CzOTO 2022, volume 4, issue 1, pp. 19-27

PRODUCTION COST CALCULATION APPROACH BASED ON DATA COLLECTED DURING MANUFACTURING PROCESS

doi: 10.2478/czoto-2022-0003
Date of submission of the article to the Editor: 29/11/2021
Date of acceptance of the article by the Editor: 20/02/2022

Grzegorz Krześniak
ZF Automotive Systems Sp. z o.o., **Poland**

Abstract: The aim of the article is to present a proposal and discuss the production cost calculation procedures based on data collected during manufacturing process, according to standard SPC control chart evaluation. It is applied as a tool to support the process of continuous improvement of the manufacturing process and improve profitability by reducing the cost of production.
Research methodology - the study uses the results of a literature review on the issue of cost analysis and their modeling. Key elements are the main cost components, but also those that are considered less important and may be overall decisive. Application of Statistical Process Control - as a method of data collection for cost modeling to improve overall cost structure is proposed.
Originality / value - the considerations presented in the study may be the basis for determining the key components of the cost of production. The proposed simulation model allows for the determination of the main quality cost factors. This, in turn, should allow to define the main directions of searching for the optimization of the product cost in order to achieve the expected level of cost and quality.
Keywords: cost calculation, cost modeling, manufacturing costs, control chart, quality costs, Statistical Process Control (SPC).

1. INTRODUCTION

Each production process is based on the use of resources. This applies to both production plants and other activities. A resource can be literally anything that will be used in the manufacturing process. Of key importance for the success of the project is their proper use and not only effective, but most of all efficient. This can only be achieved if the manufacturing process is properly designed, properly set up, effectively optimized and is subject to continuous improvement. One of the key aspects of the proper selection of a manufacturing method is the possibility of its effective selection. In the case of the cost of the production process, selection of the appropriate and effective method of processing resources, which are: building, material, processing machines, people, energy and other materials, is of major

importance. Elimination of loss sources, such as: unplanned downtime, changeovers, removal of product defects (repairs) and waste is also important.
A proper approach to these elements should give a chance for success in an undertaking whose goal is the production and sale of manufactured goods. In order to achieve this, it is necessary to have a proper approach to many aspects. The aim of this analysis is to show that the right calculation method combined with effective modeling gives a chance to effectively determine what cost components can be achieved at each stage of the production process. It should also define both quantitative and qualitative goals. At the design stage, without incurring significant costs of engaging considerable resources, to determine what can and must be achieved in order to provide a product that will be competitive on the market. It will be successful in competing effectively and will provide a product that will give the enterprise the possibility of profitable activity.
At the level of designing new products, the analysis of the production costs of products, their components and parts - in the context of market globalization, and thus the intensification of product diversity, manufacturing complexity, cooperative dependencies and computerization of production - becomes one of the most important issues in the analysis of the production process. The possibility of mass production gives the opportunity to use low-cost production methods, which in the final stage may translate into an increase in orders and the company's success on the market (Tabor et al., 2004).
With this, many companies, not only from the automotive industry, use the services of organizations that specialize in cost analysis of designed parts and subassemblies. It is becoming very popular to create specialized departments dealing with costs modeling before implementing production processes. In the case of the cost modeling departments, operating within the structure of large suppliers, there are opportunities to copy manufacturing solutions that have worked well in other company departments. Often, however, due to the specifics of the sales market, direct copying of solutions that worked well in one process may be inappropriate or ineffective in another one. Therefore, the possibility of cost modeling becomes the most effective method of checking the effectiveness of the proposed change. The choice of the technologically correct and effective production method gives the company a chance to win the tender for deliveries, which in turn will increase sales, and, as a result, ensure the company's competitiveness on the market and stability for employees. In the case of mass production, the key is the correct selection of the production method. An effective simulation of the production process will save time and production resources. A lot of cost information is required to prepare for a cost model:

• material (price of the material, mechanical properties of the parent material, properties that can or are planned to be obtained),
• machine / process (price, fixed and variable costs, changeover costs),
• definition of quality goals (waste percentage, downtime),
• production sites - country (cost of: labor, energy and servicing fixed costs),
• SG&A (general and administrative costs),
• profit enterprise.

Correctly collected data and properly evaluated will enable to establish a model, the use of which will effectively calculate the cost of the detail for which the production

process is designed. The company that uses the most aptly selected model can be convinced of the rightness of its decisions based on the results of the analysis. With mass production in excess of several million parts per year, every penny matters, and wrong decisions can result in the company's failure.
Currently, there are several programs on the market that are used for cost modeling, but due to market requirements, they are more general purpose programs.
In the case of technological processes, the effect of which is a change in the geometry of the workpiece, built-in calculators mostly have significant limitations when calculating cost changes in line with shape changes. This is the case here. An inconspicuous at first glance difference in the price of 0.01 EUR can result in large savings in large-scale production, e.g. 10,000,000 pieces - a profit of EUR 100,000. That is why it is so important to choose the right computational tool that will ensure the accuracy of the results of the production cost analysis, and thus the reliability of decisions made at the design stage of production processes. This will improve the level of confidence that the decisions made by the company will reduce the risk resulting from conducting manufacturing activities, which in the final bill of the company will translate into higher profits and improvement of the company's competitiveness on the market.
Cost saving could be also lowering the requirements, which may have a significant impact on the quality costs. Costs that may arise during the so-called lifetime of the product, and their amount may many times exceed the savings in their production. This is not a new issue and is extensively described in the study of R.S. Kaplan and D.P. Norton (Kaplan and Norton, 2001). It is known as the competitiveness triangle. The relationships between quality, cost and time are universal - Fig. 1 (Zymonik, 2003).

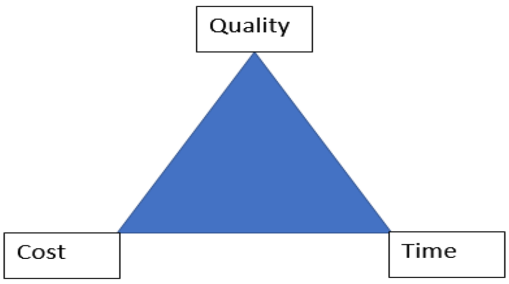

Fig. 1. The competitiveness triangle - quality costs in enterprise management (Zymonik, 2003)

Quality problems may arise during product life time. Here we can consider the loss of product features or its permanent wear. If the product is under warranty, there will be a cost of restoring these features, or even replacing them with the new ones. This means that it is necessary to carefully analyze which product characteristics can be modified so as not to lead to the loss of the product properties, and the savings, the change of which would not be adequate to the losses as a result of their loss. Time is of key importance here. If the loss occurs after the period of use, the negative effects will not have an impact on the cost. Proper determination of these relationships is of fundamental importance in cost modeling and later evaluation.

The most important for good cost modeling calculation is appropriate data collection. Many products have characteristics that must be stored. They are often referred to as key or critical characteristics. They are of key importance for the correct operation of the mechanisms to which they will be mounted, or for the safety of use. These can be measurements of distance, diameter, roughness, etc. It is done through control during production and we register them through the use of control cards used to record the measurement results. There are many control cards that allow to track the results, and thanks to real-time analysis, the operator can make adjustments to the processes to ensure that the processes are in line with expectations (Shewhart control chart).The collection is done in certain amount of time. If the collection is done appropriately, the timing is easy to evaluate and gives a significant source of process in time frame. So cost can be also easy to evaluate in the function of time. These cards are used most often:

- x-R; average value chart x (1) combined with range test R (2),
- x-s; card of mean value (x) combined with standard deviation (s),
- xi-R; single observation chart (xi) in combination with a moving range (R) test,
- M-R; median card (M) and the stretch mark (R),
- cumulative sum card,
- p; inconsistent unit faction card (p),
- e.g; card for the number of non-conforming units (e.g.),
- c; card of the number of nonconformities (c),
- u; nonconformity card per unit.

Each of the cards mentioned above can be a source of knowledge about the process, its stability and the possibility of non-compliance, or most often rejection. In the extreme case it falls out.

Control charts are most popular tools used in statistical process control. According to needs, process developer can adapt most effective method of data collection and data evaluation. During data collection, an operator has to do some calculation like average, statistical range, etc. Control chart is established according to process requirements based on evaluation. During new process development some detailed information are present in APQP and PFMEA. They are used when process has to be continuously monitored and the results of monitor have to be recorded. All necessary data packs like frequency of record and control, date, name of tester are obligatory (Sałaciński, 2009). Analyzing the above-mentioned records is tedious, especially in the long term. Therefore, most often these records are subject to additional analyzes. There are many methods of processing data collected by using control charts. The Pareto-Lorenz analysis is very effective here. It is a kind of line or bar chart in the Cartesian coordinate system (Sałaciński, 2009).

2. METHODOLOGY

The subject of analysis is process of tube elbow forming. Components bended in that process are part of flow installation. Any change of inner diameter will have influence on flow process, like reducing flow or impact on pressure. In the worst case, it could have impact on flow type and create turbulent flow. So, the evaluated parameter is very important for correct mechanism function, where that elbow tube will be assembled.

Based on data collected, an operator has to update graph, so during process we have graphical presentation process change in the function of time. It also has to be established:

- Upper Specification limit (USL) defined as maximum value of measurement - still in tolerances,
- Warning line for upper limit, when the result of process measurement is touching that line, an operator has to do correction action, according to procedure or instruction,
- Central line defined as base value of measurement,
- Lower Specification limit (LSL) defined as lower value of measurement - still in tolerance,
- Warning line for lower limit when result of process measurement is touching that line, an operator has to do correction action, according to procedure or instruction.
- Frequency of control according to process capability, or other factor.

That is why, card control which covers all points listed above is called a chart.

According to the procedure an operator has to collect three measurements for related characteristics on three different parts, It will be the best if that probe will be taken like one by one parts. In chart that is called x1, x2 and x3. The next step is average calculation (1):

$$Xa = \frac{x1 + x2 + x3}{3} \quad (1)$$

$x1$, $x2$, $x3$ - samples probe,

Xa - average value.

Standard range is calculated as delta between the lowest and the highest measured point:

$$R = x(max) - x(min) \quad (2)$$

x(max) - the largest sample probe,

x(min) - the smallest sample probe.

An operator has to mark the calculated value on the chart like in the example presented in Fig 2.Upper specification limit is a value defined at the development of component, we can name it as the highest dimension possible to assembly or other customer needs (3). It means that if the result of production process will exceed upper specification limit ,the product is not available to use and has to be held for reject or rework, if we know that tolerance specification at the beginning of development. A developer has to select process according to needs, and find process capable to fit requirements. An operator has to follow more or less the same procedure about Lower Specification Limit (4):

$$USL = Xo + 3\frac{\sigma}{\sqrt{n}} \quad (3)$$

$$LSL = Xo - 3\frac{\sigma}{\sqrt{n}} \tag{4}$$

σ - Standard deviation - is a measure of amount of variation of set of values,
X_o - nominal value of characteristics,
N - number of samples in subgroup.

If process reaches that value or exceeds Upper Warning Limit (5) and Lower Warning Limit (6), that means process is going to be out of control. For manufacturing processes it means that operator has to do an action according to instruction or a procedure.

$$UWL = Xo + 2\frac{\sigma}{\sqrt{n}} \tag{5}$$

$$LWL = Xo - 2\frac{\sigma}{\sqrt{n}} \tag{6}$$

Operation:	Charackteristic	X-R chart process OP003 - characteristic QP1,			frequesncy/reason: evry hour begin (H), every process setup (E), lot change (L).			Date start	Date stop
Tube forming	Op 003	Specyfication	Gauge	warning line upper	warning line lower		Operator Name	01.lut	01.lut
	Overal Dimension	Ø9,000; + 0,01/-0,00	PSS 007	Ø9,007	Ø8,993				

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Date	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02	1-02
reason	H	H	H	H	H	H	H	E	E	H	H	H	H	H	E	E	H	H	H	H
Hour	06:05:00	07:05:00	08:05:00	09:05:00	10:05:00	11:05:00	12:00:00	12:15:00	12:22:00	13:05:00	14:05:00	15:05:00	16:08:00	17:06:00	18:05:00	18:28:00	19:05:00	20:06:00	21:05:00	22:05:00
x1	9,002	9,005	9,000	9,000	8,997	9,000	9,009	9,008	9,001	9,001	9,004	9,001	9,001	9,001	9,007	9,009	9,004	9,001	9,000	9,001
x2	9,001	9,005	9,001	9,000	8,999	9,000	9,009	9,008	9,001	9,001	9,004	9,001	9,001	9,003	9,007	9,009	9,004	9,001	9,001	9,001
x3	9,003	9,005	8,999	8,998	8,999	9,001	9,008	9,008	9,000	9,002	9,006	9,000	9,000	9,000	9,009	9,003	9,003	9,000	8,999	9,000
Xa	9,002	9,005	9,000	8,999	8,998	9,000	9,009	9,008	9,001	9,001	9,005	9,001	9,001	9,001	9,008	9,007	9,004	9,001	9,000	9,001
R	0,002	-	0,002	0,002	0,002	0,001	0,001	-	0,001	0,001	0,002	0,001	0,001	0,003	0,002	0,006	0,001	0,001	0,002	0,001

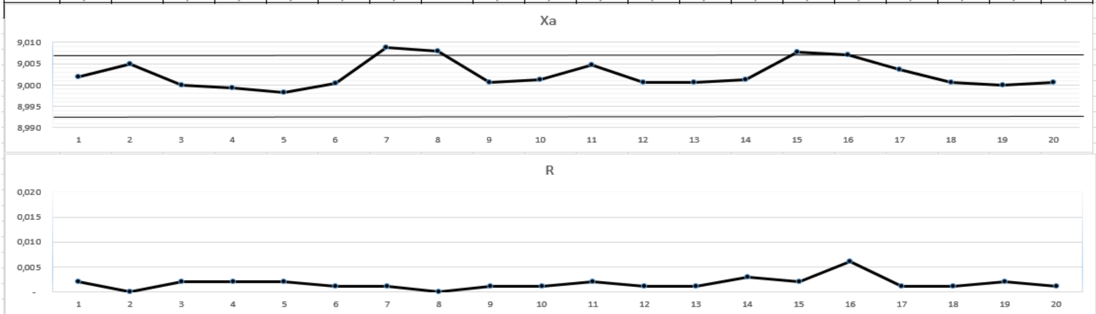

Fig. 2. x-R chart - example of x-R chart according to Shewhart (PN-ISO 8258:1996).

Example x-R chart, in the Fig. 2, represents data collection basing on process of tube elbow forming. When external diameter of tube is critical, characteristics and impact on external dimension will impact also inner diameter so flow inside tube will be affected and tube will lose function in final assembly condition. Records between 12:00 to12:22 and 18:05 to 18:28 show setup process when manufacturing process was interrupted and that periods are no production - lost production time slots. So for sure we are detecting the lost one maker. But do we know if that is the biggest problem or just a minor issue?

In Pareto-Lorenz analysis the vertical axis usually includes the frequency of observations, but can also be cost, percentage of total observations, or quantity. On the horizontal axis there are groups of events, errors, characteristics, failures, etc. That is, groups that can be easily identified in the process. Arranging the bars from the highest to the lowest gives a picture of which events occur most often, which costs are the highest, etc. By choosing the highest bars, by choosing four or five, we focus on the group that may be responsible for more than half: discrepancies, losses, discards etc.

After collecting all the information about the production process, data evaluation is necessary. Most often, before we proceed to such an analysis, there is a task, a question or a need, i.e. a goal, that has been posed. Depending on the direction of the analysis, we can freely choose the right tools as well as units of measurement and evaluation. With regard to costs, it is possible to carry out a cost-benefit analysis. Collected data from quality charts could be a value or just counting of unexpected incidents. Below, an example of Pareto based on counting process stops is showed. Data source was x-R charts for manufacturing process, for operation tube forming process characteristics Op 003.During one day observation, we can identify significant capacity loss due to process setup. Total time recorded was 53 min in one day production.

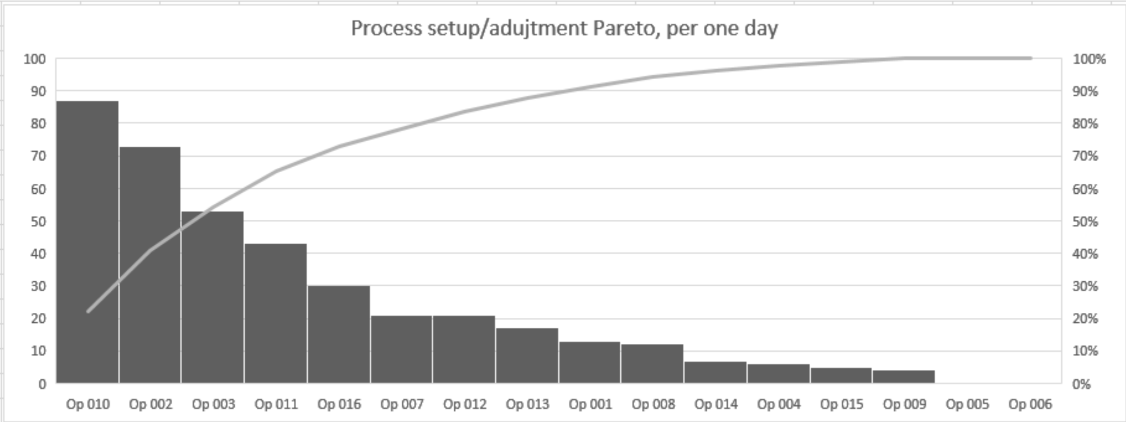

Fig. 3. Pareto chart; vertical axis: process stops due to setup and process adjustment and total percent per process, horizontal axis: a list of operations.

3. RESULTS

During one day observation, we can identify significant capacity loss, due to process setup. Total time recorded was 53 min in one day production according to Fig. 3. Based on PARETO chart we can recognize also that the problem is not only an operation Op003 but also Op010 and Op 002. Just those three operations create 50% recorded lost in the process.

Each correction of process is an additional cost, usually called quality cost. That will be process adjustment:

- machine setup - production process stop, or downtime,
- tooling change or tooling setup - cost of tools and adjustment time,
- labor loss - additional operation has to be done by an operator or other staff,
- unproductive - stop regular process and adjustment - loss of production,
- scrap due to setup - adjustment can impact some characteristics and all production during adjustment must be scrapped.

Of course, when the decision has to be taken about development direction, not only the correct calculation is enough. Reliable data collection regarding the possibilities of production processes, information about their limitations and possibilities are necessary. Collection of data from the market, the level of the product price, quality expectations, availability of materials or raw materials, logistics costs. They provide a broader spectrum of opportunities to compete on the market. Providing the possibility of production under the order gives the opportunity to reduce the levels of storage and thus reduce the costs of the so-called work in progress. All of these factors are key, and each of them can be covered by a separate extensive review. However, in this article we focused on data collection from control charts as a data source for modeling the cost of manufacturing. A typical workflow for properly modeling the cost analysis process is prepared and provided in Fig. 4.

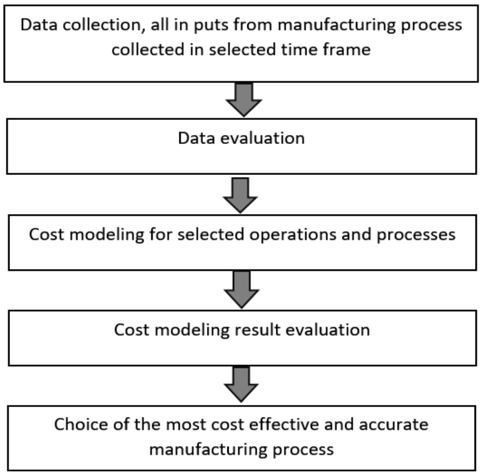

Fig. 4. Diagram of the procedure in the process of cost modeling (own study)

is As shown, the cost modeling process is crucial at every stage of the productive life cycle. The first analysis should be performed at the very beginning, when the company is analyzing the entry into a specific production segment and when the production of the product is underway and we are looking for areas to reduce costs. Modeling, supported by data that can be collected during production processes in the field of waste, analysis of changeovers, failure and downtime analysis and many other analyzes can be helpful and are implemented in the company. SPC data collected during the process are significant resource about process stability and can significantly raise understanding of the sources of losses. It gives a chance for a proper selection of cost factors and indication of those which can be improved most effectively in order to achieve the expected state. It depends on the needs: reduction of the unit cost, efficiency of the production process or change of quality. In the actual process, the purpose of the modification can be anything. Most often it dictated by the customer's orders. Depending on the needs and expectations of the market, companies have to adapt to keep up with the requirements.

4. CONCLUSIONS

Theoretically, the most desirable proposals will be those where the cost of inputs is low and the increase in benefits is high. But of course that's not the rule. The presentation of these dependencies allows for a quick determination of the dependencies between them. After performing all possible dependencies, one can start selecting the most appropriate dependences. In addition, a meeting is usually organized to determine the method of satisfying the need. By using the analyzes and visualization of the actual state and confronting the modeling results with development proposals, we can indicate what are the possible scenarios of satisfying them and what costs must be incurred to satisfy them. We can find out how analyzed change will have an impact on other processes, what threats may occur, and what are new opportunities for improvement. It is very important that at the end of this analysis there is information about the cost that needs to be incurred to introduce the change / need and what benefits it can bring. Ideally, this benefit should be presented as an amount; regardless of whether the result is a reduction in product cost, reduction of capital used in manufacturing, reduction of employment, reduction of product weight, reduction of cycle time, reduction of product quality, reduction of production capacity, or a change of process. Any change in any of them, should be represented in terms of the manufacturing cost difference. Most often, such a digital value followed by a currency symbol is reported as saving.

Conscious reduction of product quality is one of the most risky processes launched in order to reduce manufacturing costs. The choice of characteristics to be subjected to relaxation of requirements must be carefully planned. The first stage is the analysis of the influence of a given characteristic on the functional features of the finished product. Identifying them is of fundamental importance and should be carried out on many levels. It is possible and quite often desirable, but before implementation, an organization has to do deep investigation if that change can bring any benefit. One of the biggest sources of data for evaluation are collected control charts. Correct evaluation supported by cost modeling, can give argument to do improvement on manufacturing process, and bring saving home, to find new customers, due to the lower price or improving competitiveness.

REFERENCES

Kaplan R.S., Norton D.P., 2001. *Strategiczna karta wyników, Jak przełożyć strategię na działanie*, Wydawnictwo Naukowe PWN, Warszawa.

Olsen D., 2015*. The Lean product playbook: how to innovate with minimum viable products and rapid customer feedback*, John Wiley & Sons, Hoboken.

Sałaciński T., 2009. *SPC statystyczne sterowanie procesami produkcji*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa.

Tabor A., Zając A., Rączka M., 2004. *Nowoczesne zarządzanie jakością, tom 5, Projektowanie, organizacja i zarządzanie* jakością, Centrum Szkolenia i Organizacji Systemów Jakości Politechniki Krakowskiej im Tadeusza Kościuszki, Kraków.

Zymonik Z., 2012. *Koszty jakości jako miara efektywności działań w przedsiębiorstwie*, Prace naukowe uniwersytetu ekonomicznego we Wrocławiu, 2(262), Wrocław.

Zymonik Z., 2003. *Koszty jakości w zarządzaniu przedsiębiorstwem*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław.

PN-ISO 8258:1996. *Karty kontrolne Shewharta*, Wydawnictwo PKN, Warszawa 1996.