INCREASING ON-TIME DELIVERY BY SELECTING THE APPROPRIATE JOB-SEQUENCING ORDER

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ABSTRACT

In case a promised delivery date is not provided by a product or service provider, customers usually request their expected delivery dates when they place an order. However, there is always the possibility of a difference between the time a customer wants to receive a product/service and the actual time the customer receives a product/service. In a construction project, the Request-For-Information (RFI) is a formal question or clarification that the contractor asks the architect/engineering (A/E) firms regarding details in the plans, drawings or specifications. The A/E firms usually do not provide “Promised Due Dates” for each RFI. Instead, the contractor puts the expected response time on each RFI. As a result, discrepancies between when the contractors want the questions answered and the time they are received almost always occur and are sometimes large.

One of reasons for this large gap can be found in the job-sequencing problem. The hypothesis of the research is that if the performance of a production system is related to job sequencing order, then selecting an appropriate sequencing order will improve the performance and increase the on-time delivery. The research discusses the different types of sequencing rules and conducts a simulation study to test the hypothesis. The result shows that on-time delivery can be increased by selecting the appropriate job sequencing order.

KEYWORDS

Earliest due date, Job-sequencing, Lateness, On-time delivery, Shortest processing time.

BACKGOUND

A RFI is a formal question or clarification that is asked of the design team regarding details in the plans, drawings, or specifications. The contractor should clearly and concisely set forth the issue for which they seek clarification or interpretation and the reason for a response. The current RFI review is done sequentially under the contractual hierarchy. 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

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process flow. Any delay in the reviewer's (A/E firm) response to an RFI can result in the contractor's delay, consequently resulting in a delay in the project as a whole.

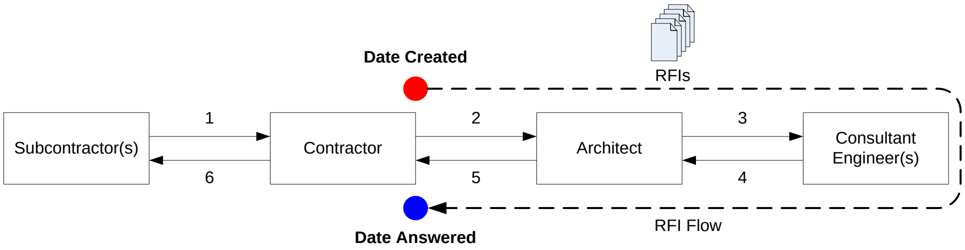

Figure 1: RFI Review Process Flow (Chin 2009b; 2008)

In the RFI review process, the contractor expects to receive clear and complete information from a design team in a timely manner without the need for further follow-up. Through interviews with the contractor, we identified two key factors in satisfying contractors' needs: 1) quick responses and 2) clear and complete information. However, actual data gathered showed that clarity and completeness of response information was not a big issue to the contractor. About 90% of the RFIs were completed without further follow-ups. The majority of the RFIs were well written for the design team's review, and the design team prepared clear and complete answers in just one review cycle. However, data analysis shows that only 48% of the RFIs were delivered to the contractor in the timely manner, and the contractor was therefore dissatisfied with late responses from the design team. Therefore, it is clear that the contractor's greatest need in the RFI process is quick response.

CASE STUDY

We conducted observations on RFI processing from several projects in different regions in the United States. The individual project selected for this research involves medical research centers located in Wisconsin in the United States. The data set for the research consisted of 1,035 RFIs gathered over an 840 day period. It is interesting to note that the contractor classified the RFI importance as none, medium, high and critical) according to the amount of potential impacts on schedule and/or cost before transmitting them to reviewers (design teams).

The company used a web-based RFI control system to maintain and control the RFI process. All the people and firms involved in the project could access the system whenever and wherever they wanted. All the RFIs were loaded into the system, and the system showed important milestones (start, ends, and progress) and people could see who was responsible for a specific RFI process. The system automatically marked the hot items which should be reviewed by the design team in high priority order. The rule to create the hot items was the Earliest Due Date (EDD) whose priority is given by entities' deadlines. For instance, the processing of a RFI which is due in a week should be ahead of a RFI due in a month. However, the contractor created a type of weekly hot list using an Excel spreadsheet which highlighted the items already overdue or close to the original due dates. The purpose of the hot list was mainly to expedite the review process. However, there is no governing rule to prepare the hot list; in general, the list was prepared depending on the priority set by the contractor. Another observation on the weekly hot list was that the due dates of items in the hot list were usually re-set by the contractor for expediting.

TIME EXPECTED VS. ACTUAL RFI LEAD TIME

As reviewers of RFIs, the A/E firms usually do not provide “Promised Due Dates” for each RFI. Instead, the contractor puts the expected response time on each RFI. Therefore, discrepancies between the expected response time and actual response time occur. In general, both parties (contractor and owner) agree on a minimum RFI review time (7 days is common practice in US construction) before starting a project. However, the minimum review time is usually determined based on their past experiences (Chin and Russell 2008). So the agreed-upon minimum review time is typically unrealistically short, often rendering the reviewer incapable of meeting the contractor's expectation. As a result, the owner is at risk of encountering legal claims resulting from the late start of tasks caused by late RFI responses, while the contractor runs the risk of not completing the job on time.

In the selected case, on average, the contractors expected to receive responses from the design teams in 8.68 days, ranging from 0.5 days to 246 days. However, it was observed that the average actual response time (15.50 days) was almost twice longer than the average contractor’s expected time (8.68 days). Table 1 summarizes important statistics of expected time and actual lead time and shows the average response times don’t seem to be affected by the priority set by the contractor.

Table 1: Time Expected vs. Actual Lead Time (days)

		Total Count	%	Average	Stdev	Min	Max
Contractor’s expected time (days)	**Overall**	**1,035**	**100.00**	**8.68**	**15.13**	**0.50**	**246.00**
	Critical	272	26.28	8.20	17.00	0.50	157.00
	High	414	40.00	9.24	19.15	0.50	246.00
	Medium	345	33.33	8.40	4.39	0.50	41.00
	None	4	0.39	5.88	3.71	0.50	9.00
Actual response time (days)	**Overall**	**1,035**	**100.00**	**15.50**	**25.22**	**0.50**	**274.00**
	Critical	272	26.28	15.05	22.83	0.50	151.00
	High	414	40.00	16.42	27.19	0.50	274.00
	Medium	345	33.33	14.88	24.69	0.50	219.00
	None	4	0.39	3.88	3.61	0.50	7.00

BATCH PROCESSING

Another observation from the current process is that RFIs were not usually sent to the reviewer one at a time, but often in batches. Following Table 2 are the resulting statistics of the batch.

Table 2: Descriptive Statistics of Batch Size

Variable	Total Count	Mean	StdDev	Minimum	Median	Maximum
Batch	378	2.74	2.22	1.00	2.00	18.00

TIME BETWEEN ENTITY ARRIVALS (INTER-ARRIVAL TIME)

The RFIs did not arrive regularly in the system for review. The average time between the RFIs arrivals was 2.25 days, ranging from 1 day to 19 days (see Table 3).

Table 3: Descriptive Statistics of Inter-arrival Time

Variable	Mean	StdDev	Minimum	Median	Maximum
Time btwn arrivals (days)	2.25	2.12	1.00	1.00	19.00

SERVICE LEVEL OF CURRENT RFI REVIEW PROCESS

The service level of such jobs as RFI review which are triggered by customer (contractor) requests and completed as to planned due dates can be measured as the percentage of jobs that are completed on time. These types of jobs are generally assembled, built, fabricated, customized, or engineered in response to customer's requests (Hill 2007; Hopp and Spearman 2000). The contractor classifies each RFI by its priority in terms of cost and schedule impacts. The following statistics represent the rate at which responses of each group are made on time. The results indicate that only 48% of the RFIs were responded to the contractor in the timely manner. Chin (2009b) and Chin and Russell (2008) revealed that the possible reasons for the late responses of RFIs were:

- Large WIP caused by flow variation;
- Capacity of the review system and batching;
- Lack of necessary information required for RFI review (e.g., material testing results, unclear/missing dimension, design conflicts, etc.)
- Reviewer's availability and skill level;
- Quality and variety of RFI document; and
- Working relationships between contractors and reviewers.

The priority set by the contractor did not seem to affect the on-time response level as summarized Table 4 below.

Table 4: On-Time Rate by Priority Set by Contractor

Priority set by Contractor	Count	# of On-Time	On-Time Rate
Critical	272	114	41.91%
High	414	189	45.65%
Medium	345	193	55.94%
None	4	4	100.00%
Total	1035	500	48.31%

JOB SEQUENCING RULES AND SYSTEM CRITERIA

Job sequencing rules (i.e. dispatching) explain that if each task has a different priority and due date, the process output will be different by selecting a specific order of processing and the process flow performance changes due to the variation impact led by the sequencing rule (Vollmann et al. 2005). One can observe the different process performance with different sequencing rules. The performance might be different according to the pursuing objective. In general, objectives are determined by such criteria as 1) total time to complete the entire set of jobs, 2) average time each job spent at the workstation, 3) average lateness, and 4) maximum lateness (Hopp and Spearman 2000; Vollmann et al. 2005).

TOTAL TIME TO COMPLETE ENTIRE BATCH VS. AVERAGE TIME EACH JOB SPENT IN SYSTEM

Suppose a job can be completed one at a time, and a batch of three jobs with individual processing times of one, five and eight hours, respectively, are scheduled. The total time required to run the entire batch under any sequence is 14 hours, i.e. 1+5+8=14, 1+8+5=14, 5+1+8=14 etc. If the jobs are processed in ascending order, the average time that each job spends in the system is (1+6+14)/3 = 7 hours. However, if the jobs are processed in the reverse order, average time in the system is (8+13+14)/3 = 11.67 hours. This result has an important consequence. Average time in the system will always be minimized by selecting the next job for processing that has the shortest processing time (SPT) at the current operation. More detail on this result will be discussed below.

LATENESS

Lateness is the difference between the due date and the actual completion date. It can be computed as lateness of job = actual completion date - due date (Vollmann et al. 2005). Hence, negative (-) lateness means an early finish while positive (+) lateness represents a late finish. The observation from the selected case shows that the average lateness of the current system was 6.79 days, ranging from -34 days to 265 days.

SHORTEST PROCESSING TIME (SPT) RULE

As previously described, it is evident that the SPT rule provides excellent results when we use the average time in system criterion (Hopp and Spearman 2000; Vollmann et al. 2005). SPT also performs well on the criterion of minimizing the average number of jobs in the system. When the criterion is to minimize the average job lateness, SPT is also the best rule for sequencing jobs (Vollmann et al. 2005).

EARLIEST DUE DATE (EDD) RULE

The earliest due date rule, which schedules the jobs in increasing order of their due dates, minimizes the maximum lateness on a single machine (Hopp and Spearman 2000; Vollmann et al. 2005). The most important conclusion from the single-machine research is that the SPT rule represents the best way to pick the next job to run, if the objective is to minimize average time per job, average number of jobs in the system, or average job lateness. However, if the objective is to minimize either the maximum lateness of any job or the lateness variance, then jobs should be run in due date sequence (Vollmann et al. 2005). For example, suppose there are three jobs, and the process times required to complete Job A, B, and C are 1 day, 5 days, and 8 days respectively and their due dates are varied as day 1, day 6 and day 14 respectively. Figure 2 represents the different performance results from different job sequencing rules.

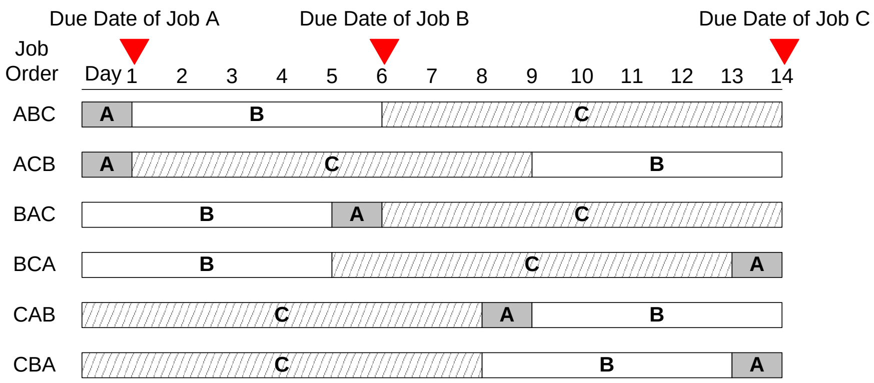

Figure 2: Different Job Sequencing Orders

Table 5 summarizes the results of the example under different sequencing rules.

Table 5: Different Performances under Different Sequencing Rules

Sequence	Total time to complete the entire set of jobs (processing time)	Average time each job spent in the system (processing time + waiting)	Lateness	
			Average	Maximum
ABC	1+5+8 = 14	(1+6+14)/3 = 7	(0+0+0)/3 = 0	0
ACB	1+8+5 = 14	(1+9+14)/3 = 8	(0-5+8)/3 = 1	8
BAC	5+1+8 = 14	(5+6+14)/3 = 8.33	(-1+5+0)/3 = 1.33	5
BCA	5+8+1 = 14	(5+13+14)/3 = 10.67	(-1-1+13)/3 = 3.67	13
CAB	8+1+5 = 14	(8+9+14)/3 = 10.33	(-6+8+8)/3 = 3.33	8
CBA	8+5+1 = 14	(8+13+14)/3 = 11.67	(-6+7+13)/3 = 3.00	13

This example shows the different performances resulting from different sequencing rules. The total times to complete the entire set of jobs are always the same regardless of sequencing rules. However, the average time each job spent in the system are different because each case has different waiting time profiles. For example, in case of ACB, the job A is done at day 1 without waiting, but the job C should be waiting until day 2 when the server is available. Hence, the total time that job C spent in the system is the sum of the processing time (8 days) and the waiting time (1 day).

SIMULATION STUDY

The simulation model in Figure 3 below was constructed using the following assumptions:

- A total of 1,050 RFIs are fed into the model and their results will be analyzed.
    - The simulation is to be run 1,000 times.
    - The entities are created in the form of a batch of 3 RFIs.

- The times required for batching are not considered.
- The times required for transmitting the RFIs were not considered because the project used the web-based project information system which enabled immediate transmission of RFIs and real time access to the system.
- Once a batch of 3 RFIs was received by the reviewer, 3 RFIs were unbatched to single RFI units because the reviewer can only review one RFI at a time.
- Once RFIs were unbatched, the priority of each RFI were assigned according to the real value from the observation. The chances of critical, high, medium and none were 26.28%, 40%, 33.33% and 0.39% respectively. Then due dates were assigned.
- The rest of the RFIs after unbatching were piled on the desk of the reviewer and were subsequently picked up by the designer in the selected job sequencing rule.
- When the reviewer was busy, the rest of the RFIs were in queue and seized until the reviewer was available.

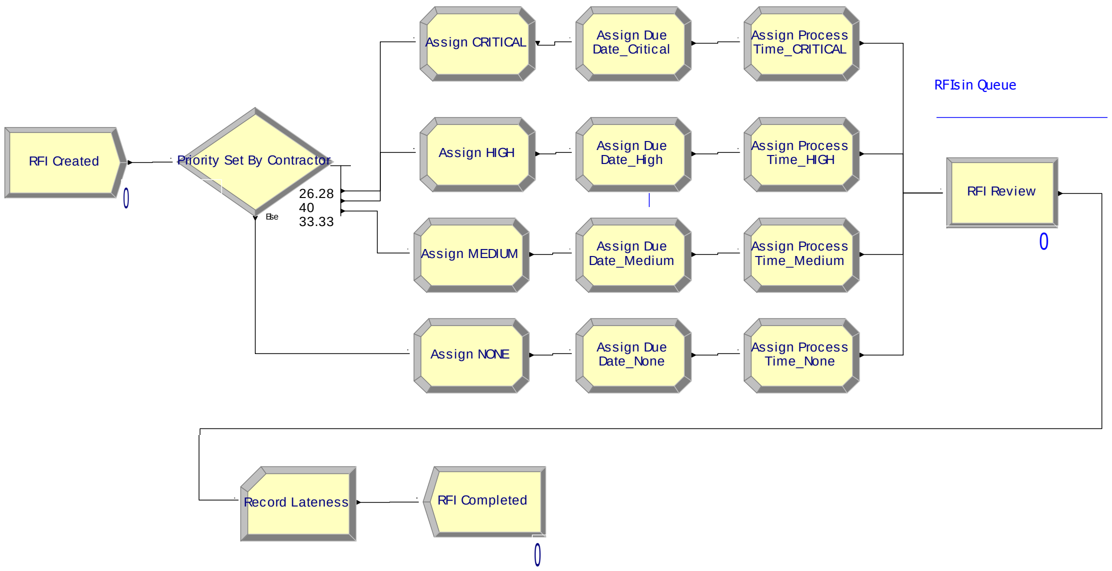

Figure 3: Simulation Model

- Simulation parameters were determined using Input Analyzer which is one of facilities of the Arena simulator and summarized in the following Table 6.

Table 6: Simulation Parameters

Parameter		Expression
Time between arrivals		0.5 + 19 * BETA(0.527, 5.19)
RFI Review	Critical	LOGN(0.376, 0.822)
	High	WEIB(0.294, 0.81)
	Medium	WEIB(0.34, 0.814)
	None	BETA(0.0622, 0.0607604)
Due Date	Critical	-0.001 + 157 * BETA(0.168, 3.06)
	High	LOGN(8.21, 6.39)
	Medium	GAMM(1.94, 4.33)
	None	UNIF(0, 9)

SIMULATION RESULTS

Under the assumptions and conditions made previously, the simulations were run and the results were summarized in the following Table 7.

Table 7: Simulation Results (days)

Sequencing Rule		Average total lead time to complete entire set of RFIs			Average time each RFI spends in the system = (3)/1,050 RFIs	Lateness	
		Average total processing time (1)	Average total waiting (2)	∑ (3) = (1)+(2)		Avg.	Max.
Variable due date	FIFO[2]	243.81	574.93	818.74	0.78	-8	60.75
	EDD	243.81	593.38	837.19	0.80	-8	60.77
	SPT	243.81	397.03	640.84	0.61	-8	93.39
	LPT[3]	243.81	572.61	816.42	1.01	-7	112.12
	Priority set by contractor	243.81	508.64	752.45	0.72	-8	93.98
Fixed 7 days of due date	FIFO	243.81	586.72	830.53	0.79	-6	69.57
	EDD	243.81	586.72	830.53	0.79	-7	69.57
	Priority set by contractor	243.81	519.18	762.99	0.73	-7	78.60

The results are discussed based on the performance criteria: 1) total time to complete the entire set of jobs, 2) average time each job spent at the workstation, 3) average lateness, and 4) maximum lateness.

- Criterion 1: total times to complete the entire set of RFIs varied greatly depending on the job sequencing rule selected because of different waiting time profiles. However, the total times used for processing RFIs were the same for the reason explained previously. As expected, the SPT rule gave the shortest time to complete the entire set of RFIs while EDD gave the longest time.
- Criterion 2: average times each job spent at the workstation were varied but achieved the shortest time by selecting the SPT rule.
- Criterion 3: average latenesses of each case were not quite different.
- Criterion 4: maximum latenesses were quite different depending on the sequencing rules selected. However as expected, the RFI review system with EDD generated a minimum lateness. FIFO gave almost the same maximum lateness as EDD did but its lead time was slightly longer than that of EDD.

DISCUSSION ABOUT SIMULATION RESULTS

The simulation models were run under two different due date conditions: variable and fixed due dates. As explained previously, the contractor set the expected due date arbitrarily even if both parties (contractor and design team) agreed on a minimum 7 days of review time. However, the simulation showed that setting the due date with a fixed 7 days can reduce the maximum lateness. What if the contractor set the expected due date much longer (i.e., the contractor prepares their RFI much earlier)? Intuitively, one might think that the longer due date (contractor's expected time) could

[2] First In First Out
[3] Longest Processing Time

lead to smaller lateness because the reviewer will have more time to review. However, Chin (2009a) illustrated that merely increasing the customer's expectation time does not help in reducing the lateness if a system has a natural tendency to generate a wide range of variation. It was observed that the current system has large variations in its arrival pattern, batch size, and processing time. Hence, the only viable solution is to increase the flow reliability by reducing the variations. In addition, ad hoc changes of due dates for the purpose of expediting the review process will bring about the reviewer's irregular job pattern, resulting in an increase of flow variability.

Numerous studies have been done to determine the optimum due date to reduce the late job completion. They discovered that the optimum due date can be selected if one can anticipate completion times of different jobs (Panwalkar et al. 1982). Similar to this optimum due date case, the SPT rule also needs anticipation of processing time. Hence, applying SPT to the current RFI review process will require the reviewer to predict how long it will take to complete each RFI. However, the complex nature of the construction process and its interwoven flows make it difficult for reviewers to anticipate the times to complete each RFI. The many factors include quality and variety of RFIs and project information required for review, coordination among project team members to obtain necessary information on time, working relationships between contractors and reviewers, reviewer's availability, reviewing speed and reviewer's skill level, RFI's arrival pattern, and number of RFIs transmitted to the reviewer.

CONCLUSION

The research discussed the different types of sequencing rules and conducted a simulation study to test the hypothesis. The current system's performance was not affected by the priority set by the contractor in terms of lead time and on-time rate. There were different performances of the same system by selecting different job selection orders. The simulation results showed that the current rule (i.e., reviewing higher priority RFI first set by the contractor) was not superior to other rules like FIFO, EDD, and SPT. The research findings will provide the project team with various options to achieve a specific goal or objective they want to pursue. They can select the SPT rule to minimize average time per RFI or to minimize average job lateness. If the project team expects the minimum lateness, they can select EDD. The study also showed that using a fixed term of due date can reduce the maximum lateness but slightly increase the process time.

The study provided a reasonable amount of evidence to support the hypothesis that if the performance of a production system is related to job sequencing order, then selecting appropriate sequencing order will improve the performance of the system and increase the on-time delivery. However, the research didn't address the consequences and actual impact resulting from a late response due to the limited data and time. Future research should include the urgency and impact of late responses on an actual construction project for a more meaningful performance evaluation from both the process and customer perspectives.

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