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SHELFS: A Proactive Method for Managing Safety Issues

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Summary. Safety knowledge is an important asset for managing safety critical organisations. In the paper we claim that reactive methods are not the more adequate approach to capture, represent and reuse safety knowledge. The organisational model of accidents and the organisational learning processes ask for a different approach in analysing and documenting safety issues. We present a proactive approach having a holistic view of the productive system, where all the system components and their interactions are analysed. Examples drawn by an experimentation of the method are used to illustrate it.

1. INTRODUCTION

Knowledge is considered the most relevant asset of modern organisations. Most of this knowledge belongs to people and it is embodied in the human practices and interactions among people and artefacts, and it could become organisational knowledge only if properly captured, managed and reused. Modern organisations strive to capture this knowledge since they consider it an important factor for improving the quality of their processes. Yet many safety critical organisations concerning safety issue prefer a reactive approach to learn from experience: the one based on the analysis of reports from accidents, incidents and near misses. Following the direction pointed out by Reason (1991) we claim that reactive methods are not the more adequate approach to capture, represent and reuse safety knowledge. We consider reactive approaches as too slow and inadequate for supporting an efficient experience feedback. Here it is presented a proactive method tailored for introducing human factors in a safety critical company, which is based on a distributed knowledge view of the working processes. This method stresses the positive face of safety and is oriented toward a positive return of experience from the human practices.

Proactive approaches do not just consider events with negative outcomes but also the vital signs of safety, such as the best practices and the solutions identified by managers and operators to overcome organisational and technical problems, and promote the development of such vital signs. Even though this approach was suggested by Reason early in the '90, there are not yet many tools and methods for introducing the approach in large organisations dealing with complex processes with safety critical implication. In addition, there is a lack of methods tailored for organisations that are planning human factors programmes but that do not have a long tradition in human factors. In most of the cases these organisations would like to introduce human factors progressively, having an immediate evidence of the results this introduction is producing. On the contrary, well established and sound methods like HazOp (Kletz, 1993), OARU (Kjellen, & Larrson, 1981) or MORT (Johnson, 1980) require large initial investments, and can be very time-consuming. In addition these methods are not straight oriented to capture best-practices and solutions. Effective organisational learning processes require a return of experience based on an everyday practice involving all the stakeholders involved in a process.

To try to face these issues we present a progressive method oriented toward short-term experience feedback as well as mid and long term actions. The method and related tools aim: 1) at analysing and documenting safety issues for identifying proactive safety actions; 2) at promoting organisational learning as an everyday practice.

In the following we outline a well-know systemic model used to consider the human role in a process and his relationships with the other process components. We elaborated the model on the base of the cultural-historical approach (Cole, 1996) and their recent version known as distributed cognition theory (Norman, 1993) and used the SHEL model as a conceptual framework for developing the method and the tools,

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described below. This method have been experimented in a program for introducing human factors principles in the Italian National Railways organisation (FS).

2. THE SHEL MODEL

Edwards (1972) proposed a conceptual model, named SHEL, to describe the behaviour of interactive system with special regard to human factors issues. SHEL is the acronym for Software, Hardware, Environment, and Liveware:

Software represents any component such as the computational code, the policies, norms, rules, procedures, practices and any other formal or informal rules that define the way in which the different components of the system interact among them and with the external environment.

Hardware represents any physical and non-human component of the system as equipment, vehicles, tools, manuals, signs.

Liveware represents any human components in their relational and communicational aspects.

Environment represents the socio-political and economic environment in which the different components of a process interact as shown in Fig. 3.

The SHEL model concentrates on the interfaces among people and all system components including other Liveware resources. SHEL offers a system view where humans cannot be considered isolated from other system components. This view is consistent with a long lasting and empirically well grounded theory of human cognition: the cultural-historical theory, of Vygotsky, Luria and Leontev (for a review see Cole, 1996). Recently, several authors have elaborated along the main ideas of Vygotsky's approach (e. g. Engeström, 1987; Hutchins, 1995; Norman, 1993). The recent elaboration of cultural-historical theory (e.g. Distributed Cognition, Activity Theory) and the SHEL model share the assumption that any productive process is always defined by a specific combination of Hardware, Software and Liveware resources which mediate the execution of human activity. The relationship between the SHEL model and the Vygotsky's unit of analysis of human activity by can be summarized in Figure 1

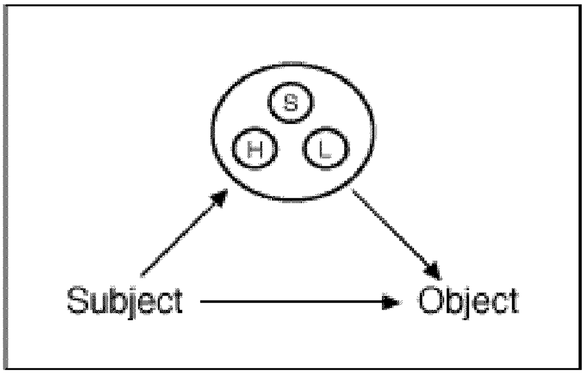

Figure 1: The SHEL model at the light of Vygotsky's unit of analysis of human activity

3. THE SHELFS METHOD AND TOOLS

Using the SHEL model as a possible simplified expression of the Cultural-historycal framework we developed a method and relative tools, named SHELFS, for identifying and managing the potential sources of breakdowns in the interaction among human and the other system components. SHELFS was developed within the programme for introducing human factors techniques in the Italian Railways Company (FS). Next sub-session will describe briefly this context of application.

3.1 The context of application

The railways transportation system in Italy is managed by a single organisation named "Ferrovie dello Stato" (FS). Different Departments of FS take care of the railways network, infrastructures, personnel and rolling stock. The "ASA Rete" Department is in charge of the rail tracks management and maintenance and these activities have a direct impact on the safety of the whole rail traffic. Operators involved in rail tracks management usually perform routinely work, in isolated operative contexts. In case of emergency they have to provide quick answers, with few opportunities to verify their decisions with colleagues or with their responsible. Operators of the maintenance section work in teams, usually in hostile environments and under stressing conditions such as the presence of time pressure. Both activities are characterised by the presence of heterogeneous systems interacting with the operators, and by the use of rapidly evolving operative methodologies and technologies. The "ASA Rete" Department identified the need to support the operators involved in these activities, in particular for the aspects of their interactions with the other operators and with the technological and procedural structures they are using. A safety analysis of the organisation evidenced also the need to collect and preserve the safety knowledge of the operators in presence of problems of turnover and downsizing of the company.

As a partial answer to these needs "ASA Rete" launched the "Line Tutor" program. Line tutors are specially selected operators that behave as tutors for their colleagues. They will also analyse the every day operators' activity, under normal and abnormal conditions, with the additional aim of extracting, rationalising and reporting the safety knowledge embedded in their behaviour. Line Tutors have been selected between operators with a well-established experience of the typical operator roles; selection was based on their knowledge and ability for this new position. The SHELFS method was developed for this Line Tutor role, which was supposed to have only a basic knowledge of human factors engineering.

3.2 Method and tools

The method supports the activity of an operator whose role is to identify critical issues and to develop and propose adequate solutions. The method supports also the organised collection, diffusion and re-use of the corporate knowledge existing at the level of single or small group of workers. In particular, corporate knowledge is used during the identification of possible solutions for the critical issues that could originate more serious problems. The operator must have a good knowledge of the working processes and of the working environment he is going to analyse. Approaches concerning "best practice", as for example the CARMAN approach of Embry and Richardson (1998) or the LINE/LOS checklist of Connelly (1997) shares with SHELFS the aim of documenting safety issues for identifying proactive safety actions. However they are mainly focused on one of the SHEL component, for example the CARMAN approach is a powerful methods to cope with gaps between procedures and practices, and the LINE/LOS checklist is carefully tailored to face Crew communication performance. On the contrary SHELFS try to capture the web of interaction among all the components. Indeed, some of the techniques used in best-practices approaches could be easily integrated into SHELFS, taking for granted that the *distributed cognition* philosophy should drive their application.

The SHELFS method is articulated in three main phases:

- definition of the process;
- identification of the critical issues;
- identification of possible solutions.

In the first phase (definition of the process) the Line Tutor identifies and models the process he is going to analyse. This is done with the direct involvement of the personnel representing each role that is needed to carry out the process. The process is defined with the first tool of the SHELFS method: the Matrix Workflow (see fig 2). The Matrix Workflow allows representing a process according to its basic activities, the personnel involved, the communication flow, the regulations and procedures and the hardware involved.

Process Description Form

A	Departure from Track 5 of Train BD-813-74 from X to Y

	ACTIVITY	LIVEWARE – ROLES INVOLVED: MAC	CT	DM	MAN	VER	VEIC	SOFTWARE (regulations, directions, procedures,)	HARDWARE (tools, instruments, material, etc.)
1	Connecting the engine to the train	■			■			Rif. ISM IPCL	Gloves, helmet, lamp
2	Check connection to the first car	■						Rif. IPCL	
3	Check brake efficiency (Brake test)	■				■		Rif. IEFCA	Hammer, lamp, consolle manometer
	Brake Test OK?					◆ NO / YES		B	
4	Delivery of TV40		■			■		Rif. IEFCA	TV40
5	Verbal communication of brake test to the MAC	■				■			

Figure 2: The representation of situated process trough the workflow matrix

The interactions between humans (Liveware-Liveware) are the element that identifies the different steps in which the process is subdivided: every time the actors change a step is identified, when the actors remain the same also the step remains the same. However, it is always possible to get into the details of a given Liveware-Liveware step by analyzing the interaction between humans and the other components (Liveware-Software and Liveware-Hardware). For example people interactions can be analysed with the conversational model, or the NASA/FAA/LOS checklist (Connelly, 1997); Liveware-Software interactions by checking compliance to procedures; Liveware-Hardware with cognitive walkthrough (Rizzo, et al, 1997).

The output of this phase is a representation of the process under analysis where the focus is on workflow and critical activities of the process itself. Using this representation the Line Tutor can start the second phase (identification of the critical issues) investigating the real breakdowns experienced by the workers while performing the process and the related causes. This is done using a simplified resource analysis method in colloquies and interviews with the workers involved in the process. The resource analysis method is a hierarchical taxonomy that relates the critical issues to the components identified in the SHEL model.

The details of the taxonomy are not very important for the proposed approach, only the 8 main classes of breakdown play an important role.

- H1 Are the tools dependable and effective in playing the role for which they have been introduced in the process?
- H2 The supporting material (e.g. manuals, workbook, signals, etc) supports the activity when needed?
- H3 The physical environment (climate, layout, furniture, etc.) allows a comfortable execution of the activity?
- S1 The knowledge needed to carry out the activity is covered exhaustively by regulations, procedures, instructions, available in the company?
- S2 Practice actually adopted to carry out the activity is consistent with regulations and procedures?
- S3 The specific knowledge needed to carry out the activity is adequate and sufficient?
- L1 The flow of communication is timing and adequate to support the activity?
- L2 The activity distribution, both for the single operator in time and between the operators in time and space, is instrumental to carry out the activity?

Indeed, many of the sub-classes included in the taxonomy are similar to that proposed by other tools as the General Failure Types proposed by Reason, or the Human Error Analytic Taxonomy (Bagnara et al., 1991), or the Project Evaluation Tree put forward by Stephenson (1997). However there are three important differences with these related works. The first is that human psychophysics conditions (e.g. attention, decision making, reasoning; motivation) are not considered as critical issues since they are strongly influenced by the interactions with all the others system components (Software, Hardware, Liveware) and cannot be faced individually. The second is that using SHELFS the Line Tutor refines the same definition and the analysis of the possible critical issues interactively and iteratively, with the people involved in the process along the three phases of SHELFS. The third is that the three main classes of the taxonomy are not mutually exclusive, on the contrary one critical issue can concern one class as well as all the three main classes. It is important to stress this point since it is at the core of the proposed method. As in the first phase the aim was to map the main classes of resources involved in a process, in this second phase the aim is to assess, according to the experience, how well the resources interact among them.

During this second phase the Line Tutor needs to go only through the 8 main potential critical issues. Three of the critical issues concern the Hardware, three the Software and two the Liveware. The 8 main classes represent different ways of mining the interaction among components. The distinction is not only phenomenological but also grounded in the adopted theoretical approach. Software resources can be prone to wrong interaction since they do not cover all the interaction among components (S1), leaving space for the development of idiosyncratic practices. It is important to note that in complex system, Software resources (e.g. Rules, procedures, computational code, etc.) cannot anticipate all the possible state of components interaction. Notwithstanding this, it is possible to be conscious of this limit and do not pretend that it does not exist. Software can be also not instrumental at good interaction when do not promote the development of working practices consistent with procedures and regulations (S2), or when it do not assure that the relevant knowledge that operator should manage is properly practised in tuition and training (S3). Hardware can embody knowledge that can conflict with Software or Liveware components since degraded, or not anymore adequate to face the evolution of knowledge occurred in the Software and Liveware components, or even since it was not designed at all for the interaction (H1). Hardware can be also prone to faulty interaction when the embodiment of knowledge is carried out with artifacts, like writing or sign devoted to represent other artifacts and modes of action (e.g. manuals, display, signals), which are not tailored to the working condition or since the knowledge representation is not relevant or effective for the interaction (H2). Finally, Hardware can mine the interaction when the physical environment instead to be instrumental to the designed interactions hamper them (H3). The Liveware resource can be fond to mis-interaction when the communication flow, for what concerns both content and form, is fragile and/or not well designed (L1) or when the work distribution among operators and/or in the single operators is not instrumental to the activity (L2).

Notwithstanding the possible lack of attention the organization can have for these sources of potential breakdowns the people involved in the productive system will strive to accommodate them locally, by modifying the relationship between the system components. Sometime this accommodation reveals and creates space for opportunities that should be properly managed by the organization to capture the knowledge they have embedded. The investigation based on SHELFS tends to identify this knowledge and to use it in the identification of solutions for the critical issues (phase 3 of the method).

The aim of the proposed taxonomy is to support the Line Tutor in catching an inadequate distribution of resources for one or more steps of a process. To this aim at least one representative for each of the working positions involved in the process under analysis, is interviewed. This allows the Line Tutor to have a complete idea of all the potential breakdowns associated with that process.

For example, taking into consideration the above reported process "Departure from Track 5 of Train BD-813-74 from X to Y", in Figure 3 we can observe the summary of the process and the related map of critical issues according to the different roles involved. The critical issues represent a grouping of potential breakdowns, that put together the problems associated with a subset of the whole process and a pool of roles. The critical issue are defined according to the techniques of "one sentence problem statement" (Newman and Lamming, 1995) and in agreement with the operators, which also rate the priority of the critical issues.

INTERVIEW PLAN AND EMERGING CRITICAL ISSUES

	ACTIVITY	MAC 1	MAC 2	MAC 3	MAC 4	CT 1	DM 1	DM 2	VER 1	VER 2	VEIC 1	MAN 1
1	Connecting the engine to the train	oo	oo									oo
2	Check of connection of the first car	oo	oo									
3	Check of brake efficency (Brake test)			oo	oo				oo			
Brake Test OK?												
4	Delivery of TV40								oo			
5	Verbal communication of brake test to the MAC								oo			
6	Verbal communication of brake test to the DM						oo		oo	oo		
7	Delivery of Train Form and M40	oo	oo				oo					
8	Check of Train Form and M40	oo	oo									
9	Opening of Departure signals					oo	oo	oo				
10	Time schedule check					oo						
11	Order of departure					oo						
12	RS plug in and train departure											
13	Reaching of maximum speed allowed	oo	oo									
B1	Communication of excluded car							oo	oo	oo		
B2	Computation of the new of braking mass							oo			oo	
B3	Delivery of S.T. and new prescription on M40							oo			oo	

Critical Issues in order of priority: 1 2 3 4

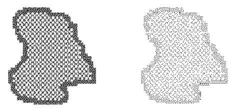

Figure 3: A summary of the critical issues associated with a process.
The MAC, CT, DM, VER, VEIC and MAN tags represent different roles involved in the process.
The numeral associated with the tag represent the number of people interviewed.
The cluster of breakdowns are represented by mean of grey patches.

At the end of this second phase the Line Tutor has a process description with the associated critical issues, and a description of the way in which they are locally managed by re-distributing the Hardware, Software and Human resources.

This constitutes the input for the last phase of the method (identification of possible solutions), where the Line Tutor organises a meeting with the representatives of all the human roles necessary to carry out the process under analysis. The meeting play an important role in the SHELFS approach, it is derived by the participatory meeting proposed by the Scandinavian school (cf. Greenbaun and Kyng, 1991). During this meeting all the critical issues are analysed, discussed and possible solutions are proposed by the same workers involved in the processes under analysis, with the mediating role of the Line Tutor. The meeting (one or more if needed) is organised in four sessions:

- declaration and awareness of critical issues
- critique and analysis of the critical issues
- envisioning solutions
- implementing solutions

In the declaration and awareness session the critical issues collected by the Line Tutor are presented to the participants with the support of the "one sentence problem statement". That is, the Line Tutor summarises in one sentence a given critical issue reporting in the sentence: the activity; the way in which this activity is hampered; the roles involved; the possible regulations and/or hardware involved.

For example, the fist critical issues of the above reported process was " The Train driver and the Train Manager could not respect/check the maximun speed allowed and reported on the Train Form but not consistent with the maximun speed reported on the M40 form"

The aim of this session is the mutual awareness of the critical issues associated to a given process by all the roles involved. The Output is a list of sentences that express the process critical issues restated and shared by all the participants of the meeting. (see figure 4)

Critical Issue	Activities involved	States of the Critical issues in order	PROBLEM IN ONE SENTENCE
1	7-8-9-10 11-13	A	The Train driver and the Train Manager could not respect/check the maximun speed allowed and reported on the Train Form but not consistent with the maximun speed reported on the M40 form
		B	The Train driver and the Train Manager could be constrained to read the travel forms when the Train is already travelling by receiving the documentation not in time or while they where performing other tasks
2	3-4-5-6	A	The communication between the Train driver and the Verificator, not adequately supported by the available tools and by the specific training for the role, could produce misunderstanding that delay the departure of do not allow to resoect the procedures.
		B	The communication flow among VER, DM, CT, MAC concerning the brake test is not always clear and efficient, with the chance that the Train could departure without that the MAC will become conscious of possible variations on the train characteristics.

Figure 4: Example of "one sentence problem statement" related to the first two critical issues of the "Departure from Track 5 of Train BD-813-74 from X to Y" process

In the Critique and analysis session every critical issues is illustrated by specific events and stories reported by the roles involved. The level of analysis is established according to actions already experimented on the field and according to the interactions among the roles. It is important that the level of analysis of the critical issue will allow the communication between roles even though there can still be substantial differences in the way the problem is perceived. If different levels of analysis are proposed by different roles, the Line Tutor will accept all of them and propose to address the levels one by one. The sentence representing the critical issue is located at the centre of a graph. The details of the criticality, defined according to the SHELFS taxonomy and the roles interested in the critical issue are also represented in the graph, in direct connection with the sentence. The aim of this session is to define the details of the critical issue and the level where it seems manageable. The output is provided by the criticality graphs, which explode a critical issues in relation to the roles involved and the possible factors foreseen by SHELFS.

For example, for the critical issue 1A we had the following S1 and S2 breakdowns:

MAC 1 - The M40 form might disturb me. There are useless prescriptions and other stuff already reported on the Train Form

MAC 2 - The M40 is misleading. If I am tired it can confuse me

MAC 2 -The regulations to which we should refer (REG.243 e PGOS) are warped. In critical situation they can even create big problems.

Which could lead to the best of the case to a violation of the regulation, and in the worse of the case to the overcoming of the maximum speed that a train could safely sustain. according to the class of cars, the percentage of braking mass, etc.

Along this session it was found that the critical issue related to the **Train Form** and to the **M40** form was due to the overlapping of the regulations governing two different type of travel documents: The Train Form itself, recently introduced, and the **Time Pamphlet**, which represent the traditional document supporting the train travel. The Time Pamphlet has always been associated to the M40 as a complementary form where to point out to the Driver possible additional prescription. The same M40 is today associated with the Train Form, which include a more appropriate description of the Train data. This could makes superfluous some of the data reported in the M4O (or viceversa). But why one should remove one of the two prescriptions of speed and which one?

During the Envisioning solution session everyone is free to submit solutions, the only constraint is the request to specify them in relationship to the Software, Hardware and Liveware components. This is a real brainstorming session, so long speech and killing sentences like "this is completely unrealistic" are inhibited by the Line Tutor. The aim of this session is to go away from established position and from defensive and conservative attitude, so to give room to alternative and possible solutions before to prepare the operative proposals.

In the envisioning session it become clear But the real critical issue laid in two different criteria for assessing and reporting the maximum speed, and their relationship with the new philosophy for train traffic management introduced with the new organisation of the FS holding. Here we will not go into the detail of the two regulations, which will need a deep understanding of the work organisation and its history. But we would highlight how the meeting allowed to goes beyond the surface of the problem (apparent redundancy of information). This was fundamental to provide the right rationale for the suggested modifications. Indeed, until the critique and analysis session the two different divisions were blaming each other for the inconvenient: the Train drivers blamed the Train Traffic Manager for providing incorrect prescriptions, instead the Train Traffic Manager blamed the Train Driver to not knowing the rule governing the use of M40. During the meeting both roles devised a shared solution: To eliminate the prescription to report the maximum speed of the train on the M40 if this is higher than the one initially scheduled for that Train. With this solution the Train Driver are not induced in confusion, and the Train Traffic Manager can highlight relevant information in a simpler way. It is important to stress that this apparently simple solution has been accepted only through the shared understanding of the two different criteria for assessing and reporting the maximum speed and their relationship to the new modalities of train traffic management.

In the Implementing solutions session the critical issues are organised by priority, everyone is free to submit his own order and the consensus on priorities in not required. The ranks average decides the order of discussion. The proposals should be feasible in the short/medium term since it is of paramount importance to test them on the field. Moreover, the proposal should specify the possible modalities of implementation and specify the new distribution of knowledge among the Software, Hardware and Liveware components, even if the critical issues is apparently well confined within one component.

The activity of the Line Tutor ends with the implementation of short term actions and their monitoring, and the collection of medium term actions together with the results of the short term actions so to present a deeper analysis for potential improvement of the whole process.

4. CONCLUSION

In experimenting the proposed proactive method we found on average 7 critical issues for each process examined, on average 5 of them where analysed and discussed in the meeting and for 4 of them a shared solution was found. In many cases the critical issues where known to the Line Tutors, but in several other cases the critical issues emerged with the SHELFS method were unknown to the same people involved in the process. For many of them a solution was proposed that could be also extended to other processes that share similar distribution of resources.

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