PROCESS CAPABILITY AND PERFORMANCE IMPROVEMENT

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A process with a wide number of variations cannot be fully capable of meeting a customer's requirements. Less variation provides greater predictability in the process and allows service providers to make reliable forecasts, meet schedules for customers' requests, and produce less waste and rework. One statistical tool that can help to determine how the process performs relative to its requirements is the Process Capability Analysis (PCA). The PCA measures the inherent variability of a given characteristic and compares the actual variation in the process to its allowed variation limits (a customer's requirements). The current empirical research includes details about the PCA's underlying concepts and procedure in a Request For Information (RFI) process. The research reveals that merely increasing a customer's requirements without reducing a process's possible variations is not a substantial solution to problems with process performance. The results, which provide a baseline of current operations and a benchmark for use when designing new processes, will help process designers evaluate and predict the performance of those processes.

Keywords: information management, process capability, request for information, statistical analysis, time.

INTRODUCTION

The ultimate goal of any process improvement effort is to make incremental improvements, striving towards perfection across the organisation. The goal of improving organisational performance is to ensure that the organisation designs its processes well and systematically monitors, analyses, and improves its performance to improve customer satisfaction. However, it is obvious that perfection can only be realised if there is no variation from the expected outcome of a process (George 2002; George 2003; George *et al.* 2005). Less variation will provide greater predictability in the process, allowing people to make reliable forecasts, meet schedules for customers' requests, and produce less waste and rework. It will also lower operational costs and provide products and services that perform better and last longer, consequently improving organisational performance and resulting in happier customers (Rath and Strong Inc. 2003).

Variation represents the difference between an ideal outcome and the actual situation. An ideal is a standard of perfection that one can strive for but never achieve and that is determined by customers (Clark 1998). After a new system has been designed and operated for a while and indications are that it is achieving an initial target for improvement, the system should be assessed to ensure that it is capable of satisfying customer requirements. Based on the results of the assessment, needed improvements

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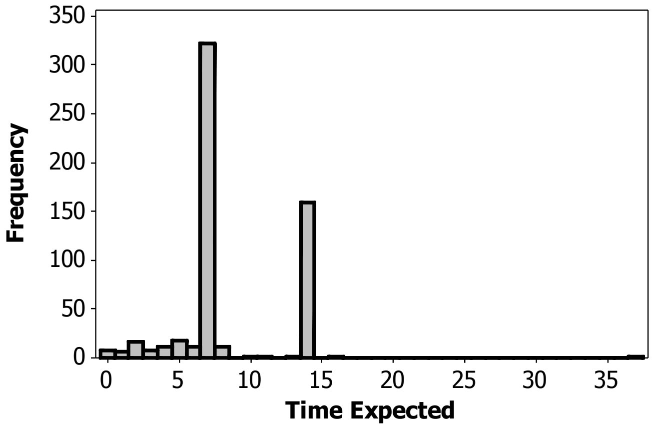
can be identified, and these improvements can be made in the pursuit of perfection. There is no absolute level of perfection but there are just incremental steps towards perfection, because the future state targeted will become the current state for subsequent continuous improvement, and the current state of a system becomes the baseline for further improvement (Crabill *et al.* 2000).

The Request For Information (RFI) is one of the important tools that is used in the construction industry to create information flow and reduce risk, and it is triggered only by a contractor's request. Responses to RFIs should be completed by or before the time the contractor specified that the response was needed. The Architect/Engineering (A/E) firms (reviewers of RFIs) usually do not provide "Promised Due Dates" for each RFI. Instead, the contractor puts the expected response time on each RFI. Hence, discrepancies between "Contractor-Expected Times" and "Actual Lead Times" occur and create gaps between the contractor's and the reviewer's requirements. The author conducted observations on RFI processing from several projects in different regions in the United States. The individual project selected for this research involves an eight-story college laboratory building located in California in the United States. The data set for the research consists of 574 RFIs gathered for a 234-day period, an average of 2.5 RFIs per day. It is interesting to note that the dates when the contractor expected to receive the responses from the designer ("Time Expected") fell mostly into two time periods, i.e., 7 days or 14 days. Figure 1 displays the frequency of each "Time Expected."



Time	Count	CumCnt	Percent	CumPct
	7	7	1.22	1.22
1	6	13	1.05	2.26
2	16	29	2.79	5.05
3	8	37	1.39	6.45
4	11	48	1.92	8.36
5	18	66	3.14	11.50
6	11	77	1.92	13.41
7	**322**	**399**	**56.10**	**69.51**
8	11	410	1.92	71.43
10	1	411	0.17	71.60
11	1	412	0.17	71.78
13	1	413	0.17	71.95
14	**159**	**572**	**27.70**	**99.65**
16	1	573	0.17	99.83
37	1	574	0.17	100.00
N=	574			

Figure 2: Histogram of "Time Expected"

The following descriptive statistical values show that the mean actual response time is longer than that of contractor's "Time Expected" and the variation of actual response time is considerably high.

Variable	Total Count	Mean	StDev	Minimum	Maximum
Time Expected	574	8.572	3.885	0.500	37.000
Actual Response Time	574	11.954	11.598	0.500	93.000

It is important to know that customer satisfaction involves not only the average delivery time but also the difference between the actual and the expected elapsed time for the customer to receive products or services (Muir 2006). Even if the average of delivery times were constant, customers are not satisfied with products or services provided if the delivery times are not predictable (i.e., greatly varied). In the RFI review system, a contractor wants to receive responses to RFIs on-time, which often means quickly. The service level of the products or services that are produced or provided in response to a customer's requests can be measured as the percentage of orders that are filled on or before the time when the customer wants to receive services or products (Hill 2007). Table 1 shows the corresponding service levels for each "Time Expected." The results indicate that the average service level is just about 48% (i.e., about 48% of responses are made on or before the time when the customer wants to receive responses).

Table 6: Service level of different values of "Time Expected"

Time Expected (days)	0	1	2	3	4	5	6	7	8	10	11	13	14	16	37	Total
# of on time	2	2	6	6	3	8	4	143	5	1	1	0	92	0	1	274
# of delay	5	4	10	2	8	10	7	179	6	0	0	1	67	1	0	300
Total # of RFIs	7	6	16	8	11	18	11	322	11	1	1	1	159	1	1	574
Service Level (%)	29	33	38	75	27	44	36	44	45	100	100	0	58	0	100	48

Figure 2 shows the ranges of actual response times corresponding to each "Time Expected," indicating that actual response times for various values of "Time Expected" vary significantly. For example, the actual response times corresponding to a "Time Expected" of 7 days range from 1 day to 93 days. This is because the determination of "Time Expected" is not based on knowledge about what a reasonable response time should be, but on the contractor's on-demand expectation.

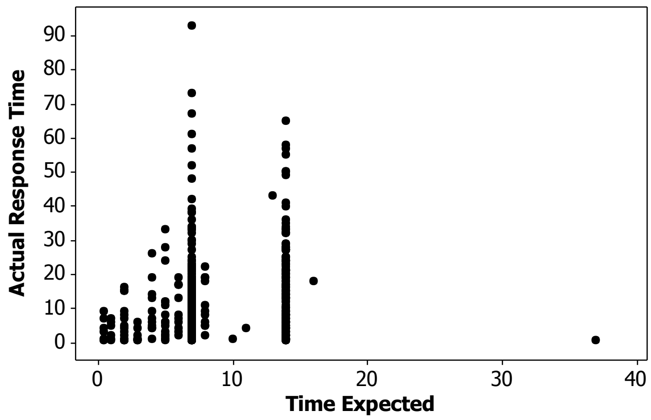


Figure 3: Time Expected vs. Actual Response Time

WHAT DOES PROCESS CAPABILITY ANALYSIS DO?

Process capability analysis measures the uniformity of the process (Montgomery 2005). There are many different metrics to measure process capability. One of them is Process Capacity Indices (PCI), which are the dimensionless numbers computed by comparing the actual variation in a process (Voice of the Process, VOP) to its allowed variation limits (Voice of the Customer, VOC). The VOC is reflected in the process specifications, while the VOP is reflected in the control limits. Process capability analysis entails estimating process capability in the form of a probability distribution. One of outcomes derived from a process capability study is the determination of Sigma Quality Level (SQL). A system with six-SQL represents near perfection because the system yields only 3.4 defects per million. Hence, the scrutiny of the distribution of VOP relating to the specification limits (VOC) will explain whether the process can meet the customer's expectations. Figure 3 shows two different process behaviours. The upper one is the case of a process being partly capable, because some proportion of outputs (both tails) fall outside the specification limits (VOC), while the lower one is the case of a process being fully capable because none of the outputs (neither tail) falls outside the specification limits. In the RFI process, VOC corresponds to the response times expected by the contractor ("Time Expected") and VOP corresponds to a range of actual response times. When a particular VOC is required, the control limits derived from natural variation of the process will decide whether the process can meet VOC by comparing VOP with VOC.

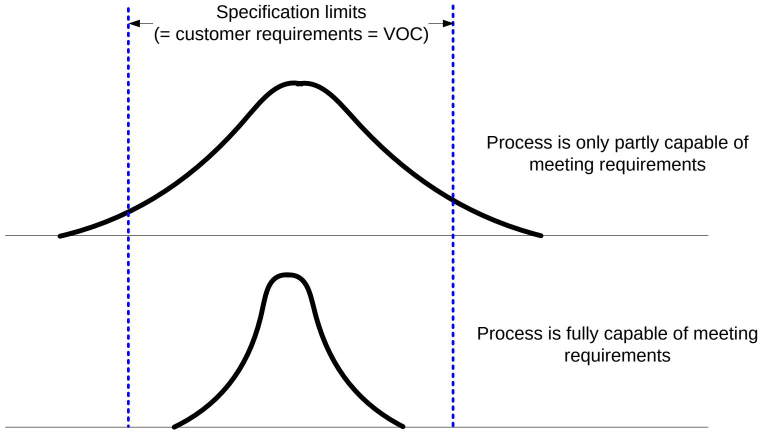


Figure 4: Process in Partly Capable vs. Fully Capable

DETERMINING STABILITY AND ESTIMATING CONTROL LIMITS

One of the prerequisites of PCA is to determine the stability of the process. If the data contain special cause variations, the result of PCA will not predict the actual capability of the process (Pyzdek 2003; Stapenhurt 2005; Taylor 2005). An individual chart, i.e., one of the Statistical Process Control (SPC) charts, was plotted in order to see whether the special causes exist in the data set.

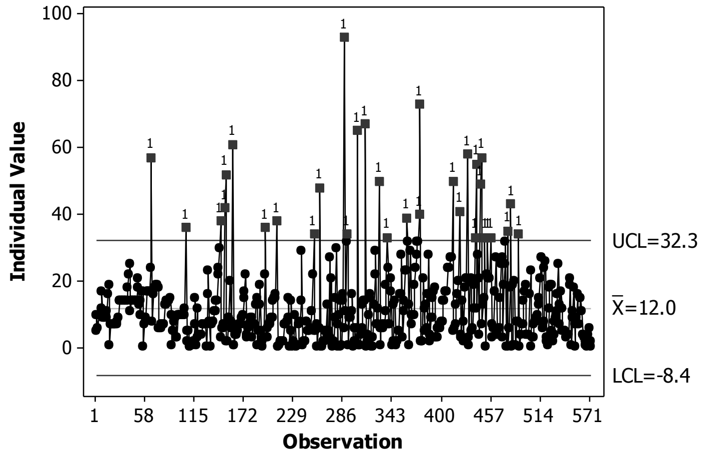


Figure 5: Individual chart of actual RFI response times

There are 32 out-of-control points in the chart shown in Figure 4, indicating that special causes are present. Note that LCL indicates the Lower Control Limit, which implies μw - Lσw, where μw is the mean of a sample statistic w, σw is the standard deviation of a sample statistic w, and L is the distance of the control limits from the centre line (mean), expressed in standard deviation units (Montgomery 2005). In addition, looking closer at the chart, it can be seen that the LCL is a negative value (-

8.4 days). Since we are studying RFI response time, results that are less than zero make no sense. However, the central limit theorem explains that, if we take many subgroups of data from a population at random and plot their average, the average will be approximately normally distributed regardless of the type of population distribution (Montgomery 2005; Pyzdek 2003). Thus, subgroups of 20 are created and tested about the normality of their averages. Figure 5 indicates that the subgroup averages are normally distributed. The p-value of 0.18 (greater than 0.05) supports this normality (Minitab Inc. 2004).

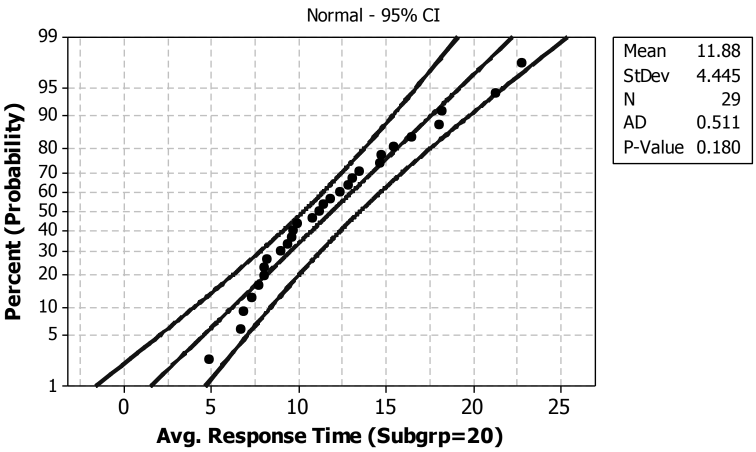


Figure 6: Probability Plot of Average Response Time (Subgroup of size 20)

Once the normality of the subgroup average is determined, we can estimate the control limits for the process capability analysis by plotting the average RFI process times of subgroup 20. Figure 6 shows that the process is in statistical control (i.e., no points outside control limits) with the LCL adjusted above zero at 0.73 days and UCL adjusted at 23.04 days. These results indicate that the process is operating in the range of 0.73 to 23.04 days.

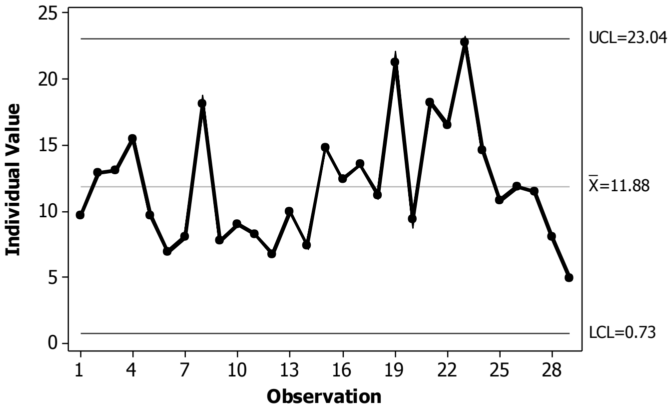


Figure 7: I-Chart of RFI response times (subgroup of size 20)

IDENTIFYING TYPE OF DISTRIBUTION

The next step is to identify the type of distribution of the process. Another prerequisite for the process capability analysis is to find the optimal distribution for the data. This is essential because inferences about process capability drawn from plots with sub-optimal data distributions may lead to serious errors (Pyzdek 2003). For this research, to determine if the process is normally distributed, the normality test was conducted using MINITAB. The results (Figure 7) show that the data are not close to falling on the straight line, and the P-value of less than 0.005 given the 95% confidence interval confirms that the data are not normally distributed.

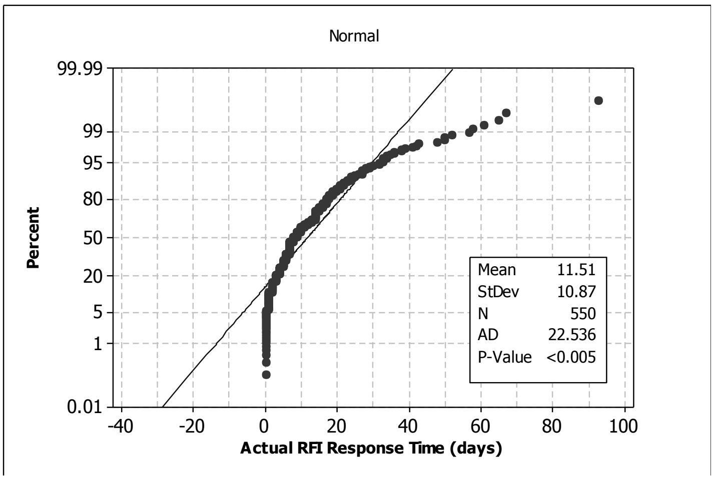


Figure 8: Normal probability plot of actual RFI response times

Once it was determined that the data are not normally distributed, the Goodness of Fit Test was conducted in order to find the best fitting distribution. The Weilbull was selected as the best fitting distribution because the AD (Anderson-Darling) statistic of Weibull is the smallest number, even though the corresponding P-value is less than 0.01. The Anderson-Darling statistic is a measure of how far the plotted points fall from the best-fitting line in a probability plot. A smaller Anderson-Darling statistical value indicates that the distribution fits the data better (Minitab Inc. 2004; Ryan *et al.* 2005).

Goodness of Fit Test

Distribution	AD	P	LRT P
Normal	26.125	<0.005	
Lognormal	10.155	<0.005	
3-Parameter Lognormal	3.549	*	0.000
Exponential	3.565	<0.003	
2-Parameter Exponential	5.921	<0.010	0.000
Weibull	**2.053**	**<0.010**	
3-Parameter Weibull	10.423	<0.005	0.000
Smallest Extreme Value	69.166	<0.010	
Largest Extreme Value	6.768	<0.010	
Gamma	2.079	<0.005	
3-Parameter Gamma	11.149	*	0.000
Logistic	14.026	<0.005	
Loglogistic	7.051	<0.005	
3-Parameter Loglogistic	4.544	*	0.025

DETERMINING PROCESS CAPABILITY

In PCA, we can predict short-term and long-term process capability by calculating two major groups of indices, i.e., process capability indices (Cp and Cpk) and process performance indices (Pp and Ppk) when the process data are normally distributed (Table 2). However, in cases in which the data are not normally distributed, it is not meaningful to obtain the process capability indices, because Cp and Cpk are based on short-term variation (Pyzdek 2003). The RFI data are not normally distributed, so the process performance indices are used to determine the current process capability level.

Table 7: Process Capability Index and Process Performance Index (Brooke 2006; George et al. 2005; Montgomery 2005; Pyzdek 2003)

Category	Index	Description
Process Capability Index	C_p	Reflects the POTENTIAL capability of the process assuming that the histogram is positioned centrally within the specification limits (VOC). $\frac{\text{Voice of the Customer}}{\text{Voice of the Process}} = \frac{\text{Width of the Specification}}{\text{Width of the the Histogram}} = \frac{\text{USL-LSL}}{6\sigma}$
	C_{pk}	Reflects the ACTUAL capability of the process by measuring the same ratio as the C_p, but only to the nearest specification limits, since this is the limit which is most likely to be failed. $\frac{\text{Nearest Voice of the Customer}}{\text{Voice of the Process}} = \frac{\text{Nearest Spec. - Process Average}}{3\sigma}$
Process Performance Index	P_p	Analogous to the C_p and C_{pk} indices but calculated using the overall (long term) standard deviation.
	P_{pk}	

The first PCA (Figure 8) is conducted for a VOC of 14 days, i.e., the contractor wants to receive the responses within 14 days, which accounts for 99.65% (572 out of 574) of total “Time Expected.” The result of PCA indicates that the process is not capable of meeting this expectation (Ppk < 1). The estimated long-term performance of the process is 317,701 PPM (31.7%), and the sigma quality level of the process is 1.97. The observed performance is 289,199 PPM (28.9%), which is slightly better than that of the estimated (317,701, 31.8%). and the difference is a reflection of lack of fit. The sigma quality level of the process is 1.97. The Sigma Quality Level (SQL) can be computed by adding 1.5 to Z.Bench, i.e., in this case, 0.47+1.5 = 1.97 (Minitab Inc. 2004).

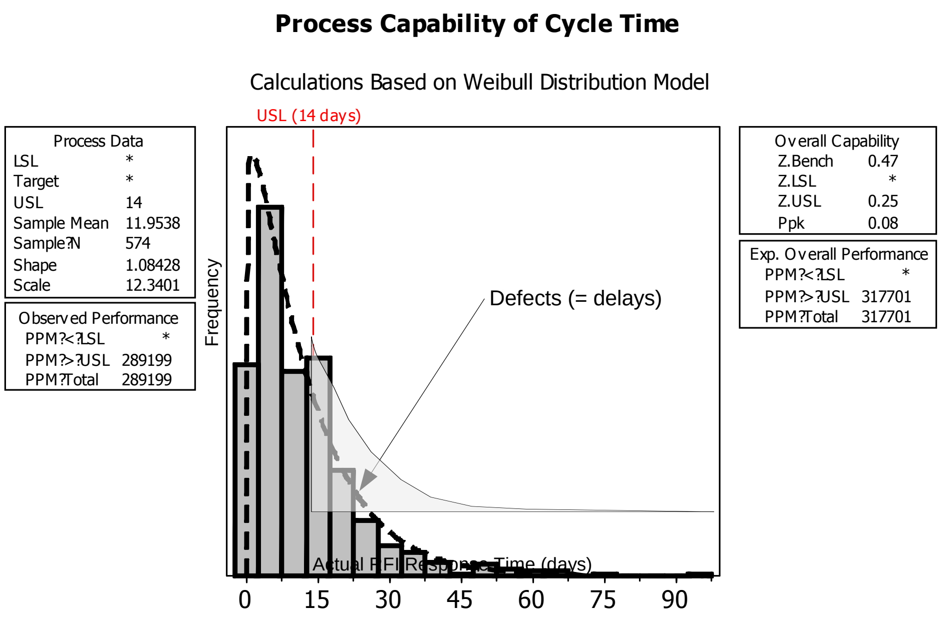


Figure 9: Process Capability of Actual RFI Response Times (VOC =14 days)

The second PCA (Figure 9) was conducted for a VOC of 21 days – i.e. the contractor wants to receive the responses within 21 days (3 weeks), which is nearly close to the process upper control limit estimated (23.04 days). The result of PCA indicates that the process is still not capable (Ppk < 1) and the estimated long term performance of the process is 168,679 PPM (16.9%) and the SQL is 2.46.

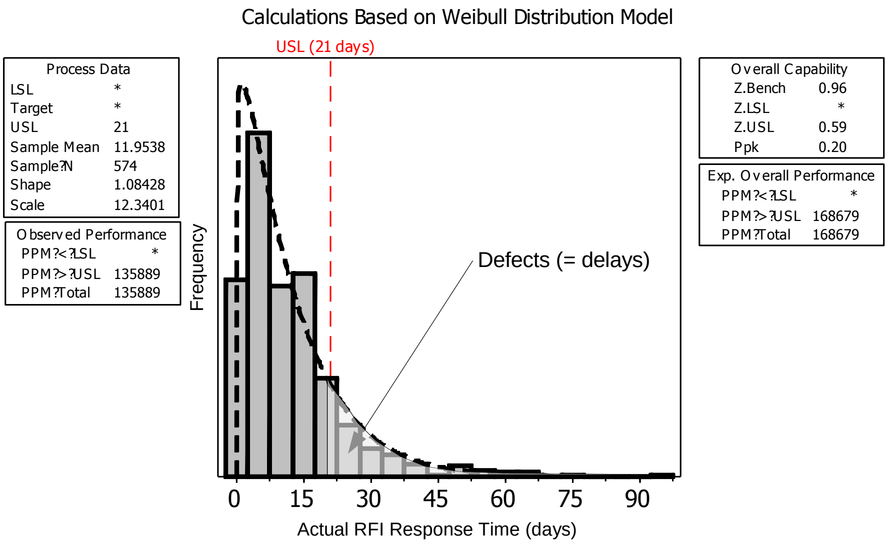


Figure 10: Process Capability of Actual RFI Response Times (VOC = 21 days)

What if the contactor wants a six sigma (3.4 defects per million - here defects are synonymous with delays in the RFI process) service level, which is equivalent to Z,Bench of 4.5 (i.e., 4.5+1.5 = 6.0 Sigma quality level) in the current RFI process? By a trial-and-error procedure, we can find the USL at around 127.5 days. The result shown in Figure 10 indicates that the contractor should prepare RFIs 127.5 days before they are actually needed so as to achieve six-sigma level quality performance if the process is being operated as it is without changes.

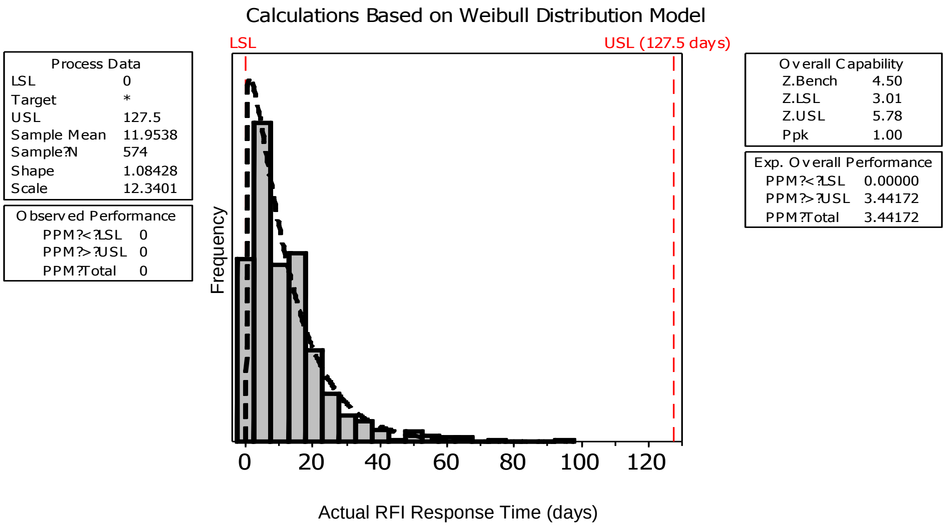


Figure 11: Required RFI Response Times if the process is capable at Six-Sigma level

CONCLUSIONS

Throughout the research, the author explored the opportunity and usefulness of process capability analysis for process performance improvement. The outcome of the study reveals that the current RFI process generates a wide range of variation in the review times, so that the process is not fully capable of meeting the customer’s (contractor’s) requirements. As a result, the service level becomes too low. We can think of two different strategies in order to increase the service level, i.e., 1) increase the contractor's expected time or 2) reduce the average process time and its variation. However, as discussed, merely increasing the customer’s expectation, i.e., longer "Time Expected," would not be a substantial solution, because the system has a natural tendency to generate a wide range of variation. Hence, there is only one viable solution for increasing service level, i.e., reducing the average process time and variation. The results from the study can be used to establish a baseline and an internal benchmark for setting up the target for improvement. Particularly, process capability indices introduced in the paper will provide those using the system with a common metric for the current state of the system and will help them evaluate and predict the performance of processes. Both contractors and A/E firms can employ this metric as a monitoring function for the performance of their current systems and as a performance and a process re-design tool for further improvement.

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