Technical Note

Experienced knowledge for the description of maintenance packages

Bernard Kamsu-Foguem [a,*], Yris Fondja Wandji [b], Germaine Tchuenté-Foguem [c], David Tchoffa [d]

[a] *Laboratory of Production Engineering (LGP), EA 1905, ENIT-INPT University of Toulouse, 47 Avenue d'Azereix, BP 1629, 65016 Tarbes Cedex, France*
[b] *Laboratoire d'Économie de Dijon (LEDi) - UMR CNRS 6307, Université de Bourgogne, 2 boulevard Gabriel, BP 26611, 21066 Dijon cedex, France*
[c] *Département d'Informatique, UMI 209, UMMISCO, Faculté des Sciences, Université de Yaoundé I, B.P. 812 Yaoundé, Cameroon*
[d] *LISMMA, Université Paris 8, 140 rue Nouvelle France, 93100 Montreuil, France*

ABSTRACT

The presented work is included in the research theme that specifies some means of capitalization and exploitation of knowledge from experience feedback processes in the context of industrial maintenance management. Our research on it is a more precise definition of the proposed project, built with a problem asking how to handle the management of repair packages. Upstream, the knowledge of various experts are materialized in the form of expert reports. Downstream maintenance wants to quickly repair products based on symptoms or change parts in advance. For this, we propose a methodology by analysing the feedback to improve the response time for maintenance services. This is implemented in the context of a manufacturing traction motors for the railway industry.

Keywords:
Experience feedback
Maintenance
Repair packages
Knowledge
Railway company

1. Introduction

The industrial maintenance services and their associated logistic organizations attach great importance to the work of the experience feedback processes to further enhance the schemes and frameworks in the future in order to keep meeting user requirements and to ensure that service levels improve continuously [1]. The timing of the events, which appear to be very similar, is a strong incentive for seeking common causes and carefully scrutinizing the experience feedback that can generate interesting lessons learnt with significant generated knowledge in the context of industrial maintenance. Capitalize these maintenance knowledge and promote the sharing of expert knowledge promotes some cross viewpoints to improve collaborative decision making [2]. The corresponding continuous improvement process depends on basic understanding, learning from experience, working together and training [3–5]. The functional analysis and the produced information with the gained experienced knowledge are important for some developments leading to the legitimization and trivialization of a type of traceability system that is reliable, robust and comprehensive [6–8].

Experience feedback management will better exploit empirical knowledge to anticipate repairs by directly applying packages, which will create a real time saver and therefore money for the company [9]. It must be kept in mind that in some markets, the time is more important than the cost of creating and repair packages can avoid having to make estimates and can enable a company to meet the needs of customers.

Currently, repair packages for maintenance are calculated statically, that is to say that at a time, the analysis is performed without the resume thereafter. The idea of this study is to make it easy to recalculate these packages (dynamic approach). One can very well imagine that we started working with components whose reliability is not optimal. These components are then included in the repair packages until you decide to change providers that optimize reliability. These components remain in the packages although they are now more reliable.

The paper is structured as followed. Section 2 exposes a situational analysis performed prior to the formulation of our proposal. Section 3 presents the methodology adopted for experience feedback reuse applied to industrial maintenance management. Section 4 presents an illustrative case study with the suggested technical

* Tel.: +33 6 24 30 23 37; fax: +33 5 62 44 27 08.
E-mail address: Bernard.Kamsu-Foguem@enit.fr (B. Kamsu-Foguem).

solution. Finally, Section 5 discusses the work we have done to criticize the solutions and related future challenges.

2. Maintenance activities in the target railway industry: a situational analysis

2.1. Definition of requirements

This analysis allowed us to identify what are the possible entries into the study environment and what has to be created with the assumptions that arise as proposed answer to the question of starting data. Upstream, the knowledge of various experts is materialized in the form of expert reports. Downstream maintenance wants to quickly repair products based on symptoms or change parts in advance. The feedback will create packages that will be used by maintenance services; we consider that these packages do improve the quality of maintenance actors by making them more reactive in order to meet their customers' demands.

Most vividly, we can now reformulate the subject as follows: "Analysis of feedback to improve the response time for maintenance services."

Table 1 presents some of the questions asked at the beginning of this research work and gives the starting-point for the reflections in this document. The adopted approach is related to the issue of "Analysis of feedback to improve the response time for maintenance services".

To answer this issue, we need a tool to integrate experience feedback processes from various experts and conflict management to create maintenance packages. This experience feedback will be an interface between experts formalizing their knowledge and maintenance service that will set packages:

- Main function service:
  - FP1: Capitalizing on experienced knowledge of the maintenance service to be more responsive to the needs.
- Secondary function service:
  - FS11: Recording experience feedback information from experts.
  - FS12: To provide rapid and effective assistance in repair packages for commercial teams of the maintenance service.
- Function constraints:
  - FC13: The experience feedback processes must be correctly executed to reduce the risk of losing valuable information from previous failure cases.
  - FC14: The conception of maintenance packages must be reviewed, updated or appropriately adjusted when necessary.
  - FC15: Protect the recorded data in order to guarantee their integrity, nature and sources.

Fig. 1 describes a diagram of interactions that provides a high-level representation of some interactions between the intelligence analysis program and other components (Experts, Maintenance Service, Experience Feedback and Packages). The diagram of interactions can help to understand the different relationships (information flows and knowledge sharing) between a given group of actors and other stakeholders.

Table 1
Analysis of feedback to improve the response time for maintenance services.

Objective: improving quality and responsiveness of maintenance service	
Who for?	Maintenance services of railway industries
When?	At each requests to the maintenance service
Where?	Maintenance services for traction systems
What?	Service quality improvements
How?	Experience feedback analysis and packages creation
Why?	Improving maintenance-processing while increasing customer satisfaction with revenue enhancement and inventory control

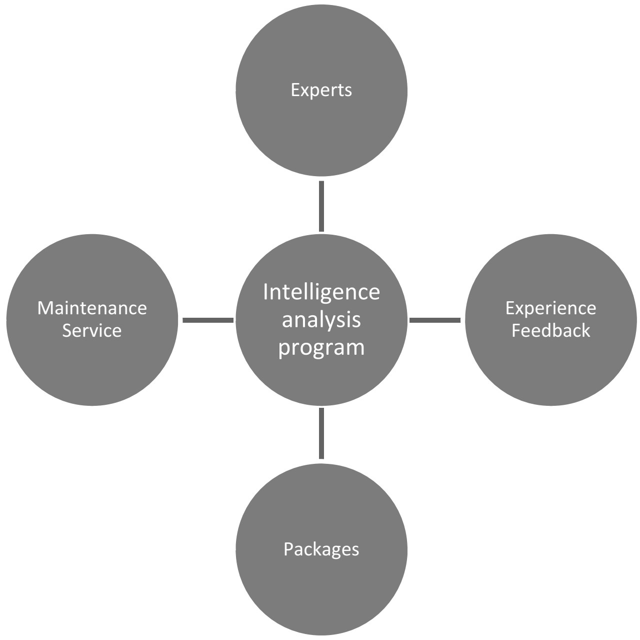

Fig. 1. The diagram of interactions.

As a first step, one has to start by examining the principle of creating packages with various mechanisms. Therefore we will focus in this task which constitutes the means of implementation of the essential dimensions of clarity, feasibility and relevance of the scientific process and the construction of the work that the original question suggests. The search for solutions is carried out in an open and transparent manner meaning that the problem-solving system may exhibit many different responses provided regarding the orientations to be fostered for the maintenance. An initial question still addresses existing propositions with statements that bridge "the best of what is or has been" and investigations about "what might be". Following the definition of the conceptual elements of the revised framework for the maintenance service, we define the scope of proposed approach, create a processing plan, identify constraints, associated rules and project management requirements, and establish problem solving reasoning and mechanisms requirements.

2.2. Maintainability assessment in industrial devices

The knowledge exploitation in industrial settings can be guided by the maintainability indicators and maintenance levels description. The information from analysis phase can be a guide to knowledge exploitation and case management regarding maintainability requirements. In addition, they also define their relationship with the relevant attributes for continuous improvement. For example, the attributes of device maintainability may be presented as its design quality, specific industrial environment and of logistics support [10]:

- Attributes related to the device design: Simplicity, Identification, Modularity, Tribology, Standardization, Failure watch, Accessibility and Assembly/disassembly.
- Attributes related to the maintenance staff and work conditions: Ergonomics, Training and Environment.
- Attributes related to the necessity of logistics support: Relation with the manufacturer, Personnel organization, Spare parts,

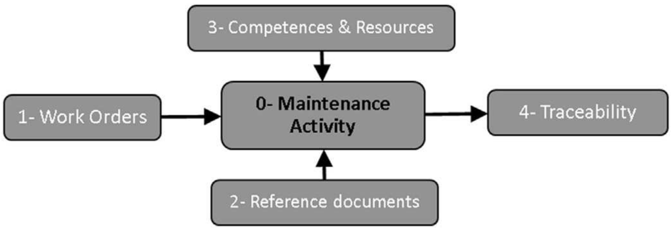

Fig. 2. The structural representation of the maintenance process.

Maintenance tools and equipments, Interdepartmental coordination and Documentation.

This overview provides a general description of maintainability attributes used as guidance for the purposes of knowledge exploitation of the contained use maintenance activities. However, every case study should provide specific details about the implementation and suitable evaluation into a concrete scenario.

Fig. 2 shows the diagram of the maintenance activity that has some inputs (work orders), controls (competences and resources), supports (reference documents), and outputs (traceability). So, the deployment of a maintenance activity shall contain direct observation of the specific maintained equipment as well as investigation of the technical documentation and procedures.

The engineering department of railway industry operates various reports, documents and traceability indicators from experience feedback to improve the overall maintenance process related to traction systems testing and production. The experience feedback process can point out to the logistics support services the information and activity indicators. Therefore it is essential to provide the experienced knowledge for the improvements of maintenance activities with indicators of replacement components and separate technical units that are associated to regular practices [11]. In the experience feedback process, we shall not attempt to survey all such practices comprehensively, but instead draw attention to the characteristics of some of the main association rules of maintenance activity. These rules are useful to start a review of possible indicators concerning the maintenance activity and work conditions of maintenance groups in the context of continuous improvement projects that are about to identify and analyses the main effectiveness problems.

The work orders are followed using the Maintenance Tasks Lists. A job card is provided to assist technicians in identifying the essential actions to take to complete the required task. Therefore they also include elements concerning the Test Instrumentation and the Control & Monitoring System (CMS). The specification of domain ontology (development of concepts and relations hierarchies with constraints and axioms) can be exploited to provide semantic support in a variety of maintenance processes [12]. The hierarchical descriptions of maintenance tasks (see Fig. 3) can be used for automatic generation of semantic tag-based resource profiles [13]. The Fig. 3 presents the hierarchical description of some maintenance tasks. The job card relevant to the maintenance is issued by a staff member and this can contain sub-concepts (Inspection, Movement...) enabling the conceptualization of the different possible actions. Their implementation should be done in accordance with the available rules and constraints of railways maintenance procedures.

3. Presentation of the proposed approach for specification of maintenance packages

3.1. Generation of useful information from experience feedback processes

Maintenance areas should pool their experience of maintenance activities so that they do not make the same mistakes. The knowledge generated by experience feedback (EF) processes can help the maintenance actors to better understand and handle the problems they are facing in their day-to-day lives [14]. Fig. 4 highlights the operating principle for specification of maintenance packages from useful information generated by experience feedback processes. The characterization of maintenance packages requires achievement of four main activities encompassing failure modes analysis, design of new products, cost analysis and packages development.

The operating principle of experience feedback for maintenance includes four main steps:

- *Reliability analysis*: Step required when one wants to make a repair plan. The reliability analysis is a useful tool for identifying the most significant failures with the evolution trend of the different parameters influencing these failures. We calculate the price of the package founded on previous repairs based on the EF.
- *Failure modes analysis*: When certain products fail, it may be necessary to change some of their components to prevent a repetition of such a failure. Based on these failure modes, one can compose different packages by performing an analysis of failure modes.
- *Design of new products*: To avoid repeating the failure modes analysis, several times (or at least on some products), we create a database to save time and get information about possible failures of new products that is created.
- *Cost analysis and packages development*: Once the composition of the packages made, it is necessary to calculate the package costs for determining executive charges that are billed to clients.

When a failure occurs, experts formalize their comments on a document containing all the information carried in the expertise including dates of investigation and serial numbers when you can have them. Packages of the repairs are calculated on the basis of possible solutions that can be achieved by combining the different types of information from EF. Before going any further, let us indicate key points of the used EF processes that has been drafted and implemented in the target industrial setting. Therefore we will focus our study on the different possible ways to determine an effective method of creating packages. This study will evaluate the function of the current system and identify and evaluate

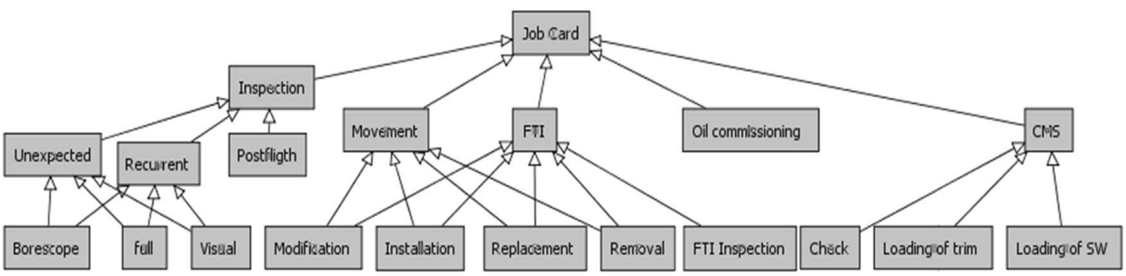

Fig. 3. The hierarchical description of some maintenance tasks.

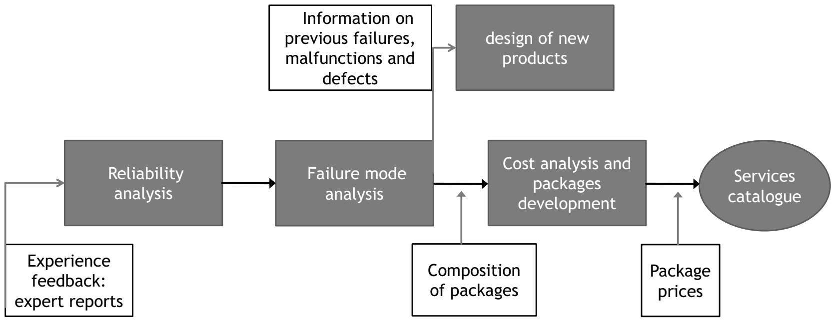

Fig. 4. Operating principle of experience feedback for maintenance services.

alternative treatment methods in concert with possible upstream improvements.

In order to organize some numerical reasoning [15], the industrial maintenance framework draws its knowledge from the wealth of information available from experts, customers, practical research and published documentation on system performance and failure modes. They concern in particular the various dates related to products (commissioning, all failures with the places at which such failures were made and recommissioning). The maintenance journal records furnish details for the extent of the work performed and the components exchanged and installed. The analysis requires the description of significant assumptions with root causes investigation and the potential use of external expertise. A lowering of corrective maintenance, and therefore an improvement in industrial performance, is achieved through experience feedback- and reliability-oriented maintenance; unplanned downtimes are reduced [16]. Some guidelines can be used for planning a reliability growth test with an applicable model (e.g. *Duane* model) and the contribution of expertise enabling us to identify failure modes, and validate facts that help us direct the focus of the investigation [17]. The objective is to find failures during test and learn from those failures by improving the conditions for the functioning of studied systems or redesigning to eliminate them. Another analysis can be conducted to identify and describe potential failure modes for assessment and inclusion in a surveillance program. The analysis and interpretation of the results are frequently determined using the *Weibull* method. Further actions can be made to define the key parameters of surveillance to support the maintenance operations, building on the identified modes of failure. To avoid any rupture in its logistical chain which may lead to a stoppage of the services and resources availability, it is up to the maintenance management to assess the appropriateness of the constitution by it of a pertinent safety stock. This requires an in-depth investigations and a detailed risk assessment to identify the manner by which a system may fail to operate correctly, predict the potential consequences of such a failure, and establish specific engineering measures (e.g. using a *Poisson* distribution) to mitigate the consequences to tolerable levels [18]. Establishing a baseline of experienced knowledge at a maintenance level is essential in order to implement the collaboration, as appropriate, in exchanging timely and accurate information concerning the problem solving and its prevention [19]. Maintenance management services benefit from more efficient, timely, and accurate collection, interpretation, and analysis of information with corresponding benefits of a shortened investigation process and more timely communication of reliability deficiencies and problem solving reports to stakeholders and the logistics.

3.2. Determination of maintenance packages with excel sorting and pivot tables

As presented in the introduction, the calculation of repair packages is done within the framework of experience feedback into a maintenance service in the context of their activities. For each context we count the number of components that have been changed and the percentage of each component are calculated relative to the total. Then, we define a rule like:

$$\text{If} = \frac{\%\,\text{studied part}}{\text{Total dismantled parts}} > 10\%$$
$$\text{Then include the component in the package}$$

To determine the number of components to include, we can take into account the symmetries of the product and the price of parts (maintenance services should make every effort not to charge for costs for assistance requested in the framework of safety investigations) [20]. It should be understood that the information discovery in databases with experience feedback is done by technicians or engineers and it takes time and therefore money. For companies with many different references, this time may be non-negligible and requires continuous improvement developments.

The experienced knowledge provided by the domain experts is directly used. This would solve the problem mentioned above, which means thereby avoiding a payment for additional services using information extraction techniques for distributed database containing multiple EF files. So we add a constraint to have a unique EF file. All information about the components are listed in dedicated computer software, we need to verify the accuracy of the information provided in this software. The verification process revealed inconsistencies in the available information, including possible variation between the multiple codifications of products from various manufacturing sites. Hence, some efforts have been made to review contents ensuring the quality and accuracy of the data and information enclosed in this software. Also, the uniqueness of the EF folder has other advantages: for example, you are sure to remember the information as the single file contains the entire database, whereas previously it was possible to forget EF files especially when the company has a lot of repair sites. We also note the time savings as the person responsible for calculating the contents of packages contains should have contacted all the sites to get the information.

The advantage of this system is that you can create tables from an EF database. We have not managed to change the main disadvantage of this system tables to use it. Indeed, it was necessary that the database has a finite size for the system synthesizes monitoring data. But the idea was to create a pivot table from the EF folder, by providing input into content of the folder and ongoing feedback as the folder evolves. Note that there is no empty line within the table; otherwise, an error message appears when saving the data.

We have examined different possible schemes with an open mind, particularly those aimed at facilitating the adoption, including the idea of an intermediary solution. The pivot tables can be an alternative solution or a least an intermediary solution that can link together the existing operational levels, the expert supports and the assessments with state vectors. In this connection, an intermediate solution can enable the maintenance service to continue their business activities and to take the time needed to implement the

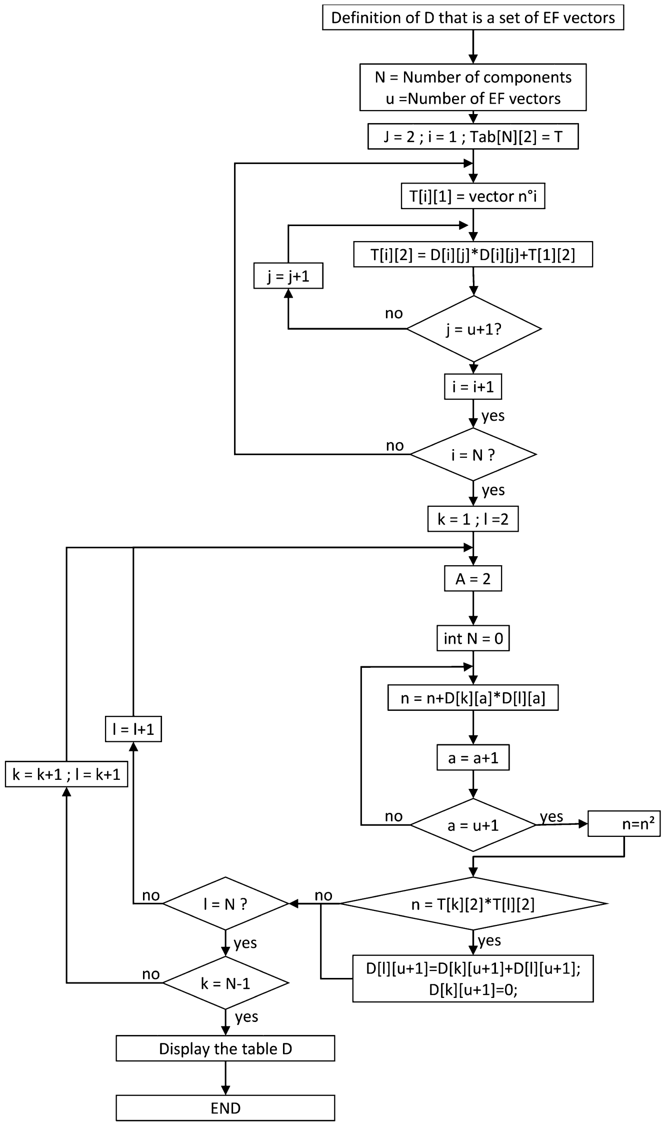

Fig. 5. Functioning of the Hierarchical Clustering Algorithm.

selected solution in the most ergonomic and most intuitive manner possible.

3.3. Determination of maintenance packages with a clustering principle using the Cauchy–Schwarz inequality

The idea is to use state vectors defined by the order of the components disposed of in accordance with the nomenclature of the products concerned. A cluster is a vector comprising a vector in each component. We could then divide the different state vectors according to a criterion in clusters and thus form the repair packages. Different clusters represent different classes of repair packages. Clusters contain vectors that are the various cases included in the package. The components of the vectors give some information about the number of failed component of each type represented directly in their corresponding box with associated index.

Fig. 5 describes the functioning of the Hierarchical Clustering Algorithm that uses an iterative procedure to split/merge a considered data set into a set of clusters [21]. In fact, the algorithm begins with a number of clusters corresponding to the number of vectors. If two clusters are similar (according to some specified criteria) then they are grouped to form a merged cluster. The procedure again carries on until a stable cluster configuration (there are no more similar vectors) is reached at or all vectors are merged into a single cluster.

Example: $(2, 0, 0, 4)$

This vector provides the following information:

- The product has four kinds of components.
- The condition of the product where we can see that there are two failed components of the first type and four failed components of the fourth type.

Since, we do not get conclusive results with previous methods; we decided to create our own decision algorithm to integrate components in a package of repair. For this, we have initially kept the idea of state vectors, which we subsequently amended, for the purposes of the algorithm. We have thus asked ourselves the following question:

"How can we differentiate similar vectors states as regards others?"

For this, we used the properties of the scalar product that is valid in a vector space R^n equipped with the canonical scalar product. The property of the Cauchy–Schwarz inequality states that for any vector x and y of R^n, it is true that:

- $|\langle x, y \rangle|^2 \leq \langle x, x \rangle \cdot \langle y, y \rangle$, when $\langle .\,, . \rangle$ is the inner product also known as dot product.
- The case of equality is present only in the case where the vectors x and y are a linked family. This means that equality holds only when x and y are linearly dependent.

This is especially the second property that interests us because it will allow us to sort the vectors according to this criterion. Sort the vectors according to their linear dependence is more interesting because if two vectors are collinear, then we can create a package that will cover the repair of two cases. There is a correlation between the collinear state vectors and the similarity of the components subject to change in the associated packages. So for the considered states of failures, the repair parts will be exchanged for equivalent. It is possible and easy to calculate since it only works with integers (an integer number of components is changed). To simplify calculations in our algorithm, we took the square inequality using the fact that the scalar product of a vector with itself is equal to the squared norm:

$$|\langle x, y \rangle|^2 \leq ||x||^2 \cdot ||y||^2$$

Therefore, we started to define the structure of the algorithm and so we describe its five steps in the following decomposition:

1. Definition of a set of state vectors x_i, $1 \leq i \leq n$.
2. Calculating $\langle x_i, x_i \rangle$ and stock results in a table.
3. Calculating $\langle x_i, x_j \rangle$ $(i \neq j)$ and comparison of the two members of the Cauchy–Schwarz inequality.
4. Accounts of similar failure states.
5. Loop until it is useful to make comparisons (and avoid duplication that would distort the data).

4. Illustrative description of the functioning of the suggested technical solution

It is believed that the study focuses on a product with six components and we have five vectors from the EF. Note that, in order to reduce computational complexity, we assume these two fixed

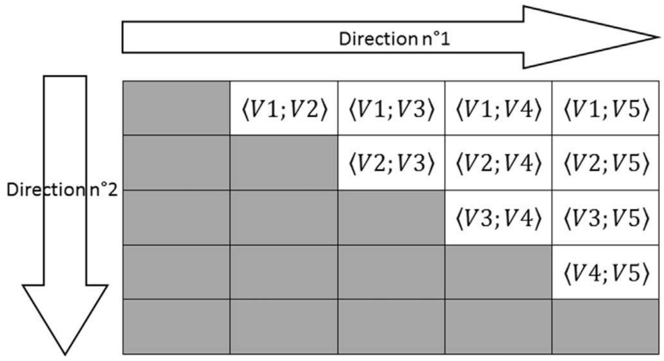

Fig. 6. Directions of reasoning processing.

numbers. This is to simplify the example. The number "1" in the last scalar component of each vector is one that is used to count the number of similar status.

Table D

$V1 = (1, 0, 0, 1, 1, 1, 1)$
$V2 = (0, 1, 1, 1, 0, 0, 1)$
$V3 = (2, 0, 0, 2, 2, 2, 1)$
$V4 = (1, 1, 1, 1, 0, 0, 1)$
$V5 = (1, 0, 0, 1, 1, 1, 1)$

- Calculation of scalar products of the form $\langle Vi, Vi \rangle$: the following table T =

$\langle V1, V1 \rangle$	$\langle V2, V2 \rangle$	$\langle V3, V3 \rangle$	$\langle V4, V4 \rangle$	$\langle V5, V5 \rangle$
4	3	16	4	4

- First global iteration:

$$\langle V1, V2 \rangle^2 = 1 \quad \text{and} \quad \langle V1, V1 \rangle \times \langle V2, V2 \rangle = 12$$

The Cauchy–Schwarz inequality is true but we are not in the case of equality, so we move on to the next iteration.

The order of the following iterations: the gray boxes are not calculated because it would be redundant calculations and that would only increase the running time of the algorithm.

The iterations are done from the top left-hand side of the table to the bottom right-hand corner of the table. The calculation is made between any couple of elements in the given vectors set. The processing may involves an important computational time and storage, because the procedures used must make many loop-through for each level in the treatment.

Iterations are performed starting from the top left of the table but skipping the first that is redundant. Then, the next calculation is performed in the direction 1 and when you get to the end of the line, it moves to the next line and the iterations are repeated in the direction 1 and so on (Fig. 6).

Results obtained in this example and interpretation

$$\langle V1, V2 \rangle^2 = 64 \quad \text{and} \quad \langle V1, V1 \rangle \times \langle V3, V3 \rangle = 4 \times 16 = 64$$

As is the case of equality, then we need the recognition to clarify the accounting. The vectors 1 and 3 are then changed as follows since the accounting is done in the last vector.

$V1 = (1, 0, 0, 1, 1, 1, 0)$
$V3 = (2, 0, 0, 2, 2, 2, 2)$

$$\langle V1, V4 \rangle^2 = 4 \quad \text{and} \quad \langle V1, V1 \rangle \times \langle V4, V4 \rangle = 4 \times 4 = 16 \,(\text{no accounting})$$

$$\langle V1, V5 \rangle^2 = 16 \quad \text{and} \quad \langle V1, V1 \rangle \times \langle V5, V5 \rangle = 4 \times 16 = 16 \,(\text{no accounting})$$

$V1 = (1, 0, 0, 1, 1, 1, 0)$
$V5 = (1, 0, 0, 1, 1, 1, 1)$

No change since the last component $V1$ is zero. We therefore proceed to the second line:

$$\langle V2, V3 \rangle^2 = 4 \quad \text{and} \quad \langle V2, V2 \rangle \times \langle V3, V3 \rangle = 3 \times 16 = 48 \,(\text{no accounting})$$

$$\langle V2, V4 \rangle^2 = 8 \quad \text{and} \quad \langle V2, V2 \rangle \times \langle V4, V4 \rangle = 3 \times 4 = 12 \,(\text{no accounting})$$

$$\langle V2, V5 \rangle^2 = 1 \quad \text{and} \quad \langle V2, V2 \rangle \times \langle V5, V5 \rangle = 3 \times 4 = 12 \,(\text{no accounting})$$

$$\langle V3, V4 \rangle^2 = 16 \quad \text{and} \quad \langle V3, V3 \rangle \times \langle V4, V4 \rangle = 16 \times 4 = 64 \,(\text{no accounting})$$

$$\langle V3, V5 \rangle^2 = 64 \quad \text{and} \quad \langle V3, V3 \rangle \times \langle V5, V5 \rangle = 16 \times 4 = 64 \,(\text{accounting})$$

$V3 = (2, 0, 0, 2, 2, 2, 0)$
$V5 = (1, 0, 0, 1, 1, 1, 3)$

$$\langle V4, V5 \rangle^2 = 4 \quad \text{and} \quad \langle V4, V4 \rangle \times \langle V5, V5 \rangle = 4 \times 4 = 16 \,(\text{no accounting})$$

Final result:

$V1 = (1, 0, 0, 1, 1, 1, 0)$
$V2 = (0, 1, 1, 1, 0, 0, 1)$
$V3 = (2, 0, 0, 2, 2, 2, 0)$
$V4 = (1, 1, 1, 1, 0, 0, 1)$
$V5 = (1, 0, 0, 1, 1, 1, 3)$

Interpretation:

We can then see that there are three cases of similar failures ($V1$, $V3$ and $V5$) and the other one has two different states that have occurred once each. This method has advantages because it takes into account the case of symmetric faults. Here, we create three types of packages repairs:

- The first comprises the necessary repairs to the states represented by $V1$, $V3$ and $V5$ because they are parallel or one of the vectors' magnitudes are zero, in a geometrical sense. So it is sufficient to charge the package that corresponds to one failure for the determination of the two others.
- A second and third respectively for the states represented by $V2$ and $V4$.

For example one can imagine a symmetric product and in an explosion, this product is totally damaged (both sides) or partially (one). The use of this algorithm would take into account these cases to gather.

In the considered context of railway industry, the maintenance service considers that packages are sufficiently distinctive in the repair scenarios that a linear combination of two dissimilar packages should be processed as a suitable aggregation of different group of actions. In each case, the group of actions is structured into a timeframe according to technical, organizational and financial considerations. However, a linear combination of established packages gives an interesting indication of the combination of well-identified group of actions and provides a rapid evaluation of the needed maintenance with clear controlled references. In this perspective, the linear combination of packages is advantageous to improve the maintenance service by specifying flexible environment and options.

In the considered enterprise that delivers the comprehensive variety of products and services in the railway industry, the catalogs are organized in a hierarchic way, in tree-like aspect with families and sub-families. The leading family of distributed maintenance services is the Parts Repair/Overhaul Catalog that includes the following: Bogies, Power modules, Tractions motors, Switchgears, Traction Drive, Control Electronics, and Auxiliaries. Each Catalog Parts family comprises different select product lines. Particularly, the Motor contains a set of product lines: Metro, Tramway, Locomotives, Multiples Units, Double Deck, High Speed Trains, Very High Speed Trains and Tram Trains. After the diagnosis, it is established the scope of different kinds of repairs (light, medium and heavy repairs) with the lead time, the warranty duration for the repair and the date of repair offer validity.

5. Conclusion and related works

In this document, we describe an approach using continuous improvement mechanisms to enhance the quality of maintenance services concerning the development of repair packages.

The obtained results with the proposed approach are interesting since they match with contextual situations of the target railway industry. We may include other reasoning mechanisms for knowledge exploitation from experience feedback in maintenance services if necessary. The described reasoning steps could certainly be improved, taking into account the plans that are not fully equivalent (but with one different component). One might also think to optimize the computation time of the algorithm.

Creating repair packages could be an added value to typical Enterprise Resource Planning (ERP) system using multiple components of computer software and hardware to achieve the integration. ERP allows enterprises to integrate data sources and processes in a unified system that can assist in activities such as inventory control, order tracking, customer service, finance and human resources.

Add a function to calculate generic package as it might be fine for large companies that cannot afford to make specific packaging of all their maintenance services with associated products. In the context of industrial use, the link with the ERP would quickly retrieve patterns and automatically derive packages in real-time from such patterns. Therefore, it can be very useful for the maintenance service to have a software system where all the data appear together and where the indicators get calculated automatically. In the event of damage to the work, maintenance service will be able to determine the associate actions in the limited time with a reasonable cost of repair.

An examination of medium-term and long-term safeties indicates that the maintenance system is characterized by the existence of a large number of supplementary and separate elements for traceability. We find these elements in the different parts of the general process of tracking and archiving process of maintenance tasks. The interests for traceability are multiple in maintenance services [22–24]:

- To justify that maintenance actions are carried out in the future through effective feedback processes, by analysis of critical tasks and specifying compliance procedures performed.
- To provide the opportunity for structuring and strengthening relations and networks between collaborative internal and external professionals in the maintenance sector.
- To reflect the aim of promoting the more systematic attainment of uniform or at least comparable standards for the certification of maintenance services, an issue linked to quality assurance, which is essential to the attainment of advanced practiced principles.

For all these reasons, it is clear that some further studies would be developed in the industrial maintenance management to treat open issues (e.g. testability, verification, validation, accreditation and traceability [25–30]). Thus, we have considered that essential to clearly delimit the scope of the study, and serious consideration is being given to the possibilities of development of complementary approaches for the analysis of maintenance reports and generation of information for continuous improvement of knowledge about the quality of services.

References

[1] Bergmann R. Experience management: foundations, development methodology, and Internet-based applications, vol. 2432 of Lecture notes in artificial intelligence. Springer; 2002.

[2] Camarinha-Matos LM, Afsarmanesh H, Galeano N, Molina A. Collaborative networked organizations – concepts and practice in manufacturing enterprises. Comput Ind Eng 2009;57:46–60.

[3] Kamsu Foguem B, Coudert T, Geneste L, Beler C. Knowledge formalization in experience feedback processes: an ontology-based approach. Comput Ind 2008;59(7):694–710.

[4] Jabrouni H, Kamsu-Foguem B, Geneste L, Vaysse C. Continuous improvement through knowledge-guided analysis in experience feedback. Eng Appl Artif Intell 2011;24(8):1419–31.

[5] Jabrouni H, Kamsu-Foguem B, Geneste L, Vaysse C. Analysis reuse exploiting taxonomical information and belief assignment in industrial problem solving. Comput Ind 2013;64(8):1035–44.

[6] Kamsu-Foguem B, Noyes D. Graph-based reasoning in collaborative knowledge management for industrial maintenance. Comput Ind 2013;64(8):998–1013.

[7] Potes Ruiz PA, Kamsu-Foguem B, Noyes D. Knowledge reuse integrating the collaboration from experts in industrial maintenance management. Knowl-Based Syst 2013;50:171–86.

[8] Potes Ruiz PA, Kamsu Foguem B, Grabot B. Generating knowledge in maintenance from experience feedback. Knowl-Based Syst 2014, http://dx.doi.org/10.1016/j.knosys.2014.02.002.

[9] Fernández G, Francisco J, Márquez AC. Framework for implementation of maintenance management in distribution network service providers. Reliabil Eng Syst Safety 2009, http://dx.doi.org/10.1016/j.ress.2009.04.003.

[10] De Leon PM, González-Prida Díaz V, Martínez LB, Márquezort AC. A practical method for the maintainability assessment in industrial devices using indicators and specific attributes. Reliabil Eng Syst Safety 2012;100:84–92.

[11] Kamsu-Foguem B. Knowledge-based support in Non-Destructive Testing for health monitoring of aircraft structures. Adv Eng Inform (ADVEI) 2012;26(4):859–69.

[12] Karray MH, Chebel-Morello B, Zerhouni N. A formal ontology for industrial maintenance. Appl Ontol J 2012;7(3):269–310.

[13] I-Ching H. Integrating ontology technology with folksonomies for personalized social tag recommendation. Appl Soft Comput 2013;13(8):3745–50.

[14] Kamsu-Foguem B, Mathieu Y. Software architecture knowledge for intelligent light maintenance. Adv Eng Softw 2014;67:125–35.

[15] Harding JA, Shahbaz M, Srnivas, Kusiak A. Data mining in manufacturing: a review. J Manufact Sci Eng 2006;128:969–76.

[16] Kamsu Foguem B, Rigal F, Mauget F. Mining association rules for the quality improvement of the production process. Expert Syst Appl 2013;40(4):1034–45.

[17] Alzghoul A, Löfstrand M. Increasing availability of industrial systems through data stream mining. Comput Ind Eng 2011;60:195–205.

[18] Beaudouin F, Munier B. A revision of industrial risk management: decisions and experimental tools in risk business. Risk Decis Anal 2009;1:3–20, http://dx.doi.org/10.3233/RDA-2008-0001.

[19] Köksal G, Batmaz _I, Testik MC. A review of data mining applications for quality improvement in manufacturing industry. Expert Syst Appl 2011;38(10):13448–67.

[20] Avizienis A, Laprie J-C, Randell B, Landwehr C. Basic concepts and taxonomy of dependable and secure computing. IEEE Trans Depend Secure Comput 2004;1(1):11–33.

[21] Xu R, Wunsch D. Clustering. Hoboken, NJ: Wiley-IEEE Press; 2009, 358 pp. Type: Book (9780470276808).

[22] Weber RO, Aha DW. Intelligent delivery of military lessons learned. Decis Support Syst 2003;34(3):287–304.

[23] Zio E. Reliability engineering: old problems and new challenges. Reliabil Eng Syst Safety 2009;94(2):125–41.

[24] Vujanović D, Momčilović V, Bojović N, Papić V. Evaluation of vehicle fleet maintenance management indicators by application of DEMATEL and ANP. Expert Syst Appl 2012;39(12):10552–63.

[25] Kamsu-Foguem B, Simeu E. Optimizing construction of scheduled data flow graph for on-line testability. Mediterr J Comput Netw 2012;8(4):124–32. ISSN: 1744-2397.
[26] Kamsu-Foguem B, Chapurlat V. Requirements modelling and formal analysis using graph operations. Int J Prod Res 2006;44(17):3451–70 (Thomson Reuters | Web of Science, Impact Factor: 1.323).
[27] Chapurlat V, Kamsu-Foguem B, Prunet F. A formal verification framework and associated tools for Enterprise Modeling: Application to UEML. Comput Ind 2006;57(2):153–66 (Thomson Reuters | Web of Science, Impact Factor: 1.457).
[28] Kamsu-Foguem B, Chapurlat V, Prunet F. Vérification de modèles de processus d'entreprise: une approche formelle. Journal Européen des Systèmes Automatisés 2005;39/9–10:1051–78.
[29] Chapurlat BV, Kamsu-Foguem B, Prunet F. Enterprise model verification and validation: an approach. Annu Rev Control 2003;27(2):185–97 (Thomson Reuters | Web of Science, Impact Factor: 1.878).
[30] Doumbouya MB, Kamsu-Foguem B, Kenfack H, Foguem C. A framework for decision making on teleexpertise with traceability of the reasoning. IRBM 2014, http://dx.doi.org/10.1016/j.irbm.2014.09.002.

Bernard Kamsu-Foguem has a PhD in Computer Science and Engineering from the University of Montpellier 2 in 2004. He got the "accreditation to supervise research", abbreviated HDR from University of Toulouse in 2013. He has obtained the status of Visiting Professor at international universities: United Kingdom (e.g. Oxford Brookes University, Oxford), Finland (e.g. Aalto University, Helsinki University of Technology, VTT Technical Research Centre of Tampere, University of Oulu, Åbo akademi of Turku University). His current interests are in Knowledge Discovery and Data Mining, Knowledge Representation, Formal Visual Reasoning, Ontology-based Semantic Analysis, Knowledge Exploitation for remote Collaboration, Decision Support Systems and Intelligent Systems. Application domains include industrial Continuous Improvement processes, Telemedicine services and Health Information Systems. He is a reviewer for a large number of international scientific journals such as Computers in Biology and Medicine, Knowledge Management Research & Practice, Interacting with Computers, Sensors, Engineering Applications of Artificial Intelligence and Knowledge-Based Systems. He is a member of the thematic group: e-Health of InterOP-VLab (International Virtual Laboratory for Enterprise Interoperability).