APPROXIMATING THE PROCESS CYCLE EFFICIENCY OF NON-PHYSICAL PRODUCTION SYSTEMS

Chang-Sun Chin[1]

ABSTRACT

The Process Cycle Efficiency (PCE), an important Lean Production metric, is the ratio of value-added time to total time required for producers to deliver goods or services to the customers and explains how quickly systems can respond to customer demands. The larger the PCE value, the leaner the system because the system has less non-value-added time. However, calculating the PCE of a non-physical production system, such as a transaction or service (e.g., RFI review and submittal processes), is problematic because measuring the value-added time requires process owners to record their pure execution times, that is, only the time used for value creation, and people tend to be fearful of the possibility that such data will be used for individual performance evaluation. However, we can approximate the PCE using the number of jobs processed quickly versus the total number of jobs processed for a given time period. Our hypothesis is that the approximation of PCE using this process is accurate. The research uses the RFI review process to demonstrate how to approximate the PCE using statistical concepts and methods and tests the hypothesis by comparing the actual PCE with the approximated PCE of engineers' RFI review process. The proposed method of PCE approximation provides a good performance indicator with which to evaluate process efficiency without imposing psychological discomfort on process owners and with which to set targets for improvement.

KEYWORDS

Process cycle efficiency, Request for information, Non-value added time, Value-added time.

CURRENT REQUEST FOR INFORMATION PROCESS

One of the essential tools available for reducing risk in the US construction industry is the Request For Information (RFI), a formal question or clarification that is submitted to the Architect/Engineering (A/E) firm by the contractor regarding details in the plans, drawings or specifications. Any delay in the reviewer's (A/E/ firm) response to an RFI can result in the contractor's delay and a delay in the project as a whole. Despite the importance of expedient RFI processing, its function and significance are underestimated in current practice. The RFI process requires information transfer and processing among many members of a project team (i.e., subcontractor, contractor, architect and consultant engineer) and is a standard requirement of the American Institute of Architects (AIA) contracts that govern most projects in the United States. According to the AIA, "before starting each portion of the Work, the Contractor shall carefully study and compare the various Drawings and other Contract Documents relative to that portion of the Work, as well as the information furnished by the Owner.... These obligations are for the purpose of facilitating construction by the Contractor and are not for the purpose of discovering error, omissions, or

[1] Ph.D., A.M.ASCE, Kevinchin255@yahoo.com

inconsistencies in the Contract Documents; however, any errors, inconsistencies or omissions discovered by the Contractor shall be reported promptly to the Architect as a Request for Information in such form as the Architect may require" (AIA 1987). However, it is a common practice for contractors to use the RFI process in a more limited way as a means of discovering design defects and pursuing a claim strategy (Zack 1999) that asserts that the project was not fully designed.

The project selected for this research is an eight-story college laboratory building located in California in the United States. The data set for the research consists of 574 RFIs gathered over a 234-day period. The project team used the conventional paper-based document transmission methods, such as UPS and Fedex. Data were available only at the sign in/off dates. The contractor stamps "Date Created" and "Date Answered" on each RFI when they are created and when the responses are received by contractors. As such, these were the only data points available to be tracked. Figure 1 represents the RFI review process flow and available data points.

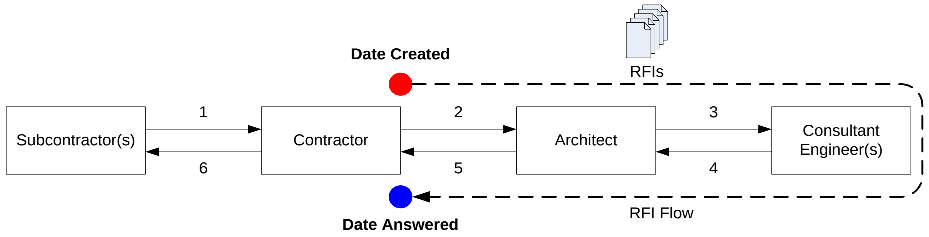

Figure 1: RFI Review Flow Diagram and Available Data Points (Chin 2009; Chin and Russell 2008)

PROCESS CYCLE EFFICIENCY (PCE)

The PCE, an important Lean Production metric, is the ratio of value-added time to total time required for producers to deliver goods or services to the customers. The PCE indicates how efficiently the process is converting work-in-process into exits/completions (George et al. 2005; Hopp and Spearman 2000). George (2002) argued that PCEs of less than 10% are common pre-improvements. Most processes—manufacturing, order entry, product development, accounting—run at a cycle efficiency of less than 10%. PCE varies by application, but an average of 25% is world class (see Table 1).

Table 1: Typical and World Class PCEs (George 2002)

Application	Typical PCE	World Class PCE
Machining	1%	20%
Fabrication	10%	25%
Assembly	15%	35%
Continuous Manufacturing	30%	80%
Business Process – Transactional	10%	50%
Business Process – Creative/Cognitive	5%	25%

Calculating the PCE in a manufacturing environment is straightforward because the start and end times of each activity are mostly automatically measured by the computerized system and clearly distinguish non-value-added time (wastes) from value-added time. However, calculating the PCE of a non-physical production system, such as a transaction or service (e.g., RFI review and submittal processes), is problematic because measuring the value-added time requires process owners to record their pure execution times, that is, only the time used for value creation, and people tend to be fearful of the possibility that data will be used for individual performance evaluation.

APPROXIMATING PROCESS CYCLE EFFICIENCY

Because of the limited data available, the research includes only the steps from RFI preparation to response receipt (Figure 2). Lead time is the total time a customer must wait to receive a product after placing an order (Hopp and Spearman 2000), so the lead time of the RFI review is the elapsed time between the date the RFI is created and the date the RFI is answered. The average total lead time required for RFI review is approximately 12 days, from RFI preparation to response receipt, and the engineering review time is a much larger part of that lead time than are other steps (Figure 2).

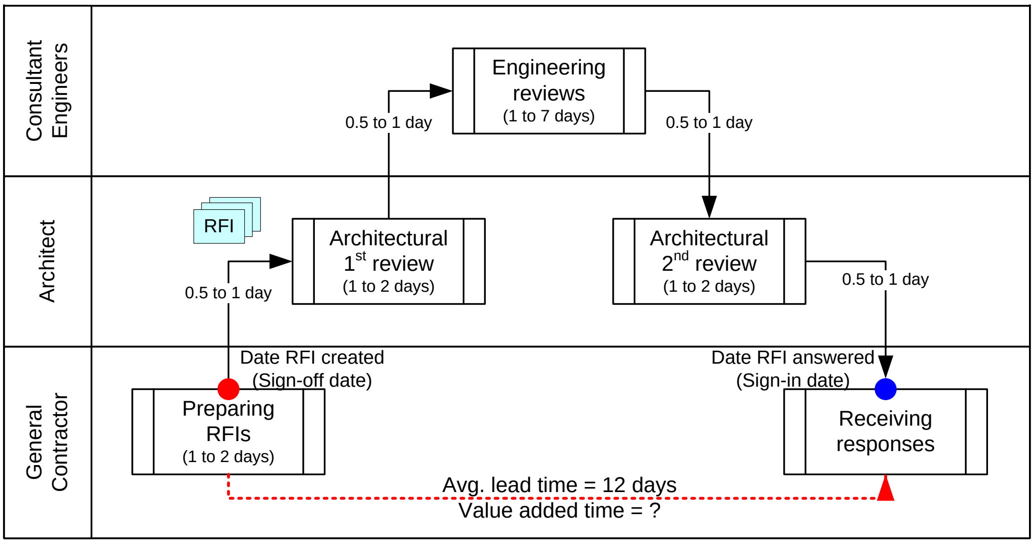

Figure 2: RFI Review Process Flow

The descriptive statistics of lead time measured are summarized in Table 2.

Table 2: Descriptive Statistics of Lead Time Measured

Variable	Total Count	Mean	StdDev	Min	Median	Max
Lead Time (days)	574	11.95	11.60	0.50	9.00	93.00

Using the individual distribution identification from Minitab, the Goodness of Fit Test was conducted to find the best fitting distribution; the Weilbull was selected because its AD (Anderson-Darling) statistic is the smallest number, even though the corresponding P-value is less than 0.01 (see Table 3). The Anderson-Darling statistic is a measure of how far the plotted points fall from the best-fitting line in a probability plot, so a smaller Anderson-Darling statistical value indicates that the distribution fits the data better (Minitab Inc. 2004; Ryan et al. 2005).

Table 3: 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

The probability plot in Figure 3 shows that the lead time has two distinct dependent components. The dotted lines extrapolate the two lead time components to an intersection in order to identify which RFIs are classified as belonging to the fast process (left side) and which are classified as belonging to the slow process (right side). We designate one day as the cutoff between fast and slow process times.

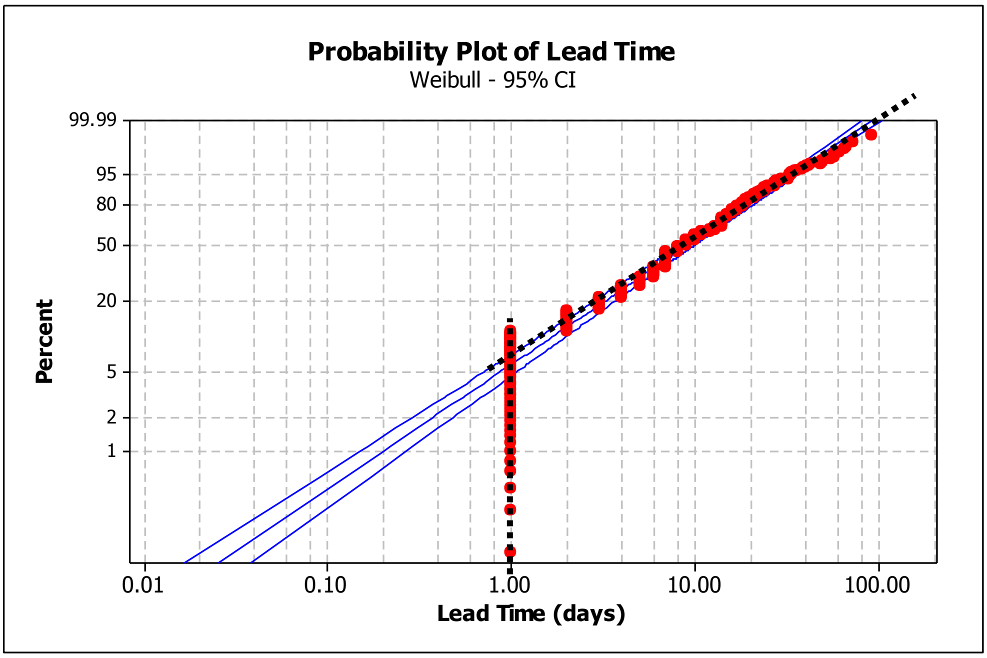

Figure 3: Probability Plot for RFI Review Lead Times

Following Table 4 is the result of the descriptive statistics of the two lead time components:

Table 4: Descriptive Statistics of Two Lead Time Components

Variable	Fast/Slow	Total Count	Percent	Mean	StdDev	Min	Median	Max
Lead Time (days)	Fast	64	11.15	1.00	0.00	1.00	1.00	1.00
	Slow	510	88.85	13.36	11.56	2.00	10.00	93.00

The measure of process efficiency is the amount of time spent in the fast process divided by the total time spent in the process (Muir 2006). Hence, the PCE can be approximated as:

$$\mathrm{PCE}_{\mathrm{Approx.}} = \frac{(\mathrm{P}_{\mathrm{fast}}) \times (\mu_{\text{lead time,fast}})}{\mu_{\text{lead time, total}}}$$

In the equation, $\mathrm{P}_{\mathrm{fast}}$, $\mu_{\text{lead time,fast}}$ and $\mu_{\text{lead time,total}}$ denote the probability of fast process, the average lead time of fast process, and the average lead time of overall process respectively. Plugging the values from the descriptive statistics of the two lead time components into the PCE approximation equation,

$$\mathrm{PCE}_{\mathrm{Approx.}} = \frac{(\frac{64}{574}) \times (1.00)}{11.95} = 0.93\%$$

According to the results, when 11.15% of the RFIs proceed through the process within one day, the efficiency of the system is 0.93%.

VALIDATION OF THE RESEARCH RESULTS

In order to validate the proposed PCE approximation method, the author conducted a series of interviews with the contractor, the architect and engineers and found that 86% of RFIs were produced for the purpose of confirmation or simple clarification about omissions, errors and inconsistencies found in drawings and specifications (Table 5).

Table 5: Reasons for RFI (Chin and Russell 2008)

Reasons	Description	No. of RFIs	%
Omissions or errors in contract documents	Omissions - clarification resulting from omission(s) by the design team (A/E) (e.g., missing dimensions, missing elevations, missing sections, details omitted) Errors - Clarification about the information provided erroneously (e.g., wrong dimensions, wrong elevations)	226	39.37
Hidden/ Unexpected field conditions	Site conditions different from the information provided in the contract documents (e.g., water table, sudden rock layers, existing pipe found)	23	4.01
Inconsistency	Inconsistency (discrepancy) in contract documents (e.g., different pipe location between structural drawing and MEP drawings)	43	7.49
Changes requested by the contractor	Changes made for constructability issues (e.g., changes in construction sequences or construction joints)	14	2.44
Just confirmation	Just confirming whether information provided or previously discussed is correct (e.g., material selection, welding method)	268	46.69
	Total	**574**	**100**

When the architect, the first reviewer of an RFI, initially receives it, he or she does a quick review from the architectural perspective that generally takes less than an hour. Then the RFI is passed on to the appropriate consultant, such as a mechanical engineer, an electrical engineer, or a structural engineer who can answer the question when the architect is unable to do so. As shown in Figure 2, the engineering review time is a much larger part of that lead time than are the other steps. Engineers explained that their review can be done quickly (within half an hour) if all necessary information is available when they start the review. The major reasons for necessary information's not being available are usually 1) architectural revisions during the engineering review process, and 2) missing architectural information, such as missing dimensions and locations (e.g., openings and partitions).

In order to validate the accuracy and utility of the approximation methods, the approximated PCE must be compared with the actual PCE. The author asked the architect and the engineers to obtain the pure execution time used for RFI review but could acquire data only from a structural engineer. (As stated previously, it seemed that people tended to be fearful of the possibility that data would be used for individual performance evaluation.) The data obtained from the structural engineer consisted of 40 RFIs; their descriptive statistics related to lead time and pure execution time are summarized in Table 6.

Table 6: Descriptive Statistics Related to Lead Time and Pure Execution Time

Variable	Mean	StdDev	Min	Median	Max
Lead Time (hrs)	51.90	56.23	2.00	24.00	168.00
Pure Execution Time (hrs)	0.61	0.40	0.10	0.50	2.00

The result was very surprising. The time used for review by the engineer ranged from 0.1 to 2 hours and averaged 0.61 hours, while the total lead time for the engineering review ranged from 2 hours to 168 hours, averaging 51.90 hours. From these results, we can directly calculate the PCE of engineering review by dividing pure execution time by lead time (0.61 hrs / 51.90 hrs = 1.18%). Then, following the same procedure as illustrated previously, the probability plot was constructed and the two lead time components were distinguished (Figure 4).

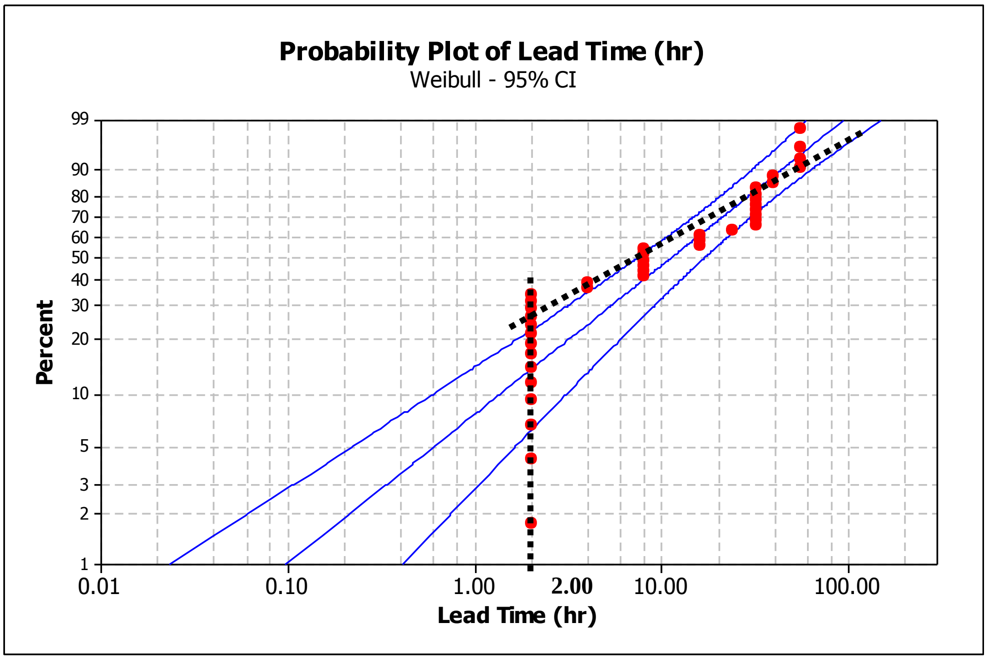

Figure 4: Probability Plot for Engineering Review Time

Following Table 7 is the result of the descriptive statistics of the two lead time components.

Table 7: Descriptive Statistics of Two Lead Time Components

Variable	Fast/ Slow	Total Count	Mean	StdDev	Min	Median	Max
Lead	Fast	14	2.00	0.00	2.00	2.00	2.00
Time (hrs)	Slow	26	78.80	52.80	4.00	96.00	168.00

These values were substituted into the PCE approximation equation:

$$PCE_{Approx} = [(14/40) \text{ x } 2.00] / 51.91 = 1.35\%$$

The actual PCE calculation (1.18%) was different from the approximated PCE (1.35%), but only slightly, so the result provides evidence for the accuracy and utility of the proposed method of PCE approximation. However, further research is necessary to validate the approximation for the entire RFI review process in a research environment in which data for the other (non-engineering) steps can be made available.

CONCLUSION

Throughout the research, the author discussed the utility and accuracy of the approximation method for Process Cycle Efficiency. The major finding of the research is that there was considerable non-value-added time in the engineering RFI review process, largely because necessary information was not available, delaying the engineers from starting their review. We observed that the PCE of the current RFI review process was way lower than the typical range of transactional business processes shown in Table 1. However, we don’t need to be discouraged because the lower the PCE is, the greater the room for improvement will be. Therefore, further investigation should be undertaken to identify and eliminate the causes of this delay. Consequently, this should result in a more efficient process.

Because of the limitation of data, the research did not include the entire RFI review process for PCE approximation, but it did provide a reasonable amount of evidence to support the hypothesis that the approximation of PCE is accurate. The proposed method of PCE approximation will provide a good performance indicator with which to evaluate process efficiency without imposing psychological discomfort on process owners and with which to set targets for improvement.

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