

# A Case Elaboration Methodology for a Diagnostic and Repair Help System Based on CBR

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## Abstract

Although the elaboration of the case representation is the key problem of the case-based reasoning system conception, there exists no proven methodology targeted to this task. This paper is a contribution to fill this gap in the maintenance domain, more precisely in the equipments diagnostic and repair help. A methodology to elaborate the case representation is proposed based on knowledge management techniques and existing engineering analytical tools that are used in the industry. Different ontological models are proposed to take into the account similarity and adaptability aspects of the case representation and to optimize the case base size.

## Introduction

Quite a lot of systems and applications of case-based reasoning applied to diagnosis and technical maintenance were built and published over the last years. Diagnostic systems are among the most successful applications of knowledge-based systems technology (Price, 1999). As enterprises keep seeking ways of decreasing their running costs and breakdown may have a huge impact, an effective diagnostic system is of the great importance and is often asked in the industry. The repetitive building of different case-based reasoning applications brings always the same problem of the case representation creation. The idea of automating the case elaboration process and of reusing parts of equipment analysis already done triggered our research. Our goal is to propose a methodology to create a case representation for the case base and to solve the lack of domain expertise. In this paper we propose a tool enabling the knowledge capitalization in the maintenance process. This process was studied in (Rasovska, Morello, and Zerhouni, 2004) on the real industrial example in Cegelec Belfort in France. It is traced by different maintenance intervention steps described in paper or

electronic documents containing information about one intervention. The document's form is changed during the intervention execution and is completed by additional information as shown in fig. 1.

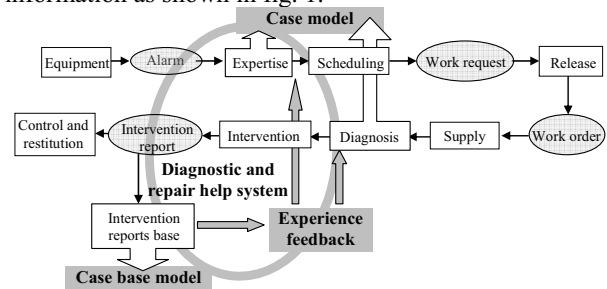


Figure 1. Diagnostic and repair help system in the maintenance process.

First of all, the need for an intervention on a given equipment is expressed by an alarm that follows an event (failure). This request is analyzed and scheduled by a maintenance service and transformed into the work request. The first expertise is worked out and similar requests are searched to help the scheduling tasks. Then the work request is released as a work order to the relevant maintenance operator. The maintenance operator is supplied with the necessary tools and spare parts and could be helped by a detailed failure diagnosis that comes from the previous intervention reports. Once the intervention is completed, the new intervention report is filled and the equipment is checked and released. The intervention reports are stored in a base that can be improved by experience feedbacks. The study of the maintenance process has revealed a possible use of a decision help system in the expertise and the diagnostic step. One of the objectives to design such a diagnostic and repair help systems is the capitalization of operator's expert knowledge during the breakdown repair and knowledge sharing by other operators in order to improve the performance and the effectiveness of maintenance interventions.

Different methodologies can be used for this diagnostic and repair help system but the most appropriate one appears to be the case-based reasoning (CBR). The current research in the case-based reasoning focuses on the detailed knowledge representation; Althoff (2001) thinks the CBR is the technology of choice to implement a knowledge-based system. Knowledge is stored as cases in a case base which can thus be regarded as a knowledge base. To present expert knowledge as past and concrete experiences simplifies its comprehension by human users. The diagnosis is one of the domains where problems are recurrent and so the previous documented solutions can be reused. Further in the retrieval of similar cases, algorithms can be used even if problems are not completely understood. In (Althoff et al. 1995) two different types of diagnostic systems based on CBR exist:

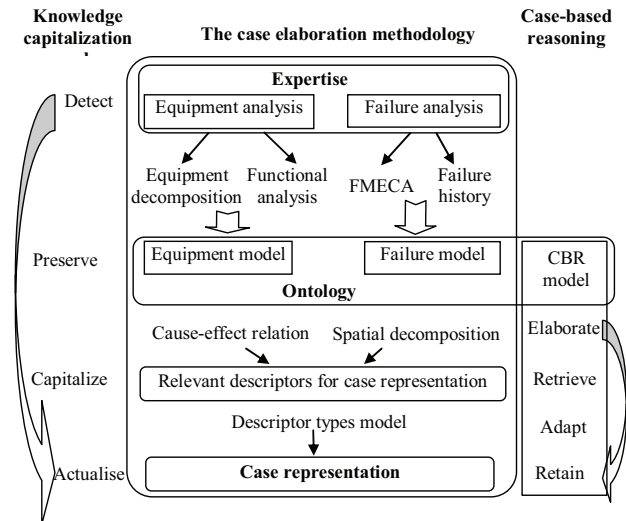
- In a “help desk” application, CBR is used as a decision support; it identifies what should be done in a certain situation. This application type is used especially in domains with lots of technical equipments used by non-specialists.
- In a “general diagnosis and repair” application, CBR is used as a decision help system for the diagnosis of complex equipments or for medical diagnosis and points out the failure cause research and the problem exploitation.

This paper has two objectives: to conceive a diagnosis and repair help system for human operators and to conceive a knowledge management and capitalization system for maintenance tasks. A previous analysis of different diagnostic systems based on the CBR pointed out the lack of a proven methodology to register a typical diagnostic case (Rasovska, Morello, and Zerhouni, 2006). In most systems, a case characterizes a diagnostic experience without reference to any kind of model. We propose to use the documents produced for a given maintenance process (alarm handling, diagnosis, etc.) as our basic building blocks for the case model. And, because all this information may be retrieved from a given intervention report, we choose the intervention reports database as our case base model. These two models will be completed and improved by the experience feedback. The concepts and terms used to describe informally a case are used to develop the suitable domain ontology. Thus, we can use knowledge management techniques to elaborate the case formal representation. The advantages of mix the knowledge management techniques and the case-based reasoning are studied in (Bergmann and Schaaf, 2003).

## Principle of the Proposed Methodology to Elaborate Cases

The underlying principle of the case elaboration methodology for a diagnostic and repair help system development is the knowledge capitalization cycle presented by (Grundstein, 2000). It is based on the knowledge model integrating the representation and the

reasoning model. This integration allows, on one side, to guide the domain expertise and to assist knowledge modelling in maintenance. On the other side, this represented knowledge can be manipulated by the case-based reasoning in the decision help system. The validity of the represented knowledge and its use in the decision support system is so guaranteed.



**Figure 2.** The principle of our methodology

As shown in fig. 2, the methodology cures the lack of expertise in the diagnostic domain by using engineering safety tools like FMECA<sup>1</sup>, functional analysis or failure history. These tools simplify the knowledge management by reducing its complexity. Two complementary types of analysis are identified. The first one concerns equipments and employs techniques of equipment decomposition and functional analysis. It determines a hierarchical equipment model). The second one concerns failures and employs the reliability concepts such as FMECA and failure history. The expertise issued from these analytical tools is enriched by information from intervention reports and then modelled and represented by knowledge engineering techniques. In more details, the ontological techniques are used to represent the domain knowledge as well as the problem solving concepts which manipulates this domain knowledge. Two corresponding models, i.e. equipment and failure model, make part of the domain ontology created in the ontology editor Protégé<sup>2</sup>. The third model participating in the general ontology proposes CBR concepts that handle the domain concepts in the general ontology. This allows the system developer to take into account important aspects of CBR cycle steps in the case representation. These models can be associated to the terminology of the most known knowledge engineering method CommonKADS (Wielinga et al. 1993). This means that the equipment model represents the domain knowledge, the failure model

<sup>1</sup> Failure Modes and Effects Criticality Analysis

<sup>2</sup> <http://protege.stanford.edu>

represents the inference knowledge and the CBR model corresponds to the task knowledge.

The knowledge items in the ontology are connected by relations as “composed-of, is, has-for-instance” and other associations. The relations between concepts are used to create supplementary models such as the cause-effect relation model (based on associations) and the spatial decomposition model (based on “composed-of” relations). They are necessary to identify and describe possible relevant descriptors for the case representation. In order to take into account common equipments characteristics and to take into account similarity and adapting knowledge, the descriptors are generalized and formalized in the descriptor types’ model (based on generalization and inheritance). These general models are proposed to create the case representation in different applications while other CBR applications propose the case model already fixed. Our models join the domain knowledge model from INRECA but try to be more general to be reused on different types of industrial equipments. The case model in (Bergmann, Pews, and Wilke, 1994) is proposed as a collection of rules on the different abstraction levels; our case is proposed as a collection of descriptors in the case base but can be translated in form of rules, too.

### Proposed Ontology

In this paper, we introduce the concrete domain ontology corresponding to the pallet transfer system SORMEL. It is done according to the general ontology (Morello, Rasovska, and Zerhouni, 2005) and with the aid of engineering analytical methods and tools. A short view of this ontology concerning the relevant concepts for our decision support system is illustrated in fig. 3. It contains the equipment model characterized by the equipment functional and component decomposition and the failure model characterized by the functional mode and the equipment condition.

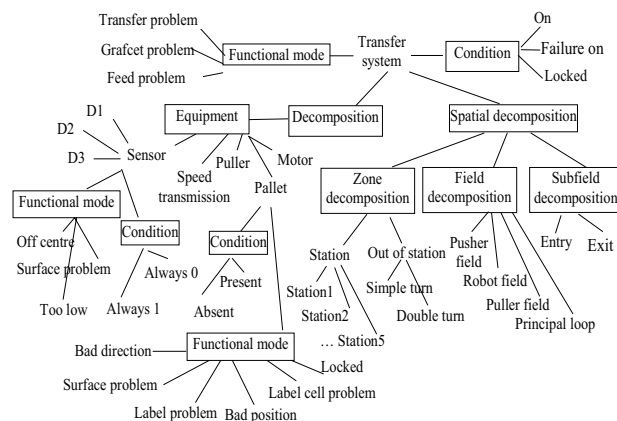


Figure 3. Domain ontology of Sormel system

A case is a problem solving episode description. There is a number of different theories on the case representation but the one most often used is structured in a list of descriptors

that take the form of complex objects (Richter, 1998). The case representation requires to list the various system components and to characterize them as eventual case descriptors. The case representation elaboration consists in facilitating the problem description in order to improve the search of the case whose solution will be most easily adaptable. The general method lies on completion or filtration of problem description which is based on domain knowledge (Mille, 1999). So that the eventual incomplete description is deduced and the weighting of descriptors is done according to identified dependencies between the new problem’s descriptors and the searched solution’s ones. The case descriptors come from components of different nature such as sensors, control and command units.

### Different models

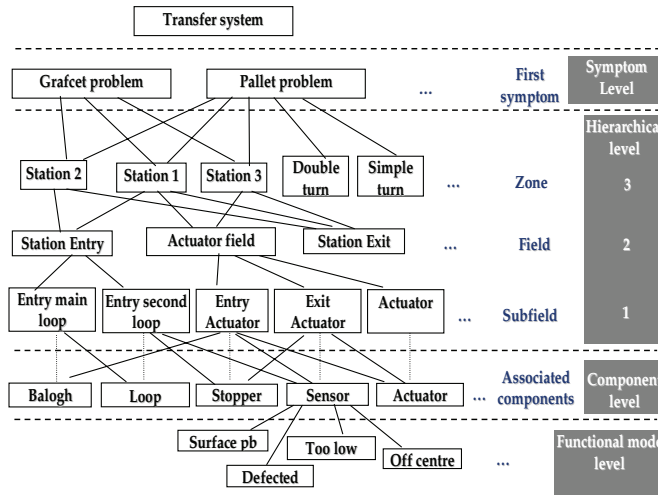
Com- ponent	Symbol	Context	Component condition	Component functional mode: <i>action</i>
Sensor	D1,D2 ... D9	Pallet: Present	Always 0	Sensor problem too low: put up sensor
				Sensor problem off centre: <i>push sensor</i>
				Sensor problem defect: <i>change sensor</i>
		Pallet: Absent	Always 1	Sensor problem surface problem (metallic element, iron powder): <i>clean sensor</i>

Figure 4. Cause-effect relation model

To characterize the case descriptors (attributes), the equipment functional mode and conditions are put in the context (cause-effect relation model). The conditions are associated as descriptors values. The failure detection rules are applied: IF ((pallet: present) AND (sensor: always 0)) THEN (sensor: problem OR pallet: bad direction) to detect the failure component. The failure component with its functional mode represents the context evaluation with the repair action as the final solution. An example of such a characterization is introduced in fig. 4 for sensor.

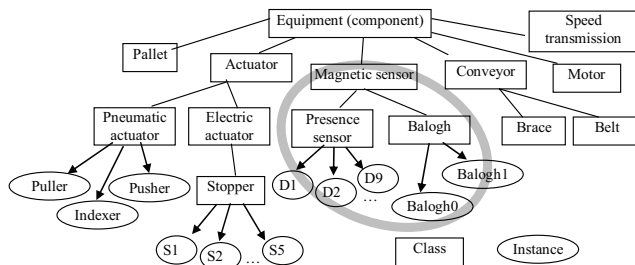
In order to create the case as a “diagnostic situation” the information hierarchy is used shown in fig. 5. This model represents the information hierarchy established for the future case base. This will facilitate the retrieval of similar cases. Every situation is characterized at the beginning by the first symptom (symptom level). Then the spatial decomposition model is used (hierarchical level) to detect the concerned zone, field and subfield. This decomposition allows identification of relevant descriptors for every diagnostic situation (component level). Every component is then described in the functional mode level. The detection of the functional mode of relevant descriptors corresponds

to the completion rules in (Bergmann et al. 1996) and is based on the component conditions issued from SCADA<sup>3</sup>.



**Figure 5.** Spatial decomposition and information hierarchy for the case base

Finally, a descriptor type model is established issued from the domain ontology. It is used for the retrieve and reuse tasks in the case-based reasoning cycle. In the model, descriptors are classified according to their functionality. The square represents the generalized concepts and the oval represents the instances of the transfer system SORMEL. As shows the marked part of fig. 6, the general class Magnetic sensor is composed of two subclasses Presence sensor and Balogh. Then the instances corresponding to the real system components make part of both classes. This model is based on technical functionalities and could be valid for all equipment types. This model issued from equipment functional analysis creates component families identical to the component hierarchy in (Bergmann, Pews, and Wilke, 1994). We can use it as the adaptation rules in (Bergmann et al. 1996).



**Figure 6.** Descriptor's type model

## The Retrieval Mechanism

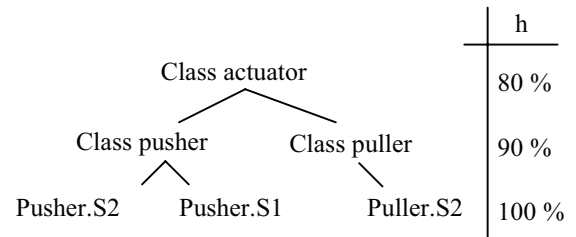
The retrieve phase of the case-based reasoning system is based on the retrieval algorithm and the similarity notion.

In the proposed CBR system the algorithm of Case retrieval nets (CRN) (Lenz, Auriol, and Manago, 1998) was implemented on the information hierarchy in the case base. This algorithm is used in order to identify the set of cases supposed to be similar to the new one. The basic knowledge in CRN is an information entity represented as terms (nodes) in the ontological structure to which we give acceptable values. A case is a set of these information entities (IE) and the case memory is a net with nodes for the IEs observed in the domain and additional nodes denoting the particular cases. IE nodes may be connected by similarity arcs (horizontal comparison) and a case node is reachable from its constituting IE nodes via relevance arcs (vertical comparison). Different degrees of similarity and relevance may be expressed by varying arc weights. Given this structure, case retrieval is performed by activating the IEs given in the query; propagating activation according to similarity through the net of IEs; and collecting the achieved activation in the associated case nodes. The global similarity measure is proposed between the new target case and the source cases from the case base:

$$\sigma = Sim(Target, Source) = \frac{\sum_{i=1}^p \omega_i \cdot sim_{Presence} \cdot sim_{Class} \cdot sim(t_i, s_i)}{\sum_{i=1}^p \omega_i}$$

where  $\omega_i$  is the descriptors weight,  $p$  is the number of attributes,  $sim_{Presence}$  is the similarity of descriptors' presence,  $sim_{Class}$  is the similarity of descriptors' common class and  $sim(t,s)$  is the similarity of descriptors' values.

The similarity between two cases is calculated on the case descriptors. Similarity measures are adapted to the object oriented case representation. First, the descriptors presence similarity is evaluated (present 1, absent 0). For two different descriptors the class similarity is calculated while going up to the first common concept in the descriptor type model as shown in fig. 7. The similarity grows as we descend in the hierarchy and is given by comparing the attributes common on this level. Then the similarities between the same descriptors are calculated by simple comparison of their values.



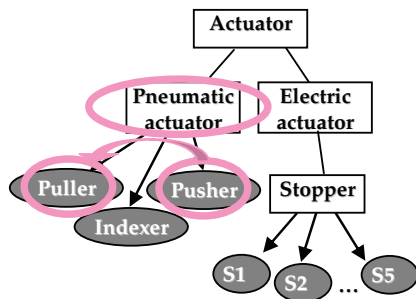
**Figure 7.** Similarity of general classes

<sup>3</sup> Supervisory Control and Data Acquisition



## The Adaptation Mechanism

In the reuse phase, the descriptors hierarchy is used in order to generalize the cases in the case base. The adaptation mechanism consists of two main parts: the adaptation based on general class ontology inheritance and the adaptation based on the substitution of real component. An example is shown in fig. 8, the general class actuator has two general subclasses: pneumatic actuator and electric actuator. If the source case contains the descriptor pusher and the target case descriptor corresponds to the puller, their common general class is pneumatic actuator (bottom up direction). This general class leads to the solution for the new problem. To every general descriptor class we associate repair operations, necessary human and material resources, appropriate technical and other documentation and the time duration of the intervention as the solution attributes. Further, in reuse phase of the CBR cycle this hierarchy is used to replace a given component of a new case by another one from the same family (the same generic class) already existing in the case base (top down direction). We reuse solution attributes of the general class to the new component. The adaptation strategy is introduced based on adaptation operators. The adaptation operator is applied to a characteristic attribute of a case solution.



**Figure 8.** The reuse step in the case representation

This hierarchy with general classes represented in the case base by general cases limits the size of this case base and so the time and effectiveness of the case retrieval. Moreover the transfer system consists of five identical stations; it is thus possible to build generic classes to adapt the solutions for each particular station.

## The Case Representation

Finally, the case representation is retained as shown in table 1. A case consists of four main parts: context, attribute-value list, its evaluation and final solution (repair action). The case is elaborated from the symptom description characterizing the problem nature. During the acquisition of a new problem description, one specifies context (symptom and its localisation), components – descriptors of this context and their values. The problem solution summarizes components identified in the context

with their failure modes. This leads to the identification of the failed one and to the repair action associated to the proposal of the operator skills for this intervention, required spare parts, required tools and suitable technical documentation.

Contexts		Attributes-values				Evaluations		Solutions
Symptom	Localisation					Failure component	General classes	
Transfer process	Station Actuator Entry	D6: 1	B1: 1	S5: 0	P: 0	Pusher Cylinder out of order	Actuator	Change cylinder

**Table 1.** The case representation

## Conclusion

For now there is no standardisation in the creation of a case and the case vocabulary. The ontology techniques aim at the systematic knowledge assets creation and storage based on the knowledge items characterization. So the CBR system is completed by using the ontology techniques which are based on the formal description and standardisations but have no reasoning mechanism allowing the use of existing knowledge.

Our approach was demonstrated on the pallet transfer system Sormel as the industrial application. The decision support system for maintenance intervention management is designed as an interactive system. It deals with the expert knowledge in form of cases created by using the proposed methodology. They connect in certain manner the domain ontology concepts according to different models developed during the methodology implementation. Thus the case representation joins the domain ontology creation and the cases as knowledge items are reused and handled by the case-based reasoning mechanism. Thanks to the methodology models, the case representation takes into account different reasoning tasks of CBR such as retrieve and reuse. Thus the retrieval and adapting process are optimized. Actually, the case base contains about 40 cases. This allowed the case retrieval testing. Tests permitted to find the general cases and to replace the non generic ones. So the case base size is reduced and the case retrieval is faster. We generated randomly 15 cases corresponding to one third of the case base and we obtained precision of 95%. These tests will follow up. The proposed methodology is now used to two other industrial applications. The first one is maintenance of submarines in DCN France in the scope of the Nemosys project and the second one is maintenance of embedded systems in Alstom France in the scope of Amimac project. The realised equipment models are reused to similar equipments in both projects.

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