RFI RESPONSIVENESS OF PAPER-BASED VS. WEB-BASED INFORMATION PROCESSING SYSTEMS

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ABSTRACT

Information technologies (IT) have brought many changes to the construction industry. One of the most prevalent is the use of the internet as a vehicle for communication within project teams. Firms may adopt a web-based information processing system to reduce processing time and increase RFI transparency to all project participants. The hypothesis of this research is that a web-based information processing system may increase RFI responsiveness by design teams.

The research discusses three similar projects in terms of the type of building, project budget, and construction duration. One of the projects used a paper-based system, and the other two used a web-based system. The flow components were measured to analyze and compare the flow efficiencies of the selected cases. Therefore, the major objective of the research is to investigate the possible factors affecting the RFI responsiveness from the production perspective.

The results show that the key factor in achieving high level responsiveness is to increase the flow reliability. The research findings and results can help project teams to diagnose problem areas in their existing systems and to design better performing systems. In particular, flow-performance measures discussed in the paper will provide those using the system with universal and unalterable common metrics for the current state of the system and will help them evaluate and compare the performance of processes.

KEY WORDS

Flow reliability, Information technology, Service level, Variance-to-contractor want, Web-based project information processing.

BACKGROUND

Information flows in a construction project include the design and technical data, the contractual details, and the management facts needed to administer and control the project (Mead 2001). Most research findings have shown that the smooth and efficient movement of that information is one of the keys to managing successful construction projects (CII (Construction Industry Institute) 1997; Mead 2001).

Information technologies (IT) have brought many changes to the construction industry. One of the most prevalent is the use of the internet (i.e., World Wide Web, hereafter, web) as a vehicle for communication within project teams. Firms may adopt a web-based information processing system to reduce processing time and increase RFI transparency to all project participants. In this virtual space, all the people and firms involved in the project can access the system almost in real time. The

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hypothesis of this research is that a web-based information processing system increases RFI responsiveness by design teams. RFI responsiveness is the ability of the design team to respond within the contractor's expected response time for an RFI. Through this research, the author aims to either reject or accept the hypothesis, and then identify opportunities for improving the RFI responsiveness from the production perspective.

REQUEST FOR INFORMATION (RFI)

For the research, the author selected the RFI process. Among the different types of information created and exchanged between stakeholders and trades, the RFI is directly related to on-site production and is carefully controlled and maintained by contractors because of their significant impact on construction production delivery.

The 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 due. Any delay in the reviewer's (Architect/Engineering firm) response to an RFI can result in the contractor's delay, consequently resulting in a delay in the project as a whole.

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 significant 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) that may be a mechanical engineer, an electrical engineer, or a structural engineer. All of them will 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.

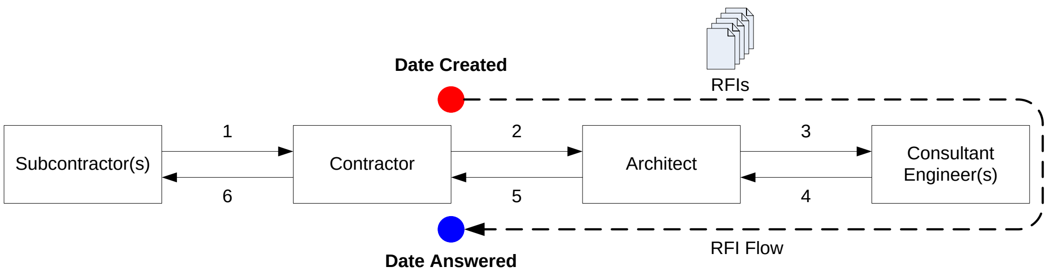

Figure 1: RFI Review Process Flow (Chin 2009b; Chin and Russell 2008b)

WEB-BASED RFI REVIEW SYSTEM

The flows of RFIs of both paper-based and web-based systems are the same except for two differences: document format and transmission method. In the conventional paper-based system, RFIs are generated in a paper format and exchanged using couriers (e.g., UPS, Fedex, etc.). In the web-based system, RFIs are created in electronic formats (e.g., doc, pdf, html, dwg, etc.) and exchanged electronically. The use of the internet is a powerful and rapid way to communicate and to exchange information. The web makes it possible for people to perform a wide variety of tasks quickly, to increase productivity, and to communicate more effectively. In recent years, many firms have adopted web-based information control systems to reduce processing time and increase RFI transparency to all project participants.

CASE STUDIES

For this research, the author selected three similar projects in terms of the type of building, project budget, and construction duration (see Table 1 below). Project delivery performance and control methods may differ depending on the type of owner, contract, and other characteristics. However, the research does not intend to analyze different RFI responsiveness level resulting from different delivery systems or contractual relationships. Instead, the research is intended to compare the RFI responsiveness on three projects by measuring the key flow metrics from the production perspective.

Table 1: Summary of Three Cases

Project	Project A	Project B	Project C
Company	Company 1	Company 2	
Type of Building	Laboratory	Laboratory + Hospital	Hospital
Owner	State Government	State Government	Private
Project Delivery System	Design-Build	CM at Risk	CM at Risk
Type of Contract	Lump Sum	GMP	GMP
Location	California, USA	Wisconsin, USA	Wisconsin, USA
Budget	$162 mil.	$144 mil.	$134 mil.
Construction Duration	36 mo.	38 mo.	40 mo.
Data Interchange Method	Paper-based	Web-based	Web-based
Sample Size (# of RFIs)	574	1,035	777

MEASURING PERFORMANCE OF RFI RESPONSIVENESS

As shown in Table 1, each project had different characteristics and system components. Each one also used different information process methods, i.e., one project used a paper-based system and the other two uses web-based systems. So merely comparing average review times (lead times) to determine which system is better or worse is meaningless because it is not an apples-to-apples comparison. Therefore, different metrics are needed which can universally and unalterably represent the properties of the RFI responsiveness.

VARIANCE-TO-CONTRACTOR WANT (VTW)

One of the most important considerations in any production system is that customers want to receive what they want not only quickly but also when they expect it (Muir 2006). Looking at the RFI process, the contactors want to receive the responses to RFIs not only quickly but also on time. The span shown in Figure 2 illustrates a measure of the width of the variation without any assumption of any particular type of statistical distribution. The Architect/Engineering (A/E) firms (who are the reviewers of RFIs) usually do not provide "Promised Due Dates" for each RFI. Instead, the contractor puts the expected response time (called hereinafter, "Contractor-Want-Time (CWT)") on each RFI. Hence, discrepancies between CWT and Actual Lead Times (ALT) occur and create gaps between the contractor's and the reviewer's requirements. This gap is called the Variance-To-Contractor Want (VTW). Measuring VTW will explain how capable the system is of meeting contractor's requirement and expectation.

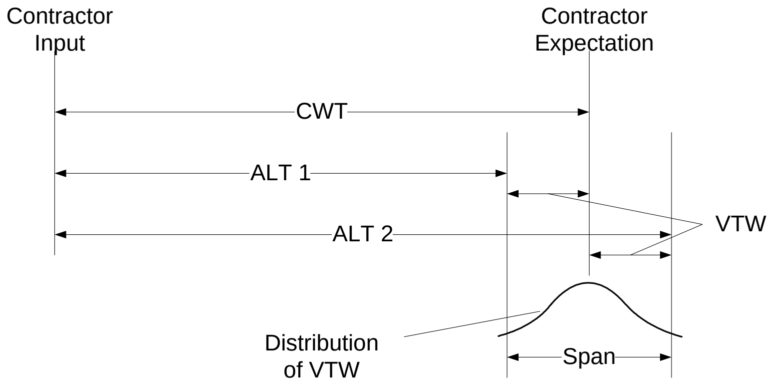

Figure 2: Variance-To-Contractor Want (VTW) (Muir 2006)

The CWT was tracked for each RFI of three projects and then VTWs were calculated from the differences between CWT and ALT. Following the usual convention, early responses are negative (-) while late responses are positive (+). For example, if the contractor wanted to receive the response from a design team by 03/20/2010 but actually received on 03/23/2010, the VTW of this RFI would be +3 days, i.e., response was made 3 days later than the contractor expected.

SERVICE LEVEL

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). These types of products and services are generally assembled, built, fabricated, customized, reviewed, or engineered in response to customer's requests (Hill 2007). The service level can be simply measured by calculating the percentage of RFIs that are completed within Contractor-Want-Time (CWT). For example, Project A data shows that only 274 out of 574 RFIs (48%) were responded to the contractor without delay, so the service level of Project A is 48%.

THROUGHPUT RATE (TH)

Throughput rate (aka, flow rate) is the output rate that the process is (expected) to produce over a period of time. In the RFI review system of Project A, the design team completed reviews of 574 RFIs in 238 days. Thus, throughput was 2.41 RFIs/day (574/238 days).

COMPARISON OF PERFORMANCE OF THE RESPONSIVENESS OF THREE PROJECTS

The RFI responsiveness was measured on three projects using ALT, service level, VTW, and TH (see Table 2 below). The average review completion times (= ALT) of three projects were 11.95 days, 15.50 days, and 15.54 days respectively. However, it is not clear that the responsiveness of Project A was better than those of Projects B and C. But by comparing their service levels, VTW and TH will help determine that the responsiveness of Project A is better than those of Projects B and C.

Table 2: Comparison of RFI Responsiveness

		Project A	Project B	Project C
Actual Lead Time (ALT) (days)	Average	11.95	15.50	15.54
	StdDev	11.60	25.22	28.44
	CV[2]	0.97	1.63	1.83
On-Time rate (service level, %)	Average	47.74	48.31	49.94
Variance-To-Contractor Want (VTW) (days)	Average	3.38	6.79	9.91
	Min	-36.50	-34.00	-18.00
	Max	86.00	265.00	212.00
Throughput (TH) rate (# of RFIs/day)	Average	2.41 (= 574 /238)	1.23 (=1,350/840)	1.04 (=777/750)

- The first evidence of better RFI responsiveness on Project A was lower VTW. The lower VTW means that the system was more capable of meeting the contractor's expectation. In addition, the maximum VTW of Project A (86 days) was much smaller than those of Project B (265 days) and C (212 days).
- The second evidence was throughput rate which was the most obvious indication of better RFI responsiveness on Project A. With 2.41 RFIs/day, Project A had almost a twofold higher throughput rate compared to that of the other two projects (1.23 and 1.036 respectively).
- The third evidence was service level. Service levels of all three projects were almost the same at 47.74%, 48.31% and 49.94% respectively. The web-based systems did not seem to be helpful in improving the service level.
- The fourth evidence was smaller variation. Project A's review time variation (CV = 0.97) was much smaller than those of Project B (CV = 1.627) and C (CV = 1.830). This means Project A had more consistent review times for the RFI process so the customer (contractor) could receive the responses from the reviewers in a more predictable manner.

[2] Coefficient of Variation. Hopp and Spearman 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. Hopp, W. J., and Spearman, M. L. (2000). Factory Physics: Foundations of Manufacturing Management, Irwin/McGraw-Hill, Boston, MA.

In summary, Project A had a shorter lead time along with a lower VTW, higher TH and higher service level. Therefore, it is definite that the RFI responsiveness of Project A was better than those of Projects B and C.

REASONS FOR LOW RFI RESPONSIVENESS LEVELS OF WEB-BASED SYSTEMS

It has been shown that the RFI responsiveness levels of two web-based systems were not superior to that of the paper-based system. Projects B and C had longer lead times, higher VTW, lower TH and lower service levels. What made their RFI responsiveness levels lower than was expected, even below a conventional paper-based system? The possible reasons can be seen from the production-level perspective. The major flow-level metrics were measured and summarized in Table 3.

Table 3: Comparison of RFI responsiveness in Flow Level

		Project A	Project B	Project C
Actual Lead Time (ALT) (days)	Average	11.95	15.50	15.54
	StdDev	11.60	25.22	28.44
	CV	0.97	1.63	1.83
Inter-arrival time of RFIs (days)[3]	Average	1.90	2.25	2.53
	StdDev	1.74	2.12	3.76
	CV	0.91	0.94	1.49
Batch size (# of RFIs)	Average	4.63	2.74	2.62
	Min	1	1	1
	Max	24	18	20
Average entity (RFI) rate into workstation per day (# of RFIs/day)	Average	2.44	1.22	1.04
Throughput (TH) rate (# of RFIs/day)	Average	2.41	1.23	1.04
Work-In-Progress (WIP) (# of RFIs)	Average	30.55	19.30	16.89
	Min	0	0	0
	Max	59	56	69

- Queueing Delay. This occurs when a number of entities arrive for service at a server or servers that have limited capacity, and the entities must wait until a server becomes available (Hopp and Spearman 2000; Lambrecht and Vandaele 1994). One of the well established general types of queuing models, where the arrival time and service time can take on any probability distribution, is the G/G/1 model (Hopp 2006). The first G denotes the distribution of inter-arrival times, the second G denotes the distribution of effective process times, and the number 1 describes the number of servers at the workstation.

$$W_q^{G/G/1} \approx \left(\frac{c_a^{\,2} + c_s^{\,2}}{2}\right)\left(\frac{\rho}{1-\rho}\right)\tau = V \text{ x } U \text{ x } T$$

[3] Inter-arrival times are simply the times between the arrivals of entities (RFIs) to the process.

The equation is also known as the VUT[4] equation or Kingman's equation, named after one of the first queuing researchers to propose it (Hopp 2007). In the equation, C_a, C_s, ρ, and τ denote the inter-arrival time's Coefficient of Variation[5] (CV), the process time CV, utilization, and average process time, respectively. The expression gives that queuing delay consists of the multiples of variation in the inter-arrival time and process time, utilization and average process time. (Hopp 2007; Hopp and Spearman 2000; Hopp et al. 1990).

In Project A, an average of 4.63 RFIs (in the form of batch) arrived at the review system every 1.90 days. Hence, the average entity rate into the workstation was 2.44 RFIs per day (4.63 RFIs per 1.90 days). The capacity is equivalent to the throughput rate if the system reaches its maximum capacity (Hopp and Spearman 2000). We can find that Project A was incapable of keeping up with the arrival rate (the average entity rate into the workstation) of RFIs because 2.44 (arrival rate) > 2.41 (TH) without considering other factors affecting queuing delay. So the work in progress (WIP) built up over time to an average of 30.55 RFIs and a maximum of 59 RFIs. Then the utilization of the review system of Project A would reach 100% and in theory, WIP can increase infinitely. However, we can see different queuing delay profiles of Projects B and C. Even though their average RFI arrival rates were less than or equal to their throughput rate, i.e., capable of keeping up with the arrival rates, Projects B and C experienced queueing delays due to the high variability in the inter-arrival time and process time.

- Variation of Flow Time. As shown in Table 3, the inter-arrival and the processing patterns of each project were different. Projects B and C had higher CVs in both inter-arrival time and process time than Project A. So Projects B and C were more affected by flow variation, i.e., less steady (predictable or reliable) process flow. In general, inter-arrival time can be affected by vendor quality (e.g., the skill level of the subcontractor 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 malfunctions), 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 (Chin 2009a; Hopp 2007).

- Work In Progress. 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. In Project A, the average number of RFIs per day was 30.55, which means the reviewer had an average of 30.55 RFIs to review each day. Projects B and C also can be interpreted in the same manner as Project A. However, it is interesting to note that Projects B and C performed worse than Project A even though their WIP levels were much lower than Project A. This is because their flow variations—

[4] VUT implies **V**ariation, **U**tilization, Process **T**ime Factors, respectively.

[5] Coefficient of variation is the ratio of the standard deviation to the mean and is unitless because the mean and standard deviation have the same units.

variations in the inter-arrival time and process time—were much greater than that of Project A.

- 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 the causes of the high level of WIP was batching, particularly arrivals of batches at a single workstation (Hopp and Spearman 2000). One might think that the variation in a batch arrival was zero because batched entities arrived at a workstation simultaneously. However, if the inter-arrival times of each entity in the batch are examined from the perspective of the individual RFIs, a very different picture emerges (Hopp and Spearman 2000). For example, in the RFI process of Project A, an average of 4.63 RFIs were batched and delivered to the reviewer at the same time, but the reviews were 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 was 1.90 days. For the next 3.63 RFIs (4.63-1), it was zero. Hence, the mean time between arrivals was 0.41 days (1.9 days divided by 4.63 RFIs), and the variance of these times was 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 was:

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

The CV of 1.9 falls within the high variation (HV) range, according to Hopp and Spearman's classification. So the batching effect, together with the combined effects from inter-arrival and process time variations, increased the flow variation to a great extent and degraded the system performance, resulting in longer cycle times. An ideal batch size would have been 1 since replacing the average batch size in Equations (1) and (2) results in CV= 0. Hence, no variation resulting from batch arrival occurred. So the one-piece flow concept has many benefits over such batching, one of which is a shorter lead (cycle) time by keeping work-in-process at the lowest possible level (Hopp and Spearman 2000). Chin and Russell (2008a) discussed the significant impact of batch processing in the context of queueing behavior.

IMPROVEMENT STRATEGIES

The possible reasons for lower RFI responsiveness levels of Projects B and C were discussed in the previous section. Based on this, any improvement strategies should be directed to decrease the variation, lower the utilization, reduce the process time, and reduce WIP level.

- Decreasing variation. Two variation components that cause waiting in the line were identified, i.e., inter-arrival and process time variations. As summarized in Table 3, all three projects had at least moderate and high variations in both inter-arrival time and processing time. Project A had lower CVs in both inter-arrival time and process time than the other two projects, which meant that Project A had a more reliable flow time. Directing an improvement effort toward making these variation components more consistent would lower the variation. Among the many techniques dealing with variation, a load leveling technique can be used to alter the distribution of arrival times, and standard setup alters the distribution of execution times (Muir 2006).

- Lowering utilization. Utilization is the fraction of time a workstation is not idle for lack of parts. In theory, as utilization reaches 100%, queuing delay would approach infinity. Utilization is computed as: Utilization (ρ) = Entity Rate into workstation / Capacity of workstations (Hopp and Spearman 2000). Entity rate into workstation is equivalent to the entity inter-arrival rate, and capacity of a system is the maximum average rate at which entities can flow through the system. Therefore, there are two options for lowering utilization, 1) reducing entity rate-in or 2) increasing the capacity of workstations. One way to reduce entity rate-in is to reduce the number of entities arriving at a workstation by reducing the number of RFIs by means of Kanban (pull), Heijunka and One-piece flow of the Toyota Production System (Hopp and Spearman 2000; Muir 2006). One way to increase the capacity of a work station is to assign more reviewers, train reviewers to improve their skills, and increase reviewer's available time.
- Reducing process time. Process time can be reduced by either direct or indirect methods. The direct method increases capacity by increasing the number of servers or workstations, such as by assigning more engineers to the RFI review process. The indirect methods include standardization, automation, training workers, and minimizing or eliminating waste.
- Reducing WIP. 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 improving synchronization (Hopp and Spearman 2000).

Unlike Projects B and C, Project A had a higher WIP level. Therefore, the Project A management team should focus on WIP reduction for further improvement. Recalling Little's Law, WIP=CT x TH, if they could reduce the WIP level by one-half, they would have a two times faster RFI processing system without a change of TH (Little 1961).

CONCLUSION

Throughout the research, it was observed that web-based systems on GMP, CM at Risk projects did not improve RFI responsiveness over paper-based systems on Lump Sum, Design-Build projects. The research investigated the RFI responsiveness solely from the production perspective without consideration of such other perspectives as delivery system, contractual relationships, owner, etc. These might affect the RFI responsiveness because they can establish incentives where project participants have to be responsive to others, possibly resulting in a greater influence on RFI responsiveness than the use of a web-based system. However, the research provided some facts that disproved the hypothesis—a web-based information processing system may increase RFI responsiveness by design teams. In order to more accurately or soundly prove or disprove this hypothesis, the future research should conduct a case study with projects that are nearly identical in scope, project delivery, contract type, owner, etc. that would strongly support such a conclusion. The research clearly argued that the key factor in achieving high RFI responsiveness is to increase the flow reliability.

The research findings and results can help project teams to diagnose problem areas in their existing systems and to design better performing systems. Moreover, the results can also be used to establish a baseline for setting up a target for improvement. In particular, flow-performance will provide those using the system with universal and unalterable common metrics for the current state of the system and will help them evaluate and compare the performance of processes.

REFERENCES

Chin, C.-S. (2009a). "Queueing Theory and Process Flow Performance." Proc. of the 17th Annual Conference of the International Group for Lean Construction (IGLC 17), July 15-17, Taipei, Taiwan, 247-256.

Chin, C.-S. (2009b). "Work-in-Process and Construction Project Information Flows." Proc. of the 17th Annual Conference of the International Group for Lean Construction (IGLC 17), July 15-17, Taipei, Taiwan, 257-266.

Chin, C.-S., and Russell, J. S. (2008a). "Identifying Significant Factors Affecting Request For Information (RFI) Process Time." Proc. of Winter Simulation Conference 2008 (WSC08), December 7-10, Miami, FL, 2488-2496.

Chin, C.-S., and Russell, J. S. (2008b). "Predicting the Expected Service Level and the Realistic Lead Time of RFI Process using Binary Logistic Regression." In: Dainty, A (Ed.), 24th Annual ARCOM Conference, 1-3 September 2008, Cardiff, UK. Association of Researchers in Construction Management, Vol. 2, 739-48.

CII (Construction Industry Institute). (1997). "An Assessment Tool for Improving Project Team Communications." University of Texas at Austin, Report 105-11.

Hill, A. V. (2007). The Encyclopedia of Operations Management, Clamshell Beach Press, Minneapolis.

Hopp, W. (2006). Single Server Queueing Models, to appear in When Intuition Fails: Insights from Simple Models, Dilip Chhajed, Tim Lowe (eds.), Springer, New York, Available at http://webuser.bus.umich.edu/whopp/publish.htm, Visited on Feb 18, 2009.

Hopp, W. (2007). Supply Chain Science, McGraw-Hill/Irwin.

Hopp, W. J., and Spearman, M. L. (2000). Factory Physics: Foundations of Manufacturing Management, Irwin/McGraw-Hill, Boston, MA.

Hopp, W. J., Spearman, M. L., and Woodruff, D. L. (1990). "Practical Strategies for Lead Time Reduction, American Society of Mechanical Engineers." Manufacturing Review, 3(2), 78-84.

Lambrecht, M., and Vandaele, N. (1994). "Queueing Theory and Operations Management." Tijdschrift voor Economie en Management, XXXIX(4).

Little, J. D. C. (1961). "A Proof for the Queuing Formula: $L=\lambda W$." Operations Research, 9, 383-387.

Mead, S. P. (2001). "Developing Benchmarks for Construction Information Flow." Journal of Construction Education, 6(3), 155-166.

Muir, A. (2006). Lean Production Six Sigma Statistics-Calculating Process Efficiency in Transactional Projects, McGraw-Hill, New York, NY.