# Assuring Quality Assurance [1]

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## 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 (in the distant past, from attending an Edwards Deming seminar), or
- Completely eradicated when perceived to be unneeded, or too expensive.

This article introduces quality efficiency indicators, which facilitate adequate sizing of the quality assurance 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.) The quality assurance sizing process presented is broadly applicable to various industries and processes. The method presented in this paper assumes there is a semi-smooth flow of performance effort, and the requirement for quality assurance is not sporadic.

## Introduction

After World War II the United States (U.S.) was the predominant industrial nation in the world. The U.S. produced. The world consumed. The quality of the U.S. products was of little concern; they would sell regardless. This economic position was held until about 1970 after which the market for U.S. products declined.

Beginning with the post-war reconstruction, Japan's business leaders learned and adopted manufacturing practices the U.S. utilized during and prior to WWII. Most notably, the Japanese were taught the methods of quality by W. Edwards Deming. As Deming had prophesied to

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Japan's leaders, economic growth came from their dedicated use of the techniques he had learned from Walter Shewhart at Bell laboratories.

During the 1980s Japan's automobile industry began to make noticeable inroads into the U.S. market. Their success was an alarming wake-up to U.S. manufacturers, who recognized that they truly had serious competition. Thus began the quality revolution in the United States.

No longer was quality perceived as an expendable portion of the production process and largely ignored. During this period, Deming videos and seminars were commonplace. Every industry was determined to improve their operation and business practices using the methods and practices of Dr. Deming. With pervasive emphasis, the methods of statistical process control and continuous improvement were taught to managers and workers alike.

The startling success of Japanese business, coupled to the loss of market share along with project failures in the U.S., created the impetus for dramatic change. The terminology describing this abrupt departure from present business practice and culture is "paradigm shift." These words have become commonplace and are integral to the jargon of those involved in process and quality improvement.

Out of the desperate desire to improve and the recognition of quality as the pathway came the creation of the Software Engineering Institute (SEI) in 1984. Possibly the most recognized contribution of the SEI to improving the software development process and product quality was the creation of the Capability Maturity Model (CMM) in 1991.

To heighten the emphasis for embracing the culture of quality, the U.S. government in 1987 created the national award for performance excellence, the *Malcolm Baldridge National Quality Award*. As well, to promote recognition for improving software development, the SEI along with the Institute of Electrical and Electronics Engineers (IEEE) created the *Software Process Achievement Award*.[2]

Today, it is apparent the culture of quality prevalent in the 1980s and 90s has diminished. The lack of concern for product and performance quality is observed in many areas. Below are recent news examples:

[2] The Software Process Achievement Award has since been renamed the Watts S. Humphrey Software Process Achievement Award to honor the significant influence Mr. Humphrey had on developing the CMM and its criteria for improving the software process.

- The reported delivery delays, lack of functionality and defects in a major weapon system's software, using the current standard, Agile, development process.

- The serious flaws in airplanes produced by a large significant company, known for quality in the past. Possibly the most disastrous of their quality failures was the door plug coming off in flight, creating a large hole on the side of the plane, thereby risking the safety of all on board. The company's frightening quality issues caused several airlines to ground a portion of their fleet. The grounding, in turn, seriously impacted travelers, and greatly reduced revenue for the airlines.

- An automobile manufacturer has become synonymous with what is termed problems with "fit," meaning the lack of consistency with the assembly of the body of the auto.

- A cellular network provider could not communicate with other networks due to a "software glitch", and a good portion of the country was without cellular service.

- In a major city, travel has been slowed to a crawl on the $2.3 billion addition to its public transportation system. Inspection revealed that segments of the train track were constructed with the gauge being too narrow. The correction is estimated to take more than one year, at a significant cost, and reduction of passenger service.

Commonly, the culprit for this regression in quality is management focusing attention on increasing profit in the near-term. This short-sightedness promotes poor practice, often stressing increase in rate of production and disregarding worker safety. Ultimately the rework created by the production process is ignored by all involved …*until its expense and loss of market is recognized.*

Another observation is the organizations striving to improve their quality no longer receive the national attention and recognition for receiving the Watts Humphrey or the Malcolm Baldridge awards. With diminished attention, the business advantage of winning the award is lost. I do not have data; however, I suspect the competition for these awards has significantly declined.

In contrast to the above bleak description of the current state of quality, the following is a positive story. After a decade of performing process improvement, rework for software development projects, performed by the organization I once managed, was dramatically reduced from approximately 75 percent of the total effort to a very low value of 3 percent.

Along with other improved performance attributes, this achievement resulted in receiving the 1999 SEI/IEEE Software Process Achievement Award.

During this period of improvement, it was observed that when the percentage was high, rework was easily identified; for a small amount of quality assurance effort, a large quantity of rework was generated. As our production process improved, it became increasingly more difficult to identify defects. When the amount of rework was reduced to 3 percent, we began to examine the economics of further improvement and the possibility of reducing the quality assurance effort. From the economics view came the concept of "right sizing" the quality assurance function with respect to the needs of the customer(s) or the quality goals of the producer organization. The remainder of this paper develops the method for appropriately sizing the QA function.

## Background

Generally speaking, companies are concerned with the quality of their products. Because of the desire for quality products an entity exists that is devoted to performing reviews, inspections, and testing for conformity to the product requirements; i.e., the quality assurance (QA) function. There are many reasons for the necessity of the QA function, such as company/product reputation, safety of product use, expense of product recall, etc. Even so, with all of the reasons, 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 quality assurance function is connected to economic benefit.

The QA function, oftentimes, is performed by an organization, separated and independent from the production process. However, my preferred implementation is having the function integrated into the production process. In this instance, QA is performed at the task hand-offs. The recipient of the output from the preceding task determines the adequacy for their subsequent task. In the event of discovery of defects, the performer for the preceding task has the responsibility to make corrections. Regardless of the method of QA implementation, the effort must be recorded for identifying defects and the subsequent rework.

As a minimum, quality assurance (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 marketplace has impact on the product price. In turn, this places a constraint on the amount of rework and quality assurance 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 quality assurance; 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, for instances of new product development, customers can mitigate their risk of accepting poor products by testing performance and inspecting physical details during the development and production process prior to receiving 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.

As just discussed, 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 which propagate, or leak, through his production and QA processes.

The point is, quality does cost and impact all involved with the product: the producer, the quality assurance function, and the customer.

## Quality Process Indicators

Minimizing the expenditure for quality assurance 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 discussion to follow, 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 any time 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 below, where f(…) indicates a function of the variables listed within the parentheses:

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 quality assurance processes. Also, the producer needs to have information concerning the efficiency of the quality assurance process itself. By having the 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 below:

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

The indicator is a measure of the efficiency 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. Note that rework can come from the customer, when good requirements management is not practiced.

2) $QE_2 = P / T$
where P = production costs
T = P + R + Q = total effort
Q = quality assurance 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.

3) $QE_3 = R(process) / Q$

The indicator is a measure of efficiency of the production and quality assurance 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 quality assurance process requires review for improvement, or possibly, reduction when R(process) is trending toward zero.

## Analysis

Satisfactory quality assurance is indicated when all three indicators approach the value of 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 percent of the total effort [Crosby].[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

[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 quality assurance and rework to achieve the product requirements.

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 quality assurance processes.[4]

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 percent 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 quality assurance process minimizes or eliminates the propagation of defects to the customer, and the production process has been optimized such that rework and quality assurance are minimized [Paulk, et al]. $QE_1$ 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 quality assurance 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 and periodic values.[5] 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?"

## Adequate Sizing of Quality Function

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 production need of the QA function can be determined. Likewise, the size of the QA function can be initially planned for a new project using the data from a historical project, as long as the production and quality processes are, for the most part, unchanged. A Statistical Process Control (SPC) Control Chart of

[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.
[5] Periodic values for the indicators come from the parameter measures for the period in which they occurred. The sum of the periodic measures from 1 through the $n^{th}$ period determine the cumulative values at period n. For example, the cumulative for $QE_2$ at period n would use the total values for P and T.

the periodic observations of $QE_3$ is used to determine if the quality and rework processes are in control [Pitt].[6] The control chart may also be used as a "Run" chart for detecting the process reaction to improvements implemented [Pitt].

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 determining $QE_3$ are statistically in control.

Upon achieving statistical control, the QA function is sized from the periodic observations of Q/P; i.e., the quality investment as a fraction of production effort. From the average of these observations and their statistical variation a 95 percent confidence value can be calculated for Q/P. Before going further, let's discuss in more detail, the term "confidence value." The term implies an application of statistics, which will now be introduced.

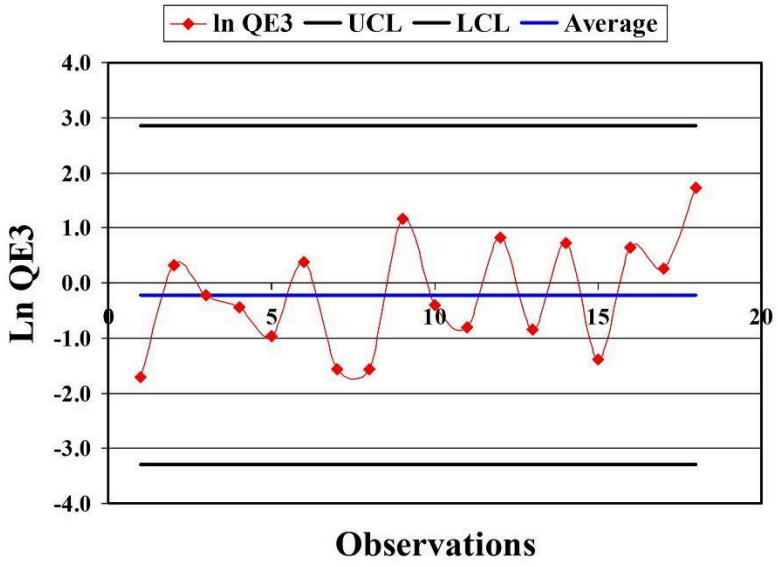


**Figure 1. SPC Control Chart**

The confidence interval is the region surrounding the computed average value within which the true value lies with a specified level of confidence, given as a percentage [Crowe, et al]. The end points of the interval are the confidence limits. The equation for the confidence limits (CL) is:

[6] It is recommended to use the logarithm values of the periodic observations of $QE_3$ and Q/P. 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 [Pitt].

$$CL = \langle x \rangle \pm z\,(\sigma/\sqrt{n})$$

where <x> is the average of the recorded values for the attribute, while z is from the standard unit normal distribution and corresponds to the area selected. For this application, z = 1.645 at 95 percent of the distribution area. The symbol σ is the estimate of the standard deviation of the observations of x, and n is the number of observations.

At 95 percent confidence, there is a 95 percent probability the actual QA requirement will be less than the size of the function created. Sizing QA at 95 percent confidence mitigates the risk of not sizing the quality assurance function adequately.

The 95 percent confidence we are seeking is the upper confidence limit of the 90 percent confidence interval; 10 percent of the normal distribution is outside of the confidence interval, 5 percent below the lower confidence limit and 5 percent above the upper limit. Creating the QA requirement below the lower confidence limit is not a consideration; therefore, only the upper limit is used.

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

**Table 1. Rp, Q, P Data**

The 95 percent confidence limit, $(Q/P)_u$, is used in a linear relationship between the production effort cost and the size of the QA function; i.e., $Q = (Q/P)_u \times P$, where Q is the expected cost for quality assurance. This relationship is to be used with the project plan, specifically the periodic (usually weekly or monthly) expenditures for production effort, to adequately size the

application of QA resources. Performing the computations for the periodic 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 percent confidence limit, the periodic observations of Q and P are used to make the statistical calculations. The standard deviation (σ) is estimated from the natural logarithm (ln) of the periodic values of the ratio, $(Q/P)_i$, while using the logarithm of the cumulative value, $(Q/P)_c$, as the estimate for the average value. The equation is shown below:

$$\sigma = [\sum (\ln (Q/P)_i - \ln (Q/P)_c)^2 / (n - 1)]^{1/2}$$

where n is the number of observations
i indicates a specific observation
$\sum$ sums the difference in parentheses from i = 1 to n

Therefore, the confidence limit is first computed as a logarithm. Thus, the equation for the calculation of the 95 percent confidence limit is:

$(Q/P)_u$ = antilog [ln $(Q/P)_c$ + upper half of the 90% confidence interval]

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

Using the project data from Table 1, the cumulative value of Q/P is 0.0629; thus, the ln $(Q/P)_c$ is computed to equal -2.7659. The variation of the periodic values, ln $(Q/P)_i$, yields the estimate of the standard deviation, σ = 0.5527. From the values for z (=1.645), σ, and n (18), the one-half value for the 90% confidence interval is calculated to be 0.2143. Adding ln$(Q/P)_c$ and the 90% confidence interval portion yields the value -2.5516. The desired ratio, $(Q/P)_u$, is then computed from the antilog of the sum, and is determined to be 0.0780. For this example, the appropriate size for the QA function is computed to be 7.80 percent of the production effort. An additional 1.51 percent above the average value assures sufficiency of the QA function by accounting for the variation in the performance data.

## Evaluating the Quality System

From evaluation of the data recorded for identification of defects, rework, and production effort, the status of the quality system can be understood. In the author's opinion very good quality for software producers would be $QE_1 \geq 0.98$, $QE_2 > 0.85$, $QE_3$ between 0.6 and 1.2, with the indicator of quality investment, QI = (Q+R)/P < 0.09. Whereas, excellent quality is characterized by $QE_1 = 1.0$, $QE_2 > 0.9$, and $QE_3$ between 0.2 and 0.8, with QI < 0.06.

Of course, the numbers above are not proven. As well, the descriptors of good and excellent may be different for industries other than software. To establish industry standards requires extensive application of the methods proposed along with analysis of the data collected. Although this effort requires considerable coordination and agreement, it is envisioned that having quality standards will create increased interest in the production of excellent products to the benefit of all.[7]

## Summary

To economically apply quality assurance requires three indicators of quality efficiency. Two indicators are measures of defect leakage to the customer and from the production process, while the third measures the efficiency of identifying defects. Upon achieving the "in control" process of the $QE_3$ indicator, the quality assurance function can be sized commensurately with the customer need, or the producer's quality goals. The indicators are useful for improving the production and quality assurance processes and for evaluating the status of the quality system.

## Final Thoughts

The purpose of the article is to promote the need for quality and, more importantly, to reduce rework. Furthermore, it is intended to enhance management attention given to the QA function. By applying the methods presented, the quality function can be stabilized, avoiding the significant increases after costly product failures and recalls, and, conversely, the major layoffs when "things are going well."

To achieve this vision, the recognition of companies having superior quality must be revived, nationally and internationally, as well. Recognition creates incentive and, importantly, business advantage. Additionally, it provides the impetus to institutionalize quality in the company.

## References:

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Paulk, M., B. Curtis, M. B. Chrissis and C. V. Weber, *Capability Maturity Model for Software, Version 1.1*, Software Engineering Institute, CMU/SEI-93-TR-24, February 1993.

[7] My hope is that a well-established, recognized, organization, such as the National Institute of Standards, or the International Standards Organization, will take on this effort.

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## About the Author

**Walt Lipke**

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**Walt Lipke** retired from federal service with over 35 years of experience in the development, maintenance, and management of software for automated testing of avionics. As a manager, a career highlight was his organization's winning of the Software Engineering Institute / Institute of Electrical and Electronics Engineers award for Software Process Achievement. 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 (ΣΠΣ). Lipke achieved distinguished academic honors with the selection to Phi Kappa Phi (ΦΚΦ).

He is the creator of Earned Schedule (ES). Mr. Lipke has published over ninety articles on the method, two books, *Earned Schedule* and *Earned Schedule Plus*, and a free on-line Earned Schedule Master Class. Additionally, he has presented research on ES and its schedule performance analysis methods at several conferences in the United States, and internationally.

For his contribution to project control, the practice of EVM, and the creation of ES, Mr. Lipke has received several awards: 2007 Project Management Institute Metrics Specific Interest Group Scholar Award; 2007 Project Management Institute Eric Jenett Award for Project Management Excellence; 2013 Earned Value Management Europe Award; 2014 College of Performance Management Driessnack Distinguished Service Award; In 2017, the Australian Project

Governance and Control Symposium honored Mr. Lipke by establishing the annual Walt Lipke Project Governance and Control Excellence Award. The award is made for excellence in research, expanding knowledge of the management and governance of projects, programs, and portfolios in Australasia.