A guideline of quality steps towards Zero Defect Manufacturing in Industry

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Abstract

Management in the manufacturing industry has often used different types of quality improvements to reach a “near zero” perfection in product and process development. Manufacturing of complex products with a large number of components, often have high probability of detective output product. Methods like Six Sigma, Lean i.e. are excellent to target these strategical goals and make improvement in production. Statistical tools and data collection are indicators that may improve the quality; however, a growing amount of data, “internet of things” (IoT) and cyber physical systems (CPS) have led to development of complex manufacturing systems, today mentioned as Industry 4.0.
Documented “Best Practices” is necessary to understand the interoperability. The author has harvested results from EU-project “Intelligent Fault Correction and self-Optimizing Manufacturing Systems” (IFaCOM), with focus on Zero Defect Manufacturing (ZDM). The project used a beyond Six Sigma approach and by structuring the TQM issues into a process map transformed to a ZDM Guideline. Process steps and quality methods which have been used with the ZDM philosophy is not only statistical methods, but also steps that can give benefit to process optimization, combination of quality methods as contribution to rework of products, less waste of material and Improved productivity.

Keywords
Zero Defect Manufacturing, Total Quality Management, Six Sigma, Industry 4.0

1. Introduction

The European aerospace industry is one of the cutting-edge industries for the growth of production in Europe. Product and process development of aircraft, machine tools and other high-tech industries are heavily dependent on efficient, safe and adaptive manufacturing processes. Improvement of products and processes can therefore be a major cost saving for those sectors that will benefit customers, as well as the manufacturers (Eurostat, 2013). Management control systems and strategies that include goal setting with zero defect strategies are more likely to have frequent feedback related to the quality and cost targets, and improves decision-making processes to determine which data that are needed (Daniel & Reitsperger, 1991) (Teti & Kumara, 1997).

Development of new manufacturing technologies and usage of integrated Information, Communication and Technology (ICT) solutions will make the work more efficient. In this environment, it is possible to reduce product and process defects, energy consumption and achieve organizations that are more flexible. It will also make it possible for employees and organizations in the industry to combine a safer working environment with these new ICT solutions (Westkämper & Warnecke, 1994).

Human interaction, of change and relationship management and flexible ICT real time solutions have therefore a potential for innovation, which again can have a major impact on these industries, and provide new skilled jobs and additional growth in new markets. Opportunities for cost savings and sustainability in new innovative technical solutions are challenging for product and process development in the manufacturing context, but the transition to an optimal flawless production solution is imminent (Colledani, et al., 2014) (Wang, 2013). The introduction of Industry 4.0 and Cyber Physical Systems is the visions that can make high cost complex manufacturing system to come true (Westkämper, 2007) (Demmer, 2015).

1.1 The framework of IFaCOM

When the EU-project IFaCOM (Intelligent Fault Correction and self-Optimizing Manufacturing Systems) started the team identifies the key internal processes that influences the "critical to quality" CQ characteristics cited by (Antony, et al., 2006) (Gutierrez, et al., 2009) as six sigma processes. The aim of IFaCOM was to use a beyond Six Sigma philosophy and used the vision of Zero Defect Manufacturing (ZDM) by use of IDEF0. This mean that ZDM philosophy, Six Sigma methodology and TQM methods are tools that use indicators that are critical to the quality and identified by the costumer. With references to (Breyfogle, et al., 2001) they find the parameters and indicators that have high impact on the quality of the product or on the service. Specific goals, based on the customer's requirements (Linderman, et al., 2003) that are grounded on a philosophy of continuous improvements, all the points that combines TQM, ZDM and Six Sigma together.

The IFaCOM framework give a picture of the different loops which is necessary to monitor in "real time production processes" and bring us to the cross-linking of system thinking and data architecture, which leads us a further step into the manufacturing ICT solutions of today, named as Industry 4.0 and Cyber Physical Systems (CPS). This is real time control of vital parameters and is key to determining process parameters that are within a desired range i.e. tool wear in machining operation, position in assembly phase. Wire vibrates in the EDM and surface conditions in polishing, which all has an important impact on the final product quality.

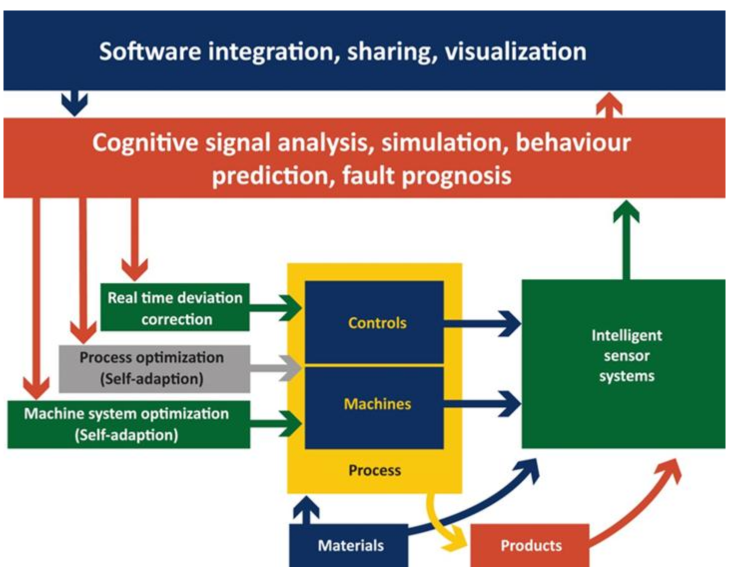

Figure 1. The framework of IFaCOM

A method to define "Machine system optimizations" and a multi-stage part programs have been specified and presented for simulating. A method for modelling and predicting part quality errors as a function of the input process parameters and a fuzzy logic based approach (fuzzy-nets) has been selected and will be able to deal with part quality prediction in manufacturing processes in IFaCOM (Schmitt & Pavim, 2009). IFaCOM has developed a system approach for data monitoring of multidimensional fluctuation in product and process parameters. Intelligent multi-sensor systems have been selected and developed, in order to meet industrial requirements for durability and reliability, and then implemented and tested this in project's industrial cases. By using a software engineering definition of the IDEF0 tool, the Zero Defects (ZD) potentials were developed in each five end-user cases of IFaCOM (IFaCOM, 2011-2015).

This to define the requirements and to specify the functions of the "as is" and "to be" situations. Researchers in the manufacturing field supports the paradigm of ZDM as a production quality approach. "Traditional six-sigma techniques show limitations in highly changeable production contexts by small batch production, customized, or even one-of-a-kind products", (Colledani, et al., 2014) refers to in a recent CIRP Annals of Manufacturing Technology and are verified by research findings from IFaCOM.

2. The end-users and demonstrator cases in IFaCOM

The IFaCOM project consisted of six academic research partners, four-technology providers within information technology and sensor knowledge, and five end-users.
In the aerospace industry we have the Norwegian company GKN Aerospace Norway (GKN), they have specialized their production on complex vital jet engine components. Their costumer include large jet engine producers like GE, Pratt and Whitney and Snecma, most of their market are civilian large passenger airplane engines. The production consists of exhaust cases (turbine rear frames), low-pressure turbine cases, other casings, shafts and airfoils.
The second IFaCOM end-user in the aerospace industry was, Europea Microfusioni Aerospaziali SpA (EMA), situated in the southern part of Italy. The company has a long product line from casting foundry to using wax technology to be able to produce and melt nickel and cobalt based super-alloy. Their main production is spare parts and critical components to the aircraft turbines on land and gas turbine applications; EMA is a part of the Rolls-Royce Group and supplier to their crafts and turbines.

In machine tool industry, we find the Swiss company Georg Fischer, AGIE CHARMILLES (GEFAC) that is one of the world leading providers of machine and services to the tools and mould making industry. The company produce several electric discharge machines (EDM), high–performance milling machines and 3Dlaser surface texturing machines and are provider of services, spare parts, consumables and automation solutions for their customers.
The Danish company STRECON, which is an SME, makes robot-polishing machine tools. Their costumers consist of tool making companies for forging and plastic moulding.

The last company ALESAMONTI, is a small machine tool manufacturer, situated in northern Italy. Their product line consists of horizontal spindle boring and boring-milling machines, used in different application such as mould large engines and machine tool manufacturing. They produce small series of large custom-made machines each year, and the company aims to innovate their products in order to be able to face the growing competition. A description of each demonstration cases are presented in Table 1.

Table 1. The industrial demonstrator cases

End User	Sector	Industrial case
GKN	Aerospace	Automate Aerospace component assembly process
EMA	Aerospace	Optimize investment-casting process for obtaining better end results
STRECON	Machine Tools	Monitor status of RAP process and control process
GEFAC	Machine Tools	Predict and correct error occurrences in WEDM process
ALESAMONTI	Machine Tools	Compensate MT errors, automatic SPC for small batch, tool wear monitoring

3. Quality Methods and Tools

3.1 Quality tools

In decades, Deming and Juran introduced the importance of Total Quality Management (TQM) as a management system, and introduced this for ensuring internal requirement and non-conformances by satisfying customer requirements (Deming, 1982) (Juran, 1979). Juran's cost optimum was the relation between failure and costs quality in work processes and customer quality conformances, while Philip Crosby and other's take that idea further to a vision of "zero defect" (ZD) where the strategy was to do the right thing at first attempt in order to avoid defects (Foche, 1965) (Crosby, 1969). The state of the art in quality is also telling us that Deming's PCDA circle is a wall of foundation for all kind of quality work from Lean and Six Sigma to different Standard's i.e. ISO.

Quality methods is coming from research framework, where a mixed approach or an interconnection of worldviews is used (Creswell, 2014). We can see tables and figures in different matrix some of them are qualitative (wording, human, improvements) and some of them are quantitative (numbers, statistics) methods. To specify type of processes there is often used mixed approaches between qualitative and quantitative methods. Figure 2.shows the use of this development in an easy and visual way. This figure describes the development of using statistical and non-statistical quality approaches in the different quality cases, when we are moving from a manual and over to a more automatically approach. Some of the methods is easy to use and describe, others is more fuzzy and need wide measurements and documentations.

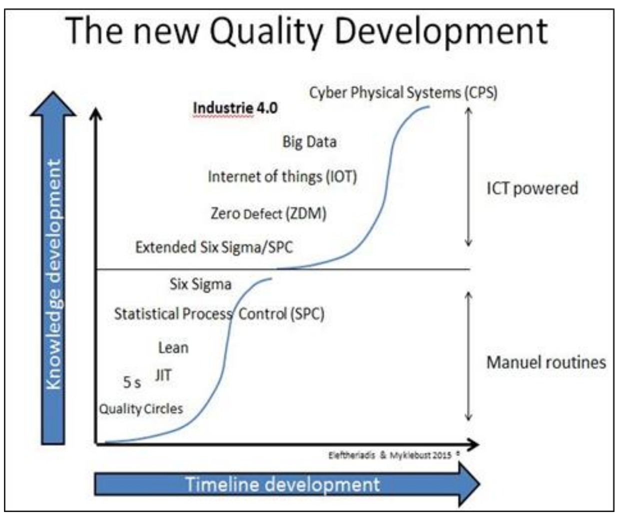

Figure 2. The new Quality Development (Eleftheriadis, 2015)

Statistical Process Control (SPC) are based on the same idea as Taguchi and Six Sigma where monitoring the variation of a feature to distinguish between natural variability and variation due to assignable causes. SPC detect the variation due to assignable causes and it is meant to be eliminated and provides hints for further process improvements (Montgomery, 2009). In this sense, SPC is not to be considered as an alternative to other zero-defect approaches such as enhanced real-time process control or improved medium- and long-term process improvement. It is rather a necessary control instance that allows the user to measure, evaluate and sustain improvements over a long period of time. SPC is based on statistics and requires a certain number of measurement values (or products, respectively) to achieve statistically significant statements on which decisions can be based. Due to these requirements, the general assumption is that SPC can only be applied very restrictively to small-batch production.

Zero Defect (ZD) is not a new concept, the US State Secretary of Defense used the term as early as 1965 and they implemented this as a quality and reliability program (Foche, 1965). The most important for implementing ZD, was what it was **not** meant to be. It wasn't a speed up program, not an employee evaluation technique, either a substitute for quality control or a technique for ensuring error. It was an approach for elimination of defects attributable to human error, to inspire personnel at all levels in the organization to do their jobs right at the first time. The ZD concept recognize that event though a person is dedicated, well trained and use many tools they do not necessarily do defect free work. It needed something more like a reminder that his contribution to the quality of a product is important and recognized by the management (Crosby, 1969).

3.2 New tools, guidelines and standards

The way forward to make a guideline of best-selected quality tools in the IFaCOM project was not strait forward, due to the differences between the different demonstrators. This will also be the case in the industry. The IFaCOM project developed many different methods, however a systematic approaches of validation, structuring and storage of acquired data was one of the most important one. Control tools that are critical to quality for the tolerances of a machine was selected and process knowledge for each of the end-users. After the feedback from the end-users on CQ tools, a guideline of how to handle Vital Process Parameters (VPP) was developed.

- This method was the preparation for data processing and as result of measurement, which can be used for production control (VPP/VDI) (Schmitt, et al., 2014). The method gives an important parameter with respect to zero defects quality and is therefore the level of integration into the production processes and as earlier mentioned the quality of information that is gained through measurements differs and depends on the measurement process. The importance's of validate the measurements results and know the level of reliability; the validation includes the usability of data for quality control and the evaluation of the measurement uncertainty, and are described in an upcoming small-batch standard ISO7870-8 (Schmitt, et al., 2014).
- The process description of how to map and use the IDEF0 is also a part of this VPP guideline and describes decision, actions, and activities of an organization on specific processes. This as a part of communicating the functional perspectives of systems, identifying all the steps in your organization by process optimizing, where identification of objectives, risks, and key controls is important parameters (IFaCOM, 2011-2015).
- An own sensor selection guideline is made for easy access to pre-select sensor. Then hardware and software system that can be bought or engineered (tailor-made) specific for each end-user from a service company. This made it easier to do the selection when sorting out new software, hardware or software architecture for each of the involved companies.

4. IFaCOM Quality Tools

Thru the IFaCOM project, the author identified different methods and quality tools some statistical and several non-statistical tools used by the companies in the demonstrator cases. The case description in Table 1. show the process mapping in IFaCOM, and it describes what kind of tool or method that can be used in each end-user cases for finding process parameters, coding of robots, statistical methods or algorithm for Neural Networks. In Table 2. It is possible to see some of the findings of quality methods and tools. Not all the demonstrators used all the tools but the matrix shows the wide range of methods used for providing the targeted outcome of the project.

It must be emphasized that each of the companies had different goals, different processes and product, and was competing in different branches. To hit the targeted strategical goals for each company was therefore a complex process, mentioned as the possibilities to reach new enabling technologies that will benefit and innovate all layers in these organizations thru the ZDM Philosophy (Westkämper, 2007).

Table 2. Tools used by IFaCOM demonstrators (Eleftheriadis, 2015)

General methods used by end-users in IFaCOM	
Type of method	**Description of content**
ZDM Philosophy	The idea of doing "the right thing at first attempt" (finding the defected process)
Project Management	Basic project management following the standard PM and WBS
The IDEF0 model	An information technology enterprise model on process capability
Several standard questionnaires	Questions which captures the input material for all the demo cases
Vital Process Parameter (VPP) (Small-Batch)	A method and feedback consideration (VDI guideline). Depending on risk category of measurement of uncertainty and proof of capability, which is proven according to current standards
Tool Mapping	Mapping of all type of processes
Audit on site	An audit on the plant to question, interview and make a visual picture of the problem to be solved
Six Sigma	Six Sigma trained, green belt and black belt personnel, use of SPC, Taguchi, FMEA and root cause
AI Techniques	Use of Neural Network, Fuzzy Logic and Artificial Intelligent systems
Sensor	Own defined current senor selection guideline, laser distance sensor, acoustic emission and sensor fusion

5. Zero Defect Manufacturing "Best Practice" Process Guideline

Thru the IFaCOM project, the author started this research by structuring and adding all the different TQM methods and tools for making a guideline based on all the five different demonstrator cases. Since the statement of making “Best Practice” is to make a linkage between action and the outcome goals, and the touched topics are complex and very cross disciplinary. This guideline can be seen as a possible step-by-step guideline with minor justifications to own organization. The guideline following a typical technical manufacturing process where problem definition has been done by questionnaires, company know-how and R&D work. This give the input for the stepwise activities, selection of sectionalized data collection, with further guiding to available choices of quality methods. All documentation and guidelines mentioned mention in this process guideline are described in process steps for further implementation and validation (Eleftheriadis, 2015) (IFaCOM, 2011-2015) (Myklebust, et al., 2013).

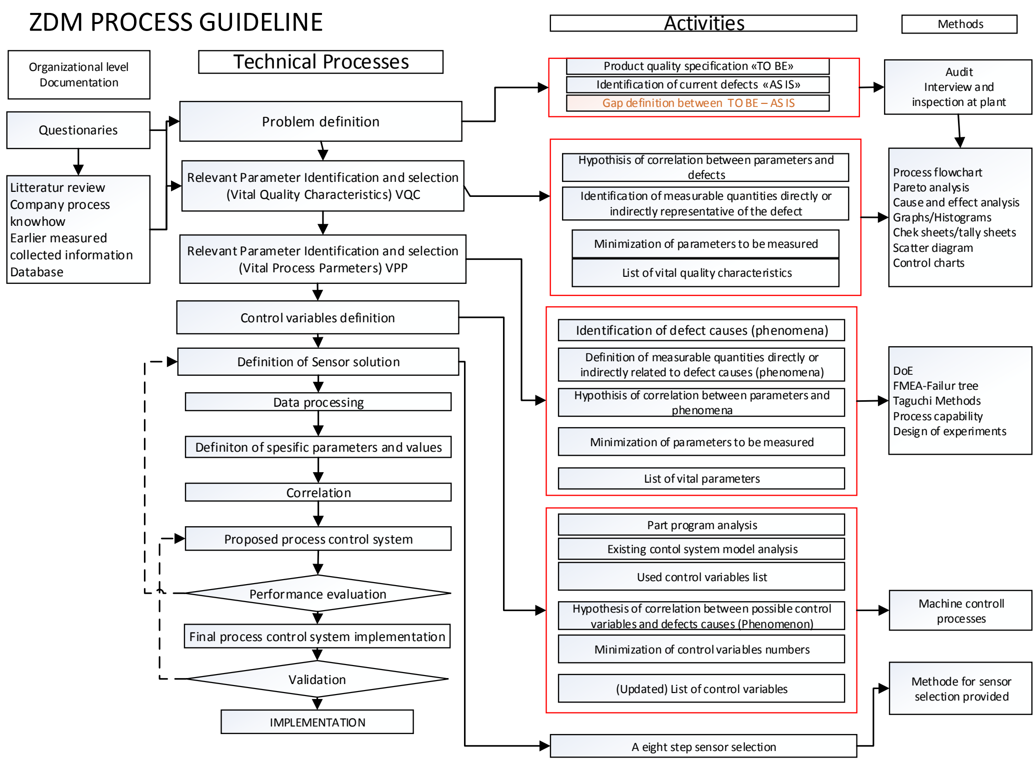

Figure 3. The ZDM Process Guideline (Eleftheriadis, 2015)

6. Conclusions and further work

Since the beginning, the IFaCOM project approach focused on prioritizing industrial applications. Thru IFaCOM it has been developed a methodology for achievement of Zero Defect Manufacturing, which has been proven effective in different industrial cases. The main concept of IFaCOM is based on the intelligent monitoring of vital process parameters (VPP) in order to enable prediction on undesired process conditions, suggestions for process corrections as well as real-time adaptive processing for a large range of manufacturing processes.

This approach, together with the quality development and the vision of ZDM, provides that for each process step of any process chain of each processed part will be within specifications. Then, thanks to the implemented sensors and monitoring systems it is possible to provide a detailed documentation of any event occurred during the process named as Industry 4.0 or CPS.

For further research the author is working on a "best practice" project guideline made out of the findings, this is based on the end-user cases as steps in the project engineering processes and will show the integration between project management procedures and quality tools.

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Biography

Ragnhild J. Eleftheriadis (female): M.Sc in Project Management with specialisation in Process and Production Quality. Senior Adviser at SINTEF, Administrative coordinator and Project Quality Manager for H2020 FOCUS and IFaCOM, financial adviser in GALA, IC2 and IMS2020. EU project adviser at NTNU in the Department of Production and Quality Engineering. M.Sc at NTNU and financial education from Trondheim Business School-topic of Economical Methods of Management, twenty-three years' experience in project control at DNV GL in the field of Quality Management and Certification.

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