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CBR and PLM applied to diagnosis and technical support during problem solving in the Continuous Improvement Process of manufacturing plants

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Abstract

Currently many multinational companies have manufacturing plants with similar processes, but they suffer from barriers to share knowledge. Knowledge Management (KM) techniques may help to capture and reuse knowledge generated during processes execution. Literature shows Case-Based Reasoning (CBR) as a technique for implementing KM, and Product Lifecycle Management Systems (PLM) as the main data repository of Product-Processes-Resources data. This paper proposes a Continuous Improvement Process (CIP) approach to facilitate the capture and reuse of knowledge, integrating CBR and PLM technologies. It aims supporting production technicians during the resolution of manufacturing daily problems directly at shop floor level.

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Keywords: Case-Based Reasoning (CBR); Product Lifecycle Management (PLM); Continuous Improvement (CIP); Manufacturing Problem Solving; Process Failure Mode and Effect Analysis (PFMEA)

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1. Introduction

Today globalization pushes companies towards a strong competition among them. Companies need to be better and better every day if they want to survive in an always challenging and changing market. In the manufacturing environment that means a strong focus on Knowledge Management (KM), among other topics. A well-known KM issue in multinational companies is that they have different manufacturing plants distributed geographically and with similar processes, but they suffer from communication barriers to share knowledge [1]. This paper proposes a Continuous Improvement Process (CIP) approach to facilitate the capture and reuse of knowledge, in multinational companies, directly at shop floor level, with the objective of supporting production technicians and operators during the resolution of daily manufacturing problems. To demonstrate the feasibility of the proposed approach, an initial proof of concept prototype application has been developed.

The CIP approach adopted in this work is based on the 8D methodology [2] as structured manufacturing Problem Solving (PS) method to guide the resolution of problems step by step. It comprises Case-Based Reasoning (CBR) [3,4] as a technique for implementing KM [3-5], and Product Lifecycle Management Systems (PLM) as the main data repository of Product-Processes-Resources (PPR) data [6] used to define the context of a problem. The adopted approach is divided into:

- Definition of an ontology of manufacturing problems.
- Description of manufacturing context of the problem under analysis by means of a PPR structure automatically extracted from the PLM system.
- Representation of manufacturing problems by using Process Failure Mode and Effect Analysis (PFMEA) to create an initial case base.
- Definition of a reasoning method based on CBR to identify similar cases to the defined problem.

The paper starts with a general review of the state of the art. Then, the proposed CIP approach and the proof of concept application are presented. The paper ends with a summary of the work contributions and future work proposals.

2. State of the art

2.1. Continuous Improvement process and manufacturing problem solving methods

It is estimated that over 70% of the total life cycle cost of a product is committed at the early design stage [7]. Designers have developed methodologies such as design for manufacturing, design for assembly, design for maintenance, or design for quality to enhance the product development process and to increase the profitability of the products. Even though these methodologies have helped to reduce the cost of the product, there is still a large space for improvement in the manufacturing step of the Product Life Cycle (PLC). This paper proposes CIP as the tool to achieve this improvement [8].

The example of Toyota with its TPS (Toyota Production System) [8] is a fundamental reference of the current CIP philosophy in the manufacturing environment. TPS requires defining a long-term vision, which the company wants to achieve. Such vision should align all actions in the company and be deployed along plants, processes and production lines. Then Target Conditions need to be defined. A Target Condition is the description of a state that the company wants to reach at some future point in time, in the way toward the long-term vision. The company works toward those Target Conditions in small, rapid steps, with learning and adjustments occurring along the way. In each of these steps, the main problems preventing the company from reaching the defined Target Condition are analyzed and solved with the help of PS methods.

Table 1 shows some of the most relevant PS methods in the industry today, and it presents a comparison of the main steps defined in each of them. As it can be observed, all the methods have mainly the same structure or path to solve a problem. The main difference among them is the level of detail used to describe the different steps of the overall process. Other authors reaching a similar conclusion are Foguem et al. [9] and Jabrouni et al. [10]. Based on this observation, it can be concluded that the selection of the PS Method will not make a big difference in the ability of solving problems, and that some additional element is needed to support this activity. In this direction, Bothe and Bothe [11] stated that PS methods are not enough to support properly the manufacturing PS activity, because methods provide a procedure and a generic structure within which PS can take place, but they do not tell the team how to solve a given problem. As explained by Liu and Ke [12], and Grey and Chan [13], the available knowledge in the manufacturing PS team will determine, to a large extent, the effectiveness of the process. Therefore, it can be concluded that the availability of some kind of knowledge-based tool could enhance the effectiveness of the manufacturing PS process.

Table 1. Comparison of PS Methods.

OPDCA	DMAICS	8D	Shainin	Kepner - Tregoe	PROACT
Observation	Define Measure	Problem Solving Team Problem Description Containment actions	Define the Project Establish Effective Measuring System	Situation Appraisal	Problem
Plan	Analyze	Root Cause Analysis	Generate Clues (about the dominant cause) List Suspect Variables Statistically Designed Experiments	Problem Analysis	Objectives
Do	Improve	Potential Corrective Actions and Verification of Effectiveness	Interaction Realistic Tolerances Irreversible Corrective Action vs Statistical Process Control	Decision Analysis	Alternatives Consequences Tradeoffs
Check	Control	Introduced Corrective Actions and Verifications	Monitoring Results		
Act	Sustain	Preventive Actions to Avoid Recurrence Congratulate the Team	Leverage lessons learned	Potential Problem and Potential Opportunity Analysis	

2.2. Problem prevention: Process Failure Mode and Effect Analysis

In addition to the PS methods, there are proactive techniques to help in the identification and prevention of problems. PFMEA [2] is one of those techniques, and it is used in the approach proposed in this work as a way to define and capture knowledge dealing with manufacturing PS. PFMEA is a systematic method for identifying and preventing product and process problems before they occur. PFMEA is focused on preventing defects, enhancing safety, and increasing customer satisfaction.

This method guides the users to create a multi-level structure of components (i.e. processes, machines, materials, persons, methods and environment) with their corresponding functions in the product or manufacturing process. All the possible failure modes of each function must be identified. Such failure modes are the different ways in which a product or process can fail. That provides multiple lines of chained failure modes, which act at the same time, as effects of the next mode and as cause of the previous mode. The very last failure mode in the line will be very simple and specific, it will be the root cause of all the previous ones, and it will be the one on which the corrective and preventive actions have to be planned.

2.3. Knowledge Management: Case-Based Reasoning Systems

KM is an increasingly important source of competitive advantage for organizations, therefore, most of the companies try to find the best way to capture and reuse the knowledge generated during their processes. Literature shows that CBR is considered as a methodology for implementing KM systems [3]. Based on this, the CIP approach adopted in this work focuses on CBR as the KM methodology to capture and reuse information derived from PFMEAs and daily solved problems. PFMEA is used as a formalized way to represent experiences and lessons learned by the employees dealing with manufacturing lines.

Applying CBR is a kind of approximate reasoning [3]. The finding of a solution to a new problem starts with the RETRIEVE of one or more previously experienced cases, REUSING the case in one way or another, REVISING the solution based on reusing a previous case, and RETAINING the new experience by incorporating it into the existing knowledge base (case base). These are the four main stages involved in the process of solving a new problem by querying existing cases with a CBR system. The typical CBR knowledge model is composed of the following containers:

- Vocabulary: It retains knowledge about how to describe explicitly the knowledge elements being used.
- Case Base: It contains experiences as cases.
- Similarity: It consists of all knowledge needed to determine what makes a case similar to another such that their solutions can be reciprocally reused.
- Adaptation: This knowledge will be used to adapt cases to solve new problems. For example this could be rules or cases based.

The most important characteristic that distinguishes CBR from other kinds of reasoning is that it does not lead from true assumptions to true conclusions. This means that even if the solution in a recorded case was correct for its original problem, this may not be the case for a new problem. This possibility is because the context in the recorded experience may not be exactly the same as the one in the new problem. This characteristic of the CBR gives a big relevance to the definition of the problem context, which can be summarized as the PPR information around the problem under analysis (e.g. the machine where the problem happens, the affected product, type of operator involved in the issue…). The presented approach proposes to extract this information from a PLM system.

2.4. Product Lifecycle Management Systems

PLM is a systematic concept for the integrated management of all PPR related information across the extended enterprise through the entire lifecycle, from concept and design, to production, distribution, maintenance, and retirement [6]. PLM solutions can improve business efficiency by providing dramatic reductions in time and cost of product changes, significantly shorter product cycle and lead times, decreased scrap and rework during production, and improved productivity in design engineering.

2.5. Research works dealing with PS and KM in manufacturing

PS and KM are two areas with extensive research. There is extensive literature proposing general frameworks to collect and/or reuse knowledge applied to the resolution of problems, for instance, the works from Kolodner et al. [14] and from Ohsuga [15]. Other authors focus their research on the development of frameworks to be applied in the Design phase of the PLC, for instance, the works from Becerra-Fernandez and Aha [1] and from Gray and Chan [13]. When considering the Manufacturing phase of the PLC, the number of works is quite limited. Among relevant ones, Bach et al. [17] propose a CBR system applied to the problematic drilling situations, Liu and Ke [12] propose a mining-based knowledge support system for PS in a production process, and Sevilla-Villanueva et al. [16] investigate the application potential of a CBR system to support the setting activity in the textile industry.

Special attention is paid to the works of Foguema et al. [9], and Jabrouni et al. [10]. All of them link CIP with PS and KM, and propose a similar framework based on Experience Feedback Systems (EFSs) as the solution to support KM in the Industrial environment. This work converges with those authors, but enhances their approach by proposing CBR as a concrete tool to manage the Experience Feedback, and the PFMEA method as tool to formalize the manufacturing related problems definition and to create the initial CBR database of cases.

In a different direction, it is also worth to mention the commercial software PROACT® Logic Tree Knowledge Management Templates [18]. This software provides hundreds of templates for the medical and industrial maintenance environment. The templates shows relationships between events (i.e. the least acceptable consequence that triggered the need for a Root Cause Analysis), and their modes (i.e. the manifestations of the failure) to PS activity. It links PS with KM but in a static way, since knowledge can only come from the experts working at software development company, missing the possibility of learning with the daily problems.

3. CBR Application for Continuous Improvement in Manufacturing

3.1. General goals and concept

Applied to the field of CIP in manufacturing, this work proposes the use of CBR as a KM methodology to help in the process of manufacturing PS, together with PFMEA as the technique to represent and capture knowledge dealing with problems related to manufacturing processes.

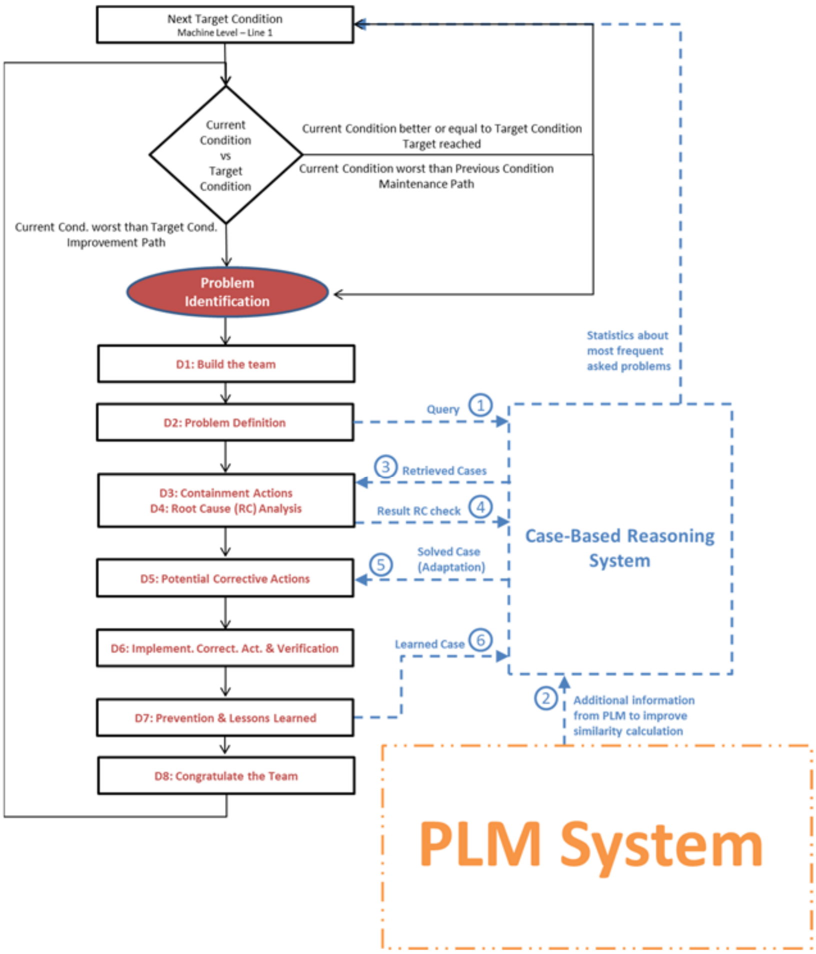

Fig. 1. Proposed MPS process with CBR application.

The main goals to achieve with the proposed CBR application are:

- Improve the company ability to solve problems from the shop floor through KM. The CBR application should support, during the PS phase, every CIP loop by capturing, storing and reusing knowledge.
- The CBR application has to fit within the common structure of a PS method to promote discipline and structured approach to PS among users.
- Share best practices and solutions across shifts and manufacturing plants.

- Increase standardization across the company.
- Avoid the loss of Knowledge when key employees leave the company.
- Reduce training period of new workers until they can work standalone (solutions to unexpected problems could come also from the CBR Application and not only from experience).
- Facilitate the collection of most consulted problems in the shop floor, to be used in the definition of next Target Conditions within the CIP Process.

Figure 1 summarized the proposed concept to achieve the defined goals. Its main characteristics are:

- The trigger to start the use of the proposed CBR application is inserted in the CIP loops of the company, at the time when a problem, which prevents from reaching the defined target condition, is identified.
- Since, as explained, the selection of a MPS method or another does not make a big difference, this work proposes the use of the 8D method. The 8D method is broadly used to analyze and present quality claims in the industry nowadays [2]. This will also help that the application is seen as a support tool rather than as an additional workload or a tool not linked to the daily work.
- To support even users with very few knowledge about the PPR around the problem (i.e. the context of the problem) it is proposed that the system gets automatically this information from a PLM system.
- The application should be simultaneously accessible by operators, quality inspectors and process engineers located in different manufacturing plants. For this, it is proposed the software framework JADE (Java Agent DEvelopment Framework) as communication infrastructure.
- The CBR application will provide the users with similar problems stored in its case base. These problems have been extracted from both PFMEA and daily CIP activity, and they are stored together with its associated solutions. The user to fix the specific issue at the line will adapt these solutions later on.

3.2. Ontological representation of manufacturing problems in the CBR application

A critical step in the development of the prototype CBR application is the definition of the representation of problems in the manufacturing domain. This will be done with an ontology based on the PFMEA method. Following the PFMEA philosophy each specific manufacturing problem can be directly associated to a failure mode. The failure mode will have always some potential effects (i.e. other failure modes that are generated when the original failure mode happens), and some potential causes (i.e. other failure modes that can generate the original failure mode). That means that both effects and causes are also failure modes that are farther or closer to the root cause. Based on this, both a problem and its corresponding root cause can be defined in exactly the same way (i.e. as failure modes). Then the ontology will have a single concept "Problem" with a link to itself defining that each problem is generated by another problem.

A relevant requirement in the definition of problems is that they have to be defined in a way that allows the CBR application to calculate similarities. As explained in the prior section, that means that the application has to be able to recognize the case introduced by the user (i.e. query), and to calculate the existing "distance" with the available cases in its case base. For this, a standard vocabulary and the relationship among their terms have to be stablished [3]. This can be done by defining taxonomies associated to the attributes of the concept "Problem". A taxonomy relates objects to each other, by means of a hierarchical structure, from general objects to specific ones. This implies that branching leads to objects that have more in common. This hierarchical structure will provide the software with the information to calculate similarity between cases. In this sense, cases, which are in the same branch (i.e. parents or sons), will have higher similarity rather than cases in different branches (i.e. with a common parent at any point of the structure but evolved in different ways).

Based on the PFMEA method, this work proposes three different taxonomies to define each problem:

- Components taxonomy: it contains the six different types of components defined by PFMEA (i.e. processes, machines, materials, persons, methods and environment).
- Functions taxonomy: it contains all possible types of functions that a component can perform in the production domain (see Figure 2).

- Failures taxonomy: it contains information related the extension in which the function fails.

In addition to the three presented taxonomies, an additional one is proposed to define the context of the problem. The information context will be filled with information extracted from the PLM system. The extraction of information from the PLM system depends on the input information provided by the user, which comprises line and station where the problem happens, the product involved, who is involved in the problem, and when it has happened.

Finally, an attribute of type integer is added to record the frequency with which the problem happens, and three attributes of type text are included, to support the description of the problem in detail (what problem and why it is a problem), and the description of the applied corrective action. These last three attributes do not contribute to the calculation of similarity.

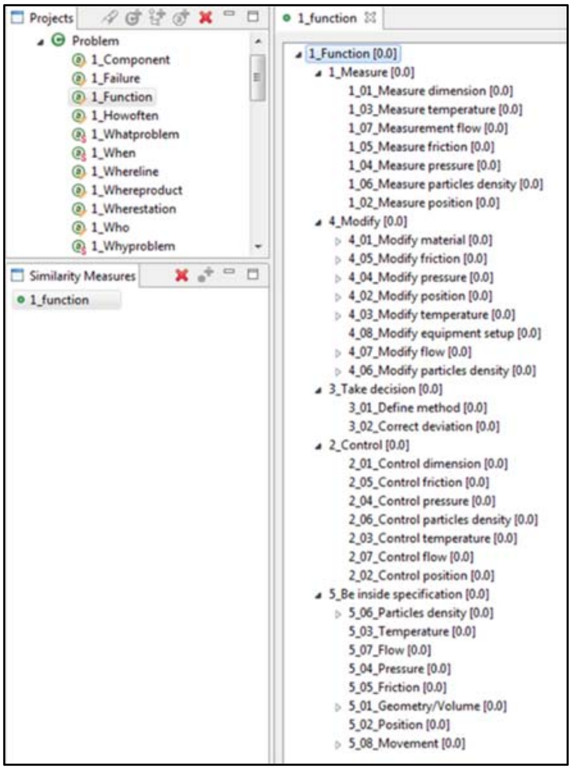

Fig. 2. Function taxonomy.

3.3. Development of an initial CBR proof of concept application

For the development of an initial CBR proof of concept application the open source software myCBR was selected (www.mycbr-project.net). The interface of this software is divided into three different editing views:

- Modeling – Projects: in this view the user has to define the domain model, which is based on the ontology of the domain. It contains the concepts and associated attributes.
- Modeling – Similarity Measures: in this view the user has to introduce the types of similarity calculation applied to each attribute.
- Case Bases – Instances: In this view, the user has to introduce the cases to populate the CBR case base.

When in a project, the three views are filled, the user can start performing searches giving target values to one or more attributes.

The PFMEA method is used to populate initially the case database of the CBR Application. PFMEA is a very much used tool in the manufacturing environment to prevent failures in the processes, and therefore its usage should not add extra workload. As it was previously explained, the PFMEA tool helps to find all possible ways of failure (failure modes). Therefore, the collection of all failure modes with their effects (problem description) and causes (root cause) that are defined in the PFMEA builds a good starting point for the case base. Later on, when the application will be in service, the continuous lessons learned out of new problems will complete the database even more, but this is a very slow process that could take months until a reasonable number of cases are collected, that is the reason to start with the collection of failures from the PFMEA.

4. Conclusions and future work

This paper presented a proposal for the development of software system with the aim of supporting the CIP of any company at the shop floor level. It combines PS with CBR, as KM tool, PLM, as source of problem context information, and the PFMEA method, as the tool to define manufacturing problems in a formalized way, and to populate initially the CBR system. A proof-of-concept of CBR application was developed to demonstrate the feasibility of the approach adopted. An initial case base of forty different cases was defined and the results of the system were compared against the decisions taken by experts. The results show that the system and experts answered a reasonable number of queries in a similar way.

As explained along the paper, there is quite a lot of research about the topics CIP, PS, and KM, but very few works combine all of them in a single environment, and even less works place the focus on the manufacturing phase. Among the different activities linked with manufacturing, this work focuses directly at production lines on the shop floor, where manufacturing PS research is even more limited.

A relevant characteristic of CBR Applications is the adaptation. This complex task of adapting the solution of a problem in a specific machine to the solution in a different one has been left to the operator. Implement adaptation to the prototype application is an issue to be investigated next.

The current implementation of the CBR prototype application is standalone. Ultimately as case study, this CBR application should be installed at least in two different manufacturing plants of a multinational company. Considering the feasibility of the adopted approach, this has been planned as a next step. To do so, the software framework JADE (Java Agent DEvelopment framework) as communication infrastructure has been selected.

References

[1] T.C. Ambos, B. Ambos, J. Int. Manag. 15 (2009) 1-14.
[2] VDA, Qualitätsmanagement in der Automobilindustrie – Qualitätsmanagement-Methoden Assessments, VDA 2015.
[3] M.M. Richter, R.O. Weber, Case-Based Reasoning: A Textbook. Heidelberg: Springer, 2013.
[4] K.D. Althoff, K. Bach, J.O. Deutsch, A. Hanft, J. Mänz, T. Müller, R. Newo, M. Reichle, Collaborative multi-expert-systems - realizing knowledge-product-lines with case factories and distributed learning systems, Proceedings of 3rd Workshop on KE and Soft. Eng. 2007.
[5] I. Watson, Knowledge management and case-based reasoning: a perfect match? Proceedings of the Fourteenth Annual Conference of the International Florida Artificial Intelligence Re-search Society, 2001.
[6] J. Stark, Product lifecycle management, third ed., Springer International Publishing, Switzerland, 2015.
[7] Y. Asiedu, P. Gu, Int. J. Prod. Res. 36 (1998) 883-908.
[8] M. Rother, Toyota Kata: Managing People for Improvement, Adaptiveness, and Superior Results, McGraw Hill, 2010.
[9] B.K. Foguem, T. Coudert, C. Béler, L. Geneste, Comput. Ind. 59 (2008) 694-710.
[10] H. Jabrouni, B.K. Foguem, L. Geneste, C. Vaysse, Eng. Appl. Artif. Intell. 24 (2011) 1419-31.
[11] K.R. Bhote, A.K. Bhote, World Class Quality – Using Design of Experiments to Make it Happen, AMACOM, 1999.
[12] D. Liu, C. Ke, Expert Syst. Appl. 33 (2007) 147-61.
[13] P.H. Gray, Y.E. Chan, Commun. AIS. 4 (2000) 12.
[14] J.L. Kolodner, R.L. Simpson, K. Sycara-Cyranski, Int. Jt. Conf. Artif. Intell. 85 (1985) 284-90.
[15] S. Ohsuga, Knowledge-Based Syst. 6 (1993) 38-62.
[16] B. Sevilla-Villanueva, M. Sanchez-Marre, T.V. Fischer, Estimation of Machine Settings for Spinning of Yarns – New Algorithms for Comparing Complex Structures, Proceedings of International Conference on Case-Based Reasoning (ICCBR 2014), 2014.
[17] K. Bach, K.D. Althoff, R. Newo, A. Stahl, A case-based reasoning approach for providing machine diagnosis from service reports, Proceedings of International Conference on Case-Based Reasoning (ICCBR 2011), 2011.
[18] R.J. Latino, Root Cause Analysis vs. Shallow Cause Analysis, Industrial Maintenance & Plant Operation, 2007.