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Experience feedback in product lifecycle management

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ABSTRACT

Given the popularity of industrial enterprises for Product Lifecycle Management (PLM) information systems capable of supporting the entire product development process, we see the emergence of new needs and new research directions in the operation of these dynamic complex environments. Reference standards are applicable to the services and industries which bring innovation and technologies to a fast-growing and demanding market. To obtain perfect control of business risks and performance and to ensure "zero defect", standards specific to the fields of transport, emergency (IRIS IN 9100 ...) and generic standards (ISO 9001 ...) are more restrictive. They involve full transparency and rigor in flawless quality management processes and monitoring products. In this field, knowledge management is paramount; it helps improve overall performance of industrial systems by structuring the information assets acquired by the company stakeholders. In a way, it is the substantive development of our research. We detailed the approach adopted to implement the Experience Feedback (EF) system dedicated to the product in the PLM business. We presented a first action with the objective of formalizing the implicit experiences generated following the response to a triggering event. In this work, we mainly considered negative events for which the information to be collected are clearly identified. We propose an approach combining Problem Solving and EF adapting the level of commitment to the criticality or importance of the problem addressed. To instantiate this approach in PLM, we have chosen to rely on the Change Management Process (CMP) because, firstly, it involves changes in product data and, secondly, it usually concerns driving developments for correction or improvement of the technical specifications related to the production process.

1. Introduction

The consideration of Experience Feedback (EF) to different levels of the company's activities is one of the safest ways to increase the quality of its products and services. Many companies wishing to capitalize or enhance their intellectual capital have adopted EF processes in their continuous improvement plan. If the general principle of EF in the enterprise is readily accepted by all, the implementation and conduct in daily life of an EF system is much harder to ensure. Indeed, despite the accession of the actors to the principles of Application of EF, many barriers appear in their implementation, mortgaging, often dramatically, the success of this approach. We are interested in these problems and try to define an action strategy for the effective implementation of PLM (Product Lifecycle Management) in the company. Many companies which lead reflection on the continuous improvement of processes and product performance have adopted or are deploying PLM solutions to support their process development. Based on this observation, the proposed work tries to ensure the proper use of functionalities and implementation of activities associated with the exploitation of the PLM tool and, above all, structured framework of its application to develop and implement an EF system.

The presented work focuses on the deployment of an EF System in a manufacturing company through capabilities of PLM software. The paper is organized as follows. We start by defining the experience feedback systems. Then, we present current practices and business barriers and highlight some industrial needs. Then we describe the principles of the solution that we implement. The conclusion presents the findings of the study with some indications of the possible action prospects.

2. Experience feedback systems

2.1. Presentation

To be competitive, companies need to develop the best economic and technical conditions, top-quality products that meet the

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requirements of customers, and which comply with applicable regulations. Both are customer-specific and therefore external and internal to the company. To achieve this challenge, product development cycle management is paramount and reuse of knowledge and know-how is a determining factor in the effectiveness of performance. An intermediary challenge to enterprises is to be able to capitalize on experiences carried out during the product development to create knowledge and to make them available in order to help the different stakeholders involved in the development processes of new achievements. The management of EF systems is one of the key issues related to knowledge engineering to achieve this ambitious, but considerably significant, goal.

EF is an initiative engaged to enhance the value of experience gained when processing a proven event or a previous situation to draw lessons for developments or future actions [1]. Among the knowledge management approaches, the EF is part of the "Continuous Knowledge memorization" that focuses on the structuring and accessibility of collected experiences. Indeed, the EF is a spontaneous approach and is rooted in efforts to achieve a comprehensive and durable actions, and the registration process of experiences is performed in the relevant context.

EF emerged about thirty years ago, to address the problems of "losses of technical memories, choices, expertise or practices" [2]. We can cite, for example, the case of transport companies (automobile, aeronautic or shipping industries), where the retirement of human resources working in the methods and quality services has considerable impact on the business's overall fundamental knowledge [3]. Today, this theme brings together a broad scientific industrial community, including a comparative analysis of approaches as proposed in [4,5]. From these works, there are four main types of EF:

- For statistical processing: system focused on collection and formalization of events,
- A cycle of Knowledge Discovery from Data (KDD): Data is collected and analysed to develop knowledge in the form of decision rules,
- Through knowledge management process: method which aims to clarify and enhance the business knowledge and technical expertise,
- By case-based reasoning: system based on knowledge building from operating experiences from problem solving processes.

Even if they have specific characteristics, these four types of EFs can fit into a global model. Indeed, the differences mainly lie in the phases of development constituting the precision of the Experience Feedback approach. EF models used in this paper integrate these four types. It consists of three phases, described more specifically in the following paragraphs.

2.2. Definition

Amongst the various definitions available in the subject literature, we selected the one proposed by [6]: "*The Experience Feedback is a structured approach to capitalization and using information from the analysis of positive and/or negative events. This approach implements a set of human and technological resources which must be managed for the assistance of reducing errors and promoting some rehearsals good practices*." Thus, the Experience Feedback is based on the development of mechanisms, processes and specific software tools to locate, capitalize, store, create, formalize and distribute experience and knowledge in order to improve business processes and eliminate previous errors [7].

The purpose of EF is to build knowledge from the generalization of one or several experiences. Experience can be defined as the set of elements that permit us to construct and implement the response to the occurrence and the treatment of a positive or negative event. EF process consists of three main phases (See Fig. 1):

- The capitalization phase, to locate and store (experiences base) the relevant data to characterize an experience,
- The treatment phase is intended to transform these experiences into rules and knowledge usable by actors (managers, technicians and/or operators) in business processes,
- The operational phase, to facilitate and promote employment of documented experience and knowledge, in business processes in order to improve performances.

Depending on requirements, an EF system can be engaged to identify and develop:

- Good practices: positive EF,
- Errors found: negative EF.

Similarly, it may be designed to be applied locally or globally. Locally, the information is used by the activity or process triggering capitalization. This is called source activity/process. In total, capitalized information is used by other activities or business processes. The source activities and the information-consuming activities are then different. The shared experiential knowledge can be incorporated in lessons-learned processes and systems deployed in military, government and commercial organizations. In the following paragraphs, we summarize the essential characteristics of Experience Feedback. For more information on

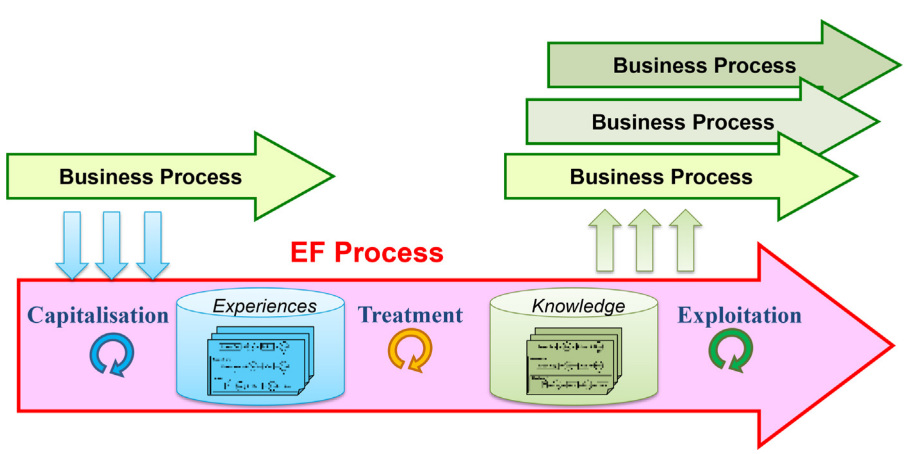


Fig. 1. EF process.

this method of continuous improvement, the reader can refer for instance to Weber et al. [8].

2.3. Capitalisation phase

This phase corresponds to the location and collection of non-intrusive data that characterize the experience related to the event that led to the commitment of activities and resources (see Fig. 2). This "Trigger" event may concern the verification of compliance with the specifications (positive EF) and the appearance of a major nonconformity needing actions to eradicate it (negative EF). The location is to identify the business processes or the source activity, the relevant data that are necessary and sufficient for the elaboration of knowledge exploitable locally and/or globally. As we previously reported, this information will help characterize an experience. Depending on requirements, the data may affect the triggering event (description of the context), actors engaged with their competencies, envisaged solutions, selection criteria, the action plan to deploy the adopted solutions and the achieved results [9]. All the relevant data will then be gathered to constitute "the vector of the experience."

2.4. Treatment phase

The acquisition is to select the results recorded by the actors:

- Or when carrying out their business activity,
- Or when solving a problem,

The localized data are relevant to the constitution of an experience vector. In storage, it is necessary to use a common database dedicated to EF with the establishment of security and access management activities. Moreover, it is important to homogenise the terminologies used in order to properly organize the volume of information capitalized and most importantly, to ease exploitation. This last point is essential because if the documented experiences are not easily identifiable, they will not be used by actors to support their decision-making processes and, therefore, all efforts to capitalize the associated information will be useless.

This first phase of EF aims to characterize each experience by a data vector: context of occurrence, trigger events, solutions designed, deployment plans and results [5]. It is the foundation of EF [10]: if capitalized information is insufficient and/or irrelevant it will be impossible to generate useful knowledge. The location of the data to be collected is therefore a major action.

The treatment process is the second phase of EF. Its role is to generalize some of the experiences recorded; that is to say to transform sparse vector data into actionable knowledge of activities and/or consuming process. The treatment process is a formal process in which key tasks are the analysis, interpretation, synthesis of information and formalization of knowledge. It requires the involvement of different experts able, firstly, to understand the quality, relevance and completeness of the data vectors and, secondly, to locally and globally assess the relevance and the scope of use of knowledge generated.

Once created, this knowledge must be formalized in a specific form adapted to working methods of actors involved in the businesses affected. Indeed, the goal is not only to create understandable rules by experts but to record knowledge generated at the realization of a process or a problem-solving exercise in models assimilated by business stakeholders, be they managers, technicians or operators. The formalization techniques are also the subject of many research works. We find especially conventional processes: the prescriptive (or normative) models and descriptive (or cognitive) models [11] that involve reasoning applied to easily interpretable information. The ontology approaches allow the production of conceptual models shared by a defined community [12].

Other more formal methods such as Methodology for Knowledge System Management (MKSM) or Method for analysing and Structuring Knowledge (MASK) [13] are descriptive analyses to define a framework for the formalization of the company's knowledge. Finally, the knowledge must be "versioned" to monitor developments. Many works deal with "versioning", according to various criteria such as conservation of data logging, coherence analysis, the complexity of developing out of which an analysis is proposed [14]. Thus, the treatment phase aims to generalize one or several experiences to develop new knowledge or update such knowledge as must be used directly by targeted business actors. It is important to specify that in EF systems, the generation of knowledge is not automatic. This transformation requires the establishment of specific processes and the input of the expertise of professionals.

We illustrate the principles of the treatment phase in the diagram of Fig. 3.

2.5. Exploitation phase

This phase should enable actors to access to knowledge, experiences and other data appropriate to their job in order to make reliable decisions and to avoid previous mistakes. For this, it is necessary to filter the information available in the common database (EF base) and make available only that relevant to the current case. Although the purpose of EF is to allow actors to use the information capitalized, this phase is still often not properly taken into account and/or is performed poorly in businesses: information does not reach the people concerned and its exploitation is difficult [15].

Thus, to properly carry out this exploitation phase, the information requirements of stakeholders must be precisely defined, in order to limit the volume accessible, and to provide

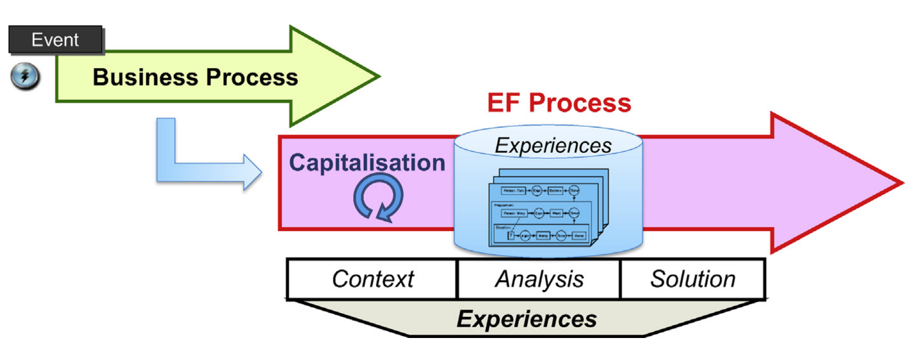


Fig. 2. Capitalisation phase.

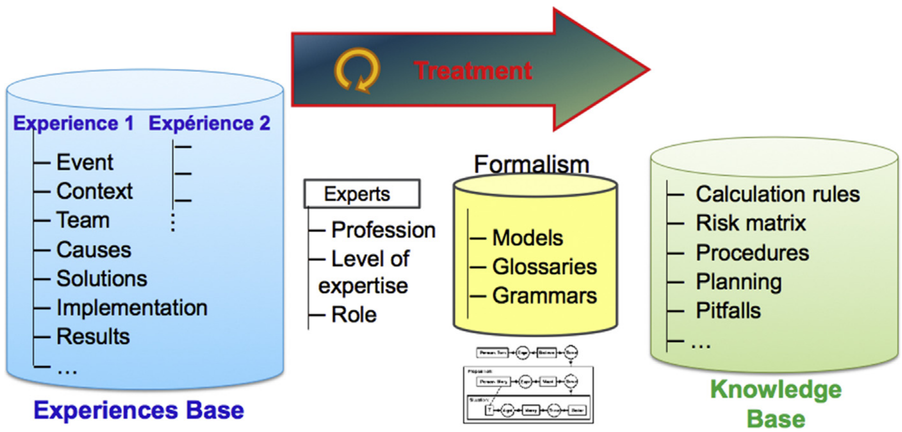


Fig. 3. Exploitation phase.

easy access while controlling rights. It is also important to allow actors to search for other types of information, in particular for comparing previous experiences. The solutions implemented for this operational phase have made use of the essential and practical EF base. There are two operating modes. The "push" mode provides information directly to the actor during the information processing of a particular event. Information is broadcast in support of decision-making processes. This mode of operation requires no research effort because the information is directly available and easily accessible. However, it is necessary to have defined exactly the current need in order not to omit useful information or to avoid polluting the decision-making processes. The "Pull" mode corresponds to information retrieval in EF base. This mode allows the actor to refer to the complete base from which it can extract all information that is deemed to be interesting. This approach requires involvement of the actor and the structuring of appropriate information for efficient storage and easy searching. Finally, we must ensure the security of the EF base with the establishment of an access management system allocating specific access rights to users. To improve information research in the EF base, there are also specific tools such as Case Based Reasoning (CBR) [16] which allows identification by similarity, calculating previous experiences that are close to the case being treated. These reasoning systems, while providing some effective solutions on the computational aspects, are little used by business actors.

2.6. Synthesis

EF is an approach based on the capitalization and exploitation of information related to business processes to enable enterprises to record and enhance intangible capital important for their development and sustainability.

The essential points of the method are the location of information to capitalize, the non-intrusive collection, the knowledge creation and exploitation in order to support decision-making. In this part, we have focused on presenting the components of an EF system in order to better understand some existing difficulties of implementation.

3. Experience feedback in a manufacturing company

3.1. Industrial context

The target company is the world leader in the development and manufacture of high technology batteries. Today, it faces an industrial context that is increasingly complex, with amplified competition, because of the globalization of markets, the emergence of highly reactive new industrial countries and the growing requirements of customers.

To remain competitive, the considered company must continually seek to reduce costs and delays, improve quality and innovate to develop new technological and commercial offers. Reducing costs and time requires actions throughout the lifecycle of the product, from the design phase of the after-sale services. Maintaining the quality of products obviously implies compliance with domain-specific standards (International Railway Industry Standard (IRIS), certification for quality in the aeronautical/space/defence industry (EN 9100)) and generic norms (ISO 9001:2015 – sets out the requirements of a quality management system), which become more and more restrictive. The expansion of regulatory requirements reinforces the constraints of traceability and reliability of products.

Finally, innovation remains the key factor of progress that allows companies to keep a technological edge over competitors. In response to changes in the industrial context, the considered company decided ten years ago to position itself in a new market for so-called complex systems. The group then incorporated new elements to its batteries, such as thermal, electronic, and supervision systems in order to extend the functionalities available. The complexity of products is involved in the introduction of new competencies in the company and the proliferation of technological tools associated with each competency. Given this situation, the considered company has decided to step up its efforts to improve the performance of its process, initially by decreasing costs and time-to-market and, subsequently, by improving the quality and product performances.

To meet these needs, improving production tools is no longer sufficient and the target company has begun to work on the formalization, exploitation and sustainability of its knowledge and expertise. Among the different approaches of knowledge engineering to achieve this objective, the considered company decided to implement a comprehensive Experience Feedback system.

3.2. Situational analysis

Experience Feedback is a long-standing practice and actions and point tools have already been developed in the company. An inventory and an audit of product development services have also been made to identify the limitations and frustrations of current practices [17]. The purpose of this first work was multiple:

- Analysis of the perception of the actors vis-à-vis the Experience Feedback,

- Identification of obstacles and strengths of the existing practices,
- Specification of user expectations for management of their intangible heritage.

The audit was conducted on a representative range of thirty people: each professional group (mechanics, electronics, thermodynamics and chemistry) with various hierarchical levels (technician, manager and supervisor) was audited. The representativeness of responsibility levels in the sample was equilibrated with 11 department managers, 10 engineers and 10 technicians. Furthermore, the low “turnover” within the considered company (up to years seniority) allowed for reliable results based on strong internal expertise. The questionnaire included thirty questions with 40% of open questions, the remaining 60% were multiple choice. The questions were organized into four parts: the context of work with the tools used, the current working methods, the points for improvement and expectations and aspirations.

3.3. Experience feedback perception

According to the occupation category, the various actors have different perceptions or sensitivity levels of expectations for the Experience Feedback. Service managers and engineers displayed a willingness to share and express an interest in the deployment of an experience feedback solution (Fig. 4). The vertical axis represents the proportion of actors in the sample interested in the experience feedback. The horizontal axis represents some specific aspects of improvements associated with work or activities. To be effective, the considered Experience Feedback system is expected to be applicable to the various technical and managerial services involved in the industrial development of products. The process generated must induce a generic approach adopted by all actors (purchaser, technician, engineer, drawer, worker and manager).

Their expectations relate primarily to development projects, the costs and the lifecycle of the product. Moreover, these actors are aware of the opportunities of such an approach, and the engendered deployment and use issues. For technicians, involvement is less and simply concerns design methods and recovery of previous solutions. Their expectations concern the activity of product design without integrating cost concepts.

Overall, all users have expressed the need to capture technical knowledge on sustainable products as well as the basic rules to standardize design and business activities. Managers seek mainly the sharing of information and knowledge acquired during development to make them easily usable and reusable in new projects. Engineers focus on the learning of working methods applicable in design as well as the capitalization of experiences to store notable facts. The vision of the technicians is less clear because they do not project themselves into the product lifecycle level and often perceive Experience Feedback as a capitalization work that it would be beneficial for other people.

Thus, the audited actors professed a more or less pronounced willingness for the deployment of an Experience Feedback system to mainly improve:

- the product quality: technical performance and optimization design,
- the sustainability of knowledge: basic knowledge and rules based on technical professions.

3.4. Tools used

Regarding the current practices in terms of EF we listed a dozen specific applications dedicated to technologies and made them available to the actors of the considered company. These are the applications dedicated to the archiving of technical results and the dissemination of information on data flows between cooperative activities. They guide the realization activities and constitute specific and shared storage spaces for results and indications.

The information, stored in these specific applications, is an exploitable source in the creation of an EF process because information is created and directly used during industrial developments. We identified three categories of tools:

- The first consists of tools specific to a technical profession. These tools are unique to a type of actors and allow storage of positive results only, without the detailed actions related to failures and employed working methods.
- The second category is composed of tools dedicated to a transversal theme such as quality, or the management of development projects. These tools are accessible on the internal network which is a shared storage space that is secured and compartmentalized per services in the concerned company. This network is the core of information sharing: each actor has certain rights of access and modification of files and directories are clearly identified. The actors can also save the data, according to the associated procedures, rules and models.
- The final category consists of oral or computer communication tools. This category is the more used internally for EF.

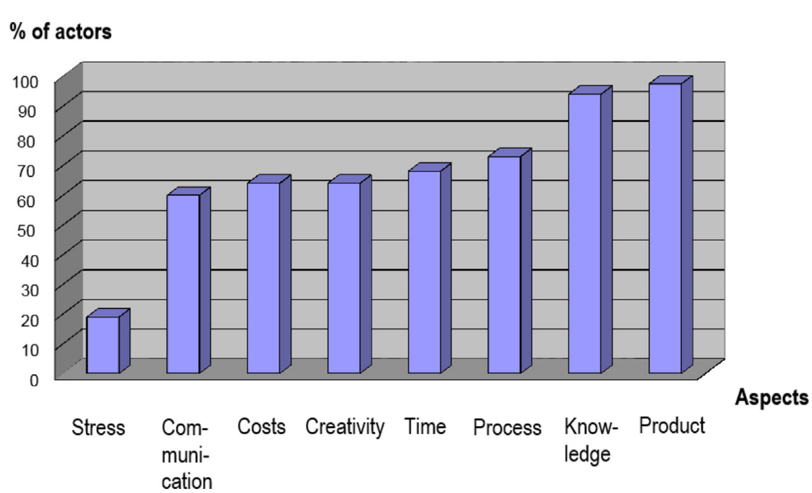


Fig. 4. Perceived interests of improvements with experience feedback.

Indeed, the actors are business experts, specialized in the product development segment. As we have already reported, the staff turnover is low and actors naturally capitalize on their activities. Thus, the first vector of EF is communication amongst experts during project reviews or email exchanges.

3.5. Barriers identified

On the basis of this audit, we could list the working methods used and identify bottlenecks to achieve an efficient EF. We classified all causes identified during interviews with the Ishikawa diagram shown in Fig. 5. Interviews were conducted on the feelings of the actors towards the tools of work used daily. This study made it possible to highlight the brakes and motivations of the audited staff. Although only about thirty people were interviewed, the questioning of these actors was particularly interesting because it was a representative sample of the different occupations involved in this issue facing the company. The main causes identified in these interviews are cross-checked with other sources of information from previous studies carried out in similar companies to ensure consistency in the information produced.

The main obstacles identified in the practice of EF are:

- ***Material***: input data entered in the process are mastered by its creator but are not formalized (simple statistical data) which generates an operating difficulty and identification of information and its relevance. In addition, descriptions are often too technical and focused on human errors which does not allow for enough contextual elements for future analysis,
- ***Machine***: the professional dedicated tools have low impact on EF. They are independent and provide heterogeneous supports, causing significant times in collection and search information,
- ***Methods***: the set of usage rules and access rights are often ignored by the majority of users, limiting the sharing of information. Restitution model is insufficiently employed, which leads to incomplete reviews and analysis.
- ***People***: the practice of working in isolation (expert) and distrust of information security generates resistance to sharing. Capitalization and information gathering is often performed from the position of staff working alone and without the use of specified tools. The lack of indicators to measure actions relating to the EF does not encourage actors to invest in this direction. Finally, the protagonists are not sufficiently aware of the benefits of the EF, since they often have difficulty writing reports in an appropriate form, using the information recorded in a comprehensive manner, putting in the necessary time or effort on Experience Feedback,
- ***Environment***: the working environment consists of many independent tools with specific functional perimeters and this engenders ignorance of actual capacity of each. Furthermore, without a bridge between the tools, information can be potentially outdated or necessitate redundant data entry.

Identification of barriers, key points to move the company forward, enables us to highlight needs, identify pitfalls and communicate on our future actions. In summary chart of Fig. 5, the expression of user barriers reflects:

- A lack of availability of actors to make EF,
- Difficulty in the choice and use of tools,
- Information gathering is fragmented as a result of the use of several different tools.
- Fear of the reliability and security of available information,
- A lack of models for structuring information,
- Information recording too often limited to statistical data, which is not contextualized,
- Reluctance to write reports for previous actions that led to a success,
- Difficulties to easily exploit information recorded in current tools,
- The feeling of loss of power following the setting of common methods or professional 'tricks',
- Reluctance to change existing working habits.

Thus, the audit of EF helped to show the limitations of current approaches in knowledge management tools.

3.6. Statement of requirements

Based on the needs expressed during the audit, the willingness of actors to improve is primarily driven by:

- Improvement of the activities involved in the product lifecycle: the product is the heart of the company. The aim being to make a robust product in optimal conditions (cost, time, quality), compliant with regulations in each country, and which satisfies the customer,

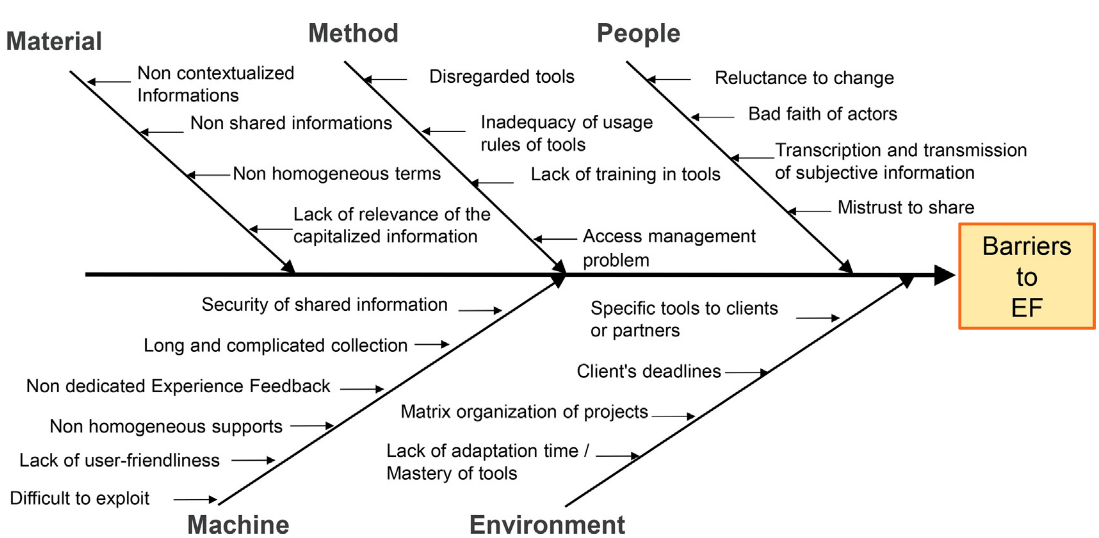


Fig. 5. Ishikawa Diagram.

- Sustainability of knowledge: to progress, one must be able to capture knowledge, to add value, for internal dissemination and reuse in order to be able to keep its leading position. Furthermore, one must implement knowledge management (versioning) to ensure that the information provided is still valid.

To meet these two objectives, it is necessary to establish an efficient knowledge management system, that is to say one able to handle experience and business knowledge and which allows all actors business processes with easy access to relevant and updated information.

The elements that should be available for domain actors fall into four main areas:

1) the provision of a common information system architecture dedicated to the product and business information management: elements needed to secure the information, control access and ensure uniqueness and updating of information.
2) specification for each profession, model ("template") to be used to describe the events, experiences and knowledge: these specified elements, on the one hand, to guarantee the contents of the EF base, the heart of the system and, secondly, to achieve a maturity stage on the field concerned by enforcing structured thought, observation and explicit expression of elements manipulated to all users [18].
3) the definition of a process for knowledge creation and update: on recorded experiences, the domain experts need a formal method to develop internal standards, to keep the knowledge support alive, and consider means to track versions available (versioning).
4) the provision of an operating system for the content of the EF database: the information must be easily exploitable, traced and updated, on the one hand, to improve product and business process performances, and on the other hand, to justify the interest of efforts made by stakeholders to deploy and to make alive the entire experience feedback system.

4. Principles of solutions

In the framework of continuous improvement, the considered company is engaged with a deployment project of PLM (Product Lifecycle Management). We propose to use this framework to implement an efficient EF system and respond to the previous requirements and barriers.

4.1. Presentation

There are many forms Product Lifecycle Management Systems (PLMS) that are implemented to create an integrated product information environment. PLMS provide a strategic approach which applies a consistent set of business solutions supporting the creation, management, dissemination and use technical data of products across the extended enterprise, from concept to end of life. PLM creates, controls, disseminates and uses this information throughout the product lifecycle. There is a complementarity of document management and product relational data management to meet PLM issues in many Small and Medium-size Enterprises [19]. PLM is supported by a software package aimed at creating a collaborative work environment for actors involved in the development cycle of some products. It allows the "orchestration" and systematization of the conduct of common and formal business processes (called "workflow"), in which the responsibilities, access rights, roles and information to input and outputs are clearly defined. The information registered in the common database of PLM are structured using metadata including individuals (objects), classes (sets of object types), attributes (characteristics or properties of objects), relationships (links between objects) and events [20]. This set of various information is structured in a metadata repository l: each metadata is set in a format definition: text, date, binary, scrolling list, etc. The use of a common metadata repository provides the homogeneity of the metadata associated with all distinct objects belonging to this repository. This allows the systematization and standardization of the reporting of results. The use of a specific word for generic information of metadata requires actors working in a business process to speak with the same terms and abbreviations, which facilitates storage, search by keyword, understanding and exchanges. Thus; PLM tools help to collect and structure the information generated during development; while orchestrating the execution of activities that make up this process.

4.2. Integration of an experience feedback system

The target of our work is to facilitate the:

- Capitalization of relevant information generated during developments to create vectors of experiences,
- Establishment of a formal process of knowledge creation with model types,
- Reinjection of the gathered information in the form of experience or knowledge vectors in a controlled and appropriate manner throughout the product lifecycle.

For this, we chose to exploit the functionalities offered by the PLM tool and induced framework to implement our EF system. The principle of this solution is illustrated in Fig. 6.

EF system will be supplied with certain information related to the development collected by PLM and centralized in its own common database. Thus, all the information will be retrieved in a single, consistent and reliable source. The documents and the nature of information manipulated in PLM are the technical data of business models. They contain information relating to results of operations, ensuring the relevance of their content in use for the EF. In addition, the use of the PLM structure offers an advantage for information capitalization and exploitation. In fact, a first formalization by using metadata is obligatory. The use of a common reference with the same management policies for all users promotes the uniqueness and update of employed information and facilitates the exchange and comprehension.

4.3. Interest of the linkage EF-PLM

Looking again to the four points identified for an efficient EF system (see §3.6), it appears that the use of PLM enables:

- To respond directly to points 1, 2 and 4,
- To provide a formal framework for point 3.

4.3.1. Point 1

PLM is based on the use of a single, common database to centralize and share information within business processes. This condition allows the eradication of problems relating to the existence of specific storage areas for each actor. Thus, the experiences are recorded in the single common database for all business processes for all services, allowing the reduction of the appearance of duplications and the promotion of the uniqueness of information. PLM also includes the features definition and access

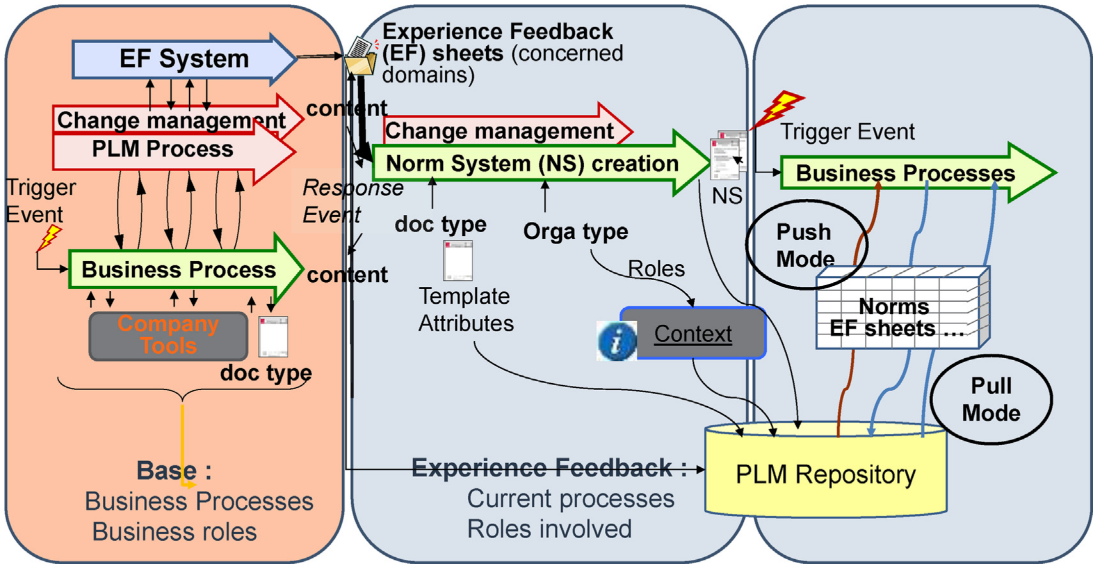


Fig. 6. Integration of EF into PLM mechanisms.

rights management to the database for all actors, which allows us to define and manage possible actions of each.

4.3.2. Point 2

the use of PLM requires the completion and use of the metadata available in the tool. However, metadata used to structure only the shape and content of information. Content that is the heart of EF system (creation of the experience vector) is not supported by metadata. To meet this need, we have implemented standard reporting frames enabling actors to describe experiences using scrolling lists and key terms. These frames or "templates" directly associated with the PLM object help actors in the seizure operations while homogenizing information capture. Furthermore, their employment facilitates the localization of some relevant information (having meaning for the knowledge creation) in the contents in order to facilitate the constitution of experience vectors.

4.3.3. Point 3

PLM is used to define formal processes and therefore orchestrate the implementation of interrelated activities. In these processes or "workflows" the sequence of activities and tasks to perform, the allocation of responsibilities and rights of access, the intervention of different business roles in process and supporting documents are to be used and described, formally. Thus, PLM provides a framework to implement the treatment phase to transform the experiences recorded into knowledge usable by business actors. Finally, PLM have in their original functionalities, workflows for managing maturity stages of documents to ensure the provision of formally validated information.

4.3.4. Point 4

using the registered information and extraction queries, PLM allows for automatic establishment of EF sheets containing synthesis of experiences. Stored in the PLM database, these EF records are easily accessible and usable by the actors. Furthermore, profession and skill levels being assigned to each actor through the definition roles in workflows, it is possible to inform actors automatically of the creation and/or update of specific knowledge. Thus, the coupling "Activity – Occupation – Actor "allows a first implementation of the EF system in a Push mode.

In synthesis, coupling to PLM with EF processes is useful to benefit functionalities "naturally" offered by this type of tool to avoid many of the barriers of EF expressed by business actors.

4.4. Computer applications in industry aspects

Some computer applications in industry aspects are essential, since in the concerned enterprise they are useful to simplify the procedures and reduce the time frame for the processing of experiences. These aspects include requirements definition, setting the parameters of the data management and other specifics required for appropriate configuration and user information.

Beyond the implementation work which supported the creation and the major configurations of the computer tool, we carried out an accompaniment of the reflection on the choices of definition of the objects and the workflows. The principles of concrete applications are used to verify that the configuration of the computer tool, the main settings and the associated documentation correspond to the functional specifications issued by the company. This verification is carried out by confirmed actors of the company's internal processes to undertake test scenarios on real cases. We took advantage of this testing stage to train users in the new functions of the tool and to collect their evaluation of them.

Therefore, we have specified the definitions of a meta-repository with the automated processes and the parameters necessary to obtain data management in line with internal processes. Similarly, we have managed the deployment, training and communication activities to ensure that we validate the established elements and maximize the adoption of the PLM tool by future users.

The technical documents, rich in knowledge and business know-how, have been integrated into the PLM database and are therefore managed as PLM objects. In the proposed solution, the computerized mechanisms exploit these elements of knowledge supports and workflows of PLM evolution to instantiate the processing process of experience feedback. This processing process aims to transform one or more experiments into business knowledge.

5. Validation with a case study

This section is devoted to the presentation of problem-solving on a concrete case of an established default in the target company.

The product on which the anomaly is detected is a battery. At the PLM level, it is declared in the production phase and consequently managed. Instigated by a customer complaint, the manifestation of the problem initiates the problem-solving experience that we present here to show the applicability of EF solutions that we have developed.

The complaint concerns certain technical characteristics of the product and is therefore directly linked to the definition of the product. The model of experience and knowledge will be generated, after the processing of modifications related to the considered experiences, by generating EF records filled out during the process.

We present this experience phase for:

1) validation of the EF solution that we proposed by verifying its applicability and that it generates re-exploitable data (EF files in the PLM database),
2) verification that the solution meets user expectations and that it can be operationalized for any change request in the PLM.

This case study will also highlight:

- The necessary prerequisites for applying the approach,
- The importance of the involvement and motivation of pilots to lead the process of structured resolution supporting the method,
- The effect of changes in work habits that must be accompanied internally to sensitize users to the resulting benefits.

It should be noted that the case presented here corresponds to a complex problem because it traces a complete problem-solving process involving an important work of analysis and search for solutions.

This work was carried out in parallel with the internal non-computerized resolution processes used in the considered company at the date of the experience; the confrontation with the developments of the approach made it possible to ensure that the solution was complete and accessible to all users.

The example is presented in chronological order of events. We present the actions, actors and information committed as they participate in the process to highlight the contributions of structuring the problem-solving methodology and the anchors for the elements of EF.

5.1. Initial situation: a customer complaint on battery hoses

The triggering event of the example is a real case, reported by a customer, concerning a set of similar components located at a specific point on several batteries: the deterioration of hoses with the detection of a white deposit on the component (aspect and sealing).

The complaint process is initiated by the customer at the company's Quality Support Service. An engineer or a technician of this service, declared with a "guest" role in the PLM product contexts, takes charge of this complaint: this is the witness. The witness initializes a problem report (PR). He declares the incident and the actions taken to respond to the complaint in PR. According to the instructions of the description task, he must:

- inform the elements of the context and of the event via the automatic fields of PLM,
- link to the PR the descriptive documents (mails, photos, complaints ...) and the objects assigned to the PLM.

The information provided by the complaint describes the context. This document formalized by the company contains information on:

- the identification of the products concerned: Battery XXX and the information relating to its configuration,
- the conditions of use of the batteries: maintenance reports, battery usage time, maintenance conditions ... ,
- the date of detection of the fault and its description: location on the battery (photo),
- the first investigations carried out to identify the defect: chemical expertise of the deposits, technical tests to test the insulation of the component.

The creator of the PR, (witness) declares and integrates the description of the technical problem arising from the complaint process. The complaint process is a business process in its own right that we do not describe in the example. Its output data is the input data of the problem report.

When the description is considered clear and complete, the PR promotion task is validated. The analysis notification is sent to the Change Administrator I (CA1).

The technical person in charge of this product (the actor who guarantees the conformity of the definition of the battery to the production state) is the pilot and, in accordance with the instructions, he must:

– read the description of the problem,
– make a general analysis of the problem supported by the tool called "5W1H (What happened? Who is involved? Where did it take place? When did it take place? Why did that happen? How did it happen?) – Is/Is not" according to the results of the chemical analysis carried out during the complaint,
– search for similar open PRs in product contexts and consult EF,
– confirm that the problem requires a resolution process involving modification of one or more components of the battery.

Problem management is necessary because there is an impact on customer satisfaction and no solution is obvious. We illustrate the behaviour of the process in the diagram in Fig. 7, in which we find all the information, actions and skills implemented.

The extract of the table attached to Fig. 7 is part of a validation tool that we used for this case study and which made it possible to verify, by gradual filling of the proposed fields, the consistency of the progression by confrontation with the case of experience. We will find this validation element in the following Figs. 8 and 9.

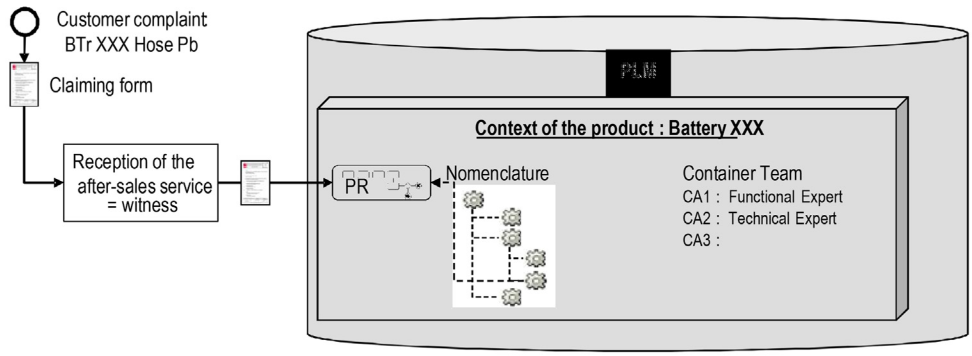
5.2. Determination of causes and development of solutions

The technical manager of this product creates a Change Request (CR) linked to the Problem Report (PR) and manages the process. He generates an instance of EF form which compiles the information fields with the elements of the PR and manually informs the free fields.

He makes a diagnosis following the observation of the analysis made at the reception of the PR. The problem is complex:

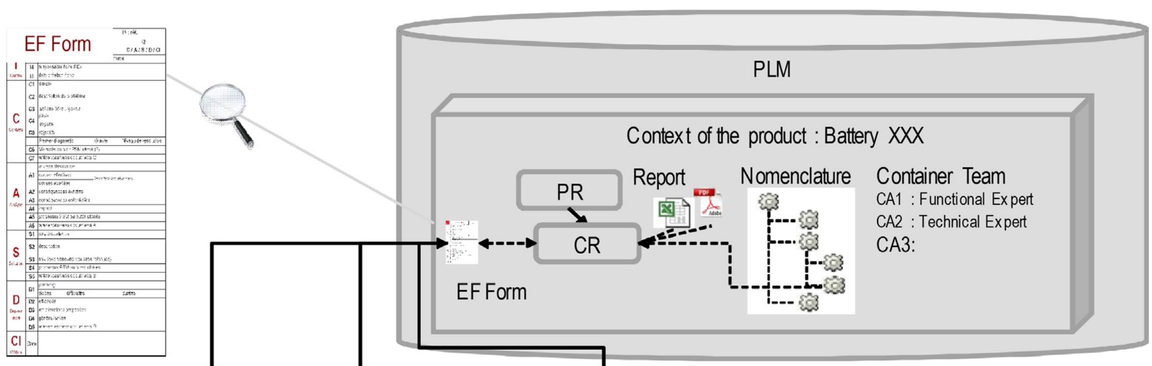
- on the one hand, the problem is recurrent (observed on four batteries) and impacts the customer product by material damage (deterioration of the hose)
- on the other hand, the solution is unknown, linked to the definition of a component; it requires the expertise of several business areas (especially technical expertise).

The selected workflow is the Full-Track process. The pilot selects a team of technical experts, the Technical Review Board (TRB), including a materials engineer, a chemical engineer and a mechanical engineer from the list proposed by the CR task and declares these experts in the EF form. He plans workshops to



Actor	Experience	PSM Phase	Restitution elements In the EF	Status EF record	Tool EF record	PLM Role	PGM Status	PLM Document Status	Company document linked to the PLM
Quality Support	Customer complaint - White crystals on hoses - Insulation problems	Detection : Need of investigation	Fields / attributes / links	Context		Witness	PR - In progress	Hose Article - Official linked objects - Official	Customer complaint
Materials Engineer	Launch of PSM		Fields		Is/Is not Visual Inspection	CA1	PR - Validated	Hose Article - Official linked objects - Official	

Fig. 7. The context of the considered problem.



Actor	Experience	PSM Phase	Restitution elements in the EF	Status EF record	Tool EF record	PLM Role	PGM Status	PLM Document Status	Company document linked to the PLM
Battery responsible	Analysis report: - quality/performances properties of materials - Customer use	Pre-analysis : complex differential diagnosis	fields/ attributes / links	Analysis	5W1H Internal tool	CA1	CR - In progress	Hose Article - Official Linked objects - Official	Analysis report
Ingénieur Matériaux Chemical engineer Mechanical engineer	Expertise Report - other materials from same suppliers -New materials/ New supplier	Search for Solutions	fields / attributes /links selected roles/ libraries	Analysis	Internal tool	TRB	CR - In progress	Hose Article - Official linked objects - Official Qualification report - In progress	Expertise report
Materials engineer Chemical engineer Mechanical engineer	Study of solutions - Supplier audit - Study request Materials qualification	Study of solutions	fields / attributes /links selected roles/ libraries	Solutions	Internal tool	TRB	CR - In progress	Audit report - Official Qualification report-Official	
Battery Responsible	Materials Problem	Proposal for a solution	fields	Solutions		CA1	CR - In progress		
Technical Manager Quality manager Purchase manager	Validation of the Materials change	Validation	fields / attributes /links selected roles/ libraries	Solutions		CRB	CR - In progress		
Battery Responsible	Transcription of the result from CRB	Validation	fields	Solutions		CA1	CR - In progress		

Fig. 8. Problem analysis and solution validation.

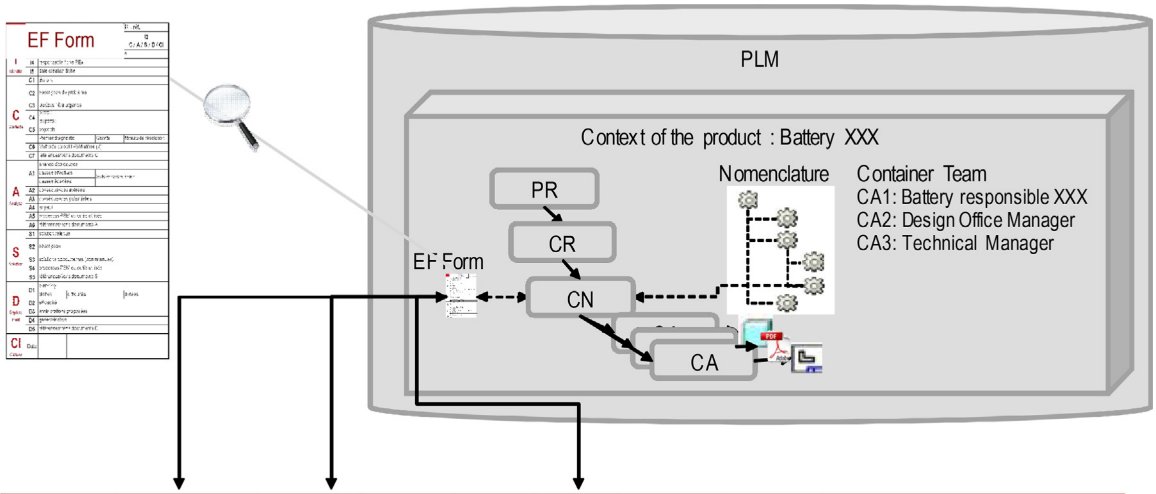
analyse causes and impacts; this activity, carried out outside the PLM context, generates an Internal Technical Analysis Report.

The Technical Analysis Report describes:

- the context of appearance (elements completed by the complaint form),
- the presentation of the tests carried out on samples: the chemical nature and characteristics of the deposit, the characteristics relating to the insulating capacities of the component,
- chemical, optical and mechanical measurements and observations (resistance to insulation),
- conclusions.

This document is related to the CR and the relevant PLM components. Findings are reported manually in the CR fields. They lead to the following causes:

- the deposit is due to misuse of the battery (by the customer),



Actor	Experience	PSM Phase	Restitution elements in the EF	Status EF record	Tool EF record	PLM Role	PGM Status	PLM Document Status	Company document linked to the PLM
Materials Engineer Chemical engineer Mechanical Engineer	Draft for Change Request	Planning	fields / attributes /links selected roles/ libraries	Deployment	Planning	CA2 + Change Implementation Board (CIB)	CN - In progress		
Mechanical Technician Materials Technician	- Changes in the product definition - Changes in the standards	Implementation	fields / attributes /links selected roles/ libraries	Deployment		Assigned Assigned	CA - In progress CA - In progress	Computer-aided design (CAD) Change request Quality document - In progress	
Mechanical Engineer Materials Engineer			fields / attributes /links selected roles/ libraries	Deployment		Proofreader Proofreader	CA – Validated CA - Validated	CAD Definition Modification Quality document - Official	
Technical Manager Administrative Manager	Request Closure Evolution		fields	Closed		CA3	CN - Closed CR - Closed PR - Closed		Computer-aided Production engineering (CAPE) dispatch for effectiveness

Fig. 9. Implementation and deployment of corrective actions.

- the failure is due to a lack of resistance and performance of the material.

In a TRB meeting, the group validates the causes. Although the conditions of use by the customer are the first parameter involved, the TRB proposes to improve the definition of the component to avoid any reoccurrence of the problem.

The TRB proposes and argues for the potential solutions. The technical manager of the product, the CA1, transcribes this information in the appropriate text fields of the CR. He declares them in EF form:

- solution 1: change of material from the original supplier. Following an audit (of which the report is linked to the CR) carried out under the Problem Solving Method (PSM), the supplier does not have a material that meets the requirements;
- solution 2: complete change of definition and material: requests for qualification of a new material from a new supplier.

The Product Manager ensures that the proposal is clear and completed in the CR and EF fields. He validates the design of solutions. He selects a team of decision-making experts in the Change Review Board (CRB) (responsible for technical service, quality manager, purchasing manager) from the list proposed by the CR task and declares them in the EF form. A notification is sent for validation to the members of the CRB.

Members of the Change Review Board (CRB) have access to the findings of the Technical Review Board (TRB) since Change Request (CR). They present the subject to the members of Management Committee (CODIR) and select solution 2: complete change of definition and matter. The agreement of each member is necessary to validate the solution. The CRB sends this decision to the technical manager of the product. The Product Manager returns to the decision of the CODIR. He validates CR by including the response message. He shall declare this information in EF Sheet. This validation automates the creation of a Change Notice (CN) and a notification is sent to the Change Administrator II (CA2), the head of the design office.

The conduct of this process is illustrated by the diagram in Fig. 8.

The information compiled in EF form traces all the decisions and activities undertaken to arrive at the chosen solution. EF sheet includes all the conclusions drawn from the technical expertise activities and the identity of the actors who generated the information.

5.3. Implementation and deployment of the solution

The head of the design office receives the request for completion of the Change Notice (CN).

- Ensures that information automatically synchronized with the Change Request (CR) is compliant.
- He selects the Change Implementation Board (CIB) team (in this case, it is still: materials engineer, mechanical engineer, chemical engineer) from the list proposed by task CR and declares them in the sheet EF.

The chosen professions are the engineers of the disciplines concerned by the implementation of the solutions.

It plans a meeting to set up a schedule of tasks where the CIB plans:

- a Change Activity (CA) involving the creation and approval of the qualifications report. The assigned is the chemical engineer, the person in charge is the technical manager,
- a Change Activity (CA) involving the evolution of the piece (change of definition and material) and updating of the plan. The head of the design office revises the object; The assigned is a draftsman/designer, the person in charge is the person in charge of the product,
- Change Activity (CA) involving the updating of all job listings and related plans. The responsible BE reviews the nomenclature (via a system of selection of all cases of use); The assigned is a draftsman/designer, the person in charge is the person in charge of the product,
- a Change Activity (CA) involving the demand for the technical specification of the component via a Problem Report (PR). The assigned is the material engineer declared in the NS library (Business Standards) Techniques, the person in charge is the person in charge of the product.
- actions described in a file, supported by an additional company's tool that manages non-PLM shares. This schedule is attached to the Change Notice (CN).

The Change Administrator II (CA2) declares the list of assigned objects and the detailed action plan in the EF form and validates the implementation task. Validation workflows for PLM objects related to Change Activity (CA) are run independently in parallel. When the validation workflow is complete, the objects are changed and go to the "Official" status, the manager passes the Change Activity (CA) to the "Resolved" state. He declares the completion of the action in the EF form.

An automatic notification of Change Notice (CN) is sent to the Change Administrator III (CA3) when all Change Activity (CA) is in the "Resolved" state. The Technical Service Manager is then required to audit the change management process. In accordance with the instructions of the audit task, he must ensure that the EF form is fully completed, in order to activate the validation process of EF plug and confirm the Change Notice (CN).

We illustrate the approach on the diagram in Fig. 9.

EF process is completed by passing the EF form to an "Official" state. The latter is approved by the company pilot EF (continuous improvement manager) after an interview with the CA1, CA2 and CA3 to confirm the completeness of the information. EF Manager moves this EF card to the EF Library container of PLM.

We presented an illustration of the principle of the Experiment Feedback/PLM approach applied to implicit knowledge. Engaged in the problem-solving process taken as an experiment, this knowledge intervenes in the resolution activities and participates in the creation of each experiment.

The principles of the Experiment Feedback/PLM coupling also offer opportunities for a similar demonstration for explicit knowledge by applying the approach to Quality documents dedicated to the exploitation of technical expertise. The creation of these documents constitutes a particular activity because it transforms implicit knowledge held by experts into explicit knowledge formalized in a form that is appropriate to their profession and accessible to all actors.

6. Discussion

The implicit knowledge of the actors of the business processes forms a very important part of the intangible heritage of this process. In this work, we have been particularly interested in this knowledge in the case of problem-solving processes. We chose this type of process because problem-solving situations constitute a privileged framework for the expression of this implicit knowledge.

We first considered the problem-solving process itself and, on the basis of a detailed analysis of the internal "mechanisms" of the company, we proposed an organization of this process to allow us to apprehend in an appropriate form the different levels of complexity that may be encountered. Using this process as a support for experiences, we have formalized the experiences that involve a large amount of implicit knowledge and we organized an EF system to capitalize the significant information of these experiences.

EF-PSM form that we have defined can be supported, in a conventional way, by PLM.

In the final phase, we extended the coupling between the EF-PSM processes and the PLM through the Modification Management process of the PLM (see Fig. 10).

The example proposed at the end of this work attests to the applicability of the proposals. The presentations made it possible to provide:

- A structured formalization of resolution process with the definition of the roles and powers of the various actors involved;
- An efficient capitalization of the information generated by the experiences resulting from the PSM support process via a standard "template" common to all, in an assisted and non-intrusive form for the actor;
- An easy integration of this information, largely derived from the implicit knowledge of the actors involved, in the process of improving the performance of the product and perfecting the structuring of processes;
- A facility to exploit previous experiences, generated and recorded in the PLM.

These first results already show the opportunity to exploit the functionalities of PLM to facilitate the realization of the mechanisms of Experience Feedback. The use of PLM offers a range of structuring tools and materials that promote the commitment of processes and data. The "synchronization" of the PLM and EF

Generic Phase	Experience
PR : Problem Report - description of the initial situation	Context
CR : Change Request – analysis and proposed solutions	Context - Analysis - Solution
CN : Deployment of solutions - Planning and management of changes	Deployment - Closure
CA : Change Activity - implementation of changes	Deployment

Fig. 10. Modification Management process of PLM.

models makes it possible to simplify and improve the EF approach and to facilitate its appropriation by the users.

The integration of a PLM solution is a sensitive project because it involves many processes within the company. It is also a complex project because of the choice of the configurations to be implemented to manage the lifecycle of the product and the need to accompany change because it impacts on work methods.

The scope of PLM extends to the full lifecycle of the product. This field is vast and impacted the deployment of the system by confronting different design problems (granularity of the product models, evolution in time of the models, the level of detail in the workflows, organization to be put in place ...).

The company has overcome the technical difficulties to define its model by gradually building it on three dedicated servers to support the development:

– the development server for design instances and first test sessions,
– the replication server of the database to validate the new settings on dummy data,
– the official work server containing the actual production information.

This organization made it possible to test the functionalities and the parameters at the base of development to set up parametric models and to test them during reception, without disrupting the development and the production of the batteries. After being declared compliant, these elements have been switched to the official server and, thus, formalized.

It should be noted that a great deal of attention has been paid to the recipe actions aimed at verifying the consistency of the instantiated parameterization in the database, by defining and carrying out a set of test scenarios representative of the intended functioning. We personally piloted these scenarios by ensuring:

• The writing of test supports,
• The realization of technical and functional tests with the business actors,
• The definition of corrective actions and the verification of corrections established by the PLM provider.

Reception was of major importance for the project because it conditioned the reception of the computer tool according to the defined functional specifications.

The technical service professions were the main actors involved in the deployment of PLM. Since their daily activities and the majority of their tools of work restitution were impacted, it was necessary to involve them in the construction and parameterization of the tool. They have often initiated proposals for functional improvement and promoting the benefits of the solution put in place. It should also be noted that we have directly implemented awareness-raising, training and support measures for users.

7. Conclusion

In this paper, we have presented work undertaken as part of an industrial partnership. To improve performance of products and processes, the company decided to take advantage of the implementation of PLM to deploy an Experience Feedback system. After having defined the mechanisms of an EF system, we presented some practical gaps in current EF systems and developed all points of interest in the integration of EF in PLM software tool. This operating solution uses functionalities of PLM framework to implement an EF system which significantly erases many barriers encountered during the installation and operation of an EF system. The expected result is to capitalize information in a non-intrusive manner and the generated experiences in business processes and facilitate the integration of this information in the future modular phases of product developments through EF sheets [21]. The work is ongoing, the adopted methodology provides concepts for a flexible deployment adaptation with options to ensure the sustainability of PLM [22].

The resulting methodology contributes to the technological innovation, an effective way to keep ahead. To maintain its leadership and differentiate itself from its competitors, the considered company invests in research and development. This company seeks to improve the existing solutions and the performance of its products. We are already able to report very positive feedback from business actors concerning the relevance of this PLM-EF association. The focus is on lithium-ion batteries, a proper battery storage system for renewable energy markets. The research is focused on the evolution of the batteries that will constitute the next generations to increase power and energy and optimize the service life of the system. This evolution of products tends towards a technical and technological complexity which multiplies the necessary synergies between business expertise and enhanced technical knowledge.

Further works will include the complete implementation of this EF system then ensure operationalization, including communication campaigns and training. An important extension should concern characterization of performance indicators to assess the effectiveness of the developed solution and its integration in the company's management system.

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