Implementation of a methodology for consideration of product quality within discrete manufacturing

M. Foehr*, T. Jäger*,
C. Turrin, P. Petrali**, A. Pagani**,**
P. Leitao***

**Siemens AG CT RTC SYE EMT-DE, Erlangen, Germany*
([matthias.foehr][jaeger.tobias]@siemens.com)
***Whirlpool Europe s.r.l., Cassinetta di Biandronno, Italy*
([claudio_turrin][pierluigi_petrali][arnaldo_pagani]@whirlpool.com)
**** Polytechnic Institute of Braganca/Artificial Intelligence and Computer Science Laboratory (LIACC) , Branganca/Porto, Portugal (pleitao@ipb.pt)*

Abstract: The present paper deals with the questions how product quality can be influenced within product manufacturing and how production control can be optimized for increasing product quality. It focuses on discrete manufacturing processes and presents a methodology to gather and analyze relevant influences on product quality and a multi-agent architecture for flexible and quality focused production control. It will be shown how both approaches can be implemented to achieve a flexible, adaptable and quality focused production process control.

Keywords: Production Control, Multi-Agent Systems, Flexible Manufacturing, Product Quality, Quality Control, Factory Automation, Model-based Approaches

1. INTRODUCTION

Plant operators are facing challenging market conditions. The pressure to produce products with proper quality rises (Crosby 1979), (Fritz 1994). At the same time pressure rises to engineer more flexible and efficient manufacturing lines at reduced costs in a very short amount of time (Diedrichsen 2008). In the area of manufacturing systems 70% of the additional costs are caused by incomplete information and unknown interaction interfaces given at the design phase (Little 2003), which in return suffer time and cost reduction. This strict time/cost optimization leads to a decrease in product quality of goods manufactured on the line.

The highest impact on the engineering costs of new manufacturing lines is with 55% situated at the automation engineering (Drath 2010). Thus, dealing with the above mentioned challenges new concepts for process and quality control are needed. Within this area of tension the EU-project "inteGration of pRocess and quAlity Control using multi-agEnt technologies (GRACE)" (GRACE consortium 2011) has been started. One focus of the project is set on the provision of a new Multi-Agent Architecture, combined with a methodology for quality assurance/improvement to provide suitable solutions for plant operators.

GRACE thereby considers the strong interactions between product design and plant engineering and focuses on the manufacturing phase. Here, all main influences on the final product quality come together:

1. The product design, creating the planned product quality by defining product Functions (F) and product components/materials (M).
2. The plant engineering, creating the manufacturing line, by defining manufacturing processes (P) and process sequences based upon the products to be produced.
3. The inbound logistic purchasing all Materials (M) needed for the manufacturing of the product.

They all meet at the manufacturing phase where the planned product quality is brought into reality by assembling procured materials within production processes. At the end the final product produced satisfies or dissatisfies the customer requirements and is being sold on the market. Here, high efforts are spent by plant operators to only sell product satisfying customer requirements to increase brand image and avoid restitution and so in the end optimize revenue. This central role of manufacturing for product quality is shown in Fig. 1.

The rest of the paper is organized as follow: Section 2 of this paper will present the MPFQ-model developed within GRACE for the integrated consideration of product quality. Afterwards a short introduction to the GRACE Multi-Agent System (MAS) will be given. Section 4 will show how GRACE MAS and MPFQ may be integrated and implemented for increasing product quality within manufacturing control. It will show the methodical approach for the implementation within GRACE project. At the end section 5 will round up the paper with a conclusion showing preliminary findings / benefits of the proposed approach and will give also a look into the future work.

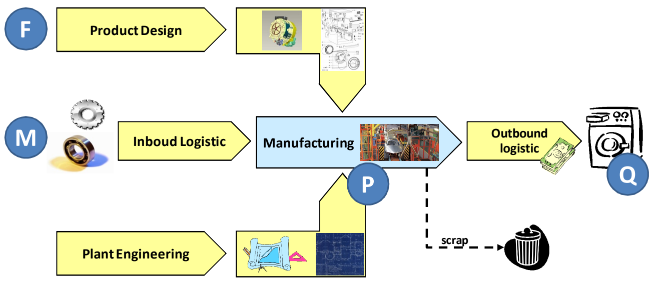

Fig. 1: central role of manufacturing for product quality

2. MPFQ-MODEL

When it comes to product quality, most of the relevant influences come together in the manufacturing of the product. Here, the intended quality defined within the product design is brought into reality by the production line. Finally this product satisfies or even dissatisfies the customer needs.

This chapter will present a model based on (Foehr et al. 2011), which can be used to describe the basic quality influences and their correlations (subsection 2.1). In the second subsection a short example will be given.

2.1 Introduction to MPFQ-model

The MPFQ-model is called after its four main elements:

- Material (M) - as a collective term for everything that is needed to produce a certain product or product component. This may include raw materials (Oxford English Dictionary 2012b), pre-products, consumables (Oxford English Dictionary 2012a), operating supplies, product components and assemblies (O'Sullivan, Sheffrin 2003).
- Production Processes (P) - processing and transforming materials into the final goods by using machines, tools and human labor. This process is defined within the plant engineering. (DIN 8580)
- Product Functions / Features (F) - as distinguished characteristics of a product item. This is mostly focused on functionalities like specific tasks, actions or processes the product is able to perform, but may also include other features like performance etc.
- Product Quality (Q) - measured, following (DIN EN ISO 9000), as the degree of conformance of final product functions and features to customer requirements.

The first three elements (M, P, F) can be described by their technical characteristics and the data obtained from measurements. The production processes (P) may be additionally characterized by their process step sequence and parameter setups. The product functions (F) are further detailed by performance indicators.

The product quality can be categorized in multiple ways. Based on the industrial experience of the authors a categorization into perceived quality, performance, durability and reliability was chosen.

The perceived quality is combining all identified and interpreted information, perceived by the customer through all of his senses (look, feel, hear, smell and taste). Typical examples are the haptic perception of the product (e.g. premium surface materials) or even the quality impression coupled with a brand name. The durability of a product describes how this perceived quality is changing over time (e.g. scratches on varnished parts, yellow staining of white plastic parts etc.).

The performance of a product is the degree to which it fulfills its functional requirements. Typical examples are the washing performance of a washing machine, energy and water consumption or the noise emitted during a washing cycle. In correspondence to the perceived quality also the time behaviour of the performance can be described. This is done by the reliability, which describes how good a product is able to perform its tasks and processes on a predefined level for a specific amount of time.

Fig. 2 depicts the four main elements of the MPFQ-model and their interrelations. Within the MPFQ-model two types of interrelations can be found: the recursive dependencies between materials processes and functions and the straight forward dependencies of the MPF-part to the quality.

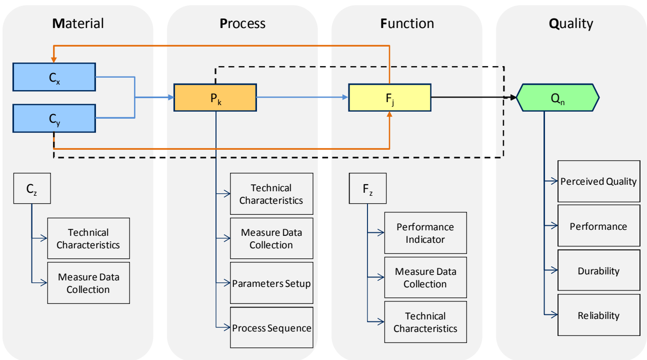

Fig. 2: MPFQ-model

Starting with a manufacturing process (P) typically two or more materials (M) are combined to form a function (F) (see blue arrows in Fig. 2). A Function is usually formed by one material acting on another (orange arrows in Fig. 2). Hence, there is a closed interrelation loop given within the MPF-part. This fact is not surprising, as it shows the strong interlocking of plant engineering (combining materials (M) in production processes (P)) and product design (defining product functions (F) realized by materials (M)).

According to (DIN EN ISO 9000) and (Hammer 2011), product quality can be defined as conformance of product functions to customer requirements. Thus, product quality is an aggregation of one or more product functions/features (black arrows in Fig. 2). Despite these primary dependencies there are also processes and materials defining the product quality (black dashed line in Fig. 2). This can be easily seen by taking the example of a green product footprint, which is e.g. depending on the energy consumption of the product and the resources spent during the manufacturing of the product. Thus, taking the example of a washing machine, the motor and heating element (materials) and the energy consumed during the single production processes primarily define the green footprint quality of the product.

2.2 Example for MPFQ modelling

This subsection gives a short example derived from the overall MPFQ-model for a washing machine created within the context of GRACE project (GRACE consortium 2011).

Within this example the quality "seal water" is regarded. This quality is related to the fact that water used for washing of clothes, should stay inside the washing machine to prevent the washing machine from damaging the surrounding/ environment. Therefore two processes assembling three materials and creating two functions are needed (see Fig. 3).

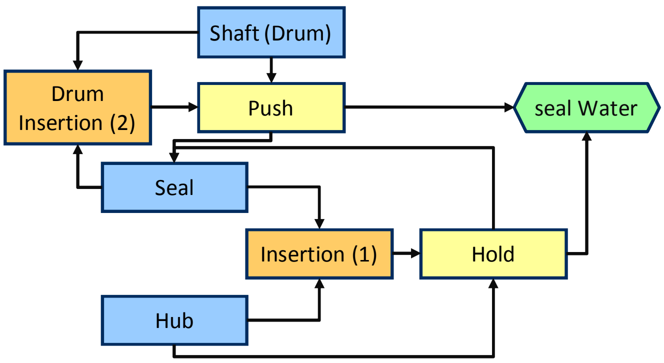

Fig. 3: MPFQ modelling example

First the seal is inserted to the tub. Thus, the tub holds the seal and due to the rubberish material of the seal water is prevented from leaking outside. Afterwards the drum and especially the shaft of the drum is inserted into the seal. By doing this the shaft pushes on the seal. Due to this pushing function the water is sealed inside the washing tub. In the end both function prevent a water leakage, as the water is stopped on the outer dimension and inner radius of the seal. This part of the MPFQ-model for the washing machine is shown in Fig. 3. For simplification other functions and processes correlated to one of the shown elements have been cut out.

For further information and detailed description of MPFQ-model as well as additional examples (GRACE consortium 2012), (Foehr et al. 2013a) and (Foehr et al. 2013b) are referred.

3. GRACE MULTI-AGENT-SYSTEM

Multi-agent systems (MAS) (Wooldridge, 2002) are being pointing out as a suitable technology in the development of the concept of Factories of the Future, addressing the requirements of adaptation, robustness and responsiveness. MAS constitutes a way to design distributed control systems based on autonomous and cooperative agents that interact with each other for the realization of efficient, flexible and robust systems. The vision of the GRACE project is to integrate quality and process control levels by using the MAS principles.

3.1 GRACE Multi-Agent-System Architecture

The designed GRACE multi-agent system comprises a society of autonomous and cooperative agents representing the manufacturing components disposed along a production line producing washing machines.

In such distributed environment, the proposed architecture identifies several types of agents, according to the process to control and to their specialization (see (Leitao and Rodrigues, 2011) for more details):

- *Product Type Agents* (PTA) represent the catalogue of products/parts that can be produced by the production line and contains the process and product knowledge required to produce the product, namely the product structure and the process plan. Note that PTAs not only act on plant/factory level but also on production line level.

- *Product Agents* (PA) handle the production of product instances along the production line (e.g., washing machines and drums). They possess a process plan to produce the product and interact with the agents responsible for the process and quality control.

- *Resource Agents* (RA) represent the physical resources of the production line, such as robots, quality control stations and operators. They manage the execution of their production/ testing/ transportation/ assembly operations in the production line. The RAs comprise several specializations according to the particularities of the resource; namely Machine Agents (MA), Quality Control Agents (QCA), Transport Agents (TA) and Operator Agents (OA).

- *Independent Meta Agents* (IMA) implements global supervisory control and optimized planning and decision-making mechanisms, e.g. defining and adapting global policies for the system. In opposite to the PA and RA agents, that are placed at the operational execution level and are mandatory, the IMA agents are positioned in a higher strategic level and are not mandatory (the system can continue working without them, however losing some optimization).

The interaction among the identified agents allows to perform the quality and process control in a distributed manner, as illustrated in Fig. 4, supporting the effective integration of these two levels.

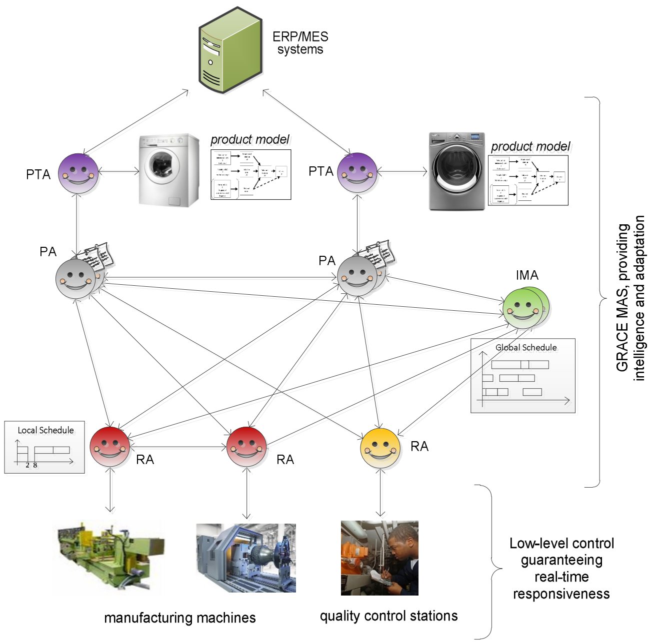

Fig. 4: GRACE multi-agent system architecture

In the proposed approach, each agent has its own objectives, knowledge and skills. Since each one has only a partial knowledge of the problem, and none has a global perspective, they need to interact with each other to achieve their global objectives. In consequence, the overall system behaviour emerges from the cooperation among individual agents, each one contributing with its local behaviour.

3.2 GRACE Ontology

As previously described, the interaction among individual agents is crucial in multi-agent systems applications. The interaction between agents requires that the agents can understand themselves to share knowledge, using interaction protocols (e.g. following the FIPA (Foundation for Intelligent Physical Agents) protocols), a proper agent communication language (e.g. the FIPA-ACL (Agent Communication Language)) and a proper knowledge representation.

Of special importance is the establishment of a common understanding among the agents, since the exchange of shared knowledge becomes difficult if each agent has its own knowledge structure. The solution is to use proper techniques that guarantee the common understanding among distributed entities. The use of ontologies addresses this challenge. The term ontology is vague and not unique (see as example (Gruber, 1995) and (Lai, 2007)), but in an easy manner, it defines the vocabulary and the semantics of the knowledge used in the communication between distributed agents.

In the GRACE project, an ontology was designed and implemented considering the particularities of the home appliance domain and the integration of process and quality control levels. This ontology formalizes the structure of the knowledge, namely the concepts, the predicates (relation between the concepts), the terms (attributes of each concept), and the meaning of each term (type of each attribute), as illustrated in Fig. 5.

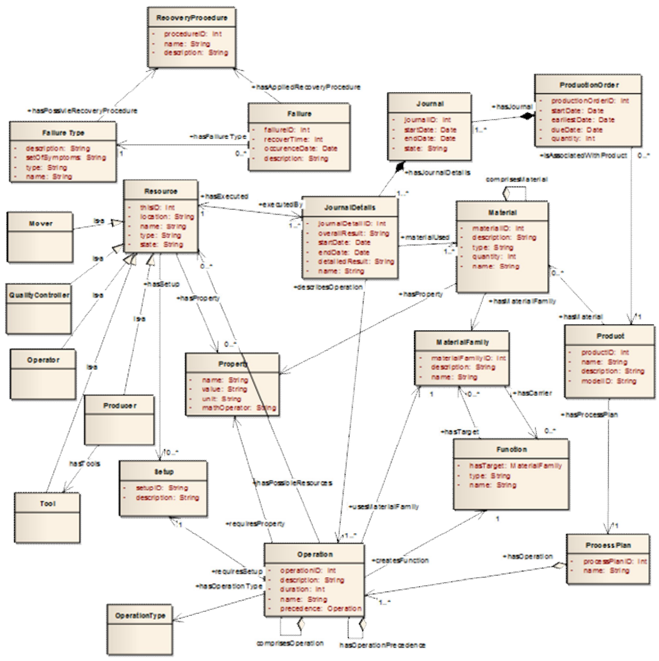

Fig. 5: GRACE ontology schema

The GRACE ontology schema was edited and validated using the Protégé framework (http://protege.stanford.edu/), which supports the Web Ontology Language (OWL) (W3C, 2004) and has an easy connection with agent development frameworks, such as JADE (Java Agent DEvelopment Framework).

4. IMPLEMENTATION OF MPFQ-MODEL IN MULTI-AGENT-SYSTEMS FOR PRODUCTION CONTROL

This chapter will deal with the question how MPFQ-model and GRACE MAS can be integrated and implemented for advanced production control. Here, the focus will be set on the improved quality control. Other advantages resulting from the implementation of a MAS like flexibility, adaptability, etc. can be found e.g. in (Mařík, Lažanský 2007) or (Pěchouček and Mařík 2008).

To enable the agent communication not only among each other but also with the production database, the Agent ontology (see chapter 3.2) is including all elements of the MPFQ-model. Thus the concepts of materials, processes, functions and quality, as well as their correlations are built into the ontology. This way, agents are able to understand and interpret all data related to the MPFQ-model coming from other agents, the production database or other sources.

As a first step for the quality assurance and improvement, quality has to be known. Therefore, QCAs and MAs are collecting data from the running production line. MAs are collecting data right from production processes. They can measure e.g. the insertion depth and insertion force during a bearing insertion process. On the other hand QCA are collecting data directly from the product by the quality control stations they control. This measurement raw data is then stored into a production database. Using the MPFQ model supports the engineers which data to measure and store. As all relevant data, technical characteristics, performance indicators and process steps having influence on the product quality are modelled within MPFQ, these are also the characteristics which potentially have to be measured.

After the data acquisition the MAs and QCAs also elaborate the data to generate quality numbers describing the quality level on which the process has produced resp. which was measured on the product. During manufacturing it can be assumed that the results from these measurements are normally distributed, where the optimal quality is also the peak of the Gaussian bell curve. By doing the data elaboration, the position of the current proceeded process/measurement can be evaluated. This quality value is also stored into the production database. The above described process can be seen in Fig. 6.

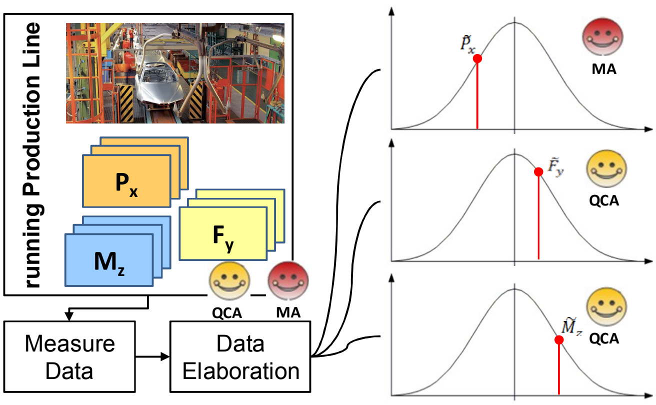

Fig. 6: Data Acquisition and Elaboration by Agents

Based on the quality numbers measured for the single processes, functions and materials measured, the product agent can evaluate the quality of "his" product. Therefore he is using a quality correlation table, which can be calculated from the MPFQ-model and is stored within a quasi-static part of the database.

The quality correlation table is a matrix representation of MPFQ-model. Here, every influence of a process, function or material on a quality feature is documented. Thus it can be seen which processes etc. having which impact on product quality. To create this table multiple ways are possible. The MPFQ-model can be transformed into a matrix easily as every connection between a quality feature and another model element result in a correlation. The question here is how strong this correlation really is. If it is known it can be written into the correlation table e.g. by experts or it may be already included in the model by weighted edges. Thus, the reasonability of the correlation table would be highly depending on expert knowhow. But there is also another way to calculate the correlations. This can be done by applying methods e.g. from potential theory. Thus, every correlation is weighted based on how far it is "away" from the quality feature (meaning how many elements are between the quality feature element and the element to be weighted). Thus every element connected directly and indirectly to the quality feature can be weighted. For sure this will only give a starting point for the correlation table. The table will then need to be tuned based on statistical correlation methods. These can be done by an IMA during production to improve table reliability. If production data is known in advance, e.g. implementing this control process on an already existing and running production line, the previous data may be used for statistical correlation analysis, resulting in a more reliable table from the beginning.

Additionally IMA may also run statistical analysis during production to detect trends in raw data, quality numbers or quality of products produced. This way additional warnings e.g. for exchanging tools to maintain high product quality are enabled. The process of PAs and IMA using data from the production database is depicted within Fig. 7.

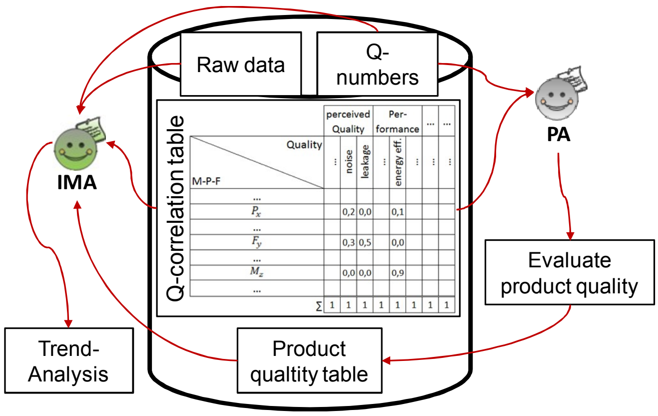

Fig. 7: PAs & IMA using production DB for quality elaboration and optimization

5. CONCLUSIONS

The paper presented a new way of production control by supporting MASs with additional quality dependency model (MPFQ-model). The presented approach is currently implemented within the GRACE project. First results are very promising as not only product quality can be improved, but also other important effects are seen; e.g.:

- Monitoring of product quality at any time within production, as quality can not only be measured at quality control stations but also after each production step.
- Improved Quality of products due to quality oriented influence on production processes based on current state of product quality. E.g. adaptation of production process parameters in order to produce a better quality for a specific product (product specific parameter setup).
- Improved efficiency of the production line due to ability to elaborate specific problems in product quality and adapting functional test plans accordingly; thus leading to reduced testing times.

- Cost reduction within production as quality can be evaluated at any time. Products may be scrapped when evaluated with bad and not improvable quality results. Thus, products can be scrapped after each process and not only after quality control stations (which would mean that additional components may be assembled to a bad product before it is identified as bad).

- Improved certainty about product quality, as 100% of the manufactured products can be evaluated on a basic level regarding their quality without any additional test / control stations.

Future work will be dedicated to validation of these findings. Therefore the implementation of this approach will be finalized to have a real production line controlled by the proposed approach. Afterwards statistical measures will be taken to validate the first findings and quantify savings in cost and time reached by implementing the approach.

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