WORK-IN-PROCESS AND CONSTRUCTION PROJECT INFORMATION FLOWS

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ABSTRACT

The inception and completion of the contractor's tasks (i.e., physical production) rely on complete and prompt responses to related information from the design team. However, observations on processing times of Requests For Information (RFI), which is one of major construction project information flows, show that the processing times are unnecessarily long and that on-time response rates are low.

The primary goal of this study is to investigate reason(s) for long information processing time from the production perspective. The study uses three similar projects in terms of the type of building, project budget, and construction duration, gathering actual RFI processing times and measuring key flow performance metrics in order to determine that the major reason for late RFI reviews is the high level of work-in-process (WIP) in the system. To fortify this finding, the study conducts regression analyses, which show a strong correlation between the number of WIP (i.e., RFIs) and the number of delays. The study also analyzes what factors make the WIP level high and suggests possible solutions to reduce the level of WIP from the production perspective.

KEY WORDS

Delay, processing time, regression, request for information, work-in-process

INTRODUCTION

Construction is an information-driven business (Mead 2001). The inception and completion of the contractor's tasks (i.e., physical production) rely on complete and prompt responses to requests for related information from the design team. Physical production can start only after all the necessary information is obtained. For example, in order to install reinforcing bars on site, placing drawings and bar lists should be reviewed and approved by an engineering firm before such following actual production activities as fabrication and assembly can be undertaken. In the current business structure and process, these sequential jobs are not fully automated and cannot be completed in a timely manner because of technological restrictions and sub-optimization. Investigation of the Request For Information (RFI) process reveals that the number of jobs in the RFI review system is so large that the current system is not capable of processing the number of RFIs in the time requested, resulting in delayed responses to each RFI. The author selected three similar projects in terms of the type of building, project budget, and construction duration (Table 1) to analyze in pursuit of this finding. Project delivery performance and control methods may differ among the three projects, depending on the type of owner, contract and so forth, but the study

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does not intend to analyze different performance levels resulting from different delivery systems or contractual relationships. Rather, the research is intended to identify the key factor(s) affecting the RFI review process time by examining selected cases at the flow level of the production system.

Table 1: Summary of Three Cases

	Project A	**Project B**	**Project C**
Company	Company 1	Company 2	
Type of Building	Laboratory	Laboratory + Hospital	Hospital
Owner	State Government	State Government	Private
Location	California, USA	Wisconsin, USA	Wisconsin, USA
Project Delivery System	Design-Build	CM at Risk	CM at Risk
Budget	$162 mil.	$144 mil.	$134 mil.
Construction Duration	36 mo.	38 mo.	40 mo.
Sample Size for the Study	574	1,035	777

PROCESS FLOW OF CURRENT RFI REVIEWS

The current RFI review is done sequentially under the contractual hierarchy, and there is always the possibility of negative reiteration to complete the review because of the nature of construction operations and the review's sub-optimization in the project delivery system. One example of sub-optimizations is the incompatible applications used for each discipline. It is common practice for architects to use CAD to create conceptual and architectural drawings, while engineers use other kinds of software to produce engineering drawings. These different systems result in a process that is a large source of variation and discrepancies in reading and interpreting project information. What's worse, even if all the project information is ready before a project starts, many changes are made during the construction, and these changes create a wasteful cycle of modifying the necessary information to conform to project requirements.

In general, RFIs are created by subcontractors and transmitted to the general contractor, and then to the design team for comprehensive review. The general contractor prepares the RFI document package and performs a first review to determine whether the RFI has a real impact on project delivery time and cost. Then the contractor forwards the RFI to the architect, who passes it on to the appropriate consultant (design teams, reviewers), such as the mechanical engineer, the electrical engineer, or the structural engineer, all of whom can answer the questions in the RFI only when the architect is unable to do so. Figure 1 represents the typical RFI review process flow observed in the three projects of this study.

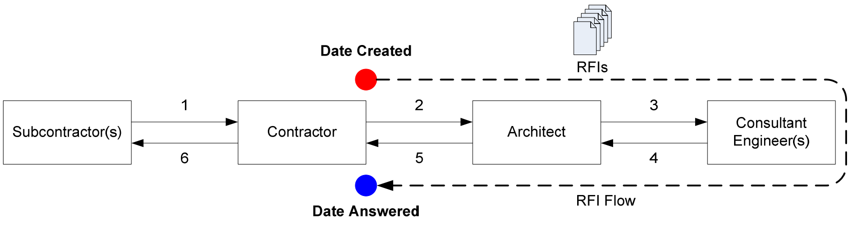


Figure 1: RFI Review Process Flow (Chin and Russell 2008)

LITTLE'S LAW

Little's Law explains the fundamental long-term relationship between work-in-progress (WIP), throughput and flow time of a production system. Little's Law indicates that a system that has a lot of inventory will have long lead times and, conversely, that a system with reduced inventory responds more quickly (Hopp 2007; Hopp and Spearman 2000; Lambrecht and Vandaele 1994; Little 1961). In other words, we can reduce cycle time by reducing WIP level. Hopp and Spearman (2000) also found that the bulk of WIP in most (physical) production systems is in queue because of variability and high utilization: waiting for batch because of batched processing or waiting to match because of lack of synchronization. George (2003) also stated that processes are slow because of too much WIP and that work can spend more than 90% of its time waiting, which inflicts substantial waste (non-value-adding time) on the process.

MEASURING WORK-IN-PROCESS

WIP is the number of entities in the system and can be measured in either physical units (e.g., parts, people, jobs) or financial units (e.g., dollar value of entities in the system) (Hopp 2007; Hopp and Spearman 2000). The samples for the study include data regarding when each RFI is created and each response is made (see Figure 1). If we assign a "1" to each day the RFI stays in the system, we can also measure the total amount of time it takes to process the RFI. For example, as illustrated in Table 2, if RFI# 0001 was created on March 1 and a response was made on March 6, the RFI must have stayed in the system from March 1 to March 6. If we assign 1 to all the dates each RFI stayed in the system, summing up the numbers on the same date will provide the daily WIP level.

Table 2: Measuring Work-In-Process

RFI #	**Date**														
	3/1	3/2	3/3	3/4	3/5	3/6	3/7	3/8	3/9	3/10	3/11	3/12	3/13	3/14	3/15
0001	1	1	1	1	1	1									
0002		1	1	1	1	1	1	1	1	1	1				
0003				1	1	1	1	1	1	1	1	1	1		
0004							1	1	1	1	1	1	1	1	1
Daily WIP	1	2	2	3	3	3	3	3	3	3	3	2	2	1	1

For the study, 574 RFIs were collected for project A, 1,035 RFIs were collected for project B, and 777 RFIs were collected for project C. Daily WIP levels were measured in the same way and are summarized in Table 3.

Table 3: Summary of WIP Levels of Three Projects

		Project A	**Project B**	**Project C**
Sample Size for the Study		574	1,035	777
Work-In-Progress (WIP) (# of RFIs)	Average	30.55	19.30	16.89
	Min	0	0	0
	Max	59	56	69

In the project A, the average number of RFIs per day is 30.55, which means the reviewer had an average of 30.55 RFIs to review each day. Project B and C also can be interpreted in the same manner as Project A. Figures 2, 3, and 4 represent the average WIPs and trends of each project. The short-term fluctuations are due to variability in the number of WIP in the system, but the long-term trend is unmistakably toward review system overload.

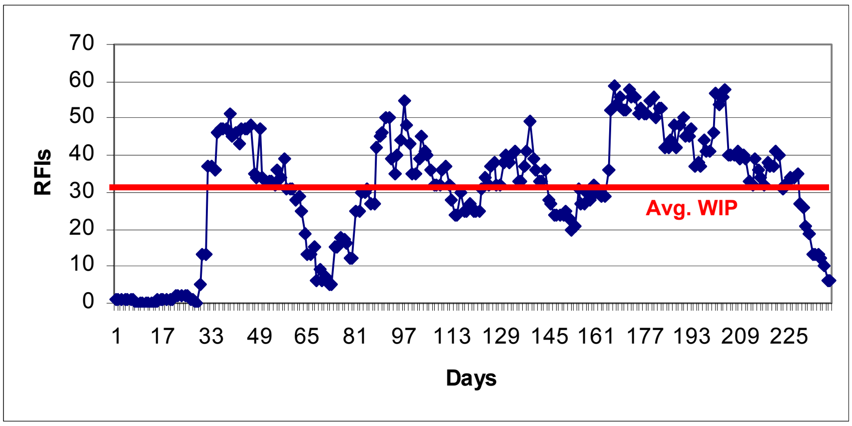


Figure 2: Actual RFI Work-In-Process of Project A

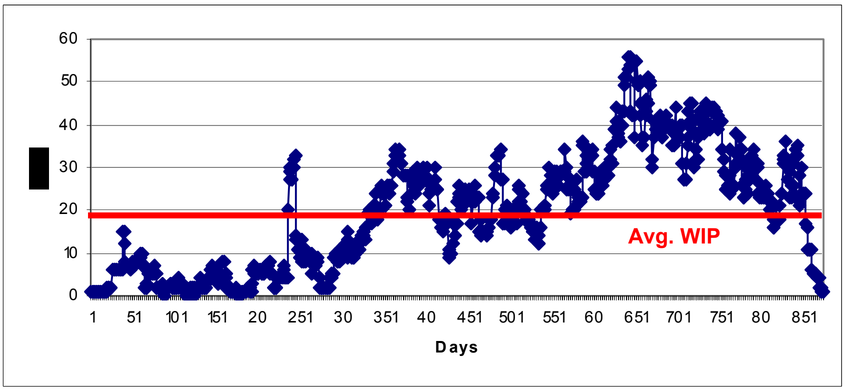


Figure 3: Actual RFI Work-In-Process of Project B

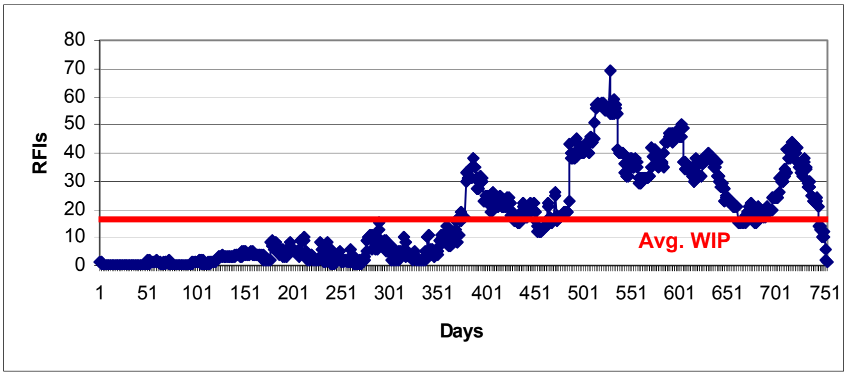


Figure 4: Actual RFI Work-In-Process of Project C

MEASURING THE NUMBER OF DELAYS

From the project management perspective, “delay” is the time period during which some part of the construction project has been extended beyond what was originally planned as a result of unanticipated circumstances (Bramble and Callahan 1999). From the production perspective, delay is the condition of customer orders not filled by their due dates as a result of late product delivery or the time entities spend in the system not being processed (Hopp 2007; Hopp and Spearman 2000).

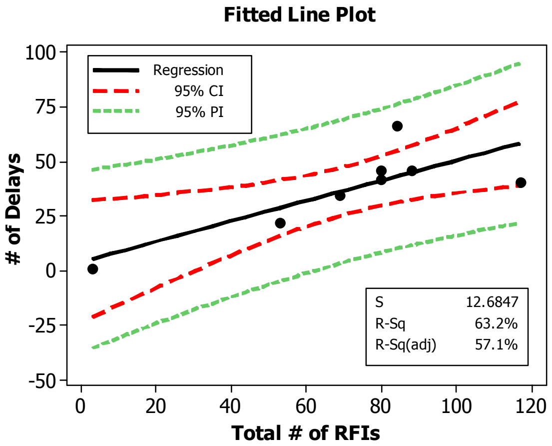
In the RFI review system, a contractor wants to receive responses to RFIs on-time, which often means quickly. The author tracked the response time expected by the contractor for each RFI and then calculated the difference between the expected response time and the actual processing time. Following the usual convention, early, on-time, and late responses will have negative (-), zero (0), and positive (+) values, respectively. The on-time rates (consisting of both early and on-time responses) for projects A, B, and C were just 48% (274/574 RFIs), 48% (500/1,035 RFIs), and 50% (388/777 RFIs), respectively.

CORRELATION BETWEEN THE NUMBER OF DELAYS AND THE NUMBER OF TASKS

Regression analysis was conducted to determine whether the number of tasks (i.e., RFIs) affects the number of delays. The results showed that the number of delays is strongly correlated to the total number of RFIs (WIP) in the system, which supports the suggestion that a high number of WIP is the major cause of delays in RFI processing time.

REGRESSION ANALYSIS OF PROJECT A

The output shows the results of fitting a linear model to determine the relationship between the number of delays and the total number of RFIs. Two further sets of lines (confidence intervals and prediction intervals) are also presented in Figure 5. The confidence intervals indicate the interval within which one can be 95% confident what the process average will occur, while the prediction intervals indicate the interval within which one can expect 95% of the process output (data points) to occur (Minitab Inc. 2004). Thus, the number of delays increases as the number of RFIs in the system increases. Since the P-value in the Analysis of Variance (ANOVA) table is less than 0.05, there is a statistically significant relationship between number of delays and total number of RFIs at the 95% confidence level. The R-Squared statistic indicates that the model explains 63.2% of the variability in the number of delays.



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Regression Analysis: # of Delays versus Total # of RFIs

The regression equation is
# of Delays = 4.14 + 0.4649 Total # of RFIs

S = 12.6847   R-Sq = 63.2%   R-Sq(adj) = 57.1%

Analysis of Variance

Source      DF      SS       MS      F      P
Regression   1  1660.60  1660.60  10.32  0.018
Error        6   965.40   160.90
Total        7  2626.00
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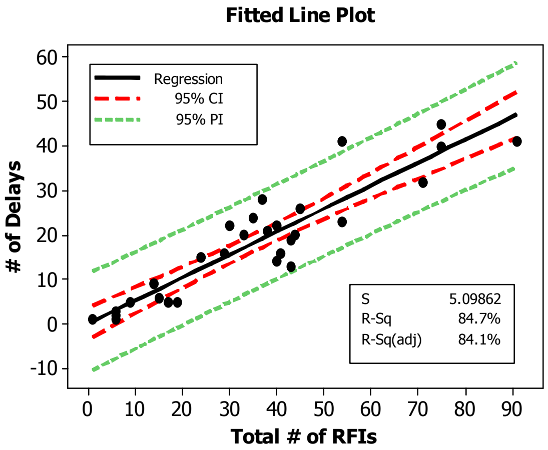
Figure 5: Fitted Line Plot and Results of Regression Analysis (Project A)

REGRESSION ANALYSIS OF PROJECT B

Like Project A, the output shows a statistically significant relationship between number of delay and total number of RFIs at the 95% confidence level (Figure 6). The regression analysis result can be interpreted in the same manner as Project A, i.e., that the number of delays increases as the number of RFIs in the system increases. P-value 0 shows a statistically significant relationship between the number of delays and the total number of RFIs at the 95% confidence level. The R-Squared statistic indicates that the model explains 84.7% of the variability in the number of delays.



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Regression Analysis: # of Delays versus Total # of RFIs

The regression equation is
# of Delays = 0.111 + 0.5138 Total # of RFIs


S = 5.09862   R-Sq = 84.7%   R-Sq(adj) = 84.1%


Analysis of Variance

Source      DF      SS       MS       F      P
Regression   1  3883.28  3883.28  149.38  0.000
Error       27   701.89    26.00
Total       28  4585.17
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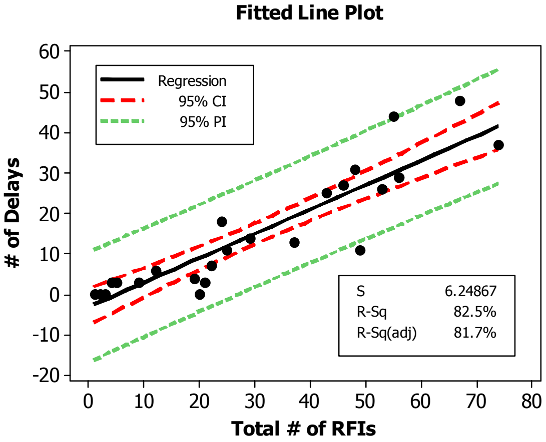
Figure 6: Fitted Line Plot and Results of Regression Analysis (Project B)

REGRESSION ANALYSIS OF PROJECT C

Like Project A and B, the output shows a statistically significant relationship between number of delay and total number of RFIs at the 95% confidence level (Figure 7). The regression analysis result can be interpreted in the same manner as Project A and B, i.e., that the number of delays increases as the number of RFIs in the system increases. P-value 0 shows a statistically significant relationship between the number of delays and the total number of RFIs at the 95% confidence level. The R-Squared statistic indicates that the model explains 82.5% of the variability in the number of delays.



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Regression Analysis: # of Delays versus Total # of RFIs

The regression equation is
# of Delays = - 3.184 + 0.6031 Total # of RFIs


S = 6.24867   R-Sq = 82.5%   R-Sq(adj) = 81.7%


Analysis of Variance

Source      DF     SS       MS       F      P
Regression   1  4234.10  4234.10  108.44  0.000
Error       23   898.06    39.05
Total       24  5132.16
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Figure 7: Fitted Line Plot and Results of Regression Analysis (Project C)

CAUSES OF WIP INCREASES AND STRATEGIES FOR WIP REDUCTION

Because the reviewers for Projects A, B and C could not keep up with the arrival rate of RFIs, WIP built up over time and delays resulted. As mentioned previously, the short-term fluctuations are due to variability in the number of WIP in the system, but the long-term trend is unmistakably toward review system overload. The bulk of WIP in most production systems is in the queue because of variability and high utilization from waiting for batching or matching. Hence, a WIP reduction program should be directed at lowering utilization, reducing variability, reducing batching and/or improving synchronization (Hopp and Spearman 2000).

UTILIZATION

Utilization is the fraction of time a workstation is not idle because of a lack of parts. We can compute utilization as the ratio of an entity's arrival rate into a workstation to the capacity of workstation (Hopp 2007). If the entity arrival rate into the workstation exceeds the capacity of the workstation, waiting will begin because the workstation is not capable of processing all the entities that flow in. To reduce utilization of the workstation, either the entity rate in can be reduced or the capacity of workstation can be increased. Queueing theory explains that, as utilization approaches 100%, any variation in inter-arrival times and effective process times can drive wait time to infinity (Conway et al. 1988; George 2002; Hopp and Spearman 2000; Lambrecht and Vandaele 1994). As a result, increasing utilization to make up for lost progress can cause an increase in waiting time unless variation is reduced.

FLOW VARIABILITY

The importance of reducing variability was affirmed in Ohno's book, Toyota Production System: Beyond Large-scale Production (1988): *"the slower but consistent tortoise causes less waste and is much more desirable than the speedy hare that races ahead and then stops occasionally to doze. The Toyota Production System* *can be realized only when all the workers become tortoises."* Two major variation components cause waiting in the line flow (Conway et al. 1988; Hopp and Spearman 2000): variations in entities' inter-arrival times and variations in process times. Inter-arrival time can be affected by vendor quality (e.g., the skill level of the (sub)contractor who prepares the RFI documentation), scheduling policies, variability in upstream processes (e.g., variability in RFI documentation), and other factors. Process times can be affected by machine failures (e.g., internet down, computer malfunction), setup times (e.g., reviewers' preparation times, such as computer boot-up, opening RFI files, preparing project specifications and drawings), operator breaks (e.g., coffee break, sick leave, holiday, vacation, travel), or anything that extends the time required to complete processing of the entity (Hopp 2007).

This study uses the Coefficient of Variation (CV) to measure relative variability. Because CV is a dimensionless number–mean and standard deviation have the same units—it is useful for comparing the dispersion of populations with different means (Minitab Inc. 2004). Hopp and Spearman (2000) established three classes of variation for measuring flow variability to determine the severity of variability in a production system: LV (low variation) for CVs less than 0.75, MV (moderate variation) for CVs between 0.75 and 1.33, and HV (high variation) for CVs greater than 1.33. As summarized in Table 4, all three projects have at least moderate and high variations in both inter-arrival time and processing time. Project C has higher CVs in both inter-arrival time and process time than the other two projects. Directing an improvement effort toward making these variation components more consistent would lower the variation.

Table 4: Summary of Variations

		Project A	Project B	Project C
Entity's inter-arrival time (days)	Average	1.90	2.25	2.53
	StdDev	1.74	2.12	3.76
	CV	0.91	0.94	1.49
Processing time (days)	Average	11.95	15.50	15.54
	StdDev	11.60	25.22	28.44
	CV	0.97	1.63	1.83

BATCHING

RFIs are not usually sent to the designer (reviewer) one at a time, but together in batches with different expected response times. One of causes of the high level of WIP is batching, particularly arrivals of batches at a single workstation (Hopp and Spearman 2000).

One might think that the variation in a batch arrival is zero because entities batched arrive at a workstation simultaneously. However, if we look at the inter-arrival times of each entity in the batch from the perspective of the individual RFIs, we will see very different pictures (Hopp and Spearman 2000). For example, in the RFI process of Project A, an average of 4.63 RFIs are batched and delivered to the reviewer at the same time, but the reviews are done one at a time. From this observation, the inter-arrival time (i.e., the time since the arrival of the previous RFIs) for the first RFI in the batch is 1.90 days. For the next 3.63 RFIs (4.63-1), it would be zero. Hence, the mean time between arrivals is 0.41 days (1.9 days divided by 4.63 RFIs), and the variance of these times is given by:

$$\sigma = \sqrt{\left[\frac{1}{4.63}(1.90)^2 + \frac{3.63}{4.63}(0)^2\right] - (0.41)^2} = 0.78 \qquad (1)$$

Hence, the CV of batch arrival would be:

$$\text{CV} = \frac{\sigma}{\mu} = \frac{0.78}{0.41} = 1.9 \qquad (2)$$

The CV of 1.9 falls within the high variation (HV) range, according to Hopp and Spearman's classification. Thus, the batching effect, together with a combined effect from inter-arrival and process time variations, increases the flow variation to a great extent and degrades the system performance, resulting in longer cycle times. An ideal batch size would be 1 since, replacing the average batch size in Equations (1) and (2) results in CV= 0. Hence, no variation resulting from batch arrival occurs.

SYNCHRONIZATION

In a production system, synchronization between fabrication and assembly is important because a assembly of a part cannot be completed until all components are available (Hopp et al. 1990). Lack of synchronization may result from variability, poor scheduling, or poor production control, and can cause significant buildup of WIP and, hence, delay (Hopp and Spearman 2000). In the RFI review process, reviewers may need such information as material specifications or shop drawings (synonymous with "components" in a production system) from suppliers for RFI reviews (synonymous with "part assembly" in a production system). If all these necessary bits of information are not obtained in timely manner, the reviewers cannot complete the reviews within the requested time. Hence, obtaining relevant information in timely manner can reduce the WIP level.

CONCLUSIONS

A large WIP leads to long lead times and failure to meet customers' (contractors') expectations. This study reveals the strong correlation between WIP level and delay of RFI and investigated the reasons for high levels of WIP from the production perspective. The complex nature of the construction process and its interwoven flows make it difficult to use the concept of lean thinking. However, if we investigate suspicious areas with well defined parameters such as WIP, variation, utilization, etc and relate them to such flow-related theories as queueing theory and Little's Law, we will be able to improve system performance.

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