ISSN 1392 - 1207. MECHANIKA. 2009. Nr.1(75)

Process modeling for quality in order-handled manufacturing system

D. Čikotienė*, A. Bargelis**
**Siauliai University, Vilniaus 141, 76353 Šiauliai, Lithuania, E-mail: dalia.cikotiene@su.lt*
***Kaunas University of Technology, Kęstučio 27, 44312 Kaunas, Lithuania, E-mail: algirdas.bargelis@ktu.lt*

1. Introduction

Order-handled manufacturing systems (OHMS) involve make to order production operations and customer-tailored end products in the form of capital equipment. Research and practical experience [1] shows that production planning and control procedures can be more difficult to carry out when jobs are produced to order rather than for stock, because the operations are complicated by inherent sources of uncertainty. The objective of an OHMS operation may be defined as the manufacture and delivery of goods of proper design and quantity to customers' specification, with an appropriate guarantee of product quality and prompt delivery at an acceptable cost [2]. Two types of OHMS are considered in theoretical and practical research domain of manufacturing science: 1) with the designing, developing and manufacturing the product and 2) without product development when product manufacturing is only needed. First type of OHMS is more complicated and it rarely occurs because customers often keep new product development in their hands. This research considers the second type of an OHMS in manufacturing of a large number product types and low production volumes.

1.1. Research reasoning

Companies that work applying OHMS approach always feel a strong pressure of customers' inquiries and requirements to product technical data, quality, cost and delivery. The high competition exists among producers to win each order because customers have very big choice in various countries and companies. At the beginning of Global manufacturing (GM) era, a lot of industrial production moved from the USA, Western Europe, Australia and Japan to the developing countries in South-East Asia and Eastern Europe, while in many industrialized nations the hollowing phenomenon of the manufacturing section is observed [3]. A hollow company undertakes itself the functions of marketing, new product development, and delivery. Lithuania is a country of producers when many small and medium enterprises (SMEs) produce various products, their parts and components according to the orders of customers. In biggest part of orders, unfortunately, the product design and development is made by customers and many quality and productivity questions appear to producers. Design for Quality (DFQ) methods [4-6] applied by new product developers in various manufacturing systems are differently implemented and required modeling of some process alternatives for quality and cost.

The consideration of Lithuanian SMEs production results has shown certain quality and low manufacturing cost problems when companies' stakeholders exploiting modern CNC facilities often have product and process quality failures. These failures deal with both the product and process design questions, and order quotation inaccuracies when producers have been very optimistic. No prevention and only small appraisal cost in considered 20 Lithuanian SMEs has been fixed.

This paper reports how process modeling for quality can facilitate and help to accelerate the enterprise business process in a new competitive age avoiding above-mentioned quality and manufacturing cost problems. In this context, some ways achieving the good quality during production – statistical process control at every stage, implementation of prevention and quality appraisal methods in manufacturing operations and foreseen appropriate techniques, resources and quality management are used. Quality improvement processes and calculations also are carried out at business engineering and work stages.

1.2. Literature review on quality cost

There are many research made and publications published related with quality cost. It is identified the efforts between quality cost and value by classifying the quality cost elements into "value added" and "nonvalue added" grounded on activity based costing (ABC); prevention-appraisal costs are value-added quality costs and failure costs are nonvalue added quality costs [7]. According to the research [8], quality costs are an indicator or a measure of the effectiveness of a quality management system, and the identification of potential failures lead to the recognition of improvement opportunities. The analysis of quality costs and a model for optimum quality costs is presented in research [9]. This model shows the interaction between three types of quality costs: prevention, appraisal and failure. It was stated, when prevention and appraisal costs are increasing then failure costs are going down. This statement was extended in research [10]; failure is the most expensive and prevention is the least expensive quality cost component. Company should not exclusively invest in appraisal because it may lead to unacceptable costs and may affect the company's reputation. It is stated that a quality cost system can be established in an attempt to increase the value of a product and process output, and enhance customer satisfaction. The authors of this research have been defined the relative dependences among quality, appraisal cost plus prevention cost and failure cost for material, machine tool and whole company. Transforming quality cost measurements into product value has been carried out in research [11]. The value of quality improvements is a measure of return on quality investments, which indicates whether the quality improvement efforts gave higher, fair, or lower return. The research methodology on relative changes in utility and cost from time i to the time (i+1) has been used. It develops and discusses a model of customer value by accommodating its relative nature, and presents a proactive way of measuring quality cost.

Reviewed papers with relative dependences among quality cost and utility mostly in large companies are related. The situation, however, in big variety and low volume production companies, in particular SMEs, is quite other and special tools or techniques for quality cost modeling are necessary at the early stage of new product development or new order engineering. No any recommendations or proposals, unfortunately, what kind of investments to process improvement would match achieving good quality with minimal cost.

The research of this paper is devoted to the process modeling for quality in order-handled manufacturing system and also the forecasting of quality cost for various processes and products when the product is developed and designed by customer. It emphasized the propositions which arise overlapping the product manufacturing cost and quality cost or even latest is neglected. The purpose of this paper is the development of process model for quality and forecasting quality cost which could help to avoid big loses in manufacturing companies. The proposed model is being implemented for the integration of product process planning with manufacturing and quality cost definition at the new order engineering stage.

2. Process modeling for quality

The classification of products, their design features and processes for decreasing uncertainties has been used in this research. Manufacturing system deals business with one or in seldom cases with some product classes because appropriate experience of manufacturing processes, tooling and traditions it has acquired. Quality problems are delicate and tough related with manufacturing processes, employees skill and work motivation, therefore, they can be easier solved in the products and processes on the separate class level when general number of uncertainties is the smallest.

The process modeling for quality on the entire of qualitative indications I of a product G which consists of the lot of original parts P and standard components S is based in the limits of a separate product class level

$$I = \bigcup_{i=1}^{n} \left(\left\{ F_{ij} \right\}_{j=1}^{m}, \left\{ E_{ik} \right\}_{k=1}^{l}, \left\{ A_{ip} \right\}_{p=1}^{r} \right) \quad (1)$$

where F_{ji} is the qualitative requirements of the product G_i functionality; E_{ik} is the qualitative requirements of the product G_i parameters; A_{ip} is the qualitative requirements of the product G_i accuracy; n is the number of product G_i qualitative indications.

The process modeling task for quality starts with the selection of the original part P work piece, operations and facilities according to the qualitative indications I that are systematized and acquired in the process design knowledge base (KB). The next modeling step is the creation of process alternatives with operations sequence and definition of manufacturing and quality cost. The third modeling step is an estimation of process alternatives and chooses of the best one with minimal cost.

Qualitative requirements A_{jp} of the product G_i accuracy depend on the geometrical form and other peculiarities of part design features. Each part P of a product G is expressed as a set of design features D

$$P = \bigcup_{i=1}^{n} D_i = \{ D_1, D_2, \ldots, D_n \} \quad (2)$$

The complexity of each D_n is denoted by a set of parameters A_{jp}, p = (1,…, p), e.g., material, geometrical form, dimensions, tolerances, roughness of surfaces and so on. The designer can vary the product structure and functionality combining different numbers of P and S, and different qualitative and quantitative parameters of D. The product design procedure has to be closely related to the process manufacturing cost and also to quality cost. It may be verified at the early product design stage by modeling procedure of manufacturing and quality costs, which is based on the design feature D_i structure and qualitative parameters.

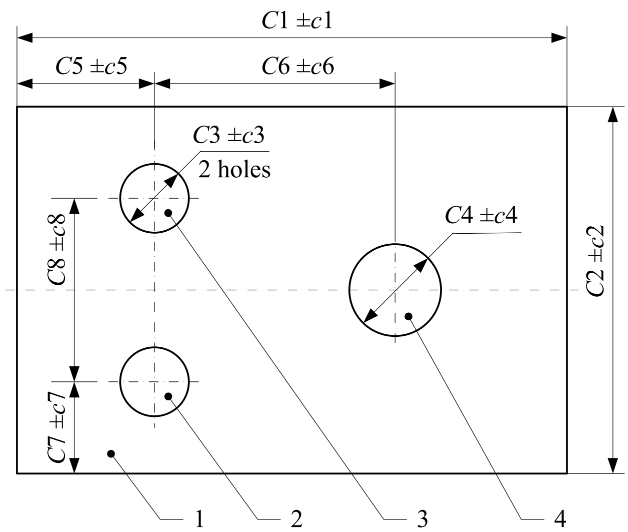

Fig. 1 Typical part of sheet metal design

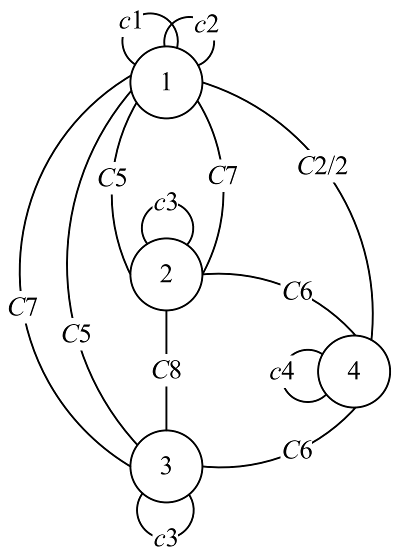

Fig. 2 The following graph of sheet metal part design features and dimensions chain

The graph theory [12] for transformation of mechanical part drawings' data into digital codes has been used. Typical sheet metal design part is presented in Fig. 1 and its following graph is illustrated in Fig. 2. Sheet metal part consists of four design features D_i and appropriate dimensional chains and tolerances. The design features D_i of a part are graph's nodes and the dimensions are the edges; edges show the reflexive relations as D_i tolerances *c*1, *c*2, *c*3, *c*4 and irreflexive relations as dimensions *C*1, *C*2, *C*3, *C*4, *C*5, *C*6, *C*7, *C*8.

Conversion of D_i structure and qualitative parameters for computation of manufacturing and quality costs can be expressed as follows

$$D_i = \left(T_i, (x_i, tx_i), (y_i, ty_i), (z_i, tz_i), \{K_{ij}\}_{j=1}^{m}, R_i\right) \quad (3)$$

and

$$R_i \in \{RA_{ik}\}_{k=1}^{l} \quad (4)$$

where D_i is design feature, $i = 1, \ldots, n$; T_i is the type of design feature D_i; x_i, y_i, z_i are dimensions of design feature D_i; tx_i, ty_i, tz_i are tolerances of design feature D_i dimensions; K_{ij} are design feature D_i location requirements in a part, $j = 1, \ldots, m$; R_i is machine tool for design feature D_i manufacturing; RA_{ik} is the lot of possible machine tools for design feature D_i manufacturing; $k = 1, \ldots, l$.

The objective W of process modeling for quality in OHMS can be expressed as follows

$$W = \sum B \Big/ \left(\sum H + \sum Q\right) \quad (5)$$

where B is OHMS benefit getting when the product is produced according to customer requirements; H is manufacturing cost; Q is quality cost.

The product manufacturing and quality costs are considered in the integrated manner together with product design by the developed model aiming the biggest benefit. Expected benefit may be checked at the early product design stage or new order engineering stage. The product and process structure is varying if necessary seeking a biggest W value. The producer always must reach the perfect ideal case when denominator of Eq. (5) is going to zero

Ideality = ∞, when $\sum H = 0$ and $\sum Q = 0$

Worst case is when $W = 0$, e.g., product production is impossible because no chances to achieve customers' requirements and denominator of a Eq. (5) greatly exceeds the product value.

Product and process design procedure is a permanent solving of the contradictions among the required best product properties as functionality, quality and desired parameters, and manufacturing and quality costs. In other words, if any product design alternative will satisfy only one requirement, e.g., when designer has achieved the best product functionality, but manufacturing and quality costs are unacceptable then the trade off is appeared and more alternatives are necessary. The designer has to continue the product development procedure and to solve an existing trade off.

The straight tool of solving the above-mentioned problem could be model for quality cost Q at the early new product development or order engineering stage. The first step of this model is forecasting of a product manufacturing cost H. The research carried out in KTU during past twenty years showed very simple and reliable way to forecast product manufacturing cost at the early its development stage according to the product qualitative and quantitative parameters. This method on the separate product class level and each material type is grounded. The decisive role to manufacturing cost of mechanical product and its parts and components has material consumption rate and cost. It is defined on the retrospective analysis of different production processes and operations by the dependencies of material consumption rate and product mass in various Lithuanian companies. Fig. 3 illustrates the sheet metal consumption rate *M*1 dependency on the sheet metal design products' mass *M* in Lithuanian company X. The regression equation representing dependency between product's mass *M* and *M*1 (Fig. 3) is as follows

$$M1 = mM + s \quad (6)$$

where m is the slope of a regression trend line; s is intercept of a regression trend line; the slope and intercept applying Fig. 3 data and standard calculations are defined, $m = 1.18$ and $s = -0.42$.

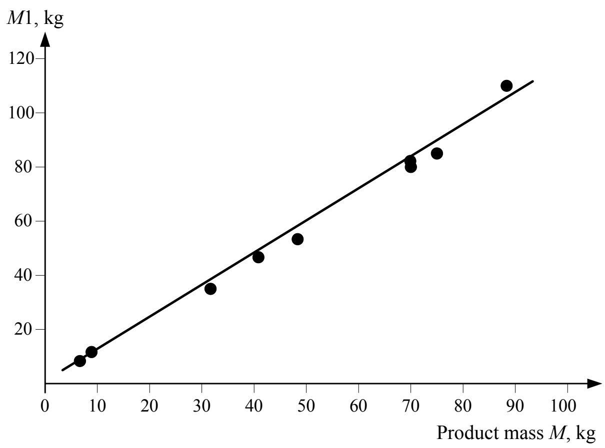

Fig. 3 Dependency of sheet metal consumption *M*1 and sheet metal design product

The values of m and s depend on product and material type, process and company manufacturing traditions. The similar dependences as illustrated in Fig. 3 can be created for any other metal type or profile. Plastics, paints and galvanized also assembling materials consumption are differently defined - according to the conditional consumption norms for coating area or other processing data.

The total manufacturing cost H of a product G_i is expressed as follows

$$H = \sum_{i=1}^{n}\left(H1g1b1\right)_i + \sum_{j=1}^{m}\left(H2g2b2\right)_j + \\ + \sum_{k=1}^{p}\left(H3g3b3\right)_k + \sum_{l=1}^{r}\left(H4g4b4\right)_l \quad (7)$$

where *H*1 is metal consumption, kg; *H*2 is plastics consumption, kg; *H*3 is paints and galvanizing materials consumption, kg; *H*4 is assembling material, kg; *n, m, p, r* are the number of material types; *g*1-*g*4, are the cost in EUR of 1 kg appropriate material; *b*1-*b*4 are coefficients evaluating the cost of workforce, machine tool depreciation and overheads.

The material cost g in various data base (DB) is available to find and parallel the values of various b in companies KB are possible to systematize and acquire. Latter data according products, processes and companies types are classified and KB structure is developed [13].

3. Quality cost modeling

When the manufacturing cost H of a new order is predicted, then the attempt to forecast quality cost as a function of H has been made. It was applied the proposition that quality cost is classified into four categories [14]: prevention, appraisal, internal failure and external failure costs. Taking into account this quality cost classification the kind and size of investments to process development matching a good quality with minimal cost for big variety and low production volume in OHMS manufacturing system has been made. The quality cost Q of product G_i can be expressed

$$Q = \sum_{i=1}^{n}(Q1)_i + \sum_{j=1}^{m}(Q2)_j + \sum_{k=1}^{p}(Q3)_k + \sum_{l=1}^{r}(Q4)_l \qquad (8)$$

where $Q1$ is prevention cost, EUR; $Q2$ is appraisal cost, EUR; $Q3$ is internal failure cost, EUR; $Q4$ is external failure cost, EUR. Prevention quality cost depends on a lot of parameters and can be expressed as an abstraction function

$$Q1 = f_1(x_1, x_2, x_3, x_4) \qquad (9)$$

where x_1 is cost of order review for quality and manufacturing process; x_2 is cost of a quality audit; x_3 is preventative maintenance cost; x_4 is employees training cost.

When developing of a forecasting model to $Q1$, different influence of various factors used in Eq. (9) on value $Q1$ was found. Preventative maintenance cost x_3 has been defined as more decisive to $Q1$ in OHMS manufacturing system. Applying statistical data of companies and manuals of various machine tools and processes also authors experience, the dependency between x_3 and total manufacturing cost H of a part has been proposed

$$x_3 = r_1 H \qquad (10)$$

where r_1 is correction coefficient estimating a machined part quality by operator; it depends on operation and part type also on the number of design features and their qualitative-quantitative parameters (Table 1).

Table 1

Correction coefficient r_1

Part class	Number of design features D	r_1
Sheet metal	Up to 5	0.002-0.003
Sheet metal	Greater than 5 up to 30	0.005-0.006
Sheet metal	Greater than 31	0.007-0.008
Solid part	Up to 3	0.001-0.002
Solid part	Greater than 3 up to 8	0.004-0.008
Solid part	Greater than 8	0.009-0.012

The costs of order review for quality x_1, quality audit x_2 and employees training x_4 are estimated by correction coefficient r_2, to the total part manufacturing cost H. The value of r_2 applying available statistical data of companies' and manuals sources also manufacturing traditions from 0.001 up to 0.005 has been used in this research.

Appraisal quality cost analogously as prevention quality cost can be expressed

$$Q2 = f_2(y_1, y_2, y_3, y_4, y_5) \qquad (11)$$

where y_1 is receiving inspection cost; y_2 is product acceptance cost; y_3 is inspection labor cost; y_4 is process control cost; y_5 is quality control equipment's cost.

Process control cost y_4 as more decisive for $Q2$ in OHMS manufacturing system has been defined. Process quality control using variables, means, ranges, charts and samples is carried out. Average of sample measurements is calculated

$$\mu = \sum_{i=1}^{k} \frac{\mu_i}{k} \qquad (12)$$

where k is the number of samples size; μ_i is measurements average of i-th sample.

The mean range R is the average of all the sample ranges and may be calculated

$$R = \sum_{i=1}^{k} \frac{R_i}{k} \qquad (13)$$

where R_i is average range of each sample;

The standard deviation of all population can be calculated applying R value

$$\sigma = R / d_n \qquad (14)$$

where d_n is Hartley constant [6].

Process control cost y_4, receiving inspection cost y_1, product acceptance cost y_2 and inspection labor cost y_3 are defined employing statistical data by correction coefficient r_3, to the total manufacturing cost H. The value of r_3 applying available above mentioned statistical data of various sources fluctuates from 0.007 up to 0.015 in this research.

Part measuring time and cost applying complicated control equipment according to the data of Table 2 is calculated and is added to last-mentioned $Q2$ cost.

Internal failure quality cost $Q3$ is expressed as following abstraction function.

$$Q3 = f_3(z_1, z_2, z_3); \qquad (15)$$

where z_1 is downtime cost; z_2 is reinspection cost; z_3 is cost of disposal and scrap because defects.

The internal failure cost is increasing when prevention defects are low; appraisal cost also is closely linked with internal failure cost when the latest is high the appraisal cost is high too. It is better to fix defects inside company than get claims from customers. Cost of disposal and scrap because defects z_3 is more obvious of $Q3$ and is defined as decisive in this research

$$z_3 = r_4 B1 \qquad (16)$$

where r_4 is conditional coefficient estimating the disposal and scrap, $r_4 = 0.03$-0.05; $B1$ is annually (quarterly, monthly) consumption of material, EUR.

Table 2

Part measuring time applying complicated control equipment

Parameter	Index	Source of cost
Control equipment	MW	Control equipment cost
Depreciation per year	DP	MW/8
Average set up time cost per year	AS	One hour per shift
Total control equipment cost per year	MC	DP + AS
Hours in operation per year	HY	12 x 16 x 8 = 1536
Control equipment cost per hour	MH	MC/HY
Part measuring time	T	Manual
Control equipment cost per part	MP	MH x T

Downtime cost z_1 and reinspection cost z_2 is defined by correction coefficient r_5 to the total manufacturing cost H, r_5 is applied as 0.01 - 0.015 in this research.

External failure quality cost Q_4 is showed as the following abstraction function

$$Q4 = f_4(v_1, v_2, v_3) \tag{17}$$

where v_1 is customer claims; v_2 is delivery delay; v_3 is other external loses.

External failure cost is attempted to show to be quite low, attributed to the high level of appraisal an internal failure cost. Cost of customer claims is more obvious of $Q4$; the aim of each manufacturer is to strive to keep it in the level of 0.0 - 0.02 of the total manufacturing cost H. Delivery delay cost v_2 and other external loses v_3 are very complicated to estimate and they are neglected in this research.

Research based on two Lithuanian SME firms related to the sheet metal design and manufacturing. It referred creation of quality cost estimation methodology in OHMS manufacturing system. The developed methodology is able to estimate and minimize quality cost by proofed manufacturing process and personal understanding of a quality problem.

4. Practical usage of quality cost estimation methodology and achieved results

In this study, quality cost definition methodology in OHMS sheet metal design companies has been tested. The sheet metal design of telecommunication product has been chosen; it consists of 12 plates produced from low carbon galvanized steel and typical part of product in Fig. 4 is shown. Monthly production volume of the product is 500 pieces. Quality cost is available to decrease applying quality control in each phase of product design, manufacturing and delivering; therefore, the product designer has made efforts to use unified design features of product parts – equal sheet metal thickness 2.5 mm and holes diameter 4.6 mm in all twelve parts. Thus the total numbers of holes diameter 4.6 mm is equal to 76. Similarly, it was made also with other design features of product parts including another alternative of part material – to use low carbon steel and painting. Such decision of a product designer has helped manufacturer to simplify process and to decrease the production time and cost.

First step of the developed methodology testing is forecasting of steel consumption applying Eq. (6). The forecasting results are presented in Table 3. Table 4 illustrates the data of forecasted total product manufacturing cost employing Eq. (7); considered product has not plastics and assembling is carried out by customer.

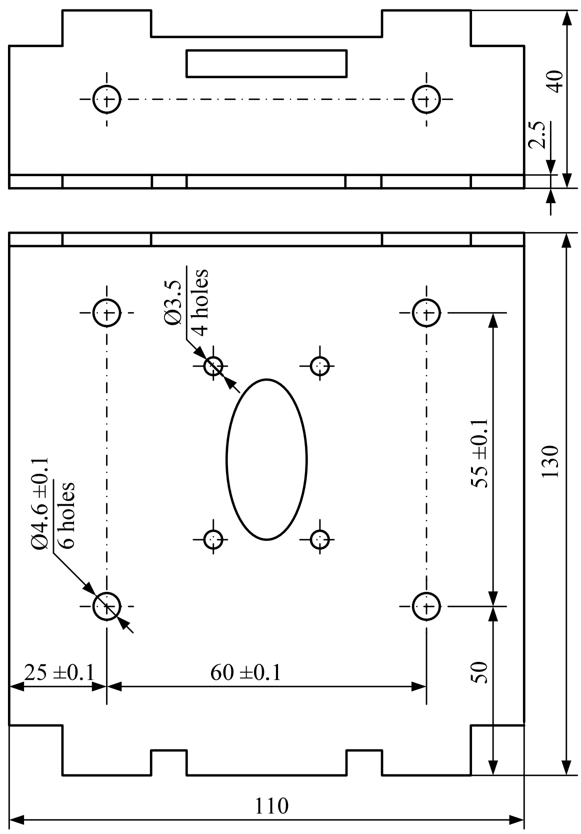

Fig. 4 Considered sheet metal part Plate 1

Table 3

Metal forecasting results

Variant	Product mass M, kg	$M1$, kg	$g1$	Material
1	4.31	4.67	1.00	Galvanized steel
2	4.31	4.67	0.89	Low carbon steel

Table 4

Manufacturing cost forecasting results

Variant	Total metal cost, EUR	Painting cost, EUR	$b1$	H, EUR
1	2335.0	0	2.00	4670.0
2	2080.0	224.0	2.00	4608.0

Table 5

Plate 1 before process correction, dimension Ø4.6 ±0.1

	Nr.	1 sample	2 sample	3 sample	4 sample	5 sample	6 sample	7 sample	8 sample
Ø4.6 ±0.1 *T*=0.2 mm	1	4.78	4.79	4.80	4.81	4.78	4.80	4.78	4.81
	2	4.86	4.79	4.80	4.81	4.78	4.80	4.79	4.82
	3	4.78	4.80	4.81	4.82	4.78	4.82	4.80	4.83
	4	4.86	4.81	4.82	4.83	4.82	4.82	4.81	4.85
	5	4.80	4.82	4.83	4.84	4.83	4.86	4.82	4.86
	6	4.81	4.83	4.84	4.85	4.84	4.86	4.83	4.85
	7	4.83	4.84	4.85	4.86	4.85	4.86	4.84	4.86
μ		4.817	4.811	4.821	4.831	4.811	4.831	4.810	4.840
R		0.08	0.05	0.05	0.05	0.07	0.06	0.06	0.05
σ		0.0315	0.0181	0.0181	0.0181	0.0285	0.0259	0.0200	0.0185

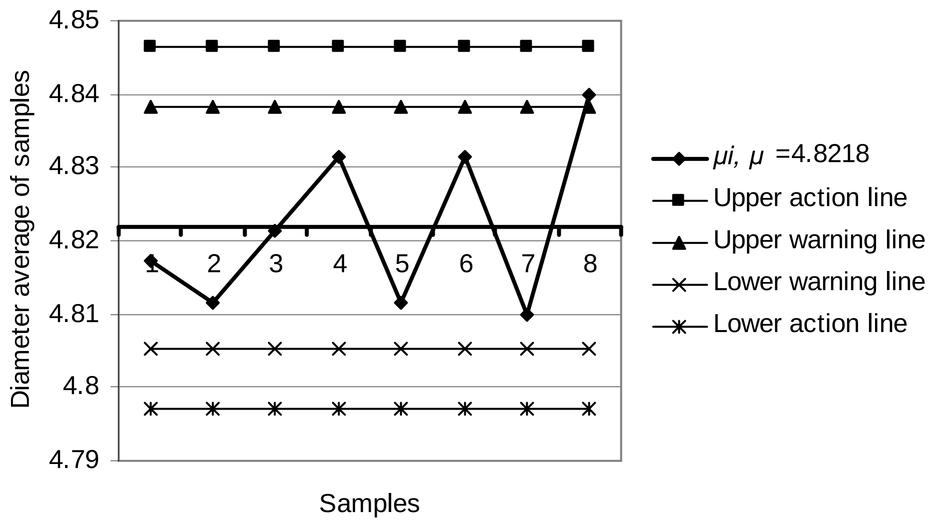

Fig. 5 Diagram of average dimension Ø4.6 ±0.1 values before process correction

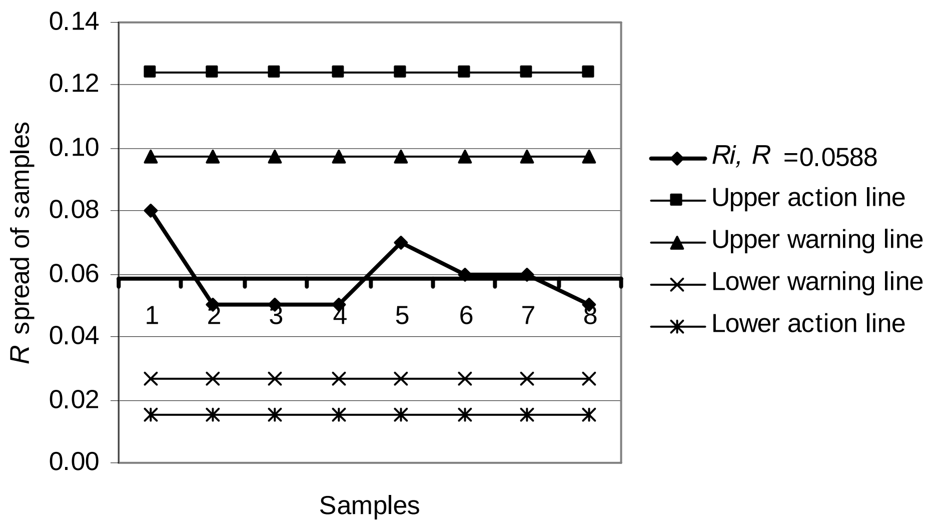

Fig. 6 Diagram of dimension Ø4.6 ±0.1 range values before process correction

Table 6

Plate 1 after process correction, dimension Ø4.6 ±0.1

	Nr.	9 sample	10 sample	11 sample	12 sample	13 sample	14 sample	15 sample	16 sample
Ø4.6 ±0.1 *T*=0.2 mm	1	4.70	4.69	4.68	4.67	4.66	4.57	4.56	4.55
	2	4.70	4.69	4.68	4.67	4.66	4.57	4.56	4.54
	3	4.68	4.67	4.66	4.65	4.64	4.57	4.56	4.55
	4	4.68	4.67	4.66	4.65	4.64	4.67	4.66	4.55
	5	4.60	4.59	4.58	4.59	4.58	4.67	4.67	4.63
	6	4.60	4.59	4.58	4.59	4.58	4.67	4.66	4.64
	7	4.60	4.60	4.58	4.59	4.58	4.57	4.65	4.67
μ		4.651	4.643	4.631	4.630	4.620	4.613	4.617	4.590
R		0.10	0.10	0.10	0.08	0.08	0.10	0.10	0.10
σ		0.0452	0.0437	0.0452	0.0355	0.0355	0.0495	0.0498	0.0504

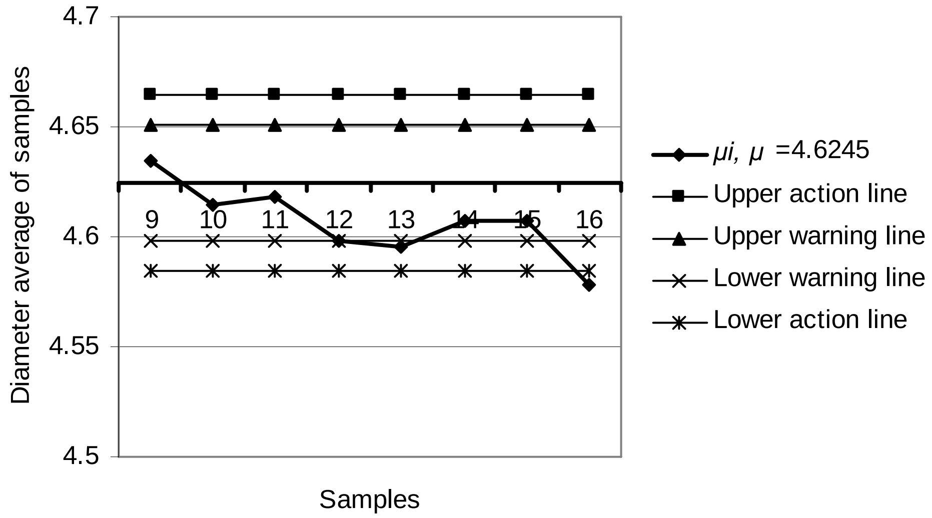

Fig. 7 Diagram of average values after process correction dimension Ø4.6 ±0.1

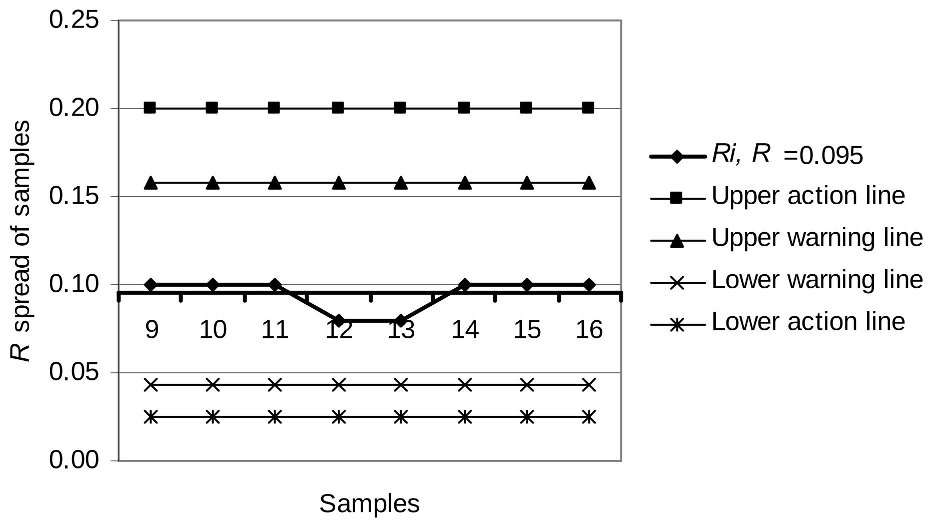

Fig. 8 Diagram of average range values after process correction dimension Ø4.6 ±0.1

Second step of the test was the definition of process control cost y_4 as more decisive for appraisal cost $Q2$ (equation 11); for checking parameter y_4 was selected Lithuanian sheet metalworking company X, which had the biggest quality problems, because it did neither neglect quality management nor quality cost definition. There were many cases when customer claimed delivered products. The investigation of claimed product batch with error of the diameter Ø4.6±0.1 mm is carried out (Fig. 4). Table 5 illustrates the measurement results of 8 claimed plates' samples and calculated μ, R, and σ values; Fig. 5 shows the diagram of average μ diameter Ø4.6 ±0.1 mm, and Fig. 6 shows the diagram of dimension Ø4.6 ±0.1 range values of clamed plates. The average of diameter Ø4.6±0.1 mm

μ = 4.8218 (Fig. 5) is so far from tolerance and though average of range R is in the tolerance limits (Fig. 6) the plate batch has been claimed.

The main reasons of defects after careful analysis were detected: 1) though CNC Laser cutting machine tool capability index C_p = 1.53 is quite good, but the process capability index C_{pk} = -1.86 is beyond any limits – it means the machine tool is suitable and the reason of errors is a bad process capability; 2) CNC Laser cutting machine operator has used the prepared program of plate machining without any dimensions control after the first part is made; 3) wrong use offset operation of machine tool before machining a new batch of parts; 4) no dimensions control after machining of the whole batch of plates before delivering. Taking into account all mentioned drawbacks of the process the appropriate corrections have been made. Table 6 demonstrates the measurement results of 8 samples produced by corrected process and calculated new μ, R, and σ values; Fig. 7 shows the diagram of average μ diameter Ø4.6 ±0.1 mm, and Fig. 8 shows the diagram of dimension Ø4.6 ±0.1 range values of plates produced by corrected process. The average of diameter Ø4.6 ±0.1 mm, μ = 4.6068 (Fig. 7) is excellent and also the average of range R ranging is slight (Fig. 8); process capability index after correction became better, C_{pk} = 1.06. The developed methodology was used to the whole products and machines in company X, and employees have been retrained to use it. The importance of human role to quality is also confirmed in research [15].

Third step of the test was checking of forecasting accuracy of a quality cost by equation (8). Quality cost forecasting results are presented in Table 7. The results are given in Euro. The cost of measurement equipment calculating $Q2$ was neglected because standard simple control tooling has been used. Total quality cost for variant 1 is a 4.8 % while for variant 2 is a 4.65 % of manufacturing cost; it means that total order forecasting cost is equal to 4894 EUR (variant 1) and 4822 EUR (variant 2).

Table 7

Quality cost forecasting results

Variant	$Q1$	$Q2$	$Q3$	$Q4$	Q
1	28.02	32.69	116.75	46.70	224.16
2	27.65	32.26	108.48	46.08	214.47

5. Conclusions and further research

Usage of quality cost estimation methodology in Lithuanian industry permits to avoid occurrences of products and process defects already in production stage, which helps to economize materials and other manufacturing resources. The proposed process modeling for quality in order-handled manufacturing system can forecast a best process and quality cost at the early new order engineering stage. Quality cost forecasting is related to manufacturing cost, i.e., knowing the latest cost developed model forecasts percentage proportion of quality cost. It was shown that fairly distributing resources to process prevention and appraisal it is possible to minimize internal and external failure cost.

Employment of suitable quality cost modeling, forecasting and estimation methods enables companies' stakeholders to foresee whether and when quality feature is not correctly situated. Such activities permit to react properly in early stages of new order engineering, production and delivery. It is proved that in OHMS also is available to use statistical process control (SPC) monitoring product quality and maintaining processes to a fixed cost, quality index and delivery deadlines. The aim of the developed methodology and SPC is to get and keep manufacturing process under control.

It was found that quality cost composes approx 4.5-4.8 % of total manufacturing cost in OHMS manufacturing systems, in particular for SMEs. Applying quality prevention strategy, it is possible to decrease this limit to 3.0-3.5 %. The developed methodology has been tested and validated for confirmation of the theoretical consumptions with the industrialists experience in companies.

Future research will focus on the expansion of the investigation various manufacturing processes, machine tool and tooling capabilities aiming to cost minimization and increase the quality indices.

Acknowledgement

This research was partially supported by contract with industry No 8405-2007 "Modeling of estimation productivity and quality for production the mechanical components".

References

1. **Barber, K.D., Hollier, R.H.** The use of numerical analysis to classify companies according to production control complexity. -Int. J. of Production Research, 1986, 24, no1, p.203-222.
2. **Shewchuk, J.P., Moodie, C.L.** Definition and classification of manufacturing flexibility types and measures. -Int. J. of Flexible Manufacturing Systems, 1998, 10, no4, p.325-349.
3. **Hill, T.** Manufacturing Strategy: Text and Cases, 1999, Antony Rowe Ltd Chippenham, Wiltshire, GB.-634p.
4. **Swift, K., Allen, A.** Techniques for quality and manufacture. -J. of Engineering Design, 1999, 10, no3, p.81-91.
5. **Gien, D.** Towards to unified representation of quality in manufacturing systems. -Int. J. of Computer Integrated Manufacturing, 1999, 12, no2, p.141-155.
6. **Stasiškis, A., Bargelis, A., Leibl, P.** Modeling of product design for process capability. -Mechanika. -Kaunas: Technologija, 2001, Nr.4(30), p.43-49.
7. **Tsai, W.H.** Quality cost measurement under activity-based costing. -J. of Quality and Reliability Management, 1998, 15, no7, p.719-752.
8. **Dahlgaard, J.J., Kristensen, K., Kanji, G.K.** Quality costs and total quality management. -Total Quality Management, 1992, 3, no3, p.211-221.
9. **Gryna, F.M.** Quality and Cost. In Juran J. M. and Godfrey, A. B. (Eds.), Juran's Quality Handbook, 1999, 5th ed.-New York: McGraw-Hill.-748p.
10. **Omachonu, V.K., Suthummanon, S., Einspruch, N.G.** The relationship between quality and quality cost for a manufacturing company. -Int. J. of Quality & Reliability Management, 2004, 21, No3, p.277-290.
11. **Setijono D., Dahlgaard, J.J.** The value of quality improvements. -Int. J. of Quality & Reliability Management, 2008, 25, No3, p.292-312.

12. **Goodaire, E.G., Parmenter, M.M.** Discret Mathematics with Graphs Theory. -New York: Prentice-Hall, Upper Saddle River, 1998.-348p.
13. **Bargelis, A.** Web-based integration for knowledge sharing in hybrid manufacturing system. -10th Commemorative.-Int. Conf. on Productivity and Quality Research ICPQR [electronical source]: February 15-19, 2004, Miami, Florida, U.S.: Proceedings, p.1-11.
14. **Plunkett, J.J., Dale, B.G.** A review of the literature on quality-related cost. -Int. J. of Quality & Reliability Management, 1987, 4, No1, p.40-52.
15. **Ollikainen, M., Varis, J.** Human errors play a remarkable role in sheet metal industry.-Mechanika.-Kaunas: Technologija, 2006, Nr.5(61), p.51-56.

D. Čikotienė, A. Bargelis

PAGAL UŽSAKYMUS DIRBANČIŲ GAMYBOS SISTEMŲ PROCESŲ MODELIAVIMAS SIEKIANT GEROS GAMINIŲ KOKYBĖS

R e z i u m ė

Straipsnyje pateikta pagal užsakymus dirbančios gamybos sistemos gamybos technologijos modeliavimo, siekiant geros gaminių kokybės, metodologija. Sukurta metodologija tiria gaminio ir proceso kokybinių ir kiekybinių rodiklių įtaką proceso kokybės užtikrinimo modeliui. Tyrimai grindžiami gaminio konstrukcinių elementų kokybiniais požymiais – medžiaga, geometrine forma, matmenimis, tolerancijomis, paviršių glotnumu ir pan. Mechaninių detalių ir komponentų duomenims transformuoti į skaitmeninius kodus buvo panaudota grafų teorija. Sukurtas modelis leidžia prognozuoti gaminio gamybos ir kokybės siekimo sąnaudas ankstyvoje gaminio kūrimo ar naujo užsakymo galimybių tyrimo stadijoje. Modeliuojant kokybės siekimo sąnaudas galima gerokai sumažinti paklaidų atsiradimo riziką didelės gaminių įvairovės ir mažų gamybos apimčių sistemose, teisingai įvertinant jų galimybes, ir tinkamai parinkti proceso struktūrą, įrenginius bei įrangą. Sukurtas modelis testuotas ir patvirtintas dviejose Lietuvos gamybos įmonėse ir yra tinkamas naudoti pramonėje bei techniškųjų universitetų studijų procese.

D. Čikotienė, A. Bargelis

PROCESS MODELING FOR QUALITY IN ORDER-HANDLED MANUFACTURING SYSTEM

S u m m a r y

This paper deals with mechanical products process modeling for quality in order-handling manufacturing system. It investigates an influence of the product and process qualitatives-quantitatives indications to the manufacturing quality. The research is based on product design features peculiarities as material, geometrical form, dimensions, tolerances, and roughness of surfaces and so on. The graph theory for transformation of mechanical part drawings' data into digital codes has been applied. The developed model can forecast product manufacturing and quality cost at the early stage of a product design and also it is useful at the new business consideration phase in order-handling manufacturing systems. Modeling of quality cost can decrease the risk of production errors in high variety and low volume manufacturing system rightly estimating its possibilities and suggesting decision making for creation of a right process structure and fabrication facility and tooling aiming the minimal production and quality costs. The created model is tested and validated in two Lithuanian manufacturing companies and it is able to use in mechanical engineering industry and also for study process in technical universities.

Д. Чикотене, А. Баргялис

МОДЕЛИРОВАНИЕ ПРОЦЕССОВ ДЛЯ ДОСТИЖЕНИЯ КАЧЕСТВА В ПРОИЗВОДСТВЕННЫХ СИСТЕМАХ, ДЕЙСТВУЮЩИХ ПО ЗАКАЗАМ ПОТРЕБИТЕЛЕЙ

Р е з ю м е

В публикации представлено моделирование процессов для достижения качества в производственных системах, работающих по заказам потребителей. Разработанная методология позволяет учесть влияние качественно-количественных параметров продукта и процесса на процесс для достижения требуемого качества. В исследованиях используются качественные параметры конструкционных элементов продукта – материал, геометрическая форма, размеры, допуски, шероховатость поверхностей и др. Для трансформации данных деталей и компонентов в численные коды была применена теория графов. Разработанная модель способна прогнозировать производственные затраты и затраты достижения качества в ранней стадии разработки нового продукта или оценки заказа. Моделирование затрат достижения качества может значительно уменьшить риск дефектов при производстве большой разновидности и низком производственном объеме продуктов при правильном выборе оборудования и технологической оснастки. Разработанная модель тестирована и проверена на двух предприятиях Литвы и может быть использована в промышленности и также для обучения студентов в технологических университетах.

Received August 12, 2008
Accepted January 07, 2009