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Analysis reuse exploiting taxonomical information and belief assignment in industrial problem solving

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ABSTRACT

To take into account the experience feedback on solving complex problems in business is deemed as a way to improve the quality of products and processes. Only a few academic works, however, are concerned with the representation and the instrumentation of experience feedback systems. We propose, in this paper, a model of experiences and mechanisms to use these experiences. More specifically, we wish to encourage the reuse of already performed expert analysis to propose a priori analysis in the solving of a new problem. The proposal is based on a representation in the context of the experience of using a conceptual marker and an explicit representation of the analysis incorporating expert opinions and the fusion of these opinions. The experience feedback models and inference mechanisms are integrated in a commercial support tool for problem solving methodologies. The results obtained to this point have already led to the definition of the role of "Rex Manager" with principles of sustainable management for continuous improvement of industrial processes in companies.

Keywords:

Root cause analysis
Semantic similarity
Transferable belief model
Experience feedback
Railway industry

1. Introduction

For several years now, the need for continuous improvement in industrial products and process management has led many companies to establish standardized procedures of Problem Solving Methods. The objective set for these processes is to address problems that arise at all levels in the company including suppliers and third parties, in a streamlined, gradual, controlled and structured manner. Different processes of classical problem-solving methodologies are used for this purpose and we can cite in particular: the PDCA process (Plan Do Check Act), the Eight Disciplines (8D) process, the DMAICS (Define Measure Analyze Improve Control Standardize) process or, more recently, the Productive Thinking Model process (a survey of problem-solving methodologies can be found in [1]). A number of key themes can be considered from the problem solving literature for the analysis of a methodology [2]: generality versus domain specificity of methods; problem structure; generic problem solving tasks; diagnostic problem solving; and remedial problem solving. In general, these processes have in common steps describing the context of the problem followed by the analysis stages (research by experts of the causes of problem) and finally for proposing and implementing corrective and preventive actions [3]. If the introduction of process

problem solving is now widely spread in engineering applications, it is not the same for the reuse of expert knowledge used in these processes (experience feedback). However, the investment made, including those made by experts, in solving a complex problem is often considerable and this can lead to knowledge creation and retention [4]. Knowledge management must therefore be able to respond to such uncertainties and contain elements of learning-by-doing or experience feedback. For instance, high-level knowledge such as project constraint reasoning, problem resolution methods, solution generation strategies or supply chain knowledge must be captured and re-used, but as much as is needed for a reliable and profitable knowledge capitalization and exploitation [5]. We therefore propose in this paper to identify reuse mechanisms of previously conducted analysis (including processes for the reuse or recycling of analysis and the treatment of knowledge directly associated with these activities) to guide the resolution of a new problem.

Academic research published in the area of experience feedback can be organized into two broad categories. In the first category, there are the studies that focus on the organizational aspect. Organizational management does not cover the explanation and the justification procedures, nor the decision of whether to use competitive selection procedures for the assignment of technical analysis or not. Included in this framework is the model of experiential learning [6], the model of lessons learned [7] or the generic model of experience feedback systems [8]. In a second category, the emphasis is more on knowledge representation and

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Table 1
the Criticality Matrix.

CRITICALITY= (5*S+2*R+Q+M)*P			
S	Safety	7	Risk of catastrophic: Fatality or multiple injures
		3	Risk of critical: Single fatality, severe injury
		1	Marginal: Minor injury
		0	Insignificant
R	Revenue Service	7	Major impact on customer revenue service, stop or ramp up. One or several trains or line section not in operation, or service not provided.
		3	Revenue service below nominal, one or more major functions or performances not achieved. Potential impact on revenue service or service ramp up.
		1	Revenue service below nominal, one or more minor functions or performances not achieved.
		0	No Impact
Q	Quality of Service	7	Major delay on delivery or/and delivery with major non
		3	Minor delay on delivery or/and delivery with minor non
		1	N/A
		0	No impact
M	Maintenance	7	Major impact on maintenance costs
		3	Minor impact on maintenance costs
		1	N/A
		0	No Impact
P	Progress	7	No owner assigned and/or no 8D methodology yet in place.
		3	Owner assigned, 8D tool available, root cause under investigation but not yet found, Containment action completed (D4closed)
		1	Root cause identified, solution being developed but not yet finalized (D6 ongoing)
		0	Root cause confirmed, solution being implemented and REX feedback provided (D8 closed)

the associated inference mechanisms, necessary to instrument the feedback processes. An experience feedback approach is supported where the relevant knowledge can be shared, categorized and updated for their formal use in knowledge-based engineering applications [9–11].

Most works done in this objective are based on the use of inference mechanisms similar to those proposed in Case-Based Reasoning [12]. This is the case of works proposed by Bergmann [13] and more recently another work described by Armaghan [14]. This point seems very important and we will resume our proposal ideas commonly used in the field of Case-Based Reasoning (similarity search in particular). Finally, the thesis presented in [15] shows the importance of integrating subjective data in order to enrich an information system for the experience feedback. In the same viewpoint, Aven and Zio provide new insights on the treatment of uncertainties in risk analysis context to faithfully represent and express the knowledge available to best support the decision making [16]. In complex domains it is usually quite difficult to introduce contextual information using expert's rules as background knowledge. However, sometimes that information should be taken into account when making decisions, as it provides some relevant knowledge [37]. Our propositions include both objective and subjective views relating to analysis and the characteristics of analysis, in problem solving processes. In industrial practices, feedback from technical investigations will help improve process management practices and the quality of products or services and, thereby, strengthen feedback and the sharing of experience with the development of a prevention culture, which targets each employee as well as management. In the context of processing various non-conformances, we specified an evaluation phase of the criticality (Table 1) of the problem to be solved to define the means put in place to deal with it. For example, the appropriate analysis of conformances and corrective actions may yield information that could lead to changes in resource examination and maintenance management, thereby improving quality service and the progress of safety programs.

As shown in Fig. 1 (below), we consider, in our work, experience that corresponds to a container incorporating the context (problem

description and analysis), analysis (expert on finding the cause of the problem), E_i and experience will be represented by a triplet $E_i = Co_i, A_i, S_i$ where Co_i, A_i and S_i are respectively the context, analysis and solution E_i of the experience. A base of experience corresponds to a set of experiences: $B_{Exp} = \{E_i, i \in \{1, \dots, n\}\}$. In Fig. 1, we also indicate different inference mechanisms that can be constructed from information stored in the experiments. The first mechanism is an investigation of problems solved in the past using a similarity measure of context. This operation is fairly standard in the reasoning Case-based, but we will propose a particular method, adapted to the subject matter. The second inference mechanism is the intended reuse of analysis expert. On this point, the proposal described in this article has, to our knowledge, never been addressed in the available scientific literature. The third inference mechanism suggested in Fig. 1 is the adaptation of the solutions. This point is not described in the article.

The article is structured as follows: in Section 2 we present the proposed context representation (Section 2.1) and the mechanisms associated research previous experience relevant to reuse (Section 2.2). Section 3 is devoted to the description of expert analysis (Section 3.1) and the principles proposed to guide the analysis when a new problem is to be solved (Section 3.2). Finally, a sample application and the software implementation are provided to illustrate these principles (Sections 4 and 5). Section 6 indicates the findings of the study.

Table 2
Different distributions of belief masses.

	S1	S2	S3	S4	S5
\emptyset	0	0	0	0	0.4
H_1	0	1	0	0.3	0.3
H_2	0	0	0	0	0
H_3	0	0	0	0	0
$H_1 \cup H_2$	0	0	1	0.7	0.3
$H_1 \cup H_3$	0	0	0	0	0
$H_2 \cup H_3$	0	0	0	0	0
$H_1 \cup H_2 \cup H_3$	1	0	0	0	0

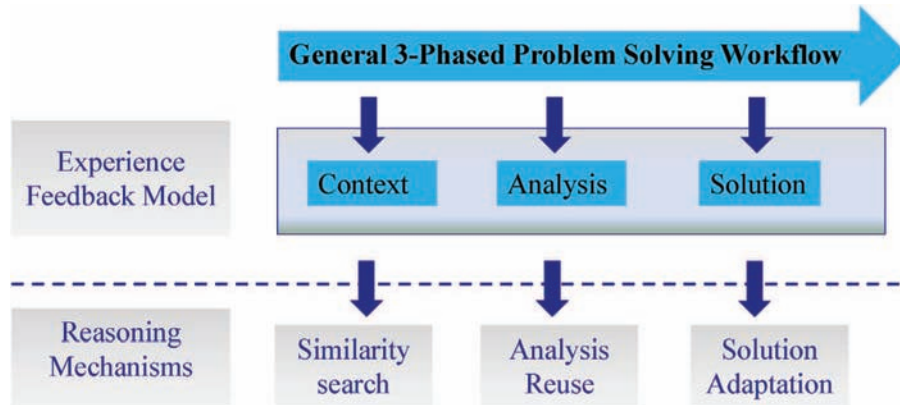


Fig. 1. Framework of the industrial problem solving process.

2. Model of the context and the search mechanism

2.1. Context modeling

In order to simplify and systematize research of past experiences, we propose to represent the context of the problem by means of at least two descriptors. The first represents the type of product or component affected by the problem. Depending on the available knowledge, this product may correspond to a very general entity (e.g. a train) or a more specific entity (e.g. a pneumatic brake). To formalize this aspect of the problem description, the usage of a taxonomy (hierarchical relationship type “is-a” between concepts, as shown in Fig. 2) is particularly suitable. Indeed, it will be in the description context, to associate a concept from corresponding taxonomy (here that of the products/components). We call the concept Co_i “component” associated E_i experience.

Similarly, we associate each experiment to a concept that best suits the type of problem met. It can also be taken from a taxonomy of problems. Thus, the context of an experience will be described by two concepts: respectively, the taxonomy of products and the taxonomy of problems. The context of an experience E_i is denoted by the following pair $Ci = \langle Co_i, Pbi \rangle$

Note that the description of the context would, where appropriate, involve additional descriptors (type attribute – value) but this possibility will not be covered in this article. In this case, it is possible to use additional similarity measures adapted to the attribute types concerned.

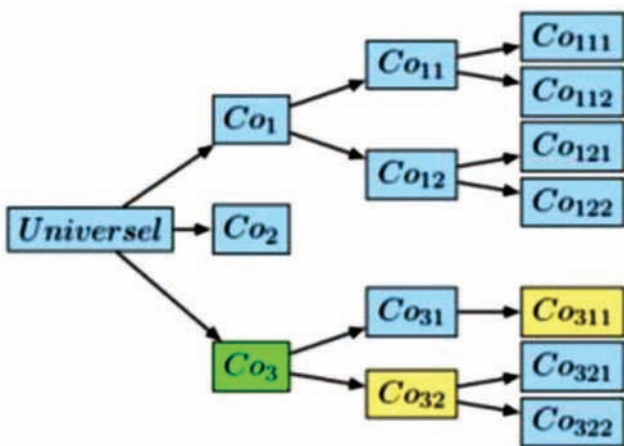


Fig. 2. The components taxonomy.

2.2. The search mechanism

The search mechanism is proposed based on the assessment of the similarity between the context of a new problem and the context to solve problems already solved. Assume the context of the new problem is described as a pair $C' = \langle Co', Pb' \rangle$, where Co' and Pb' denotes respectively the “Component” and the “Problem” concepts associated with the new problem. The goal is, then, to measure which level of similarity with each $Ci = \langle Co_i, Pbi \rangle$ of an experience to the experiences base. To evaluate this similarity, we propose to use a measure of semantic similarity between concepts from the same taxonomy. Taxonomies provide a classification based on similarities and are natural to human beings who often work by association and abstraction. In addition, taxonomies provide a structure based on two basic inferences that we do every day and are at the heart of information retrieval:

Identification: ability to recognize the class of an object from its characteristics.

Specialization: ability to address the more specific categories than those requested in a search.

Ontologies are often equated with taxonomic hierarchies of classes, class definitions, and the subsumption relation, but ontologies need not be limited to these forms. In practice, one can consider the taxonomy as an element contributing to the formation of the skeleton of ontologies, without axioms constraining the possible interpretations for the defined terms [17]. Ontologies are interesting, since there are linked to human nature, existence and properties of the mind with the formal representation of knowledge [18].

In the literature, several similarity measures have been proposed. Overall, it is possible to distinguish between measures based only on the taxonomic structure and exploiting further information, usually from corpus texts of the domain, which can refine the level of the similarity between concepts. In our proposal, since the exploitable corpus texts are rarely available in sufficient quantities, we limit ourselves to measures based on the taxonomy structures. Several measures have been proposed in this background where consideration lies on the exploitation of taxonomical features, for example the measure proposed by Wu and Palmer [19]:

$$Sim_{WP} = (Co', Co_i) = \frac{2 * N3}{N1 + N2 + 2 * N3}$$

Other similarity measures based on taxonomies can be used as those of Leacock and Chodorow [20], Choi and Kim [21] or Al-Mubaid and Nguyen [22]. More recently, in Batet et al. [23] an original similarity measure is proposed to improve the previous

measurements (using only the structure of taxonomy) without imposing the use a corpus text that is difficult to obtain and process. According to experimental results proposed by the authors, this measure gets very good performances, comparable to similar measures based on the use of a consistent corpus text [24]. This measure is based on the notion of superconcept. Let us consider a concept C , a superconcept of C is an ascendant (i.e. ancestor) of C in a given taxonomy. For example, in taxonomy shown in Fig. 2, of super concepts Co_{32} are Co_3 and Universal. We write, for a concept C , the set $T(C) = \{SC \mid SC \text{ is a super-concept of } C\} \cup \{C\}$. The measure is based on the calculation and aggregation of the total number of super concepts needed to characterize the two compared concepts ($|T(Co') \cup T(Co_i)|$) and the number of common super concepts ($|T(Co') \cap T(Co_i)|$).

$$sim_{BSV}(Co', Co_i) = -\log_2 \frac{|T(Co') \cup T(Co_i)| - |T(Co') \cap T(Co_i)|}{|T(Co') \cup T(Co_i)|}$$

This measure is not, however, normalized. In order to bring this similarity measure within a normal interval $[0,1]$, we add a normalization coefficient of the measure in the following way:

$$Sim_{JGC}(Co', Co_i) = \begin{cases} \frac{Sim_{BSV}(Co', Co_i)}{\log_2(H+2)}, & Co' \neq Co_i \\ 1, & Co' = Co_i \end{cases}$$

where H indicates (appoints) the height of the taxonomy. For the example already used to illustrate the measure of Wu and Palmer, we obtain:

$$Sim_{BSV}(Co', Co_i) = -\log_2 \frac{5-2}{5} = -\log_2 \frac{3}{5} \approx 0.75$$

And for the normalized measure, we obtain:

$$Sim_{JGC}(Co', Co_i) = \frac{-\log_2(3/5)}{-\log_2(5)} = 0.32$$

We call sim_* the conceptual similarity measure selected from the group of available measures (for the rest of the article, and because this measure reveals good performance in practice, we choose $sim_* = sim_{JGC}$). The aggregation of two similarity measures calculated (on the component and the problem) will be carried out using a mathematic operator, which would, for example, be based on a Minkowski distance of order p between two points on Euclidean space:

$$Sim_{Mink}(Co', C_i) = 1 - \left(\frac{1}{2} (1 - Sim_*(Co', Co_i))^p + \frac{1}{2} (1 - Sim_*(C p', C p_i))^p \right)^{\frac{1}{p}}$$

where p is a parameter used in order to modulate the aggregation (for $p = 1$, we obtain the average of elementary similarities and one for infinite p a *max* operator). Thus, for each context of experience belongs to the experiences database we can associate a similarity measure with the context of the problem. The experiences can then be selected (or not) for reuse, according to a tolerable range of this similarity measure (by thresholding).

3. Model of the analysis and the mechanism of the analysis reuse

3.1. Model of the analysis

The principle of analysis frequently used in problem solving processes is the search of root causes by the deepening of understanding of the central elements or issues associated to the

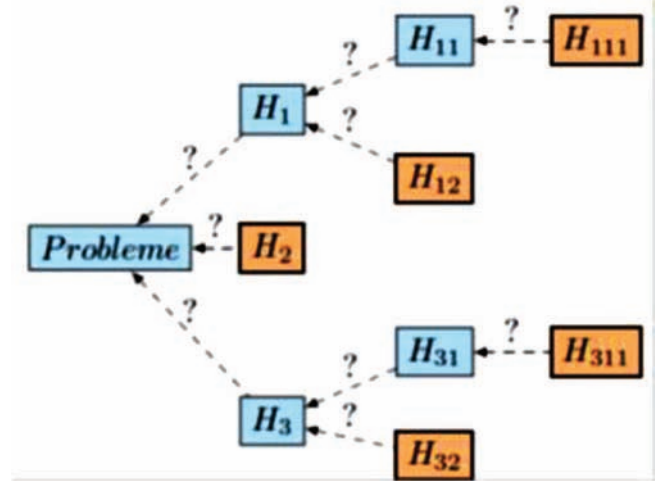


Fig. 3. Root cause analysis.

investigated problem (Root Cause Analysis). In this approach, some potential causes at the first level are expressed by experts and then, on the basis of these assumptions, a further investigation is carried out by interviewing experts on the underlying origins of the causes described at the first level. Data mining discovered knowledge [38] can be used as a complementary source of knowledge for the expert knowledge, which might in turn lead to a renewed effort in the data mining process that can help to suggestively increase existing domain knowledge [25].

Thus, step-by-step, experts are progressing toward a set of profound causes so-called "root causes" that are considered to be the most profound because they are fundamentally at the root of the problem. Studying a problem in such great depth is typically implemented in the "five whys" method. Here we will not only focus on the mechanisms allowing domain experts to gradually express their analysis, but we shall also consider whether the analysis has pinpointed the potential root causes of problem, and helped determine how to make them soluble and more controllable with preventive actions. We shall call after hypotheses, noted H_k^i to indicate the k^{eme} hypothesis associated with an experience E_i . For an experience E_i , we shall note H^i all the associated hypotheses. In the example of Fig. 3, these hypotheses are: H_{111} , H_{12} , H_2 , H_{311} and H_{32} .

To identify the promising leads, we suggest that by privileging the individual expression and the groupware on every cause root, the experts contribute to the emergence of consistent solutions. For that purpose, the use of the Transferable Belief Model (TBM) [26] is interesting. Indeed, this model allows simultaneously, a representation in expert opinions (with, where necessary, of the uncertainty) and the manipulation of a set of opinions to merge them and obtain summarized information about the hypotheses.

As an example, let us assume that, in an experience, the analysis phase realized by the experts have led to formulate three hypotheses H_1 , H_2 and H_3 . The frame of discernment (also known as reasoning space) is then $\Omega = \{H_1, H_2, H_3\}$. By using the MCT, the expert can fully express himself on all the disjunctives combinations (with "or") of hypotheses by distributing a Unitarian mass on all the possible combinations. Here, all these combinations are: $2^{\Omega} = \{H_1, H_2, H_3, H_1 \cup H_2, H_1 \cup H_3, H_2 \cup H_3, H_1 \cup H_2 \cup H_3\}$ combinations of 2^{Ω} must be equal to 1, i.e. $\sum_{B \in 2^{\Omega}} m(B) = 1$.

We call this distribution of mass BBA (Basic Belief Assignment). From a BBA, it is possible to calculate the measure of plausibility Pls and the measure of credibility Bel of every combination A of 2^{Ω} :

$$Pls(A) = \sum_{B|B \cap A \neq \emptyset} m(B) \quad \text{and} \quad Bel(A) = \sum_{B|B \subseteq A} m(B)$$

Table 3
Credibility and plausibility of assumptions.

	S1	S2	S3	S4	S5
$Bel(H_1)$	0	1	0	0.3	0.3
$Pls(H_1)$	1	1	1	1	0.6
$Bel(H_2)$	0	0	0	0	0
$Pls(H_2)$	1	0	1	0.7	0.3
$Bel(H_3)$	0	0	0	0	0
$Pls(H_3)$	1	0	0	0	0

Such measures have the great advantage of being relatively easy to interpret as the provided values are simple percentages, and thereby allowing experts to gain an understanding of the challenging beliefs and complex situations that industrial organizations encounter in their daily lives.

Table 2 illustrates various situations, which can be met with regard to the distribution of the Unitarian mass.

Table 3 provides measures of plausibility and credibility associated with the assumptions in these different situations. Situation S_1 corresponds to an almost total uncertainty (the credibility of all the hypotheses is equal to 0, their plausibility is equal to 1). Situation S_2 corresponds to a certainty of hypothesis H_1 (the plausibility and credibility of the hypothesis H_1 are equal to 1 and the plausibility and credibility of other hypotheses are zero). Situation S_3 involves the exclusion of hypothesis H_3 but a residual uncertainty of hypotheses H_1 and H_2 . In situation S_4 we excluded hypothesis H_3 ; hypothesis H_1 is favored relatively to hypothesis H_2 . In situation S_5 , a part of the mass was transferred to the empty set (\emptyset), which means that the expert does not rule out a hypothesis not yet explained (the possibility that mistakes or omissions might arise).

If several experts express themselves, it is possible to merge their opinions using a hierarchical fusion technique with the “cautious conjunction” operator (for experts in the same discipline) and the “non-interactive disjunction” operator (for experts from different disciplines) [27]. We pick up on the work of [28] from a methodological viewpoint and extensively detail the mechanisms of reuse integrating both subjective judgment of experts and objective evaluations. In all cases, the result will be a unitary distribution of mass on 2^{2^2} . Since it is difficult to keep all this information (combinatorial and computational aspects can be quite large), we propose to synthesize information by performing a pignistic transformation [29] (the BBA is then transformed into a probability distribution over the frame of discernment). This is calculated as follows for the hypothesis H_k :

$$sub_k = \sum_{A \in 2^{2^2}, H_k \in A} \frac{m(A)}{|A|(1 - m(\emptyset))}$$

The result is then a probability distribution over the set of hypotheses that synthesizes the subjective judgment of experts regarding the problem as one that has been resolved. At a later stage, additional tests [39] can validate (or invalidate) the hypotheses and in this case we consider this result objective (the hypothesis becomes an assertion and much greater reliability is given to the associated knowledge). Thus, for each hypothesis, we have a subjective judgment of experts and an objective result (which one has ultimately been validated on problem solving). This information is recorded, enriching the analysis that becomes: $A_i = \{ \langle H_k^i, Sub_k^i, Obj_k^i \rangle \}$ where Sub_k^i and Obj_k^i denote, respectively, the summary of subjective opinions of domain experts and objective outcomes associated with hypothesis H_k^i .

3.2. Mechanism for analysis reuse

The mechanism which we propose for the re-use of the analysis is as follows. During the phase of research for similar experiences

(by using the context), we have selected a set of candidate experiences (of which the level of similarity in context with the current problem is considered sufficient (above a given threshold)).

This set of experiences is noted E_{sim}^α , with $E_{sim}^\alpha = \{E_i | Sim_{Mink}(C', C_i) \geq \alpha\}$.

The set of hypotheses that we consider to propose an a priori analysis is the union of all hypotheses associated with the experiences of E_{sim}^α . Let us presume that $H_{sim} = \cup H_k^i$, $E_i \in E_{sim}^\alpha$.

We will assign two scores to each hypothesis H of this set (which will decide whether this hypothesis will be proposed or not to resolve the new problem). The first score, called “subjective score” and noted $\sigma_{sub}(H)$, is calculated from the similarity in contexts and from the subjective opinions of the experts. The second score, called “objective score” and noted $\sigma_{obj}(H)$, is calculated from the similarity in contexts and from the validation of the hypotheses. We then have the following definitions:

$$\sigma_{sub}(H_k) = \Psi_{E_i \in E_{sim}^\alpha} (\theta(Sim_{Mink}(C', C_i), sub_k^i))$$

$$\sigma_{obj}(H_k) = \Psi_{E_i \in E_{sim}^\alpha} (\theta(Sim_{Mink}(C', C_i), obj_k^i))$$

where θ indicates a function of local aggregation and Ψ indicates a function of global aggregation. It is possible, for example, to choose a product operator for θ and indicates a maximum operator for Ψ .

4. Illustrative example

The example we present in this section concerns a problem (corresponding to a simplified version of a real-life case from Railway Industry) of failure power on a pneumatic brake of a train. In Table 4, the context of six experiences already recorded is listed. The column “Co” is the concerned component, the column Pb is related to problems. The columns sim_1 , sim_2 and sim_{mink} match respectively to the values of similarity with the current case (pneumatic brake + power supply) of component, of the problem and the synthesis of both. Taxonomies used to describe the contexts of experiences are shown in Fig. 4 (for components) and Fig. 5 (for problems).

We assume that semantic (context-based) search has produced the outputs quantified in the following paragraphs. Through a threshold $\alpha = 0.6$, the following set is obtained: $E_{0.6}^\alpha = \{(E_1, 0.68), (E_3, 0.77), (E_6, 0.86)\}$, the second value of each couple indicates the degree of similarity between the context of the current problem with:

$$\begin{aligned} A_1 &= \{ \langle H_1, 0.6, 1, 0 \rangle, \langle H_2, 0.3, 0, 0 \rangle, \langle H_3, 0.1, 0, 0 \rangle \} \\ A_3 &= \{ \langle H_1, 0.1, 0, 0 \rangle, \langle H_2, 0.8, 1, 0 \rangle, \langle H_4, 0.1, 0, 0 \rangle \} \\ A_6 &= \{ \langle H_1, 0.7, 1, 0 \rangle, \langle H_3, 0.2, 0, 0 \rangle, \langle H_4, 0.1, 0, 0 \rangle \} \end{aligned}$$

We deduce, using a local aggregate function “Product”, the following values:

$$\begin{aligned} A'_1 &= \{ \langle H_1, 0.41, 0.68 \rangle, \langle H_2, 0.20, 0.0 \rangle, \langle H_3, 0.07, 0.0 \rangle \} \\ A'_3 &= \{ \langle H_1, 0.8, 0.0 \rangle, \langle H_2, 0.62, 0.77 \rangle, \langle H_4, 0.08, 0.0 \rangle \} \\ A'_6 &= \{ \langle H_1, 0.60, 0.86 \rangle, \langle H_3, 0.17, 0.0 \rangle, \langle H_4, 0.09, 0.0 \rangle \} \end{aligned}$$

Table 4
Contexts and similarities of the studied example.

	Co	Pb	Sim_1	Sim_2	Sim_{mink}
E_1	Brake	Electrical	0.68	0.68	0.68
E_2	Train	Mechanical	0.17	0.17	0.17
E_3	Pneumatic	Electrical	1	0.68	0.77
E_4	Bogie	Pitting	0.17	0.11	0.14
E_5	Motor	Electrical	0.13	0.68	0.34
E_6	Air treatment	Voltage spike	0.86	0.86	0.86

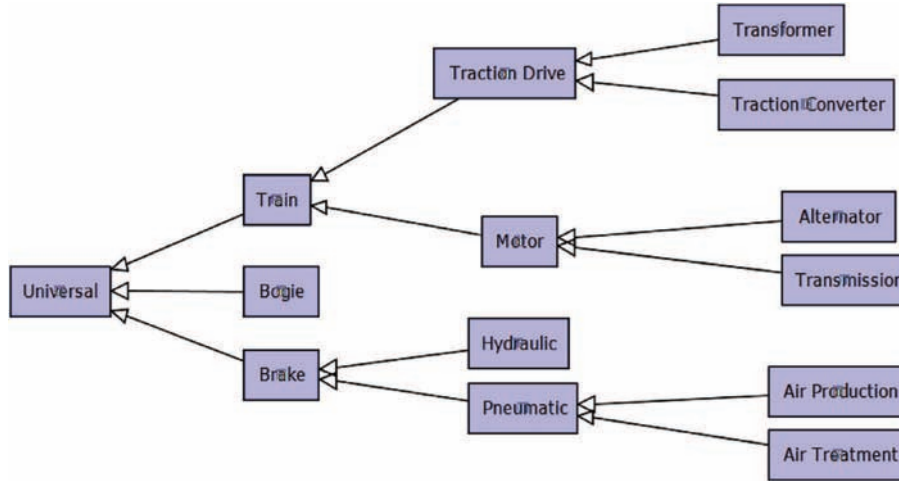


Fig. 4. Taxonomy of components for the example.

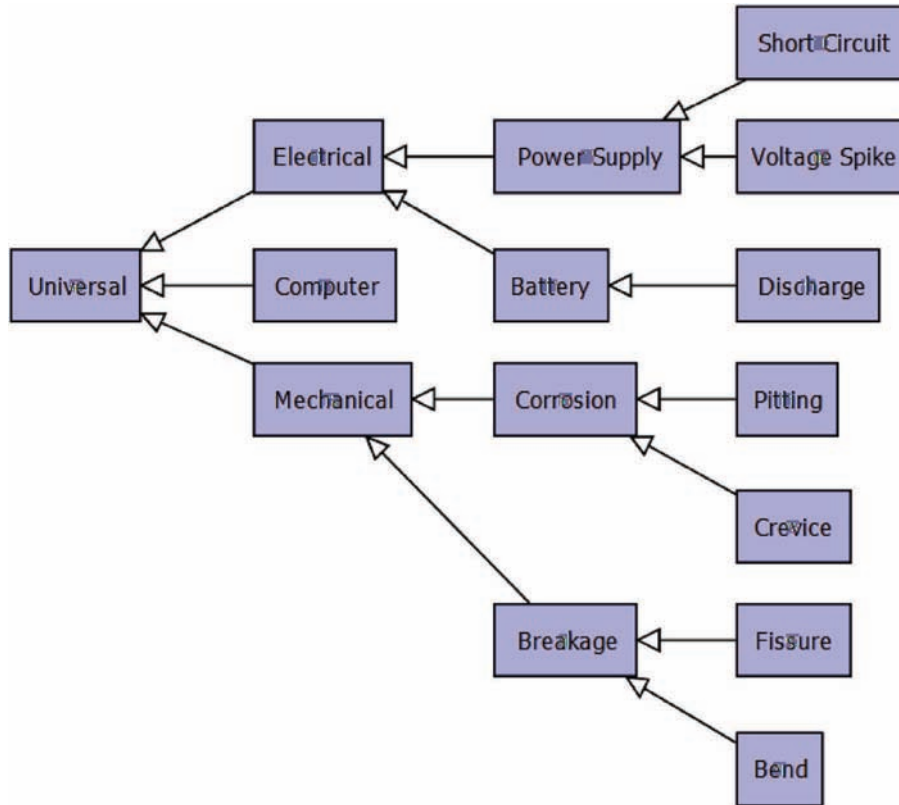


Fig. 5. Taxonomy of problems for the example.

In this example the set H_{sim} is defined in extension by $H_{sim} = \{H_1, H_2, H_3, H_4\}$.

We will determine at this stage the interests of each hypotheses of this set. We will use a global aggregate function, here the maximum function is "max". We obtain the following result: $\sigma_{sub}(H_1) = \max \{0.41, 0.08, 0.6\} = 0.60$

Similarly, we obtain $\sigma_{sub}(H_2) = 0.62$, $\sigma_{sub}(H_3) = 0.17$ et $\sigma_{sub}(H_4) = 0.09$. For objective scores, we obtain $\sigma_{obj}(H_1) = \max \{0, 9, 0.0, 0.8\} = 0.90$, $\sigma_{obj}(H_2) = 0.7$, $\sigma_{obj}(H_3) = 0.0$ et $\sigma_{obj}(H_4) = 0.0$.

We note here that the assumptions H_1 and H_2 can be proposed to the user if they get a good score on the two criteria.

Taxonomy was later enriched approximately 4000 concepts through analysis of a set of working documents (examples

provided by experts). Concepts were combined using a set of diagrams, where processes have been identified with their relevant inputs, the outputs, constraints and methods to support the provision of services. These concepts were then compiled into a set of diagrams representing an ontological model with appropriate conceptual relations that have been specified [30]. It is important to support the further development toward domain ontology with axiomatic knowledge [31].

We interviewed 11 experts to assess the final taxonomy (interviews with experts). The interviews included a presentation of 20 min and were then asked to assess the relevance of the concepts of root causes, their relationships, and their use in different contexts. This included a set of questions on the

comprehensive and consistent inclusion of all concepts; expertise can have an actor, the process in which this actor is normally involved. This is a very effective and widely used for the validation of ontologies [17,32]. The strict application of these issues provides a means to ensure full coverage of concepts (whenever a concept is considered related to existing concepts, if necessary, it is added to the domain vocabulary).

Nine major concepts form the overall structure of the taxonomy component:

- *Vehicle body*: carcass, external design, entrance facilities, draw and buffer gear, gangway, windows.
- *Running gear*: supporting structure, suspension, damping, wheelset guidance, wheelset, running gear and vehicle body connection, running attaching part, ancillary element.
- *Energy supply*: current guide, network voltage system protection, switch and detection, main transformer.
- *Traction equipment*: drive control, electrical power converter, propulsion.
- *Brake system*: brake control, brake actuator pneumatic brake, brake actuator electromagnetic track, dynamic braking.
- *Auxiliary supply*: compressed air supply, battery equipment.
- *Interior*.
- *Central control and communication*.
- *Operations instrumentation and control*.

The integration of experience feedback methods and other methods such as FMEA is a promising avenue for progress. Regarding the similarity exploitation mechanism, it would be interesting to go beyond the similarity measure based on the taxonomies (concepts connected by a relationship is-a(X,Y)) and to propose a similarity measure incorporating the concept of nomenclature (concepts connected by a relationship part-of(X,Y)). This would enable one to obtain information related to enlargement descriptions, which, in this case are the additional properties that are not explicitly part of the taxonomy structure.

The practical implementation of the mechanism of reuse analysis assumes that hypotheses are made in the same manner from one experience to another, although in real situations, this constraint is rarely satisfied. Indeed, experts who express their experience, in general, use a personal vocabulary; so it is difficult to define a formalized expression of hypotheses in a consensual and

exhaustive manner within the framework of a dynamic, iterative, and incremental solutions model. This difficulty can be circumvented by creating a taxonomy of root causes (like taxonomies of components and problems) to assign each hypothesis with a concept from this taxonomy that best represented the type of expressed causes with the underlying events and circumstances relevant to that concept. It would be easy enough to assign each concept "Cause" two global measures (subjective and objective functions) using the mechanism presented for the processing of hypotheses.

5. T-Rex: a workflow management system

It is interesting to know experience feedback from the stage in the processing of non-conformances, which depends on the level of information generated (contexts-analysis-solutions). This dimension is critical to monitor, define the history and traceability of the physical flow. This is why we focused on a technological solution oriented software tools like "workflow management". Workflow tools are presented as a technological ideal to meet the objectives set by reengineering activities [11]. Workflow management tightly controls the flow of information according to the specifications of a given process. Processing tasks transfer information from one person to another in a well-defined manner and also involve the development of communication and networking.

The software T-Rex is a tool supporting the process of problem solving and feedback based on the approach outlined above.

We have compiled a list of the various criteria that must satisfy T-Rex in a comprehensive or targeted management and maintenance of. We divided these criteria into four sections (as shown in the following table (see Table 5)): Non Conformances Management, Problem Solving, Action Plan Management, Records, and Measurements and Reports.

The T-Rex software supports several standard methodologies for problem solving: PDCA (Plan, Do, Check, Act), 8D, 9S. The main activities in this process are:

- Training team problem solving in a stepwise approach.
- a description and evaluation of criticality events,
- characterization of the problem,
- analysis of events in order to find the root causes and validate this analysis (e.g. "is/is not", "5 Whys" Ishikawa diagram),

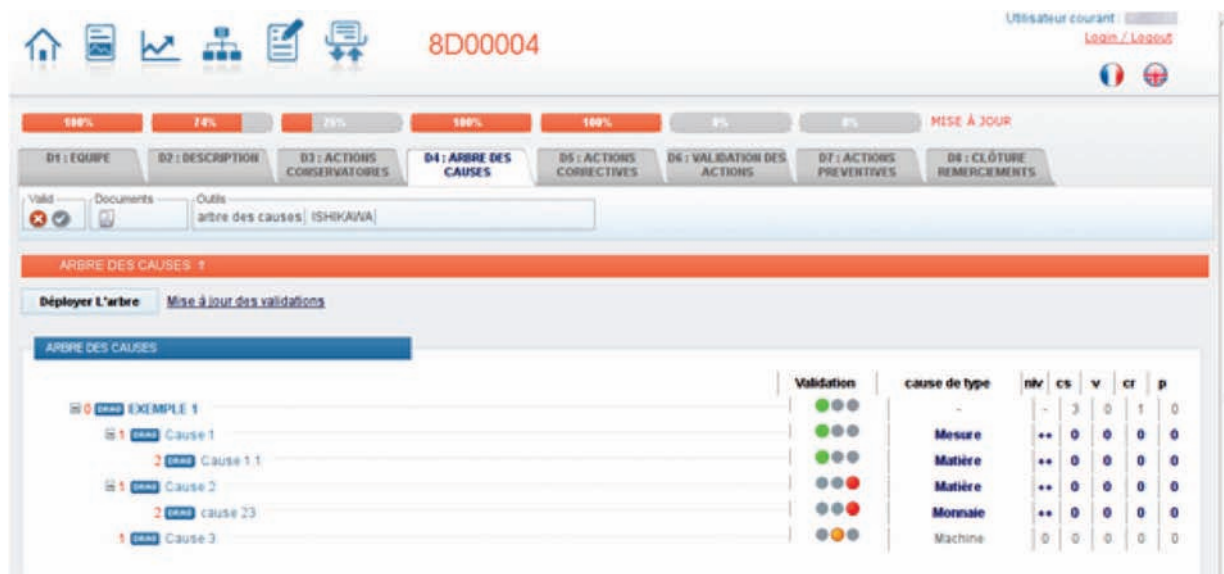


Fig. 6. A partial view of T-Rex software for root cause analysis.

Table 5
Functional properties of the T-Rex software.

Non conformances management
Deal with quality issues (product, project, services, processes) including top 10 issues
Stakeholders identification:
Activity manager = person in charge of the planned activity (e.g. WP, program, project ...)
Quality Manager of the activity
Technical manager of the activity
Delegation by the activity manager
Unique identifier
Link to origin/cause
Critically scored based on Top 10 scoring (safety, revenue service, quality of service, maintenance, progress)
Description
Dates = target date, forecast date, closure date
Project/Program/Technology/Region/Product Line/Platform/Sub-system/Site/
Process identification from list
Identification of repetitive issues
Problem solving
8D workflow (Alstom Transport definition) with tools supporting causal analysis
PDCA workflow
Link with action plan management
Problem closure and archiving
Action plan management
Action title
Action description
Links origin–action/causes–actions
Multi-site and multi-entity (Product Line, Platform, Sub-system): access for monitoring and action allocation.
People identification:
Action requester (accountable)
Action owner (responsible)
Notification to action owners via Lotus Notes
Attributes: type, severity, priority, status
Dates = target date, forecast date, closure date
Effort (man*month) and cost of action (forecast, to complete, actual)
Records, measurements and reports
KPI extracts (per group of actions, versus time...):
Time open, time to close, delay, closure date trend
Cost at completion, actual cost
Actions to be done rate, progress indicator
List of linked/interdependent actions
To-do list (Non Conformances/Actions/Problems current or not closed in due time)
List/extract per Region/Product Line/Platform/Sub-system/Site/Project/Process
Capability to generate Excel report (field selection)
Monthly report and report on request
Common language for man-machine interface, data recording and reporting = English

- a proposal for a solution to the problem and its application (curative solution),
- the suggestion of actions to prevent reoccurrence of the problem (preventive solution and lessons learned),
- the addition of semantic capacities to the textual search engines (by keyword or similarity).

The T-Rex software, in its current version, gave satisfaction to the different users and the first pilot evaluations of the results by the end users are very encouraging. This software has made it easier for experts, especially in the process of validating the potential root causes (see Fig. 6). The evaluation of the application T-Rex has led to promising results regarding both the responsiveness and efficiency of the resolution. Note that beyond the provision of tools, implementation of feedback the company has been accompanied by a serious consideration of this need within processes and led to the definition of the role of “Rex Manager” of which some activities is shown in the following table (see Table 6).

6. Conclusion

The issue of experience feedback applied to problem solving processes through sound and factual information is in the best interests of the industry. We proposed in this communication a new enriched experience representation (resulting from a particular problem solving) and two mechanisms to exploit the information content of context and analysis belonging to this experience. This proposal, which also supplements the approaches already established as the Failure Modes and Effects Analysis (FMEA), is based rather on a priori analysis system and not on an approach based on experience. In many application domains the existing experienced knowledge could be put to more uses than those provided by priori analysis systems. The proposed approach also emulates the people's cognitive structure and reasoning model to achieve better quality and more understandable outcomes to support the capture and reuse of analysis and knowledge.

Finally, we defined performance indicators to assess the effectiveness of experience feedback process that we put in place, that is to say its ability to needs specified by end users.

Measurement indicators are selected and approved by management to:

- analyze the time evolution of the situation in relation to each objective,
- make the corrective or preventive decisions that are needed,

Table 6
Mechanism for monitoring REX actions and progress.

REX meetings	Responsibilities	Attendees	Frequency
Implementation of REX capitalisation	REX Manager is in charge to follow the action plan, supported by impacted functions that are action owners depending en the REX typology	REX Manager The REX pilot in the case of issue (8D/PDCA) PQM in the case of Rex an project QMS Manager or Process Owner in the case of REX on Process	Every 2 weeks
REX Committee Meeting	Definition of Product/functions/project impart perimeter. Definition of main action plan to capitalize REX, with evidences and Verification of the capitalisation, through concrete evidences chosen during previous REX meeting Deliverables: REX Card approval + REX Review Report	REX Manager and Site Quality Director (optional), Product Director/Project Director/TCE Product Director, Industrial Director. SQA Mgr, Chief Engineers (Including technical networks representatives, CCN, skill leaders, if relevant to the topic), RAMS Mgr	Each month
Multi-site Workshop among REX Managers	Delivrables: Read Across Matrix (Transversalization)	REX Managers from different sites (BE Comp VP or BE Subsys. Directors should participate to give PL recommendations)	Every 2 months

- measure and evaluate the effectiveness of the associated actions to continually improve the effectiveness of experience feedback system.

Two types of indicators have been defined for this purpose:

- internal monitoring indicators.
 - Number of Rex cards issued.
 - Number of capitalization shares ended in months.
- KPIs (Key Performance Indicator)
 - Actions of feedback resulted in the past month (KPI).
 - Level of capitalization.
 - Rex cost avoidance = cost of non-quality.
 - Cost of obtaining quality.

Finally, the software T-Rex has been functionally validated on several cases of solving some of great complexity. Currently, the state of maturity of the software is a commercial version (named ProWhy[®]). We wish to integrate others components of the experience feedback models and inference mechanisms for others problem solving methodologies. This integration will allow news means for tracking progress and pursuing specific targets and goals in collaboration with other relevant national and local stakeholders.

The taxonomy-based information structuring delivers the foundation to capitalize knowledge along with associated belief assignments. Taxonomies classify a number of high-level concepts and provide ways of tagging information from cases description in various domains. Tagging the cases hence becomes a valuable way of assisting with the root cause analysis and possibly the formulation of recommendations for improvement. The user can better understand the steps leading to the problem resolution and learn along the way. The quality (applicability, efficiency and simplicity) of the taxonomy model and the business-oriented evaluation are the essential elements to ensure semantic interoperability and to support decision making in a more rigorous manner [33].

Within a domain specific target application, a dedicated approach can aim the knowledge reuse to perform various objectives (e.g. performance, reliability or safety). So, a taxonomy model can be semantically organized according to structuring perspectives such as a structural view, a functional view, a service view or an application view. Implementation issue deals with the characterization of specialized tools with dedicated indicators at diverse levels as well as the processing (modulated by expert beliefs to generate forthcoming opportunities and to drive continuous improvement on industrial process issues.

This means of extensibility to other domains can enable the manipulation of similarity measurement and exploitation of reuse analysis that are defined in our approach. For example, this is possible in a maintenance application where the major indicators are related to concepts of reliability engineering and system safety [34]. In this context, it would seem convenient for industrial systems facing high failures to opt, among the reliability engineering instruments available, for system regeneration to restore their availability [35]. Availability of the system is defined on the basis of the possible states of the required functions for a mission and notably in the modeling method; the starting point remains the conceptual taxonomies model for the description of systems. When system failures are being addressed, the maintenance recognizes the justification for additional knowledge that may be gained by studying the problems associated with specific root causes [36]. As a result, the proposed methodology from the problem-solving context has a pragmatic potential of extensibility to other domains in which the suggested techniques would be deployed through adjustments to appropriate mechanisms.

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