# "Right Sizing" Quality Assurance

By Walt Lipke, PMI Oklahoma City Chapter

Abstract

Generally, quality assurance (QA) functions are sized at the direction of management and are rarely sized commensurately with their need. Over the years, influenced strongly by in vogue attitudes and real world circumstances the size of the QA function has exhibited extremes:

- *Inordinately large after an embarrassing product failure, or an executive's overreaction from attending a Deming[1] seminar*
- *Completely eradicated when perceived to be unneeded, or too expensive*

This article introduces quality efficiency indicators, which facilitate "right sizing" the QA function, i.e., sizing QA to the customer's need or the producer organization's own quality goals. The interpretation and application of the indicators is explained, and a simple example is provided demonstrating the calculation for sizing the QA function. (A basic knowledge of statistical process control and statistics, specifically confidence interval, is helpful to the understanding of this article.)
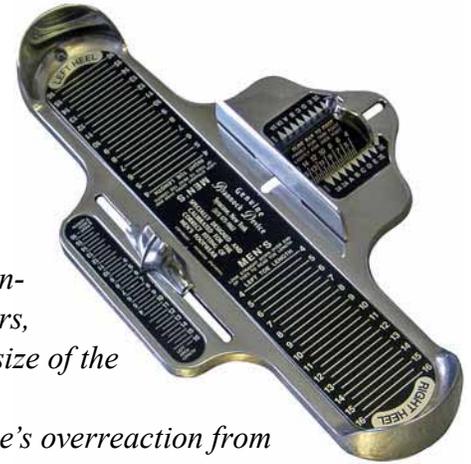
Foreword

This article, excepting this foreword, is from an article with the same title, previously published in the July 2004 issue of *CrossTalk* (Lipke, 2004). To use the methods described, some resolution in accounting for costs incurred is required. Most organizations can identify project costs by total, production, and quality function; however, knowing rework cost is oftentimes hidden and unknowable.

Explicitly identifying rework cost is critical to these methods. Knowing the cost of rework enables the potential of significant improvement benefits for both production and quality assurance (QA) processes. The recommended approach to identifying rework cost is to create rework tasks corresponding to major reviews and testing. In this way, overly tedious recording is avoided. These rework tasks have no planned duration or cost ascribed. They are solely for the purpose of collecting rework cost. Employing this method, problems identified in the reviews and testing can then be corrected and resolved while simultaneously capturing the cost of rework.

This approach to establish the cost of rework provides further information to those organizations applying earned value management (EVM). By segregating the rework cost, the cost performance efficiency (Cost Performance Index or CPI)[2] can be viewed from two perspectives: 1) including all cost and 2) excluding rework cost. By including and excluding rework cost in the computation of CPI (especially when subsequently applied to forecasting), its impact is more readily seen. This, in turn, increases the desire to make improvement and thereby create competitive advantage.

Furthermore, the CPI calculated while excluding the rework provides additional understanding of how well the project was planned, including the management reserve. For example, if the CPI (without rework cost) is near the value 1.0, an analyst could deduce the task cost estimates were reasonably good. Furthermore, if the forecast using CPI (total cost) indicates management reserve will become insufficient, the analyst could deduce the risk of rework was not evaluated very well.

The remainder of this article discusses additional potential from capturing rework cost. Sizing the QA function appropriately has significant business impacts, requiring management attention and planning as well.

Introduction

After a decade of performing process improvement, rework for software development projects at Tinker

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[1] W. Edwards Deming is credited with transforming manufacturing in Japan after WWII from the use of his philosophy and methods pertaining to quality. The gains made from quality improvement created an international demand for Japanese products.

[2] CPI is defined as the earned value divided by the actual cost.

Air Force Base was dramatically reduced from approximately 75% of the total effort to a very low value of 3%. When the percentage was high, rework was easily identified; for a small amount of QA effort, a large quantity of rework was generated. As the production process improved, it became increasingly more difficult to identify defects. When the amount of rework became 3%, the software organization began to examine the economics of further improvement and the possibility of reducing the QA effort. From the economics view came the concept of "right sizing" the QA function with respect to the needs of the customer(s) or the quality goals of the producer organization.

Background

Generally speaking, companies are concerned with the quality of their products. Because of the desire for quality products an organizational entity exists that is devoted to performing reviews, inspections, and testing for conformity to the product requirements, i.e., the QA function. There are many reasons for the necessity of the QA function, but it is also recognized that the function is a cost affecting the price of the company's products. *Thus, there is a cost for quality; it is not free.* Consequently, the QA function is connected to economic benefit.

As a minimum, QA functions should be sized sufficiently to satisfy the customer's requirement for product quality. In conflict, several pressures influence the size of the QA function. The customer wants the product at a low price with no flaws. The producer wants to make money, be competitive, and increase business and, thus, sees QA as a cost to be trimmed. Clearly, it is impossible to simultaneously satisfy the self-interests of these parties.

There are conflicting dynamics within the producer's organization too. In competitive areas (multiple producers of the same product), the market place decides the product price. In turn, this places a constraint on the amount of rework and QA the product can have and still be competitively priced. Regardless, the QA function has the desire to achieve zero defects for the entire production process and believes it's in the best interest of the company to provide enough resources to achieve this goal. If QA has the capability to assure the product is completely free

from defects, it most likely will not be affordable. Without some balance to the interests of the QA function, it can become too large.

A classic dilemma is the impact of QA on market share of a new product. Too little QA will likely yield a very defective, unacceptable product; too much QA delays fielding the product, and thus, market share is lost to competitors. Neither extreme is good for business.

From the perspective of the producer, QA needs to be efficient and rework minimized. Minimizing the cost of QA and rework makes the product more competitively priced and maximizes profit. Optimally, a good production process will satisfy nearly all of the customer's requirements without QA; i.e., quality is *built in*, not *inspected in*. Likewise, a good QA process will identify most, if not all, of the nonconformance. Achieving this synergy between production and QA is the goal of any quality system.

The customer, reasonably, cannot expect a perfect product; however, customers can mitigate their risk of purchasing poor products by testing performance and inspecting physical details during the production process and prior to accepting delivery. By performing product acceptance, the customer increases his cost of acquiring the product. His investment in product testing and inspection is an expense, and a portion of the product price is attributable to the customer-generated rework.

Defects not identified by the producer are subject to detection by the customer during his product testing and inspection. The customer's perception of product quality is created largely from the defects he identifies. To gain repeat business or good references for new business, the producer strives to minimize the defects that propagate, or leak, through his production and QA processes.

The point is, quality does affect cost and impacts all involved with the product: the producer, the QA function, and the customer.

Quality Process Indicators

Minimizing the expenditure for QA yet meeting the customer's quality requirement is not a simple matter. To accomplish the task, management must have indicators for improving the processes and achieving the needed level of quality. In the following discus-

sion, three measures of quality efficiency are proposed for determining the effectiveness and stability of the production and quality processes.

To better understand the subsequent discussion, our intended meaning of defects and rework is provided. The product requirements are the potential defects. A defect is non-conformance to a requirement, created as a function of the production process and its employees. Defects may be identified at anytime during the production process up to customer acceptance. Rework results from the defects identified. Therefore, rework is a function of the QA process, QA employees, and the customer testing and inspections. In mathematical form defects and rework are expressed as follows:

Defects = f(production process, production employees)

Rework = f(QA process, QA employees, customer verification)

For an adequate understanding, a producer must have knowledge of the effectiveness of the production and the QA processes. Also, the producer needs to have information concerning the efficiency of the QA process, itself. By having this information the processes can be improved and the amount of improvement can be quantified.

Three measures are proposed to satisfy the information needed by the producer. These measures provide the capability for determining the "goodness" of the production and QA processes. The definitions of the measures are described as:

$QE_1 = R(process) / R$
where R = total rework costs
$\quad$ R = R(process) + R(customer)
$\quad$ R(process) = rework from the production process
$\quad$ R(customer) = rework from the product inspections and testing conducted by the customer

The indicator is a measure of the efficiency (QE) of the quality process. When QE_1 indicates the customer identifies an excessive number of defects, improvement is needed from the QA process and its employees. Rework can come from non-requirements, when good requirements management is not practiced. However, only rework from non-conformance to requirements is used in the calculation of the indicator.

$QE_2 = P / T$
where P = production costs
$\quad$ T = P + R + Q = total effort
$\quad$ Q = QA costs

The indicator is a measure of efficiency of the production process. When QE_2 indicates excessive defects from the production process, the performance of the production process and its employees requires improvement.

$QE_3 = R(process) / Q$

The indicator is a measure of efficiency of the production and QA processes. When QE_3 is much greater than 1.0, the production process is examined for improvement. Conversely, when QE_3 is much less than 1.0, the QA process requires review and improvement.

Analysis

Satisfactory QA is indicated when all three indicators approach the value 1.0. As seen from examining the equations, it is possible for QE_1 and QE_3 to be equal to 1.0; however, it is not possible for QE_2 to have a value of 1.0 when R and Q are nonzero. The only condition for which QE_2 can equal 1.0 is when R = 0.0, and Q = 0.0, i.e., perfect process quality. It has been written that the minimum value of QA needed to maintain a high achieving quality process is 2.5% of the total effort (Crosby, 1979).[3] Thus, the maximum value expected for QE_2 is 0.975.

The indicator QE_1 has the most influence on the customer's perception of product quality. Of the three indicators, it is the only one for which perfection (QE_1 = 1.0) can be consistently achieved. Thus, R(customer) = 0.0 (i.e., zero defects are identified by the customer) can (and should) be an expected outcome of the production and QA processes.[4]

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3 By the term "high achieving", it is meant that nearly all of the producer's effort is in production. Extremely small efforts are performed for QA and rework to achieve the product requirements. In the author's opinion, very good quality for software producers would be $QE_1 \geq 0.98$, $QE_2 > 0.8$, and QE_3 between 0.6 and 1.2. World class quality would be characterized by $QE_1 = 1.0$, $QE_2 > 0.9$, and QE_3 between 0.8 and 1.1.

4 The customer is still at risk of product defects, even when R(customer) = 0.0. Defects may be missed by the customer's inspection and testing.

Under normal conditions the value of QE_3 will approach 1.0 when the QA process is effective. However, as QE_1 and QE_2 approach the value of 1.0, QE_3 will approach zero. Using the equation for QE_3, this circumstance is more clearly understood. As the production process improves and approaches zero defects, the numerator, R(process), approaches 0.0. Concurrently, the denominator, Q, approaches its minimum value (2.5% of total effort), and thus, QE_3 approaches 0.0.

Indicators QE_1 and QE_2 may be used as evidence of defect prevention. The concept of defect prevention is that the QA process minimizes or eliminates the propagation of defects to the customer, and the production process has been optimized such that rework and QA are minimized (Paulk et al., 1993). QE_1 provides information concerning the amount of defect leakage from the QA process to the customer. Simultaneously, QE_2 provides information concerning the optimization of the production process. Taken together, these indicators show how well defect prevention is being achieved. When QE_1 approaches 1.0 and QE_2 simultaneously nears 0.975, the production and QA processes are performing defect prevention at a level nearing perfection.

The indicators, QE_1, QE_2, and QE_3, are to be observed as both cumulative[5] and periodic values. The cumulative number provides information as to the status of the process over a span of time. The periodic values yield trend information and help to answer the question, "Is the process improving, or is it getting worse?"

Quality Function Sizing

When the indicators QE_1, QE_2, and QE_3 are satisfactory with respect to the customer's needs or the organization's quality goals and QE_3 is in statistical control, the QA function can be reliably sized. Likewise, the QA function can be sized for a new project using the data from a historical project as long as the production and quality processes are unchanged. A Statistical Process Control (SPC) "Control Chart" of the periodic observations of QE_3 is used to determine if the quality and rework processes are in control (Pitt, 1995).[6] The control charts may also be used as a "Run" chart (Pitt, 1995) for detecting the process reaction to improvements implemented.

As an example, Figure 1 is a SPC control chart created from real project data, shown in Table 1. As clearly seen from the figure, all observed values are within the upper and lower control limits (shown as UCL and LCL, respectively, in Figure 1). Thus, the processes governing QE_3 are statistically stable.

On achieving statistical control, the QA function is sized from the periodic observations of Q/T, i.e., the quality investment as a fraction of total effort. From the average of these observations and their statistical variation a 95% confidence value can be calculated for Q/T. At "95% confidence," we are 95% certain the actual QA requirement will be less than the size of the function created. Sizing QA at 95% confidence mitigates the risk of not sizing the QA function adequately.

The 95% confidence we are seeking is the upper confidence limit of the 90% confidence interval; 10% of the normal distribution is outside of the confidence interval, 5% below the lower confidence limit and 5% above the upper limit.[7] Having an actual QA requirement less than the lower confidence limit is not a concern; therefore, only the upper limit is used.

The 95% confidence limit, $(Q/T)_u$, is used in a linear relationship between the total effort cost (T) and the size of the QA function:

$$Q = (Q/T)_u \times T,$$
where Q is the expected cost for QA

This relationship is to be used with the project plan, specifically the monthly expenditures for total effort, to "right size" the application of QA resourc-

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5 Cumulative values for the three quality efficiency indicators are computed using the total values of the two parameters involved. For example, the cumulative for QE_2 would use the total values for P and T.

6 When applying statistics, it is recommended to use the logarithm values of the periodic observations of QE_3 and Q/T. These parameters have been statistically tested as logarithms and appear to be normally distributed. The results of statistics applications, such as SPC and confidence interval, are improved when the representation of the observations approximates a normal distribution.

7 The confidence interval (CL) is the region surrounding the computed average value within which the true value lies with a specific level of confidence. The end points of the interval are the CLs. The equation for the CL is $CL = <X> \pm Z \times (\sigma/\sqrt{n})$, where <X> is the average value of X, while Z is from the normal distribution and corresponds to the area selected (for this application, Z = 1.645 at 95% of the distribution area), σ is the standard deviation of the observations of X, and n is the number of observations. (Crow et al., 1960).

es. Performing the computations for the monthly values of Q will yield a funding profile for the QA function. In turn, this profile may be converted and used as the staffing profile.

To compute the 95% confidence limit, the periodic observations of Q/T are used as logarithms to make the statistical calculations (see footnote 4). The standard deviation (σ) is estimated for ln (Q/T), while the logarithm of the cumulative value, $(Q/T)_c$, is the estimate for the average value. Therefore, the confidence limit is first computed as a logarithm. Thus, the equation for the calculation of the 95% confidence limit is

$$(Q/T)_u = \text{antilog } [\ln (Q/T)_c + 90\% \text{ confidence interval}][8]$$

The antilog value, $(Q/T)_u$, is the appropriate number to use in the sizing computation.

Using the project data from Table 1, the value of ln $(Q/T)_c$ is computed to equal –2.7662, with a standard deviation σ = 0.5048. From the values for Z (=1.645), σ, and n (=18), the 90% confidence interval is calculated to be 0.1957. Adding ln $(Q/T)_c$ and the 90% confidence interval yields the value –2.5705. The value of $(Q/T)_u$ is then computed from the antilog of the sum and is determined to be 0.0765. For this project, the right size for the QA function is computed to be 7.65% of the total effort.

Summary

To economically apply QA requires three indicators of quality efficiency converge and approach 1.0. Two indicators are measures of defect leakage to the customer and from the production process, and the third measures the efficiency of identifying defects. The indicators are useful for improving the production and QA processes. Ultimately, upon achieving "in control" processes, the QA function can be sized commensurately with the customer need, or the producer's quality goals.[9]

References

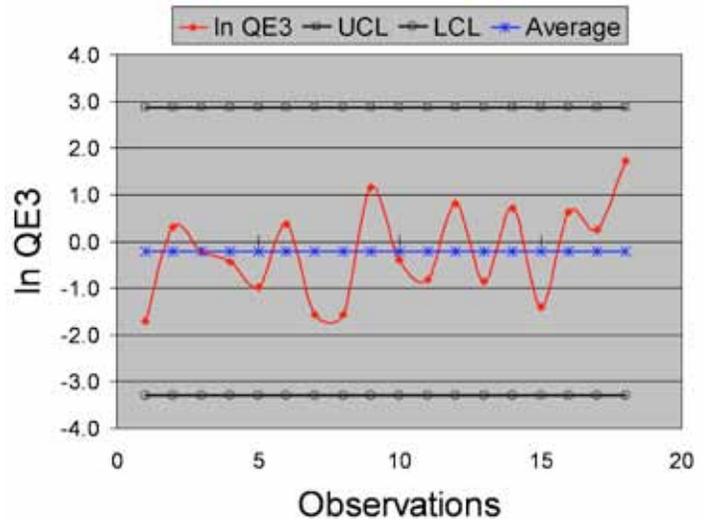Lipke, W. 2004. "Right Sizing" Quality Assurance. *CrossTalk*, July.

Figure 1. SPC Control Chart

Table 1. R_p, Q, T data.

Month	R_p	Q	T
1	15	83	1784
2	234	170	2808
3	124	154	3445
4	106	165	3051
5	39	103	2303
6	546	373	6178
7	30	143	2371
8	32	154	3374
9	247	77	2020
10	53	79	2321
11	75	169	3638
12	82	36	1473
13	221	518	4294
14	227	111	1111
15	191	768	4669
16	159	84	3571
17	144	111	3218
18	449	80	2059

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9 Sizing the QA function using the method presented in this article assumes there is a semi-smooth flow of effort, and the requirement for QA is not sporadic.

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About the Author

Walt Lipke retired in 2005 as deputy chief of the Software Division at Tinker Air Force Base. He has over 35 years of experience in the development, maintenance, and management of software for automated testing of avionics. During his tenure, the division achieved several software process improvement milestones, including the coveted SEI/IEEE award for Software Process Achievement. Mr. Lipke has published several articles and presented at conferences, internationally, on the benefits of software process improvement and the application of earned value management and statistical methods to software projects. He is the creator of the technique *Earned Schedule*, which extracts schedule information from earned value data. Mr. Lipke is a graduate of the USA DoD course for Program Managers. He is a professional engineer with a master's degree in physics, and is a member of the physics honor society, Sigma Pi Sigma ($\Sigma\Pi\Sigma$). Lipke achieved distinguished academic honors with the selection to Phi Kappa Phi ($\Phi K\Phi$). During 2007, Mr. Lipke received the PMI Metrics Specific Interest Group Scholar Award. Also in 2007, he received the PMI Eric Jenett Award for Project Management Excellence for his leadership role and contribution to project management resulting from his creation of the Earned Schedule method. Mr. Lipke was recently selected for the 2010 Who's Who in the World. Contact Mr. Lipke at 1601 Pembroke Drive, Norman, OK 73072 or 405.364.1594.