An account of scientific transfer to the industry: the co-development of an incident analysis tool

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Summary

This paper is an account of scientific transfer to, and co-development with, a commercial organization. The context is that of safety management of an energy distribution network. A company called EnergyCo approached the authors about their need of an incident analysis method. The company wanted a tool that would help them better capture the causes of incidents during maintenance operations on their network. The expertise they particularly asked for was that of human factors; an angle to work analysis they valued but had not been able to deploy at the time.

Beyond the mere technical contents of the tool that was developed, we wish to provide an account of the various transactions, exchanges and collaborations that took place during the development of this method. We will highlight a particular angle of scientific transfer: co-development. In doing so, we will try to convey the message that scientific transfer goes beyond a mere "push" model. Indeed, we are of the opinion that in the case of the development of a method for the industry, transfer can be turned very productively into a co-development collaboration.

1. Introduction

The authors have been approached in the recent past by a French energy distribution company: EnergyCo. This company had just set a new safety target related to the operation of their distribution network. Within the company, top managers rapidly acknowledged that their ongoing approach to safety (essentially based on a technical analysis of incidents) would not allow them to meet the target. This opened the way for a drastic cultural shift: the integration of human factors (HF) in the analysis of safety performance. Within this shift, our mission would be to integrate HF within an incident analysis tool in order to facilitate organizational learning across the entire company. Because this tool was meant to be used by operational team managers without HF training, the challenge would essentially be that of transferring en encapsulating our skills under some usable form for the final users. This is essentially what the paper will describe. We will go through the process by which academia and industry collaborated with each other in order to fulfill a need that implied using science for operational non-specialists. In doing so, we will set the focus on the collaborative aspects more than on the scientific contents of the method.

The paper begins with a brief overview of EnergyCo's operations, followed by a presentation of the scientific standpoint proposed by the authors and accepted by the company. The paper then reports on the process of understanding user needs and requirements and moves on to a description of the development of the tool. Emphasis is given to the adjustments and compromises made to meet the needs of the company. The main features of the tool are then presented and a case study is discussed. As a concluding remark, the authors comment on the experience of transferring academic knowledge to a practical environment with the assistance of those who are the ultimate beneficiaries of that knowledge.

1.1. EnergyCo operations

EnergyCo is a nationwide energy distributor in France. Within the largest branch of the company, several thousands of people are involved in maintaining the distribution network, a task that basically obeys two main scenarios:

- *planned operations*, whereby works are taking place under controlled conditions (time, allocated resources, schedule, etc.);
- *emergency operations*, whereby an unplanned event is happening on the network, interrupting the delivery of energy to consumers, whose number ranges from a dozen to several thousands.

For workers, a significant portion of the work time is spent on excavations, at the direct contact with network infrastructures buried into the ground. The role of team managers is that of coordinators, especially when critical works on the network implies interacting with public authorities, safety professionals, the public, the media and so on. Although the activity of workers and managers is significantly different by nature, all contribute to a mission that is very clearly identified by all: continuity of service. Indeed, energy is a service that is meant to reach customers without interruption. It follows that any energy loss in the network is dealt with carefully, with particular attention paid to how many customers would be cut off in the case where the network had to be disconnected for repairs.

Another particularity of energy infrastructures is that they carry a service to physical habitations. In dense urban areas, this is challenging working environment since the energy network cohabits with other infrastructures (water, telecommunications, sewers, etc). What is more, this mesh of disparate infrastructures is buried underneath roads or pavements whose topography changes along with urban development. This causes updates in the mapping of the network difficult, a point that is a source of problems.

Finally, as an energy supplier whose network is several thousands of kilometers long in densely populated areas, EnergyCo cannot monitor all the parties working at the vicinity of their infrastructures, not check the qualifications of every worker from each subcontracting company. So-called third parties are a source of mishap to EnergyCo managers since they do not always comply with company regulations and legal requirements.

The three features above, and their implications in terms of EnergyCo workers, subcontractors and the public, entice EnergyCo to thoroughly manage the operations that take place on their network. Historically, this management relied (at least in part) on recording factual data on incidents, and discuss potential causes within units, during informal "on the fly" meetings[1]. We now turn to a more precise description of the safety practices within EnergyCo units.

1.2. EnergyCo safety approach

At EnergyCo, at the time when the research team was contacted, a number of practices were in place that impacted on how precisely incidents were analyzed, how thoroughly the contributing human factors were captured, and how the gathered information could feed organizational learning:

- Generally speaking, human and organizational factors had not permeated the safety culture of site managers at the time, thereby causing incident analysis to focus on the technical dimension alone;
- Minor incidents were discussed verbally during informal meetings within local teams scattered over the entire country;

1 A serious accident would trigger a formal procedure whereby a safety expert would be sent to the unit to analyse the case.

- Tools that were used to analyze minor incidents were essentially computer-supported data collection sheets focusing on factual information about the case;
- The collection sheets were shared digitally across the company but several tools existed, that were home-made and did not contribute to the company databases;
- Only major incidents were analyzed formally with the assistance of a company expert, but relied on traditional tools such as root cause analysis.

EnergyCo's safety approach is at a point of change with the incorporation of human and organizational factors in their incident analysis. At the mean time and as a result of this shift, EnergyCo is also modifying their process of learning from experience.

1.3. Learning from experience

Because analyzing incidents generally aims at preventing future occurrences, a mere repetitive analysis of incidents is not a productive answer. Instead, an organizational learning mechanism has to be put in place in order to systematically capitalise experience, communicate the lessons learned and influence future practices. This is the context within which the need of EnergyCo, in terms of incident analysis, took place. Organizational learning by a learning from experience process is composed of 4 steps: detection and information collecting (knowing), analysis (understanding), formalization and capitalization (stocking) and sharing and reutilizing (learning) (Van Wassenhove & Garbolino, 2008; Gauthey, 2008).

Organizational learning (learning from experience) is mostly implemented in an organization by the means of a tool. Such a tool must be thoroughly conceived with a clear definition of the objectives of the process in mind. If not, there is a possibility that the data collected could not contain the information needed to satisfy the general objectives and questioning. Too often in industry an learning from experience process is implemented by merely collecting facts with little concern for analysis and interpretation of collected information.

The conception of learning from experience process consists of the integration and articulation of the four major steps of the process. We were approached by the company to develop an incident analysis tool, that is, step two in the organizational learning process ("understanding: analysis of the informations"). Furthermore, the tool that was to be developed for EnergyCo was a "second level" analysis to investigate the human and organizational factors of some of the incidents or accidents. The first level analysis corresponds to a systematic *technical* analysis already in place at EnergyCo.

So EnergyCo was changing a fair amount of their organizational learning structure. Capturing the causes of incidents in a systematic way made sense, especially when the latter was meant to be deployed nationwide across the entire company. It was just difficult, to us researchers, to integrate one part in a process without having a general view on the objectives and the design of the whole process.

The company had acknowledged the need to know what to do with the data before collecting it. On that front, a computer-based structure existed that would accommodate the data that were to be collected thanks to our tool[2]. Our job would then be to design a collection and analysis tool that would help EnergyCo capture human dimensions of incidents during operations on their network.

2. General approach and scientific standpoint

2.1. Understanding human performance

Our general approach to human performance (whether safety-related or not) is to understand work and to pinpoint the conditions under which operators performed their task. The assumption behind this approach ties back to the Common Performance Conditions (CPC; Hollnagel, 1998), a set of criteria that influence human performance. The idea was not totally new at the time: a similar concept had been proposed by Swain and Guttman (1983) and coined performance shaping factors. The philosophy behind the CPC is what underpinned the second generation accident analysis methods: human performance cannot be reduced to an equation relying on a nominal failure rate[3]. Instead, it is the context in which people work that determines for the most part how well or badly they are going to perform on a given task.

Table 1: Overview of the 9 Common Performance Conditions

2 What this computer-based structure was composed of falls outside of our scope and will not be discussed here. However, we will touch upon the organisational learning loop and discuss the fit between the latter and the incident analysis tool.

3 The CPC are actually only one sub-set of an accident analysis and risk assessment method authored by Hollnagel: CREAM.

Conditions	*Description*
Adequacy of organization	The quality of the roles and responsibilities of team members, additional support, communication systems, Safety Management System, instructions and guidelines for externally oriented activities, role of external agencies, etc.
Working conditions	The nature of the physical working conditions such as ambient lighting, glare on screens, noise from alarms, interruptions from the tasks, etc.
Adequacy of MMI and operational support	The Man-Machine Interface in general, including the information available on control panels, computerised workstations, and operational support provided by specifically designed decision aids.
Availability of procedures and plans	Procedures and plans include operating and emergency procedures, familiar patterns of response heuristics, routines, etc.
Number of simultaneous goals	The number of tasks a person is required to pursue or attend to at the same time (i.e. evaluating the effects of actions, sampling new information, assessing multiple goals, etc.).
Available time	The time available to carry out a task and corresponds to how well the task execution is synchronised to the process dynamics.
Time of day (circadian rhythm)	The time of day (or night) describes the time at which the task is carried out, in particular whether or not the person is adjusted to the current time (circadian rhythm). Typical examples are the effects of shift work. It is a well established fact that the time of day has an effect on the quality of the work, and that performance is less efficient if the normal circadian rhythm is disrupted.
Adequacy of training and experience	The level and quality of training provided to operators as familiarization to new technology, refreshing old skills, etc. It also refers to the level of operational experience.
Crew collaboration quality	The quality of the collaboration between crew members, including the overlap between the official and unofficial structure, the level of trust, and the general social climate among crew members.

The principle behind the CPC is simple. They are used as a set of criteria to assess the conditions in which people perform their task. This assessment is performed against qualitative scales: very efficient, efficient, inefficient, deficient.

In the case of EnergyCo, we suggested this approach since it matched their needs of understanding the so-called human factors at play during maintenance operations. The CPC also had the advantage of being designed as a set of basic work analysis criteria. This would ease their translation into a tool, a possibility that EnergyCo saw as an asset.

2.2. Incident analysis and safety management

Typically, at EnergyCo, an incident is an event that:

- produces unwanted outcomes;
- causes injuries (to EnergyCo employees or the public) and/or loss of assets;
- disrupts the continuity of service to an unacceptable extent.

In dealing with incidents, top managers at EnergyCo took the decision to manage human factors along with the traditional set of technical causes. The high-level objective was to capitalise on causes of incidents, both on the technical and human factors sides. In doing so, managers were of the opinion that widening the spectrum of the search for causes would also widen the spectrum of the cures to incidents. This is consistent with the following safety proverb: *What you look for is what you find, and what you find is what you fix.* Indeed, to EnergyCo top managers, it was clear that concentrating on the technical dimension of incidents would only bring up more instances of known technical causes without increasing safety records. And because the company safety record was plateauing for several years, only a significant paradigm shift would allow them to further improve safety performance. This situation is the very same one that commercial aviation is facing in western countries: mastering the technical design of aircraft and introducing crew resource management programmes in the 1990s lowered accident rates to some unprecedented level . However, statistics now show that the number of aviation accidents, although at an all-time low, is now asymptotic (Boeing, 2005), revealing that the philosophies and actions deployed over the past decades have come to their limits in terms of improving safety records.

Accompanying EnergyCo through their paradigm shift was our mission. This is where our human factors standpoint and the company's objective met. Concretely, this translated into turning the CPC into a tool; a development that was undertaken under a collaborative model. This is what the following sections will describe.

3. Analysis of requirements and early specifications

This section is not a step-by-step account of a typical development project. Instead, we will focus on the phases were co-development was the driving force. Our intention is to highlight the contribution of both parties (EnergyCo and our team) to the method. Another interesting aspect is that any one party would have been able to produce some version of the final tool on their own. However, the co-development strategy revealed fruitful in:

- saving development time, each party bringing their expertise into the development process;
- making sure the scientific assumptions behind the use of the CPC were understood and shared;
- capturing the reality of the work of maintenance operators through the involvement of EnergyCo former unit operational managers.

3.1. Understanding the need

In order to understand the needs and requirements, as well as the constraints, of the company, the research team conducted an assessment. This assessment involved:

- visiting a couple of operational sites and workshops;
- speaking to several people within the organization, including a number of local managers.

As we did this, we made an effort to explain our approach, i.e., the importance of understanding why people do not perform as expected. Our assumption, as explained previously, is that the causes are to be found essentially in the conditions of work.
It became clear to us that the tool should be able to quickly assist in the identification of good practices and failures. In addition, the tool should serve as a first level of incident analysis, and therefore assist in the identification of incidents that merited deeper investigation.

3.2. Understanding the context: factors of adoption and rejection

Another requirement is that the method has to be simple because it is was meant to be used by non-specialists. An important factor of acceptation of a new tool are the benefits that the tool gives to the persons who use it:

- gain of time/effort to do the incident analysis compared to other (existing) methods or tools;
- the information obtained from the use of the tool should be useful, i.e., lead to an improvement in safety;
- the tool should add value to the job and be a factor of motivation for the user;

The co-development is a way to assure that the management of the company obtains a tool that fits their needs (and a tool that is scientifically based), but attention must be given to the final use of the tool. The feedback of the learning process to the operational managers and field operators is an important step in a successful organizational learning process; without it the efforts of the persons who collect (and analyze) the information aren't rewarded and the long term success of the process can't be guaranteed.

3.3. Early specifications

From the 2 subsections above, we came to the conclusion that a CPC-driven method would match the above requirements best. Indeed, it would bind together several essential points:

- a tool that would make the analysis of incidents more systematic;
- an approach that would focus on human and organizational factors;
- a philosophy that would be based on the conditions of work;
- a product that would be simple and match as many as the acceptance/rejections factors as possible.

Other points mentioned by the company were:

- to introduce dynamics in the organizational learning process and to avoid methods that are too complex to use

- share information and experience efficiently
- a simple and fast method: no special skills are needed and no more than 90 minutes are needed to analyze an event
- the method must be compatible with the "level one" analysis that is based on technical factual data (see section 1.3);

As a technical answer to the identified requirements, the specifications were as follows:

- a set of analysis criteria derived from Hollnagel's (1998) CPC;
- a portable, cross-platform spreadsheet-based analysis grid;
- a simple quantitative assessment system for the analysis criteria.

A tool can satisfy only two of the following characteristics at a time: simplicity, generality and precision (Weick, 1999). In this case, the tool had to remain relatively simple and precise. The tool is targeted at the detection of human/organizational factors for the context of the working conditions of EnergyCo. The general approach of CREAM, which is rather complex to implement, had to be transformed into CREAM-light, a simple and specific tool to the context of EnergyCo.

4. Co-development of the method

4.1. The co-development team

On the academic side of the project, 2 senior and 3 junior researchers were involved. The company participated with 1 engineer from EnergyCo's Research & Development Department, and 1 former operational manager who served as project lead. Although the company engineer was for all purposes responsible for the project, the presence of a person with field experience was essential, not only because he knew what would work and what would not, but also because he was able to open the doors of the company to the academic team. In that sense, he performed the role of the "gatekeeper" described by (Lofland et al. 2006).

4.2. Scientific foundations

Hollnagel's (1998) initial set of 9 CPC (see section 2.1) stemmed from a cognitive view of human activities, based on generic classical psychological dimensions. This was both the strength and the weakness of CPC. Indeed, CPC were designed as generic and versatile indicators, and offered a wide range of potential fields of application. However, this also meant that before being deployed, CPC would need some tuning to mirror the exact type of activity performed by EnergyCo. Therefore, the following modifications occurred:

- *Renaming conditions*. This was done to increase the ease of understanding of non-specialists.
- *Redistributing conditions*. Some of the conditions were not easily transposable to EnergyCo since they were heavily focussing on a very specific cognitive dimension (e.g. *Number of simultaneous goals*). The condition was dropped, its underlying contents were renamed and eventually redistributed to other conditions.
- *Adding conditions*. The new set comprised 12 indicators instead of 9. The added indicators were *Maps*, *Communication*, and *Third parties*. This addition was very important to capture the specificity of operators' work since EnergyCo is constantly using maps to locate their installations, communicates a lot between operational managers and on-terrain operators, and also deals with third parties who work on, or in the vicinity of their network.
- *Increasing the level of detail*. The new set of 12 indicators was given 44 subcriteria altogether, in order to adopt a finer granularity in the analysis of performance conditions, guide the assessment, and dampen the effects of individual interpretation.

The 12 indicators[4] and their subcriteria[5]. are described in Table 2 These conditions and subcriteria were the first concrete outcome of the co-development process. It probably also was the most important since it touched on the very heart of what aspects of work would be captured in the final incident analysis method. The fist phase of the co-development of the indicators

Table 2: Overview of the 12 indicators and their subcriteria

Conditions	*Subcriteria*
Work organisation	Individual ● Team
Working conditions	Working environment ● Individual protection equipment ● Temperature ● Noise ● Light
Tools	Fit to task ● Maintenance ● Tidying and layout ● Computer support
Procedures	Task description ● Availability ● Updates ● Emergency ● Terminology
Maps	Availability ● Structures ● Background
Workload	Nature of activity ● Work pace ● Compatibility of objectives
Time management	Work flow ● Preparation ● Pauses ● Regularity
Time of day	Shifts ● Regularity of working hours ● Concentration
Training & experience	Initial training ● Safety training ● Long-term training
Collaboration	Workforce ● Awareness of objectives ● Team cohesion ● Versatility
Communication	Language ● Jargon ● Redundancy of channels ● Transmission
Role of third parties	Notice of work ● Compliance to EnergyCo regulations ● Foreman

4 From here onwards, we will use the term *indicator* to avoid any confusion with Hollnagel's seminal CPC.
5 The precise contents of each subcriteria are not described here in order to keep the table readable. A more precise description exists in the final tool, screenshots of which will be presented in further sections of the paper.

4.3. *Prototyping*

Numerous iterations of the method, many discussions to adjust contents, adapt wording to end users. Because time constraints were tight, conducting an intensive field study to capture the reality of the activity was not an option. Instead, a former operational manager worked with us in order to bring the context into the development cycle. Although not ideal, this strategy ensured that an acceptable compromise between time and ecological validity could be achieved.
We developed the tool with people who belonged to R&D and management. The latter personnel used to work within network management units and knew the job very well. That the co-developers knew the job was essential to producing a method that would be used. Because they were people who could have been the method users themselves, the development team had a very precise idea of what would be understood and what would not, what would pose a problem and what would not.
A particular challenge was to make sure that the scientific principles behind the tool were respected. This is because the development team, on EnergyCo's side, had a limited grasp of Human Factors approaches. Thus, the process of educating company personnel on HF was taking place simultaneously with the development of the tool. Conversely, the academic side of the development team had to learn about the specific characteristics of EnergeyCo's business, and in particular, of the risks its infrastructures faced and the means available to keep them at bay. The learning process took the shape of multiple in-loco and remote iterations, with both sides presenting their views and aiming at reaching satisfactory compromises when questions arose.

4.4. *Keeping requirements in mind*

Throughout the development of the tool, the team constantly went back to the list of requirements identified. Simplicity of use was a major requirement because we were well aware that the final users would have limited opportunity to learn about the principles of human and organizational factors behind the tool. This simplicity was to be reflected both on the design of the tool, i.e., what the tool would in effect do for the user, and on its interface.

5. The incident analysis tool

5.1. *Presentation*

The version of the incident analysis tool (IAT) that is presented here is the generic version. The final version is owned by EnergyCo and will not be presented here. The main differences between the two versions are about the exact subcriteria used to to assess indicators and the use of professional terminology.

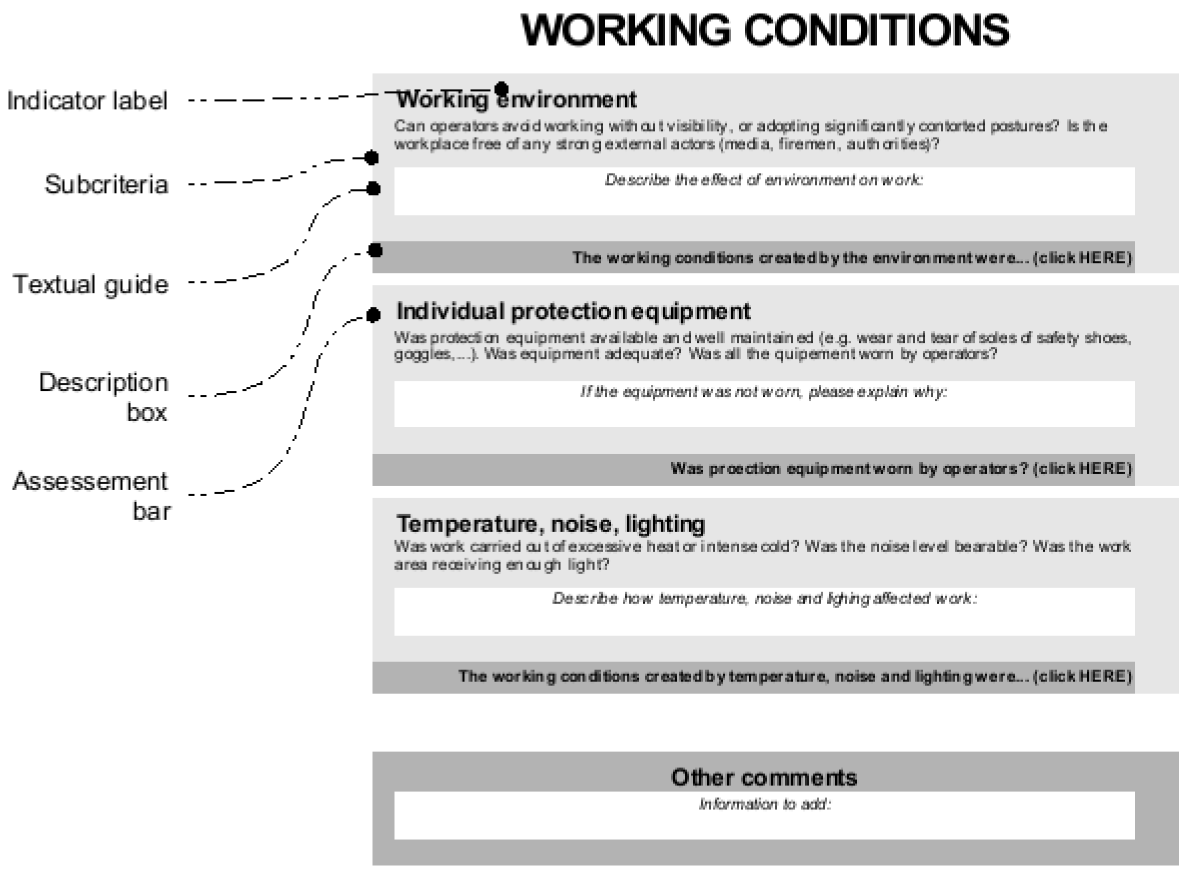

Figure 1: Screenshot of the layout of an indicator with its subcriteria and comments boxes (computer window and menu bars not displayed in this graph)

IAT is supported by a spreadsheet that hosts the 12 indicators, their subcriteria, a textual guide for the subcriteria, description boxes, assessment bar (this latter point will be described in the next figure), and comments boxes. Each indicator has a spreadsheet page of its own. As described in Figure 1, the page includes the indicator label, its subcriteria and a textual description of each subcriteria, a description box and an assessment bar. The spreadsheet is therefore composed of 12 pages of indicators, each broken down into further subcriteria (see table 2).

This paper does not aim at describing the method in detail. Instead, it focuses on co-development. Therefore, it might suffice to say that each subcriteria is aimed at receiving a qualitative assessment, and comments if need be. The indicator itself (*Working conditions*, in our example) can also receive extra open comments in a box located at the bottom of the page.

Following with our example indicator, the task of the incident analyst is then to assess the contribution of each subcriteria to *Working conditions*. To do so, the analyst selects an assessment option (*Working environment* in our example in Figure 2) by clicking in the assessment bar, and then selecting the desired option from the pop-down menu.

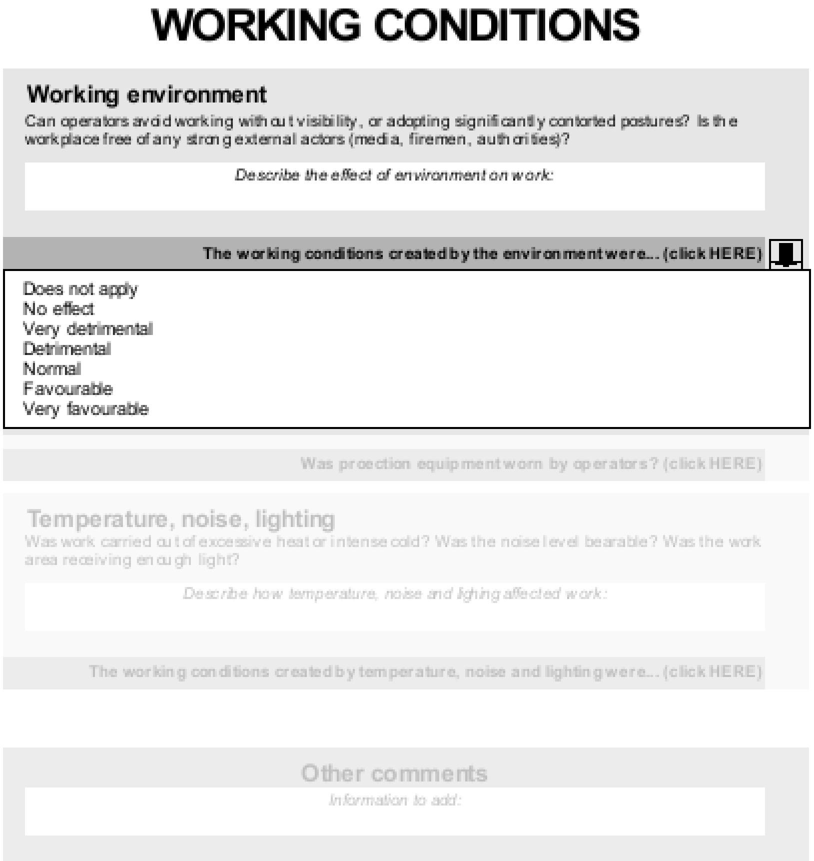

Figure 2: Screenshot of an indicator tab with a pop-down menu showing assessment options (shaded area added for readability purposes)

Each assessment option corresponds to an individual score. Once all subcriteria have been assessed, the spreasheet then calculates an average score for this indicator, and then converts it to a centesimal scale[6]. The incident analysis process is a mere 12-fold repetition of the short procedure described above.

In order to provide the analyst with more than a series of scores for each indicator, the latter are displayed as a radar graph on a separate page of the spreadsheet. This graph is composed of 12 branches, one per indicator. Each branch comprises 10 notches where the indicator score is plotted (see Figure 3).

6 This latter scale is used across the 12 indicators of the spreadsheet in order to obtain comparable scores even when the number of assessments in not equal.

GRAPH

Summary of scores

WORKING CONDITIONS	50
WORK ORGANISATION	70
TOOLS	78
PROCEDURES	78
MAPS	47
WORKLOAD	65
MANAGEMENT OF TIME	70
TIME OF DAY	30
TRAINING AND EXPERIENCE	70
COLLABORATION	65
COMMUNICATION	69
THIRD PARTIES	25

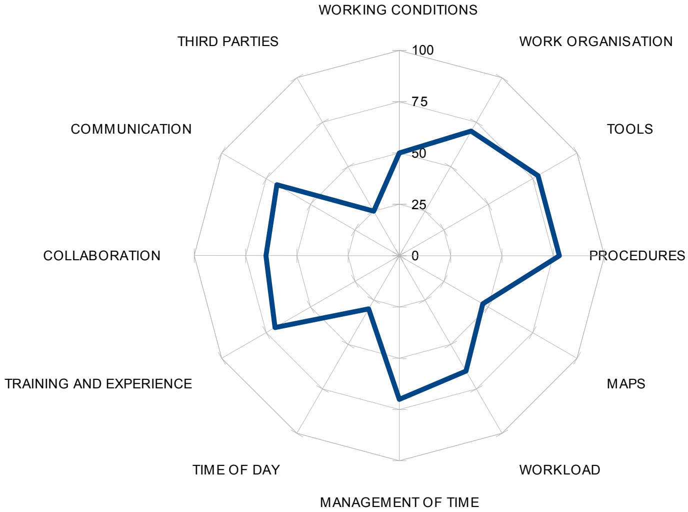

Figure 3: Screenshot of a radar chart after evaluation of the 12 criteria

This graph serves 2 purposes. First, it graphically summarizes the pedigree of a work situation, thereby offering a one-stop view of the state of the conditions of performance at the time of the incident. Basically, the lines of the graph that are close to the edges (high scores) depict conditions that are supportive of a high level of performance. Conversely, the lines that are close to the center of the graph (low scores) depict unfavorable conditions of performance. The second purpose for the graph is to serve as a transversal means of comparison. Indeed, EnergyCo wished to capitalize the analyzed incidents into a central database. Radar charts would then then allow very fast, pattern-driven comparisons across families of similar events. The image used during the development of IAT was that of a set of acetate sheets with radar chart on them, one per incident. Superimposing them would provide the analyst with a compiled vision of many events at a time. Reading cues such as global graph shapes or variation of line thickness (emerging from superimposition) would potentially provide a historical summary of scores of each of the 12 indicators over any period of time or data sample.

Last, a summary page that compiles all comments entered during the analysis and displays color codes that mirror the average mark received.

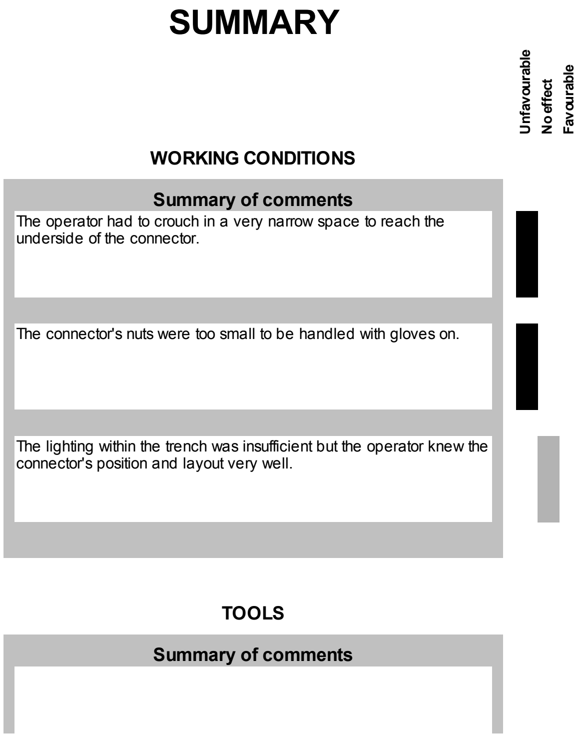

Figure 4: Screenshot of a section of the summary page.

5.2. Strengths and weaknesses

At the conclusion of the project, a final version of the tool was delivered to EnergyCo. Below, the strengths and weaknesses of this tool are addressed:

- Co-Development: Co-development of a custom-built tool, as opposed to one just off-the-shelf, helps ensure the the product is well adapted to EnergyCo's needs. In addition, because company personnel was directly involved in this process, a sense of ownership is created, which would otherwise be absent;
- Domain jargon: The language used in the tool – in the menus, in the help boxes, but most essentially, in the revised CPC table – is compatible with EnergyCo's lingo. This reduces the user's effort to understand “what the computer means,” and ensures that the analyses done with the tool are understood at all levels of the organization;
- Takes into consideration human and organizational factors: the tool incorporates human and organizational factors into data collection and analysis of incidents, which until then had been overlooked by EnergyCo. The tool, if effectively deployed and used, will assist EnergyCo in determining in what areas it must concentrate its efforts in order to improve safety;
- Easy to learn, easy to use: the tool is built upon a software platform already used by EnergyCo. This ensures that from a “computer literacy” point of view, users will find it extremely easy to find their way around when using the tool. A particular effort was made to

ensure that the criteria presented for assessment are explained in detail, so as to prevent confusion;

- Serves as an “entry point” for a more detailed investigation: large-scale events are often unique in nature and require the use of more powerful analysis tools than the one presented in this paper. On the other hand, not all small- and medium-scale events are the same. Events of a repetitive nature may receive a faster, simpler treatment. Because the IAT is intended to feed a database, it serves an added function of helping identify repetitive cases as well as unique cases. The latter can then be deepened with other auxiliary analysis tools;

Nevertheless, we must also note that the tool developed has some weaknesses, to which we now turn:

- The simplicity/generality/precision compromise: given the requirements of the project, the development team prioritized simplicity and precision over generality. This means that the tool was custom-built to address only a specific type of event, namely, incidents affecting the company's distribution network. It is not in the scope of the tool to handle incidents taking place at EnergyCo's administrative buildings and workshops, for example;
- Cost in time: although the tool is quite simple to use, time will be needed to train users to exploit the IAT to its full capacity. In addition, some time will be required until sufficient experience with the tool exists for a discussion of the analyses to emerge. Finally, users are “practical people” who may quickly abandon the tool if they see it as extra paperwork added to their workload without any visible benefits. EnergyCo is advised to ensure that the use of the tool is rewarded with prompt action;
- Incident feedback: likewise, the research team has no information on incidents investigated, so that the actual benefits of using the tool, compared to EnergyCo's previous incident investigation tool, remain to be evaluated. As mentioned above, it is nevertheless important that EnergyCo makes sure that incidents analyzed with the aid of our tool result in visible benefits for the users;
- The analysis is meant to be done as a group (during debriefing meetings) but this can introduce biases on the assessments left:
- It is possible to fill in the spreadsheet even if the data is incomplete or even missing: the major risk here is the temptation to complete only the easier sections of the spreadsheet and to disregard those which require more effort. The company will be able to detect instances of such behavior, but if it wishes to make sure that investigation meets high standards, it must provide workers with the resources needed;
- the tool only analyses human/organizational factors, no technical analysis: even though this was what we had been asked to do, we list it as a weakness. It would have been desirable to

promote an integrated approach that covered technical, human and organizational factors of incidents. However, the company believes it already has the methods and tools in place to handle technical factors.

6. Training, evolution and deployment

A small number of training sessions were organized for some pre-selected teams. Feedback was then gathered internally and some amendments were done to the tool. Namely, the data collection sheets that EnergyCo used for technical analysis ("level one") were integrated to the tool. The idea was to enrich the factual and technical description of an incident. Also these collection sheets have been used for several years already. Therefore, it allows one to ensure some continuity between the data that used to be collected in the past, and the data that is handled by the new tool. The feedback we were able to gather indicates that users like the tool and are eager to give it a chance. From the perspective of the research team, this type of feedback is probably the most interesting output of the co-development process.

7. Lessons learned and recommendations

At the end of this account of scientific transfer, we wish to highlight what we have learned, and what our recommendations might be for researchers who wish to embark on developing methods and tools for the industry. We wish to do so to share our experience in priority with:

- *academics*, in order to describe what interacting with the industry might look like;
- *researchers from R&D departments*, who are meant to work with operational units from their own company.

7.1. Changing the method to accommodate operational needs

To the authors, the most obvious trait of EnergyCo's position during the co-development was their great effort to tune the method to their practices and existing tools. Some of their concerns were about the psychological terminology used, which in places had to be made less technical. Examples include the words *cognitive*, *heuristics*, *interface*. Also, some indicators of IAT were not understood as conditions of performance but as criteria of compliance to regulations. An instance of the latter was the *Individual protection equipment*. The latter was not seen as having an influence on the way work is done (e.g. gloves can prevent one from getting a good grasp on tools or objects) but was used to assess whether the equipment was worn fully or not. For this subcriteria, the assessment options retained by EnergyCo were a mere yes or no. Such a view can be a problem since it will not leave room to capture the reason why the equipment was not worn entirely (e.g. clumsy, uncomfortable, too hot, lack of feedback from objects, etc.). In the long run, this compliance-driven approach might become a factor of lack of safety, thereby leaving behind a latent condition waiting for future mishaps. This clearly linked to top management decisions regarding the orientation of the final method. Wearing protective equipment, when not complied to, was interpreted as a failure in itself and was simply not tolerated, although the idea that such violations have causes too was accepted (see Alper & Karsh, 2009).

7.2. Trade-off between scientific grounding and industrial wishes

From the section above, one might get the impression that scientific transfer towards the industry is sometimes in danger of being more about transfer than science. It is not exactly so. Indeed, when the industry adopts a scientifically-informed method or tool, they still have to reconcile constraints. To them (it certainly was the case for IAT), the choice is between a less-than-perfect method that everybody understands, against a perfect one that only a few people can deploy. Because of this tension, the temptation is great for the industry to adapt the method beyond what it can reasonably accommodate. The opposite temptation exists for researchers to keep the method unchanged because of all the carefully chosen pieces of underlying research. In hindsight, we stood as moderators. That is, we did not try to defend perfection but promoted informed adoption instead. We assisted the company in finding a reasonable compromise between a method whose roots would still be in contact with some scientific ground, and yet allows its final users to easily achieve what the company wanted initially.

CPC had to be adapted to EnergyCo operations, which require intense participation of EnergyCo personnel. While the research team is knowledgeable about principles of human and organizational factors at work, its members are not specialists in EnergyCo's domain of activity. Transfer is therefore a matter of contextual awareness and transformation of knowledge. This did not imply any scientific breakthrough from us (as the scope of the project was transfer, not research) but needed a fair amount of explanation to get the concept of CPCs through, and demonstrate the usefulness of using working conditions as analysis criteria.

Conditions of performance were a totally new approach to EnergyCo operational managers and although it remains to be seen whether we were able to effectively “convert” them to the HF approach, we are confident that we have at least raised their awareness of the subject.

8. Conclusion

Co-development can be fruitful for both researchers and the industry. Indeed, the industry is often pulled forward by market-driven operations and ventures. In terms of reflection, this can be detrimental to long-term performance since little time and resources are set aside for the integration of new views and philosophies. In this paper, we focused on a new set of indicators for incident analysis at EnergyCo but this rush-forward phenomenon is widespread in the industry and potentially touches any domain of activity. A striking aspect to this situation is that academia has the exact opposite problem: performance is assessed from publications, an exercise that focuses on new ideas first and overlooks industrial needs, and even potential application.

Our position is that the industry and academia have a lot of opportunities to collaborate that are yet to be discovered. On the one hand, industry has very interesting problems waiting to be solved, with limited resources to allocate. On the other hand, academia is a wonderful think tank whose outputs are vastly under-used. From this point of view, transfer is an intention to make these two worlds come together to produce a piece of knowledge or engineering that none of these two worlds could have produced alone as effectively as through collaboration.

One might now wonder why transfer might be such a good thing to do, after all. A simple and immediate answer is that it can be good for society. In the case of our interaction with EnergyCo, it will bring a new way to look at incidents and hopefully decrease the occurrence of serious events. Beyond this potentially naive and maybe oversimplified view, transfer gives industry the opportunity to try new ideas without necessarily have in-house research force. For academia, transfer is a chance to see how research ideas and prototype methods get tuned and adapted and tested though real-world applications.

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