tanks, sensors, pipelines), boiler room (including steam production), gas supply (nitrogen, oxygen), logistics (chemical trucks), but also consulting (e.g. safety case, risk analysis, management, environment) relied on the contribution made by external organisations. Some of these subcontractors were present all year long in the plant, while some of them only from time to time for specific tasks, depending either on specific needs or frequency of work (e.g. consulting, periodic maintenance, inspection). Companies that were on site permanently provided about 15 to 20 people, and sometimes up to 40 to 60 people, mostly during the summer when maintenance works were planned while production slowed down. The growth in number of external companies involved in the daily activities of the plant had many consequences. One of them was the presence of contractual relationships, which brought a legal, commercial, and bureaucratic dimension to the plant’s operations. The interactions between the plant and the external

organisations were indeed framed and mediated by a contract which stipulates what to expect in terms of operations or delivery of services.

Negotiating, writing, then following the contract was one important activity of the managers in charge of the external expertise. There was another contractual, or formal side to this externalisation. The presence of people from other companies, regularly or from time to time, had also to be managed from an HSE point of view. It was important to make it clear to external people where the risks were, but equally, what risks they were likely to bring to the plant with their work. This aspect was also quite strictly framed by the law. These activities represented a fair proportion of the activity of one member of the HSE service (who joined the service around this period, in 2006, partly because of such a need). It is necessary that the integration of external companies on site does not lead first to safety problems, then, second, that it complies with the law in this respect. Although operationally oriented for preventing risks, this activity contains a bureaucratic, paperwork-related dimension. This topic was also covered by a corporate standard, as part of the new safety minimum requirements discussed in the previous section.

Beyond the contractual and the HSE facet of subcontracting, relational, operational and managerial dimensions were also associated with it. These were well illustrated with the subcontracting of the water treatment station. This new strategy represented another important change occurring at the plant in the mid-2000s, in view of the central role this technology has for the process. The origin of this decision was the construction of a new sophisticated water treatment station for which there was insufficient in-house expertise. Following a serious event involving a technical-biological problem at the station (the treatment involves the production and maintenance of the right amount and type of bacteria), it was decided that the plant's employees in charge (two operators and a team leader) didn't have sufficient knowledge to operate the station.

Operating the station required a degree of professionalism which was only available elsewhere. A contract was signed with WaterT (a multinational well-established in the sector) to externalise the operation of the station. However, this created new issues to be dealt with - one of which was that *WaterT* did not provide the quality of skills and management needed to operate the station as was hoped. This created many issues: the plant manager was unable to hire the right people since he depended on the ability of

the subcontracted multinational to do so and couldn't enforce any solutions. He was tied to a ten-year contract which he couldn't afford to contest legally and had to therefore make do with the situation. One solution to this was to include that station's team members in the daily production meetings so as to improve coordination, identification and anticipation of problems.

One pressing issue was that production depended on the ability of the water treatment station to process various chemical wastes produced by the various reactions. These chemical wastes can be different depending on the type of reactions. Different wastes sometimes mean different treatments by the water station, which in turn requires the right level of expertise. It was therefore imperative that a good coordination be established between the production teams and the station team. Their good relationships and the ability of the *WaterT* members of the station to be responsive to problems which would trigger unexpected chemical wastes, was needed. Without it, delays in production could result, with potential commercial or financial consequences when customers were not being served. Other issues were of course safety ones which always require a good level of coordination due to the plant's complexities. By externalising this activity, new contractual, operational, relational and managerial dimensions were introduced, thus changing practices, work, and organisation. While externalisation made sense, it could also complicate daily operations. This reasoning can be applied to externalisation *in general*: it brings many changes, and sometimes new complications along with it.

4. Discussion

This case study illustrates how a plant can considerably modify its mode of operating in a relatively short period of time: less than a decade. Change in this case is a broad, multilevel phenomenon which simultaneously affects several aspects of a plant. In the introduction of this article, we argued that the operating landscape of safety-critical systems had evolved over the past decades - moving towards networked, digital and global configurations (figure 1). It is interesting to see how such trends stand in the light of this case study:

1. As regards the digitalisation trend, the advent of information infrastructures introduces the automation of chemical reactions supervised in control rooms (e.g. *Fox*) and computerisation of workflows (e.g. *Ccms*, *Excel* spreadsheets, *Ross*).

2. As regards the combined effects of the standardisation, self-regulation and financialisation trends, the new matrix organisational structure of the multinational rearranges the way that productivity performance and compliance to HSE's new standards is managed across continents

3. As regards the externalisation trend, the growth of externalisation in multiple areas helps organisations benefit from expertise considered to be outside the internal competence of the group.

Thus, the connections between the mega-macro transformations of the operating landscape of safety-critical systems and their meso-micro implications in a specific case is one captivating outcome of this ethnography, as the narrative exemplifies. And it is highly comparable with other ethnographic studies in the maritime (Kongsvik et al., 2020) or aviation (Haavik et al., 2020) industries which testifies to the ubiquitous realities of these trends across sectors worldwide. Regarding the maritime world, these authors observe that "*while ships were traditionally autonomous organisational systems that the seafarer on board could – and were expected to – master alone, ships are now increasingly part of large networks of ships, internal and external IT systems, shipping companies, yards, certification agencies and national and international regulations*" (Kongsvik et al., 2020). The consequences of these transformations are important, and in this case study they are expressed in many ways in terms of the nature of tasks and activities, professional identities, patterns of social interactions and distribution of power (decision-making):

1'. the advent of information infrastructures modified the job content of operators and supervisors, their identity as workers, but also their social interactions (e.g., reduced team size) as well as their role in relation to new actors such as the IT engineer in the programming and supervising of chemical recipes,

2'. the new matrix organisational structure of the multinational redistributed power and decision-making, diminished the autonomy of the plant manager (a change of work identity), but also introduced new patterns of social interactions

inside and outside the plant with corporate people endorsed by the new managers, while also increasing bureaucratic work (e.g., standards, reporting).

3'. the growth of externalisation in multiple areas (e.g., gas supply, boiler room, maintenance, inspection, risk analysis, water treatment) modifying the operational and managerial context of the plant and included the handling of contracts, new type of human relations, and dependence on other organisations – all of which also came with an increase in bureaucratic regulatory compliance (i.e., health and safety).

From the early 2000s to the early 2010s, a different safety-critical system emerged as a result of these cumulative and multi-faceted transformations. They reflected widely felt trends across the world, as is shown in other studies (e.g., Haavik et al., 2020, Kongsvik et al., 2020) and in the case of disasters, for instance BP in the 2010s (Bergin, 2011, Hopkins, 2012).

Now what about current new prospects, in the 2020s, in areas such as big data, artificial intelligence, cybersecurity, remote work, de-globalisation, shifts in markets, climate change or ecological degradation? Clearly, as one would expect from researchers practising ethnography, the answer is that only empirical data can tell how new contexts, opportunities, threats and potentialities concretely shape practices and strategies.

However, there are potentialities which come with the changes described in this case study. Thus, the proliferation of information infrastructures creates possibilities for more centralised management. It is possible indeed to imagine greater supervision from headquarters through a higher level of data exploitation based on existing infrastructure (by controlling some reactions at a distance through increase of digital automation or through data collection; use of the *Ross* software introduced in the narrative is a step in this direction).

This also opens avenues for more remote work options, even if, as explained, the absence of humans in plants is hardly conceivable considering the imperfections, and the limits of automation, computerisation and digitalisation in complex chemical plants. These imperfections are always compensated by professionals and their collective expertise, as shown and introduced in several places in this article. Another dimension

consistent with the study is that as information infrastructures grow, the importance of IT expertise grows with it and this often comes with further externalisation (data centres, IT engineers) in the absence of internal competences, and in the absence of engineering hardware and software infrastructures which are needed for the expansion of data-driven production.

The increasing dependency on IT infrastructures carries with it the risk of exposure to cybersecurity threats. This will likely become another important aspect of safety management. In the context of organisational structure, de-globalisation is now being considered in response to current events. This may lead to shifting global value chains from a transnational and cross-continental dependence to more regional value chains, and thus also to strategic re-orientations, with consequences for existing patterns of interactions, distribution of power, and all the other aspects. This next stage would be yet another transformation of the chemical plant.

Conclusion

This article is a contribution to the special issue of safety science research in the new age of work by conceptualising change as a multilevel phenomenon involving the connection between mega-macro trends and meso-micro levels of analysis. An analytical (integrated) framework is used to grasp the evolution of the operating landscape of safety-critical systems towards networked, digital and global configurations. By applying an ethnographic approach to the study of a chemical plant, the article concretely shows some of the implications of this evolving landscape.

Analysing the advent of informational infrastructures through automation of chemical processes supervised in control room and the computerisation of workflows in maintenance or supply, it discusses how it affected work, including identities and modes of coordination between workers. Deciphering the ambition and effects of the new matrix organisational structure on patterns of social interactions but also distribution of power among managers, it illustrates the higher level of standardisation, coupled with higher demands from state's regulation, required in the HSE domain. The resulting amount of bureaucratic work and reporting increased, and this goes along with the ambition to exercise centralised corporate control of standards in a multinational.

Finally, by describing the externalisation of some activities - from maintenance to consulting - it exemplifies the conditions needed (or, in this case, lacking) for contracts between separate legal entities to work as expected. When power asymmetries favour external organisations, work coordination can suffer, and changes are difficult to make. Despite the presence of a contract, clauses may protect one of the two parties at the expense of the other. Reflecting on the future, the article argues that in a context of big data, artificial intelligence, cybersecurity, remote work, de-globalisation, shifts in markets, climate change, or ecological degradation, some chemical plants might have to undergo profound changes again, as illustrated in this article, in a rather short period of time.

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