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Quality Improvement Model At The Manufacturing Process Preparation Level

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Abstract: *The paper expresses base for an operational quality improvement model at the manufacturing process preparation level. A numerous appropriate related quality assurance and improvement methods and tools are identified. Main manufacturing process principles are investigated in order to scrutinize one general model of manufacturing process and to define a manufacturing process preparation level. Development and introduction of the operational quality improvement model is based on a research conducted and results of methods and tools application possibilities in real manufacturing processes shipbuilding and automotive industry. Basic model structure is described and presented by appropriate general algorithm. Operational quality improvement model developed lays down main guidelines for practical and systematic application of quality improvements methods and tools.*
Keywords: *Quality improvement model, Simulation, Modelling, DFSS*

1. INTRODUCTION

Every type of industrial production is based on production processes. To survive in a demanding market, and still be successful, it is necessary to achieve the high level of the products quality. High product quality cans only results from the high quality of manufacturing process.

Continuous improvement of manufacturing process can effectively be achieved by the systematic approach with the appropriate application of different methods and tools.

The goal of research was to find appropriate systematic approach to quality improvement in the production preparation, within the frame of metal production. Starting from the main principles and methodologies of manufacturing process quality improvement, in the paper are identified possibilities of integration of methods and tools in an operational model of quality improvement in the process of production preparation. Phases of the implementation of developed model are shown with the corresponding main algorithms, indicating possibilities of implementation of various methods and tools for quality improvement.

2. QUALITY IMPROVEMENT MODEL AT THE MANUFACTURING PROCESS PREPARATION

Developing the structure of the quality improvement model, the existing models of quality improvements at the production preparation level are taken into account.Systematic methodology that take into account the application of different methods and tools of quality improvements, with the goal of designing products and processes that meet the customers expectations is called Design for Six Sigma, DFSS [i].

DFSS methodology enables designing a process that ensures a high level of quality in the design and preparation phase of manufacturing. It takes into account the requirements and expectations of customers and with application of various statistical analysis tools enhance the design process. In this effort it is necessary to understand the requirements of customer, and ensure that those requirements are successfully implemented in the product or process.

In order to successfully implement DFSS methodology the entire cycle of development and production of products must be taken into account, starting with collecting ideas and finishing with the modes of product exploitation. Unlike Six Sigma methodology, where DMAIC model of quality improvement is used, with the DFSS methodology there are several models. One approach of DFSS methodology is an IDOV model. Implementation of the IDOV model is carried out through four phases, which are *Identify*, *Design*, *Optimise* and *Validate*. Basic features of each phase are [ii]:

- ***Identify*** customer requirements, feasibility and costs, technical requirement, responsibilities, phases of product and process development;
- ***Design*** a product concept, estimate the possibility of nonconformity, identify key product quality indicators, select materials for the product manufacturing, and define the production plan.
- ***Optimise*** process capability, product design, design for robustness and reliability, remove existing and prevent potential nonconformities, select product tolerances based on statistics, optimise process quality.
- ***Validate*** product prototype, know the product features in operation, determine product failure modes, analyse reliability and risks. Final product control.

Other known model of the application of DFSS methodology is called DMADV model. With DMADV model the process behaviour in the exploitation is trying to be predicted.

Based on the obtained results the improvements are implemented, and the best option is selected. General features of the DMADV model are [iii]:

- **Develop the project** - Select the required material, define schedules, and estimate the required resources.
- **Estimate the satisfaction of customers and the quality of the process** - Identify the customer's priority requirements. Identify the key indicators of the process quality, their values and tolerances.
- **Analyze collected data** - Analyze the manufacturing process and equipment, its functionality, cost and reliability, as well as the possibility of the appearance of bottlenecks in the process.
- **Design the process** - Functionally relate output process variables with the input process variables. Define criteria for projects selection based on analysis of input and output variables. Choose the most appropriate project, make a feasibility study and select suppliers. Analyze possible deficiencies in the production. Defined the standard production procedures.

Confirm process tolerances - Optimize input variables, define the tolerances, analyse robustness, capability and reliability of the process. Make the required experiments using the design of experiments methods. Start pre-production, assess customer satisfaction, and document suggestions for possible improvements

2.1Development of quality improvement model

During development of the quality improvement model it was assumed that, before the implementation of the model, the project improvements objectives are defined, improvement team members are selected and deadlines to achieve certain objectives defined. Also, it is assumed that team members are familiar with methods and tools for quality improvement included in the model.

The structure of the quality improvement model is designed by analyzing and improving the structure of the existing models for quality improvement used in the production preparation, and above all, quality improvement models covered by DFSS methodology [iv]. Specifically, the existing quality improvements models at the production preparation level are generic and deals with activities that take place in pre-design phase. Therefore, the proposed structure of the quality improvement model is such that provides guidance on the production preparation phase, especially in the technological preparation of production.

The implementation of the model takes place through six consecutive phases. In the first phase of implementation of the model it is necessary to consider project objectives and determine what is known about problem under consideration. This phase of the model is named *Define*. Next phase named *Data Acquisition*. Within this phase of the model implementation all the necessary information are collected. Then, during the *Simulate* phase, an appropriate simulation model of the manufacturing process is developed, which is, in the next phase of the model implementation, used to perform the necessary analysis with the aim of obtaining data that will serve as a base for improvements. This model phase is named *Analyze and improve*.The results obtained in previous phases of the application of quality improvement models is analysed in *Check* phase. If the project objectives are met, the last phase of the quality improvement model implementation, phase *Error proofing and improvement implementation* follows. Within this phase of the model implementation possibilities of defects appearance and prevention are analyzed and identified improvements are implemented in the process. The general scheme of phases of the model is shown in Figure 1 [v].

2.2 Define

Implementation of the quality improvement model begins with the *Define* phase. In the beginning of work on the project of quality improvement, the responsibilities have been identified, as well as the approach to the problem and the steps in solving the problem. It is imperative to immediately begin to define the scope of the project and to distinguish and exact define the variables that will be deal with.

2.3 Data acquisition

Once all the key quality improvement project variables have been defined, all necessary information have to be acquired.

At the beginning of ***Data acquisition phase***, based on previously created graphic representations of the process, FMEA and QFD methods, taking into account the scope of the project, the data that should be collected are determined.

The manufacturing process that is in the scope of improvement is analysed, key input and output process variables are noted, production equipment, product features, transport and handling equipment identified.

The sources of data are recognized and needed forms for data collection are prepared [vi]. The determination of liabilities and responsibilities of the team members is next task, needed measurement and control equipment is defined, and appropriated data collection plan prepared.

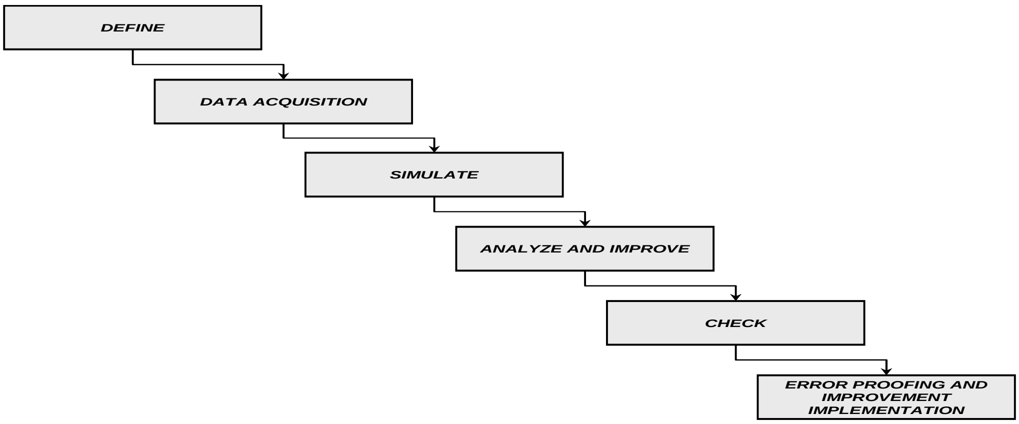

Figure 1. Scheme of phases of quality improvement model

In cases where data is collected by measurements, it is necessary to determine and define the measurement procedures. For the applied measurement system the appropriate R&R analysis have to be done in order to asses its capability and accuracy.

After the adequate measurement system has been selected, it can be preceded with the data collection and analysis.

2.4 Simulate

In this quality improvement model implementation phase the manufacturing process has to be modelled. At this point of time a manufacturing process is designed, but is not yet operational, so to improve it a process should be adequately represent, which is done by simulation modelling. After the simulation modelling is finished, the model should be validated, and, if successfully validated the model is ready for further use within the framework of process quality improvement.

2.5 Analyze and improve

Validated and verified simulation model of the manufacturing process will be used in the *Analyze and improve* phase, to research opportunities for the processes quality improvement in the production preparation phase.

Methods that can be effectively applied to the processes analysis and improvement in the production preparation phase are design of experiments methods. Selecting appropriate design of experiment methods all the essential features of the implementation of experiments are defined, as well as the procedure for later analysis of the results.

Before the experimentation, the key process input and output variables should be selected. It is necessary to select those output variables that will provide the necessary information for the process quality improvement. To assess variation of the output variables, it is necessary to select the appropriate measurement system.

When the all the necessary conditions are defined it can be processed with the experimentation and analysis of obtained results. Based on the conducted experiments results the optimal input variables values are selected.

The optimal solution should be validated and confirmed whether the selected optimal values of input variables provide the desired results and quality improvement. If the expected improvement of the quality is achieved, the previously selected optimum values of input variables are adopted. If this is not the case, it can be concluded that the conducted experiments were not included all the key variables or that the selected simulation model of the process is not adequate for the problem. In that case the simulation model can be modified, considering the other input variables and values that will be used in the experiments, and furthermore, the interdependence of, in previous analysis, not included variables are studied.

Final results of *Analyze and improve* phase are selected values of the process input variables in such a way that, for assumed environment conditions, the optimum value of output variables are achieved.

2.6 Check

When the optimal values of input variables are selected and adopted, in the *Check* phase verification of successfulness of activities conducted in previous phases of the implementation of the quality improvement model is conducted. Quality improvement activities, within the *Check* phase of the process, take place mostly during the pre-production, when the process is for the first time operational.

The goal of *Check* phase is, also, to ensure that the results of the quality improvement project take place over a longer period of time. Next objective is to document adopted production processes and methods.

2.7 Error proofing and improvement implementation

In this, last, phase of the quality improvement model implementation, possibility of deficiencies appearance is assessed, as well as methods for their prevention and removal. Identified changes and improvements are implemented in the process, and their continued use are ensured. Activities carried out during this phase of the application of the model; provide a systematic approach to defects reduction and the application of adopted improvement. Quality improvement activities of the process, within the framework of the implementation of this operating model ends by the formal closing of the improvement project.

2.8 Main structure of an integral algorithm of the quality improvement operating model in the production preparation process

Following the considered phases of the quality improvement operating model and their main algorithms leads to the main structure of an integrated algorithm of the operating model, shown in Figure 2. The structure of the specified algorithm models indicated only the base for implementation of the model. However, in the operational application of the model, several decisions have to be made that affects the flow of model applications. There are, also, several feedback connections within the individual phases, as well as between different phases of model implementation.

Comparing developed operating model of quality improvement with the existing and previously described models, it is evident that the existing models of quality improvements are implemented through up to four or five phases, such as PDCA and DMAIC models, while developed model of quality improvements is implemented through six phases. Furthermore, it is necessary to emphasize that, unlike the existing models of quality improvements, which can be applied at all phases of production, developed model is designed primarily for use in the production preparation phase. Also, it is necessary to emphasize that developed operating model supports the principle of continuous quality improvement

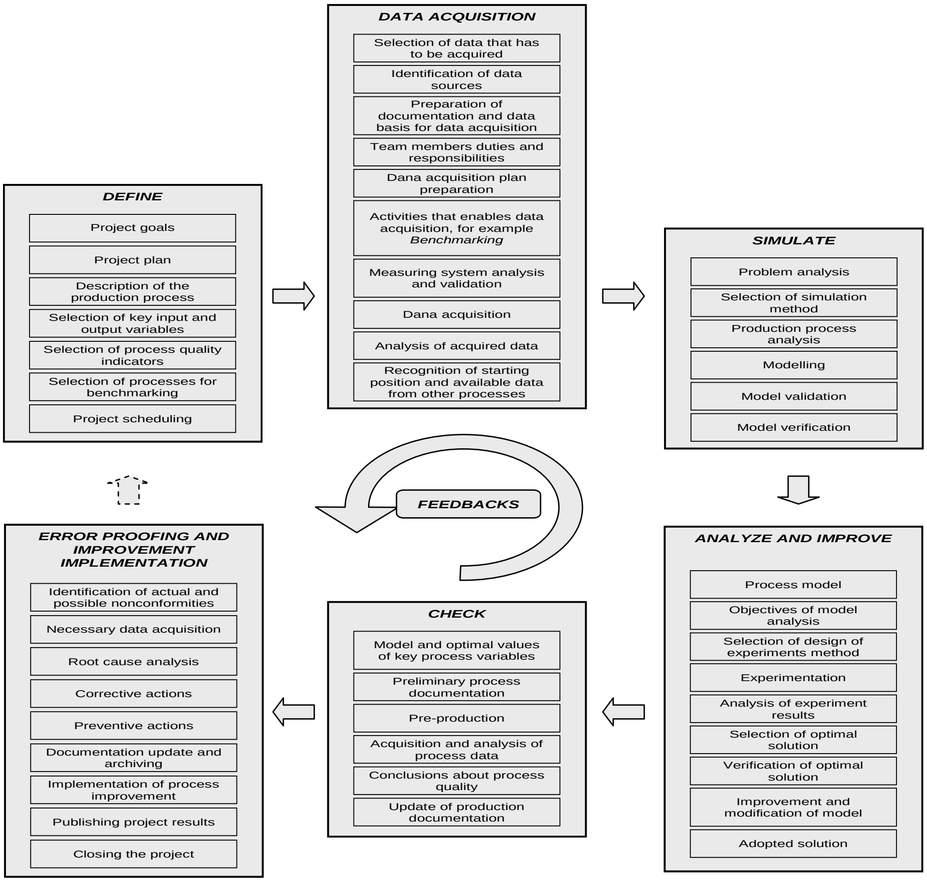

Figure 2. Main structure of an integral algorithm of the quality improvement operating model in the production preparation process

A common practice is to name quality improvement models with appropriate acronyms, such are previously mention PDCA and DMAIC models, so developed operating model of quality improvements could, for example, be named DASICE, according to the names and activities of individual phase of the model: *Define, Data Acquisition, Simulate, Analyze and Improve, Check, and Error Proofing and Improvement Implementation*.

Once, when the production process begin, activities on the process quality improvement does not stop.

A new quality improvement projects are opened, with an application already adopted, affirmed and recognized programs and quality improvement models, based mostly on Deming PDCA cycle, Pareto principle, Six Sigma DMAIC methodology, applying EVOP methods, etc.

3. MODEL IMPLEMENTATION

Analysis of the adequacy of the application of the quality improvement operating model at metal manufacturing processes in the shipbuilding and automotive industry showed that the developed model can be successfully applied in real production environment in the process of production preparation, with the objective of achieving successful results in the process quality improvement.

Application of the quality improvement model in the shipyard process was conducted for the process of profiles and strips preparation for welding. On the simulation model of production line for the cutting of profiles are carried out necessary tests in order to determine the optimal value of production line input parameters.

Experiments were conducted with the application of design of experiments method. The number of required experiments is reduced to a minimum. Model, which is suited to the selected shipyard, simulates the production line for cutting profiles, and at the level of the computer program allows variation and analysis of a number of different production scenarios.

It is expected that decisions on final configuration of production line, based on the analysis of different scenarios of simulation modelling, has less risk involved than one based on the conventional approach.

On production line simulation model, an experiment is conducted taking into account selected inputs values. Comparison of results of simulation modelling before and after production line optimizations is shown on Table 1 [7].

Line optimization results in very high usage of the robot cutting lines and significant total cutting time reduction. It should be also pointed out that the robot cutting speed has been kept constant, as previously mentioned.It can be concluded that setting the value of input variables in accordance with the proposed results in a total reduction of cutting time by 20.3 %, while increasing the production line autonomy for the 19.9 % for station 1 and 17.4 % for station 2. It is also expected increase in usage of stations for cutting profiles and strips, 25.3 % for station 1 and 25.6 % for station 2.

Table 1. Comparison of results before and after optimization Legend:
t_u – total cutting time
f_{Sl} – cutting station 1 usage factor
f_{S2} - cutting station 2 usage factor.

Results	t_u min	f_{S1}	f_{S2}
Before optimization	**5306**	**0,676**	**0,678**
After optimization	**3649**	**0,990**	**0,997**
Improvement, %	**31**	**46**	**47**

4. CONCLUDING REMARKS

In order to achieve adequate synergic effect of manufacturing process quality improvement, the possibilities of applying various methods and tools through an operating model of quality improvement in the process of production preparation are discussed.

As already noted, when the existing process is in the focus of improvement, the Six Sigma methodology is successfully used, supported by principles of Deming quality circle, while in cases of quality improvement in the phases that preceded the production process, DFSS methodology models are successfully used.

By studying existing models and researching in the area of quality improvement in the field of metal manufacturing processes, both in engineering and shipbuilding, it was seen nonexistence of a complete model of process quality improvement, especially at the production preparation level. So, the main guidelines of an operational model of quality improving in the production preparation are set, the main algorithms of each phase of the model are developed and the possibilities of applying the model are discussed.Developed operating model of quality improvement is implemented through six phases, which has emphasized a systematic approach to the achievement of quality improving project objectives.

The work on quality improvement project also involves the intensive teamwork, and application of appropriate methods and tools of improving quality.

For the implementation of quality improvement in the production preparation there are typically short deadlines defined in accordance with the planned production start. For this reason the iterative analysis for elimination of non-conformances is usually not possible.

Perceived non-conformances, as well as those who still can possibly occur, are analysed in the last phase of the model implementation. In that phase are, also, defined the necessary corrective actions to remove non-conformances and prevent their subsequent appearances.

As model implementation implies involvement of complex methods, which requires a good knowledge of the mathematical statistics, it can not be expected that an engineer in practice will be able to apply the above mentioned methods without appropriate professional help.

It is therefore, for the successful implementation of DFSS methodology, necessary to provide adequate professional support, so that engineers can focus on ensuring the quality of those activities that add value.

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