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MODELLING OF AN ALSTOM ELECTRICAL ENGINE MANUFACTURING LINE ACCORDING TO PROCESS APPROACH ADVOCATED BY STANDARD ISO9000:2000

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The customer's satisfaction in term of time, cost and quality of the product is today the major concern of the company. To optimise this satisfaction, the company has to master in best way, its processes and to decentralise its decision-making levels closed to the field components to react quickly and to anticipate the quality drift. A contribution to this challenge is proposed in this paper by developing a methodology based on the process approach. This approach is formalised with UML for a manufacturing process as advocated by the ISO9000:2000 to lead first to a meta-model in which some quality modelling constructs are integrated. Then, the meta-model is specialised based on the quality requirements for an ALSTOM manufacturing line of electrical engines in order to validate all the methodology and to obtain a reference model to be particularised and usable in operation.

1. INTRODUCTION

The customer satisfaction in terms of time, cost and quality of the product is today the major concern of the companies. To optimise this satisfaction, the company has to master in best way, its processes and to decentralise its decision-making levels closed to the field components to react quickly and to anticipate the quality drift. In that way, the quality standard advocated by the ISO9000:2000 (ISO/CD1 9000, 2000) proposes an approach different from the version 1994. Indeed in the precedent version 1994, the quality document composed of the twenty chapters imposes, on the company, a repository with rigid functioning but without specific method in the continual improvement of the quality.

In the opposite way, the new version 2000 defines general frame enabling continual improvement by the approach called "Process" approach. This approach requests the company to identify the whole of its activities under shape of processes, to establish the processes cartography by the relations which connect them and to

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master them by the continuous improvement of their performances (processes, interactions between processes). Process characterising a transformation between an "input" product and an "output" product, everything is then process in the company because the transformed products can be of service, software, mechanical, or informational as a variable of the manufacturing system to be controlled.

In this context of process approach, the paper presents CRAN works done in relationships with the group ALSTOM[1], of which the major concern of its subsidiary implanted in Nancy (East of France) is better to master quality at the level of the manufacturing lines of its electrical engines. Indeed short-term objective on these manufacturing lines within the new factory site, is to operate autonomous teams (responsible for a process) which will have the capacity and the means to observe process, to define and to implement adequate corrective actions (minimisation of unavailability and no quality) and especially preventive actions to master the manufacturing process. This has to succeed a decisions decentralisation (aiding in monitoring, diagnosis, prognosis and decision-making phases) in closer processes of manufacturing (Pétin *et al.,* 1998) to be locally reactive and to anticipate so as soon as possible the quality drift (logic of continuous improvement and of tracability by having the good information, at the right time and in the good place). Our contribution to these works within Enterprise modelling approach context (section 2) is mainly methodological by exploring on the foundation of Information and Knowledge technologies, an approach integrating collectively the product and the production process all along its manufacturing life. It is mainly based on two first steps:

- A modelling of the process approach for a manufacturing process under the shape of a loop **P**lan-**D**o-**C**heck-**A**ction (Deming, 1986) (figure 1) as advocated by standards ISO 9000:2000 to lead to a meta-model (section 3) of the approach process for the manufacturing processes.
- The integration of "modelling constructs" (section 4) in the meta-model by mainly considering the concepts issued from the General System Theory, from the maintenance standards and from failure cause analysis (method 5M).

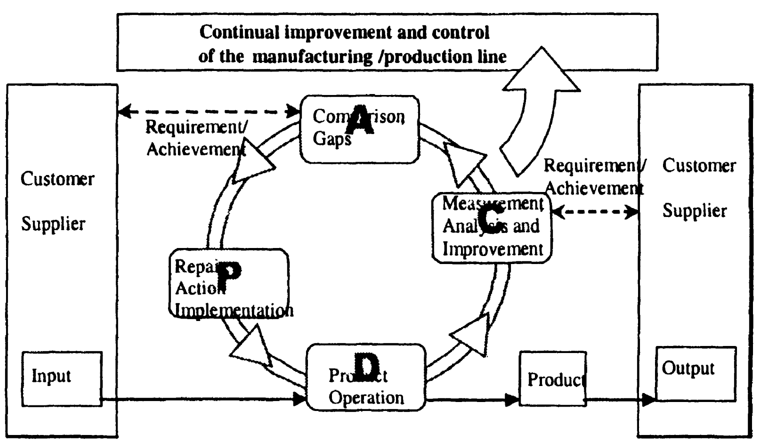

Figure 1 - Entities conceptual view of process approach for a manufacturing/production process (ISO/CD1 9000, 2000)

On the base of these two steps, the continuation of the methodology consists in specialising the meta-model in the context of an ALSTOM manufacturing line of electrical engines (section 5) and more precisely to the assembly process of rotor ALSTOM to build a partial model of the product class "assembled rotors" manufactured in Nancy. The global result of this methodology gives rise, on one hand, to tools which support its engineering and operation, and on the other hand, to conclusions and prospects for this work (section 6).

2. QUALITY CONTROL IN ENTERPRISE MODELLING

Quality Control strategies and operations should be considered as complete Enterprise process which the goal is to provide confidence that customer needs and requirements for product will be met while interworking with other shop-floor and business processes to carry out the global Enterprise goal. Engineering such a Quality Control system within an Enterprise system states a holistic approach for integrating views and evaluations, not only of the systems themselves, but also for their mutual interactions and their interactions with the environment (Morel *et al.*, 2001). It is so necessary in the sense where today, several companies are certified or in phase of certification, that Enterprise modelling framework (Vernadat, 1996) such as CIMOSA (Amice, 1993), GERAM (IFAC/IFIP, 1998) supports concretely methods, models and tools to integrate also the product quality and quality control points of view.

In that way, works were already led on the process modelling (Spur *et al.*, 1996) (Mertins *et al.*, 1999) in a context of Enterprise modelling. For example, a process model based on the approach CIMOSA, was developed allowing the implementation, the use and the maintenance of a quality control system at the company level and which fulfil the requirements of standards ISO 9000:1994 (Kosanke and Zelm, 1997). The application of this model guarantee an easy management of the quality documentation system but without taking into account the modelling of the life cycle of quality continuous improvement at the manufacturing/production process level in terms of PDCA loop. The integration of this PDCA loop within a flexible manufacturing cell was tested, in CRAN, on the basis of functional and informational modelling but without taking into account the requirements of the standard ISO9000:2000 (Richard *et al.*, 1994).

From these works, it results that the quality control as developed in the precedent version of the ISO9000 standard can be already integrated within the Enterprise modelling framework by means of models, while numerous works have to be done to integrate this point of view at the process level as advocated by the new version.

A first contribution to the integration at the process level is proposed in this paper by means of a new methodology for quality control which is based on the process approach defined in the standard ISO9000:2000. This methodology fits within the CIMOSA framework because :

- the meta-model of the process approach for the manufacturing process (generic object model) is supported by the information view of the view generation axis, at the generic level of the instantiation axis and at the requirements level of the model derivation axis.

- the partial model is supported by the same information view and at the same derivation level but at the partial level of the instantiation axis.

This partial model can be particularised (particular level) with various types of rotors made in Nancy. All the models are formalised by means of the language UML (UML, 1999) supported in our case by the MEGA Suite[2]. It allows defining, thanks to the uses cases concept, the quality product at the manufacturing process level among complementary points of view proposed by the standard (e.g. quality control at the Enterprise level).

3. META-MODEL OF THE PROCESS APPROACH

The first phase of the methodology consists in modelling the process approach for the manufacturing process as defined in the standard ISO 9000:2000 and in the way to be consistent with the "Enterprise - Control System Integration" principles proposed by (Isa/ds95, 1999). The modelling aims at :

- formalising in an explicit way all the normative text concerning the process approach for the manufacturing processes (quality control at the shop-floor level). The modelling leads to create a meta-model of the process approach for the manufacturing processes. It represents the object (data) of this process approach, their interactions and the constraints between these objects. This meta-modelling principle is already used in "application protocols" standardisation of STEP ISO/10303[3].
- integrating the standards at the first step of the design of company process model,
- allowing the company to obtain the certification ISO9000:2000 more easily because the manufacturing processes work and are organised so as to fulfil the requirements of this standard.

The meta-model is developed from the conceptual view of the entities represented in the figure 1. That means on one hand, to take into account the input and output in terms of product quality requirements and the satisfaction of these requirements by the supplied product, and on the other hand, to implement the manufacturing process under the shape of a PDCA loop. It is so necessary to extract from the standard all the terms with their definitions, all the parts of the concepts diagrams (these diagrams show the links existing between the terms of the standard), all the requirements of the standard related to conceptual view of the entities and to interpret them so as to delete all the ambiguities of the standard. On these bases, the meta-model formalisation has been realised (with UML) by specifying first the use case diagram for the standard ISO9000:2000 with the external actors who interact with it. Then, for this use case, a class diagram is elaborated by modelling :

- the terms of the standard in relation to this use case. Each term is materialised with a meta-class.
- the links existing between these terms. It is done on the basis of the relationships already defined in the concept diagrams, of the term descriptions but also of a "justified" interpretation of the normative text. Each link between

two meta-classes is materialised with an association relationship having a name, a role and multiplicities.

- the constraints between relationships defined by justified interpretation of the normative text. Each constraint is materialised with a link between meta-classes or between association relationships.

The figure 2 shows a part of the meta-model of the process approach for the manufacturing process as advocated by the standard ISO9000:2000.

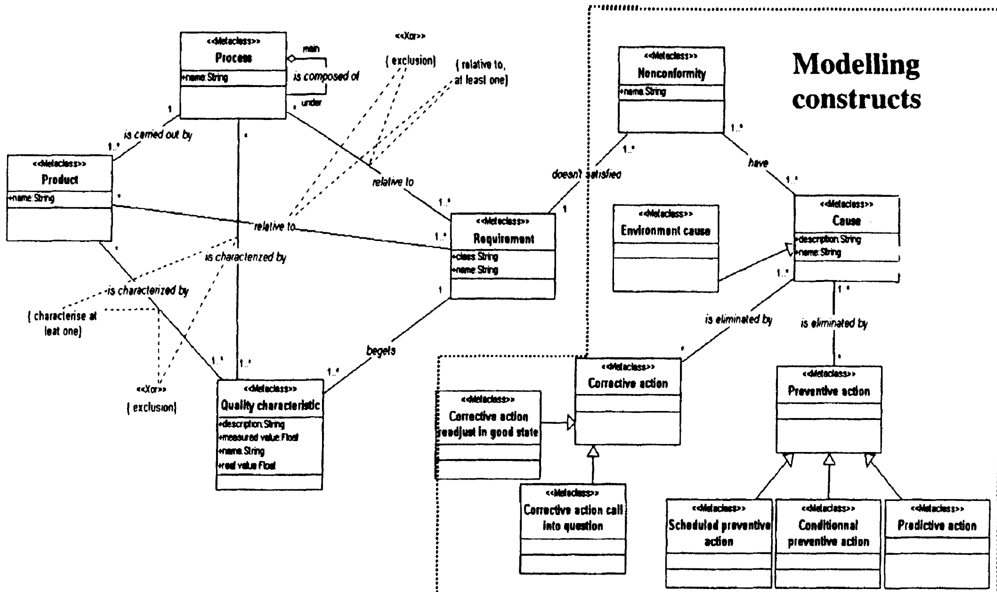

Figure 2 – Part of the meta-model of the process approach – and some quality modelling constructs

4. INTEGRATION OF QUALITY MODELLING CONSTRUCT

From the formalisation of the normative text, the second phase of the methodology consisted in integrating quality modelling constructs into the meta-model by considering other concepts such as :

(a) The general system theory already used in Manufacturing Engineering by (Mayer *et al.*, 1995),

(b) The maintenance standards as defined by IEC-50(191)[4],

(c) The principle 5M (Ishikawa, 1963).

(a) One aspect of the general system theory is to define a mechanical object by three attributes (shape, space, time) knowing that one process transforms **at least** two of these attributes whose one is mandatory **time** (time - shape or time - space). So, we made the assumption that a process, which transforms **only** two of the object attributes, is an **elementary process**. This implies for the meta-model that a process can be defined as a elementary process if it transforms only two attributes or can be decomposed in relation to the attributes transforming into several sub-processes until elementary processes (activities). Due to this principle and as an object has these three attributes, a product must have its requirements defined related to these three attributes. It leads to add to the meta-model, subtypes related to the meta-class Requirements (Product requirements, Process requirements) and with a disjunction constraint between these two subtypes. Moreover it allows adding stereotypical subtypes (Time, Space, Shape) related to the meta-class Product Requirement with totality and junction constraints between these three subtypes. Indeed a "Product Requirement" is necessarily described as Time, or Shape or Space type (by integrating also the rule that Time is required to characterise any Transforming) and a same product can have one or several requirements with regard to these three types.

(b) The principles and definitions issued from the maintenance standards are meta-modelled by specialising subtypes (Figure 2) related to the meta-class Preventive Action : scheduled preventive action, conditional preventive action, and predictive action. The subtypes are constrained in the way to ensure that a preventive action is necessary linked with one and only one of these types.

(c) The principle resulting from the 5M is meta-modelled by specialising the meta-class Cause with five subtypes M : Machine, Method, Material, Man power, environMent. The subtypes are constrained so as to ensure that a cause is necessarily a cause related to one and only one of these 5 types. All these subtypes (exhaustive way) have to be checked in relation to a nonconformity of the product.

5. SPECIALISATION PROCEDURE OF THE META-MODEL

On the base of these two first steps, the continuation of the methodology consists in specialising the meta-model in the context of an ALSTOM manufacturing line of electrical engines. In our case to demonstrate feasibility and interest of such methodology vis-à-vis of ALSTOM, we developed a specialisation procedure related to the assembly process of the rotors ALSTOM to build a partial model of the product class "assembled rotors " manufactured in Nancy.

Specialisation consists in developing, in a chronological way, seven stages allowing to specialise all the meta-classes of the meta-model due to "engineering" questions that translate, in a pragmatic way, the association relation-ships, the constraints and the multiplicities of the meta-model. Every specialisation is represented with the modelling language by a sub-class of the meta-class of the meta-model. These seven stages are : 1 - definition of the context of the study (Sub-classes Product, Process, Customer and Provider); 2- qualification and characterisation of the product (Sub-classes Requirements and Quality Characteristics); 3- identification of the means to determine the quality characteristics (Sub-classes Test, Observation, Measure); 4- identification of the means to determine the conformity or the nonconformity (Sub classes Validation, Verification, Objective Evidence, Inspection); 5- identification of the conformities and nonconformities (Sub-classes Conformity and Nonconformity); 6- processing of the nonconformities (Sub-classes Scrap, Regrade, Rework, Repair); 7-processing of the nonconformity causes (Sub-classes Cause, Preventive action, Corrective action).

For example, in relation to the ALSTOM manufacturing line, the first instantiation phase allows to define the study environment in terms of creating (a) the sub-class "rotor assembled" of the meta-class Product, (b) the sub-class "to assemble rotor" of the meta-class Process and all sub-classes related to the sub-processes (elementary processes such as to pile sheet metal, ...), (c) the sub-class "autonomous team in charge of rotor assembling" of the meta-class Provider, and (d) the sub-class "autonomous team in charge of rotor assembling calibration" of the meta-class Customer. Every elementary process has been, in another step of the process approach methodology, the starting point for the new application of the seven stages of the specialisation procedure in order to have, at last, the partial model of rotor products assembled in Nancy. It leads to master the quality of the ALSTOM manufacturing line by a process approach imbricating a set of sub-processes formalised with the PDCA loop. This partial model (figure 3) can be considered as a reference model that can be particularised with various types of rotors made in Nancy and usable directly in operation on the manufacturing line.

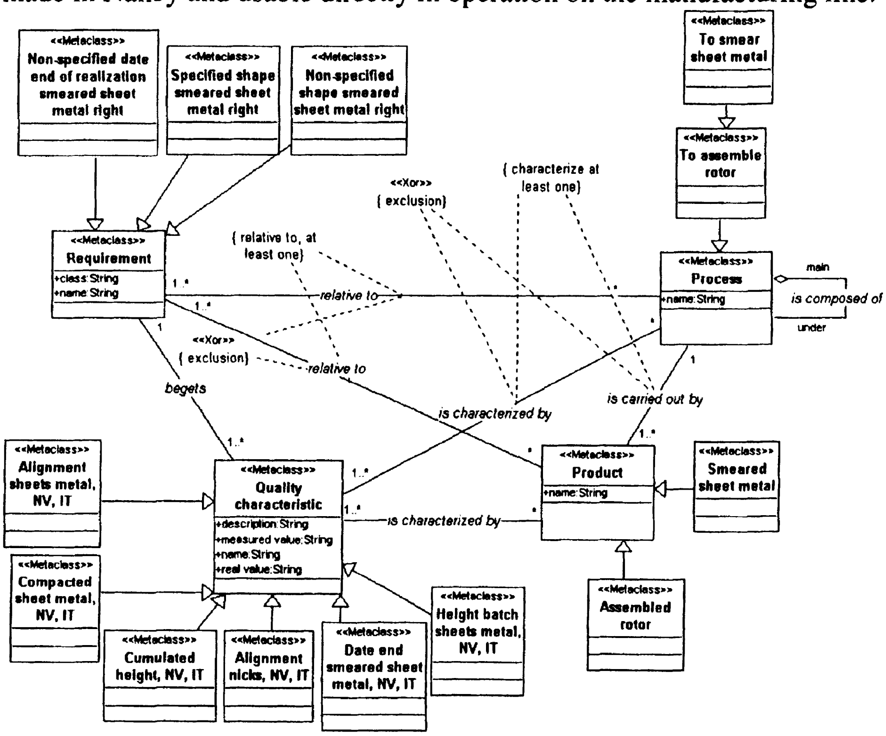

Figure 3 – Part of the partial model of the product class "assembled rotors "

6. CONCLUSION

The contribution developed in this paper led to the development of a generic methodology for manufacturing processes modelling. It is generic, first at the partial level, because a new global process related to a product application class (e.g. assembled rotors) is developed from a specialisation procedure of the normative model (meta-model) whatever the process is, and second at the particular level, because a particular process related to a specific product of the application class (e.g. rotors made in Nancy) is developed from a particularisation procedure of the partial model.

The feasibility and efficiency of this methodology is tested today until end of this year, from an engineering and operation levels, on the rotor assembling line in Nancy. Indeed, a software prototype supporting all the methodology has been developed (from UML models towards data base SQL-Server, from questions towards Access interrogation forms of the data base), on the hand, to help the engineers to inventory all the required knowledge on these line processes (to fulfil the partial model in accordance with the meta-model), to underline where are the quality mastering problems (what is missing to fulfil the models) and then, by exploiting the knowledge encapsulating in the prototype data base, to propose on site to each unit responsible of one line process, some help (document or screen views) to make correct diagnosis (knowledge on causes) and actions (preventive or corrective actions) in relation to the anticipation of a non-conformity product.

In addition to the operational tool, one work in progress is to integrate methods such as SPC, FMEA, HAZOP, with this methodology in order to define more precisely each of the causes and preventive actions. Finally a step towards the use in UML 2.0. of formal language SDL (Specification Design Language) has to be envisaged to allow the verification of the model UML.

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[1] http://www.alstom.com
[2] MEGA SUITE is a software provided by the MEGA International company – http://www.mega.com
[3] http://www.pdtsolutions.co.uk/standard/papers/pdtag/paper.htm#infounit
[4] IEC-50(191) International Electrotechnical Vocabulary - Chapter 191 "Dependability and quality of service".