IDENTIFYING ROOT CAUSES OF LONG REVIEW TIMES FOR ENGINEERING SHOP DRAWINGS

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ABSTRACT

Every construction project requires approved shop drawings. Design drawings do not show details required for installation, so (sub)contractors cannot construct/install without approved shop drawings. Shop drawings are generally produced by subcontractors and should be reviewed and approved by appropriate parties promptly in order to avoid production delays. Observations on the shop drawing review process reveal that engineering review times of such major construction components as structural steels and reinforcing bars are unnecessarily long and often fail to meet the time frames within which contractors expect to receive responses from the design team.

The primary goal of the study is to identify and speculate about possible measures for eliminating the root causes of long review times for engineering shop drawings. Since it is not a simple task to identify and eliminate root causes of any problem because problems are always coupled with their business and work processes, the study uses a systematic problem-solving technique: problem understanding, problem-cause brainstorming, problem-cause data collection and analysis, and root-cause identification. The study reveals that the root cause of long engineering review time is insufficient and unclear information, rather than capability or availability of reviewers.

KEY WORDS

Engineering review, problem solving, root causes, shop drawings

INTRODUCTION

As the design of projects produce ever more complex building systems, more specialty design and construction contractors get involved, increasing the number of organizations involved in projects and the possibility of disputes. Among the different types of information created and exchanged between stakeholders and trades, shop drawings are directly related to on-site production and are carefully controlled and maintained by contractors because of their significant impact on construction production delivery.

A problem is often the result of multiple causes at different levels (Andersen and Fagerhaug 2006); some causes affect other causes that, in turn, create the visible problem. Causes can be classified as symptoms, first-level causes, and higher-level causes (Andersen and Fagerhaug 2006), and the highest-level causes are often called the root causes. We first conducted brainstorming sessions with the purpose of identifying and understanding the possible problem-causing areas. Then we collected the real data to verify the facts offered during the brainstorming sessions. For the

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study, the author selected three engineers from a medium-sized engineering firm with whom to conduct the root-cause analysis. The different types of delivery systems (e.g., design-build or design-bid-build etc), owners, contracts, etc. present important contexts that each affect the engineering review time in a different way. However, the purpose of the study is not to analyze different performance levels resulting from different delivery systems or contractual relationships but to identify the commonly occurring causes for long review times of engineering shop drawings by measuring the delay time and frequency, and then estimating the impact of each specified cause.

PROBLEM UNDERSTANDING

Many of the problems that occur in organizations are coupled with their business and work processes. Hence, understanding a process flow is a good starting point from which to evaluate the problem areas (Andersen and Fagerhaug 2006). Figure 1 represents the typical shop drawing review and approval process, along with times spent for each step and the focal area for the study. Shop drawings are generally produced by fabricators or manufacturers. Once produced, the drawings should be reviewed and approved by appropriate parties in order to insure that they conform to the design requirements. For instance, rebar shop drawings should be reviewed by both an architect and a structural engineer because incorrectly installed rebars can affect both architectural and engineering requirements. If the shop drawings conform to the design requirements, they are approved and released to the fabricator for fabrication and construction. If not, they should be carefully reviewed and reproduced by the fabricator for approval.

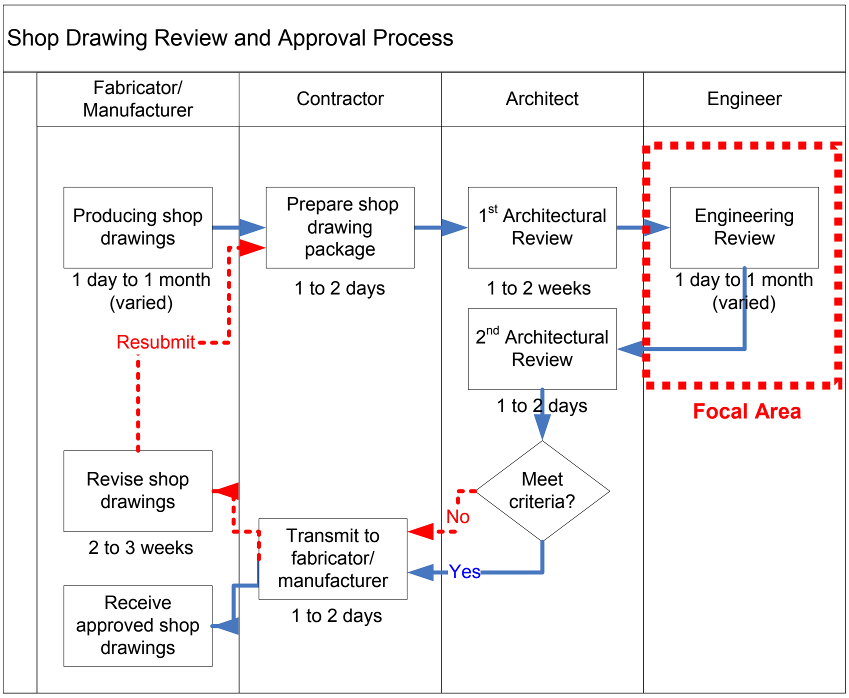


Figure 1: Overall Shop Drawing Review and Approval Process

Observation of the practical shop drawing production and approval process shows that the average total lead time required is approximately two (2) months from job order receipt to final approval. The engineering review time is a much larger part of that lead time than are other steps (e.g., preparation of shop drawing packages, architectural reviews) and sometimes accounts for over half of the total lead time. In addition, the engineering review times of such major construction components as structural steel and reinforcing bars vary greatly, are usually unnecessarily long, and often fail to meet the time frames in which contractors expect to receive responses from the design team. Hence, the study focuses on the engineering review process and investigates the common causes for the long engineering review time (see Figure 1).

KEY STAKEHOLDERS AND CUSTOMER NEEDS

After understanding the overall process flow, we constructed a simple process map using the SIPOC (Supplier, Input, Process, Output and Customer) diagram, which defines the key stakeholders who are affected by the current process (Figure 2): customers (those affected by the output of the process), suppliers (those who provide input to the process) and workers (those who work and manage the process). The purpose of the shop drawing review process is to ask why each process is important and adds value to the customer: the answer should be because it provides clear and complete information for fabrication or manufacturing of construction components in a timely manner without missing design criteria (requirements) described in the project information.

The customer needs to receive review results for each shop drawing on time, and customers tend to expect a response from the reviewer within a week, which includes the lead times for the 1st- and 2nd-architectural and engineering reviews. In general, both parties (contractor and owner) agree on a minimum review time before starting a project, but the minimum review time is usually determined based on their past experiences, without considering the system's capability. The agreed-upon minimum review time is typically unrealistically short (7 days), and the reviewer is often incapable of meeting the contractor's expectations. More detail on this issue will be presented later in the paper.

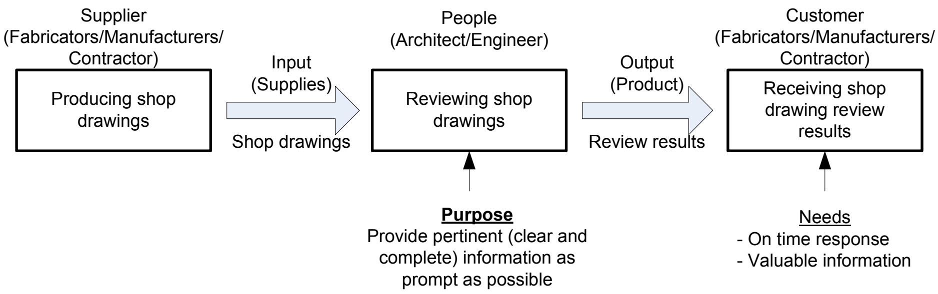


Figure 2: SIPOC Model for Shop Drawing Review Process

MEASURING CUSTOMER SATISFACTION

The service level for response to a customer's requests can be measured as a percentage of jobs that are completed on or before the time the customer expects to receive them. Products and services are generally assembled, built, fabricated, customized, reviewed or engineered in response to customer's requests (Hill 2007), so we can measure the service level simply by calculating the percentage of shop drawing reviews that are completed within the time requested by the customer. The data from the study shows that the engineering review takes 6.98 days on average, and ranges from 24.25 days to 0.16 days. Out of 29 shop drawings, 20 were reviewed by engineers within 7 days. Since the customer's requirement is usually 7 days for both architectural (1st- and 2nd reviews) and engineering reviews, including the architectural review time would make the service level (i.e., on-time rate) much lower.

BATCH PROCESSING

Another observation from the current process is that shop drawings are not usually sent to the designer one at a time, but in batches. For instance, one submission may be two 8½ x 11 pages that include only miscellaneous angles on the job, while another may be 30-30 x 42 sheets that include all of the structural columns and beams. There should be some correlation between the substance—project-specific, contractor-specific, material-specific, and so on—of the shop drawing being reviewed and the review time. However, even if the shop drawings are produced in different volumes, there is no explanation, outside of "this is how we've always done it, for why shop drawings are transmitted to reviewers in batches. The one-piece flow concept has many benefits over such batching, one of which is shorter lead (cycle) time by keeping work-in-process at the lowest possible level (Hopp and Spearman 2000).

PROBLEM CAUSE IDENTIFICATION AND ANALYSIS

Once the participants (engineers) understood the process flow, they were all asked about the possible causes for delays in engineering shop drawing review time by way of a brainstorming session. The objectives of brainstorming are to generate a list of problem areas and possible causes, and to identify possible consequences resulting from the problems to be analyzed. In the first round of brainstorming, participants, participants were asked to rank the 1st-level possible causes using a 100-point allocation method in order to find the focal area. Each individual was to allocate 100 points to each category based on its severity in the shop drawing reviewing process.

Table 1: 1st-Level Possible Causes and 100 Points Allocation Results

1st-level possible causes	100 Points Allocation				Rank
	Engineer 1	Engineer 2	Engineer 3	Total	
Schedule	60	50	40	150	1
Project coordination	30	30	40	100	2
Procedure	10	20	20	50	3
Total	100	100	100	300	

As shown in Table 1, the "schedule" category ranked as the most significant cause, so it was selected as a starting point for further analysis. However, the second-highest 1st-level cause (project coordination) also should be investigated further because the result of point allocation indicated that it is also significant, especially compared to the lowest scoring category (procedure). Then the second round of brainstorming was conducted to develop the higher level possible causes and to prioritize them. Based on the perception data showing possible problem areas, two questions concerning frequency and time were asked in order to verify their perceptions. From the impact analysis of frequency and time delay, three major problem causes were identified: lack of architectural information, architectural revisions during the engineering review process, and unclear items in Request For Information (RFI) not addressed (Appendix 1 & Table 2).

Table 2: Workload vs. Impact Rank by Perception

1st-level possible causes	2nd-level possible causes	Rank by perception		
		Freq. (F)	Avg. delay time (D)	Impact (F)x(D) in 10 Shops
Schedule	Tight schedule (resulting in insufficient time)	6	None	None
	Submittals after the fact	7	None	None
	Poor planning by GC	2	None	None
Project coordination	Architectural revisions during the engineering review process	3	4	3
	Lack of architectural information	1	2	1
	Coordination items with architect	8	1	4
	Unclear items in Request For Information (RFI) not addressed	3	4	3
Procedure	Copying red marks	3	3	2

PROBLEM CAUSE DATA COLLECTION AND ANALYSIS

To verify the perceived facts offered during the problem-cause brainstorming step, ***real data*** was collected. The perceptual data gathered during the brainstorming session was reliable for revealing problem areas, but it was based on perception, rather than actual data. Hence, systematic collection of valid and reliable data is necessary for meaningful analysis (Andersen and Fagerhaug 2006). The tools used in this step can include sampling, surveys, and check sheets. A check sheet that was developed to gather the data from 29 shop drawings (see Appendix 2) includes the delay time that is due to the second-level causes identified during perceptual data collection (Table 3). "Delay time" indicates the amount of time that engineer(s) lost (i.e., time in which they did nothing for the shop drawings) as a result of each possible cause specified.

Table 3: Summary of Real Data Collection and Results

1st-level possible causes	2nd-level possible causes	Freq. (times)	Avg. delay time (hr)	Freq. x Avg. delay time (hr)	Rank
Schedule	Tight schedule (resulting in insufficient time)	0	0.00	None	n/a
	Submittals after the fact	1	0.25	0.25	7
	Poor planning by GC	2	64.00	128.00	3
Project coordination	Architectural revisions during the engineering review process	3	92.00	276.00	2
	Lack of architectural information	1	6.00	6.00	6
	Coordination items with architect	4	3.25	13.00	5
	Unclear items in Request For Information (RFI) not addressed	0	0.00	None	n/a
Procedure	Copying red marks	10	2.58	25.80	4
Others	Delay caused by late input from GC and suppliers	3	96.00	288.00	1
No delay	No Delay	12	0.00	None	n/a
	Summary	36*			

Note*: The number of causes is larger than the number of samples because some shop drawings have multiple causes for delay of engineering review.

In terms of frequency, the most significant cause was procedure, specifically, copying red marks. ("Copying red marks" was excluded from the major problem causes because it is a unique case of the particular engineering firm involved in this study.

However, this is obvious “low hanging fruit” for this particular engineering firm.) The next most significant causes were identified in the order of 1) coordination items with architect, 2) architectural reviews during the engineering review process, and other causes, and 3) poor planning by GC. Here, “other causes” include late provision of necessary product information by suppliers and fabricators.

If we considered only frequency in determining root causes, we could miss important information because frequency tells only how many times specific causes make delays and does not consider the amount of time delayed. Thus, we should also consider the delay time of each cause in order to determine which cause most significantly affects the total engineering review time. Hence, frequency x delay time was used to measure impact, and the major causes were identified as 1) Other causes, 2) Architectural revisions during the engineering review process, and 3) Poor planning by GC. There was a huge difference between perception and data results in terms of average delay time. For instance, engineers answered that no delay time was caused by poor planning by GC, but actual delay time from that cause was 64 hours (8 days). Table 4 compares the causes in terms of perception vs. real data.

Table 4: Ranks of Causes by Perception vs. Real Data

1st-level possible causes	2nd-level possible causes	Rank by perception			Rank by real data
		Freq. (F)	Avg. delay time (D)	(F)x(D)	
Schedule	Tight schedule (resulting in insufficient time)	6	*	*	*
	Submittals after the fact	7	*	*	7
	Poor planning by GC	2	*	*	3
Project coordination	Architectural revisions during the engineering review process	3	4	3	2
	Lack of architectural information	1	2	1	6
	Coordination items with architect	8	1	4	5
	Unclear items in Request For Information (RFI) not addressed	3	4	3	*
Procedure	Copying red marks	3	3	2	4
Others	Delay caused by late input from GC and suppliers	n/a	n/a	n/a	1

ROOT CAUSE IDENTIFICATION

Thus far, we have identified the possible causes of problems with drawing reviews, but not the root causes. Even if the first- and second-level causes lead to the problem, sometimes they do not directly cause the problem (Andersen and Fagerhaug 2006). In order to uncover the root causes, we need to analyze the chain of cause-and-effect relationships that ultimately create the problem (Andersen and Fagerhaug 2006; Finster 2006). To do so, we distributed a short questionnaire in which participants were asked to give examples of each possible cause. We chose this approach because, if we tried to determine the root causes based on the results from the problem understanding and data-gathering sessions alone, a considerable amount of valuable information would remain hidden (Finster 2006). Hence, we asked the participants about the most typical (common) example for each possible cause and then summarized the responses in Appendix 3.

Based on the findings summarized during the questionnaire session, we conducted cause-and-effect analysis with the Ishikawa diagram (aka the fishbone diagram or the C&E diagram) by relating possible root causes with findings (Ishikawa 1982). The fishbone diagram shown in Figure 3 represents the cause-and-effect relationships that ultimately create the problem for each possible cause.

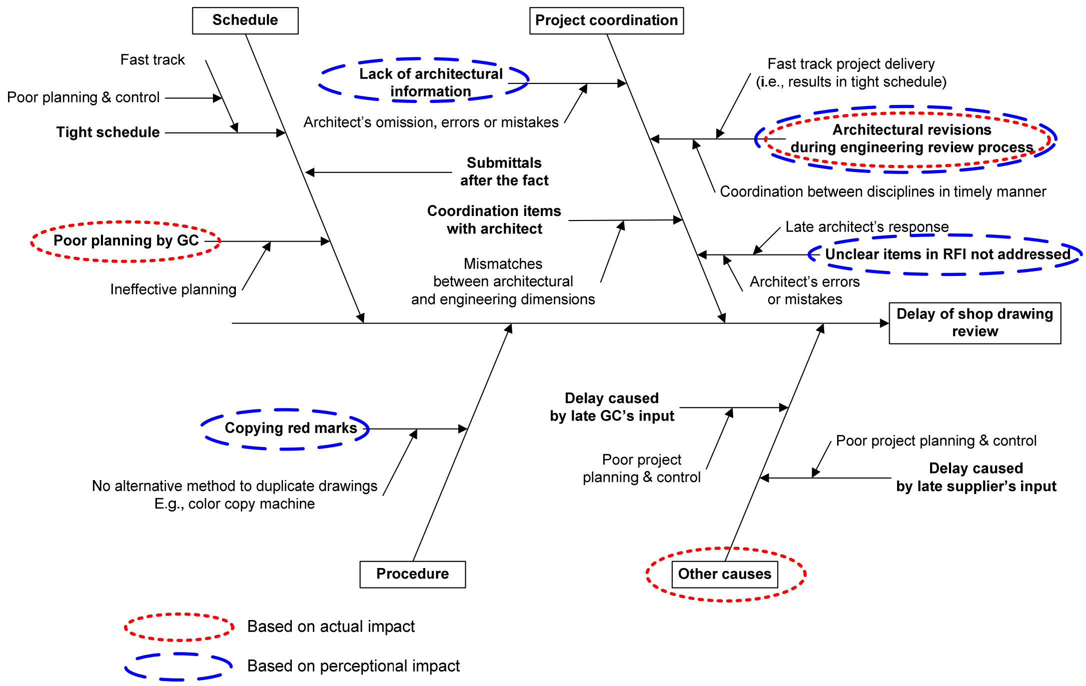


Figure 3: Cause-and-Effect Relationships and Three Focal Areas Based on Impact by Perception and Real Data

Another tool for identifying the root causes is the "5 whys" method. Ohno (1988) described this method as asking why *"five times whenever we find a problem. . . By repeating why five times, the nature of the problem as well as its solution becomes clear."* By repeatedly asking "why?" we can get past the symptoms and find the root cause of a problem. (In practice, the question may need to be asked fewer or more than five times.) Despite its powerful function, the 5 whys method has been frequently criticized, including by Teruyuki Minoura, former managing director of global purchasing for Toyota (Toyota Motor Corporation 2003). Minoura stated that the 5 whys method can result in investigators' stopping at symptoms, rather than going on to higher-level root causes; the five whys are dependent on the investigator's current knowledge since one cannot find causes of which they are not already aware or if one doesn't ask the right "why" questions or if results aren't repeatable. Different people using the five whys will come up with different causes for the same problem. Minoura also emphasized the importance of direct observation from the actual place where the problem occurs, rather than relying solely on deduction. To respond to Minoura's concerns and suggestions, we used a combination of fact-based and perception-based cause-and-effect analyses. We made this choice because the use of factual data alone can lead to the loss of chances to observe causes that may have great impact but that might not be observed during a 7-month actual data-gathering period. Perceptual data can help investigators identify such causes because people remember the significance of the impacts. Thus, the study used a combination of factual and perceptual data analysis and shows some discrepancy between perceptual and real data in the study.

OTHER CAUSES

"Other causes" include late follow-up or input by the GC or suppliers. This specific cause occurred three times over 7 months, but the resulting average delay time was 96 hours. Hence, the impact of this cause makes up 288 hours of delay in review times over a period of about 7 months (23% of the total available hours during the data-gathering period for which data was gathered, i.e., 288/1,256[2] hours). This is a significant waste of time because the engineer does nothing on shop drawings that lack required information. This category was not discovered during the perceptional data collection session.

ARCHITECTURAL REVISIONS DURING THE ENGINEERING REVIEW PROCESS

Engineers had ranked architectural revisions during the engineering review process as second among the first-level causes for long review times. However, real data collected shows that this is the second most significant cause as a whole. Like "other causes," it occurred three times during the data-collection period, but its average delay time was marginally than that of "other causes." The total estimated delay time was 276 hours during the data-collection period (i.e., 22% of total available hours during the data-gathering period).

LACK OF ARCHITECTURAL INFORMATION

Lack of architectural information was ranked as the most significant cause from engineers' perception, but real data collected showed that it is the 6th more important cause. Lack of architectural information occurred just once during data gathering period, causing a delay of 6 hours. When this problem happens, engineers usually call the architect by telephone and clarify missing information immediately. However, we will include this possible cause as a top priority because of the possibility that it may have a large impact on review time by chance.

POOR PLANNING BY GC

Poor planning by the GC was ranked first among the possible causes during the perceptional data gathering session but was identified as the third most significant cause of time delay from the data gathered. It occurred twice during the data-gathering period, with an average delay time of 64 hours, or 128 hours' delay over the 7-months data-gathering period (i.e., 10% of total available hours during the data-gathering period).

UNCLEAR ITEMS IN REQUEST FOR INFORMATION (RFI) NOT ADDRESSED

Engineers' perception ranked "Unclear items in Request For Information (RFI) not addressed" as one of the top three causes for delay in shop drawing reviews, but the real data showed no evidence of any delay caused by unclear items in Request For Information (RFI) not addressed during the data-gathering period. However, we will include this possible cause as a top priority for the same reason as we did "lack of architectural information case."

[2] From February 27, 2008, to October 2 (3+21+22+22+21+23+21+22+2 = 157 days, 1,256 hours (157 days x 8 hours/day))

POSSIBLE SOLUTIONS TO ELIMINATE THE ROOT CAUSES OF LONG ENGINEERING REVIEW TIME

Identification of root causes is not at its end until the root cause has been eliminated by finding a solution to the problem (Andersen and Fagerhaug 2006). However, finding a solution requires creative thinking and approach. We conducted another session of brainstorming and asked participants about possible solutions to the root causes and to relate them to available technologies and concepts.

"Other causes" result primarily from suppliers' late or absent responses to engineers regarding the information for specific items. Hence, an improvement effort should be directed to increase the promptness and quality of information transmitted between engineering firms and suppliers. A possible approach would be to establish an integrated information system such as Electronic Data Interchange (EDI), which provides a set of standards for structuring information that is to be electronically exchanged between and within businesses, organizations, entities and other groups. More advanced technology would also include Building Information Modeling (BIM), which makes it possible for project team members to generate and exchange information at all stages of project delivery (Autodesk 2009). A reduction in such suppliers' late or absent responses to engineers regarding the information for specific items can be achieved by using the Last Planner^{TM} system, whose focus is to make work ready so that, as tasks are coming up to be performed, all constraints to performing the task are resolved prior to the start of the task, e.g., availability of competent staff, materials, tools, specifications, authorizations (Ballard 2000).

"Architectural revisions during the engineering review process" is due primarily to the lack of coincidental information shared among project team members. Like the case of "other causes," this cause can be eliminated by adopting EDI or BIM, which will allow all the trades, parties, and stakeholders in a project to share information in real time.

"Lack of architectural information" is the result of omissions, errors and mistakes made by the architect. A reduction in such omissions, errors and mistakes can be achieved by using the Last Planner^{TM} system or by establishing EDI or BIM.

"Poor planning by GC" may result from the minimum review time's being determined based on the GC's past experiences (Chin and Russell 2008). The agreed-upon minimum review time is typically unrealistically short, often rendering the reviewer incapable of meeting the contractor's expectation. Hence, one solution would be use the Last Planner^{TM} as a better planning and controlling function.

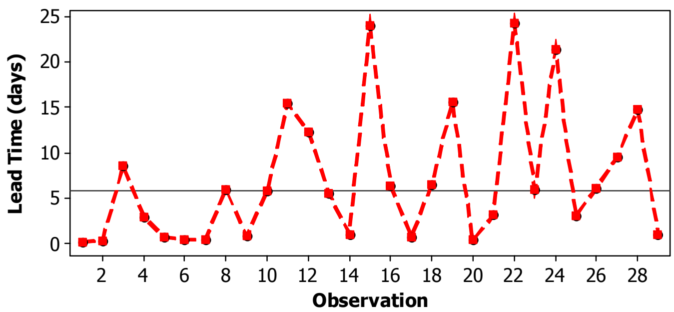
"Unclear items in Request For Information (RFI) not addressed" can also be addressed by using the Last Planner system or BIM in order to clarify muddy or add missing items in shop drawings before they are submitted to the A/E firm.

DISCUSSION – "HOW LONG IS NECESSARY?"

Even after identifying and eliminating the root causes for long engineering review times, a critical question would remain: "How long is necessary?" In order to answer this question, we should relate the question to "What do customers want?" (the voice of the customer), and then compare what customers want to process capabilities (the voice of process). This approach will eventually lead to a determination of whether the process is capable of meeting customers' requirements. An essential part of this approach is knowing how customer demand determines the business process capability since misunderstanding either customer expectations or process capabilities will lead to a wide range of variation (Muir 2006). However, it is obvious that, if the process is not capable of meeting customers' expectations, the process must be improved.

As we observed, the customer's expectations for the process is 7 days, but the average actual engineering review time of about 7 days does not include the time required for the 1st and 2nd architectural review. Thus, the current review system is not capable of meeting customer expectations. However, customer satisfaction involves not only the average delivery time, but also the difference between the actual and the expected time for the customer to receive products or services (Muir 2006). That is, even if average delivery times were constant, customers are not satisfied with products or services provided if the delivery times are not predictable because they vary widely, as observed in the case. Therefore, it is not so much the average review time that must meet customer expectations as it is that the variation must be low.

We can think of two different strategies by which to increase the service level: 1) increase the customer's expected response time or 2) reduce the average process time and its variation. However, merely changing the customer's expectation to a longer response time would not be a substantial solution, because the system has a natural tendency to generate a wide range of variation. Hence, reducing the average process time and variation is the only viable solution for increasing service levels. In order to visualize what may cause the wide range of variation, we constructed a run chart to find evidence of special causes of variation prior to determining the range of process outputs (Figure 4). Special causes arise from outside the system and cause recognizable patterns, shifts, or trends in the data (Minitab Inc. 2004). As Figure 4 shows, the actual number of runs is not greatly different from the expected number of runs, and the p-values for clustering, mixture, trends, and oscillation are greater than the α-level of 0.05 (Minitab Inc. 2004). Therefore, we can conclude that the data does not indicate any temporal patterns, that is, no evidence of special causes of variation.



Number of runs about median:	15
Expected number of runs:	15.48276
Longest run about median:	4
Approx P-Value for Clustering:	0.42747
Approx P-Value for Mixtures:	0.57253

Number of runs up or down:	16
Expected number of runs:	19.00000
Longest run up or down:	3
Approx P-Value for Trends:	0.08619
Approx P-Value for Oscillation:	0.91381

Figure 4: Run Chart of Engineering Review Time (Days)

Assuming, then, that no special causes are responsible for the variations in the process, we constructed an I-Chart to determine the "voice of the process"—the natural range of process outputs (Figure 5). The lower boundary (LB) of "0" was set because we are studying the review time, and no times less than zero are possible. The I-Chart indicates that the process is operating in the range of 0 to 29.24 days, with an average of 6.98 days. Therefore, the voice of customer (customer's expected response time) should be 29.24 days in order for the process to be fully capable of meeting customer requirements. Inclusion of 1st-and 2nd-architectural review times will increase this range.

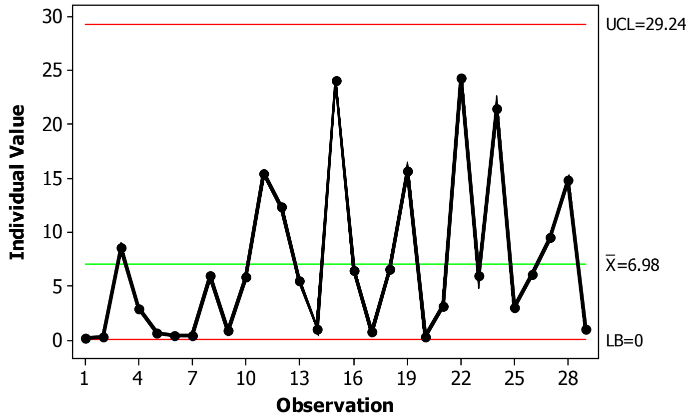


Figure 5: I-Char of Engineering Review Time (Days)

CONCLUSION

Despite some discrepancy found between perceptional and real data gathering sessions, information-related causes (i.e., late, missing, insufficient, and unclear information at the point when the reviewer starts reviewing) are the root causes that significantly affect engineers' shop drawings review time. Identifying root causes is not a simple task because process steps and flows are usually interwoven, but the study shows the usefulness and effectiveness of a systematic problem-solving technique in discovering the underlying root causes of long engineering review times. In addition, the study suggests possible solutions, particularly the use of EDI, BIM, and Last PlannerTM. Further research should include performance evaluations like before-and-after analysis to verify that the findings are valid and the suggested solutions effective.

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APPENDIX 1: IMPACT ANALYSIS BASED ON PERCEPTIONAL FREQUENCY AND TIME DELAY

1st level possible causes	2nd level possible causes	Frequency (% of shop drawings)				Time delay				Impact (F)x(D) in 10 shop drawings review (days)
		Engineer 1	Engineer 2	Engineer 3	Avg. (F)	Engineer 1	Engineer 2	Engineer 3	Avg. (D)	
Schedule	Tight schedule (resulting in insufficient time)	15%	50%	50%	50%	None	None	None	None	0
	Submittals after the fact	75%	Various	10%	43%	None	None	None	None	0
	Poor planning by GC	10%	75%	75%	75%	None	None	None	None	0
Project coordination	Architectural revisions during the engineering review process	10%	80%	60%	70%	1 day	Various	1-2 days	1.5 days	10.5
	Lack of architectural information	80%	75%	20%	78%	1-2 days	Various	2-3 days	2.5 days	19.5
	Coordination items with architect	25%	n/a	15%	20%	0.5 day	Various	4-5 days	2.75 days	5.5
	Unclear items in Request For Information (RFI) not addressed	60%	Seldom	80%	70%	1-2 days	Various	1 day	1.5 days	10.5
Procedure	Copying red marks	50%	n/a	90%	70%	1-2 days	Various	1-2 days	2 days	14

- For a conservative estimate in terms of risk, the average of frequency and time delay were computed by calculating the average of the two most frequent and longest-delay figures.
- Frequency was converted into the number of shops given 10 shop drawings to be processed (e.g., 70% was converted into 7 shop drawings). Then, the impact was calculated by multiplying the frequency (number of shop drawings) by estimated time delay.

APPENDIX 2: REAL DATA COLLECTED AND CHECKSHEET DESIGNED

No	Type of shops (e.g. Rebar, str. Steel, Wood Truss	Description (e.g. F-1 foundation footing rebar shop etc)	Stamp-in time (e.g. Feb 02, 02:00pm)	Actual receiving time in your hand (e.g. Feb 03, 10:00am)	Actual starting time (e.g. Feb 03, 10:00am)	Actual finishing time (e.g. Feb 04, 03:15pm)	Stamp-out time (e.g. Feb 04, 05:00pm)	Total Lead Time		Time delayed (hr) due to 2nd level causes	2nd level cause code (e.g. SCH-01)
								Hr	Day		
1	Rebar	Fdn footing, wall & pier rebar shops	2/27/08 1:20 PM	2/27/08 1:25 PM	2/27/08 2:00 PM	2/27/08 2:30 PM	2/27/08 2:35 PM	1.25	0.16	-	-
2	Steel	Steel posts at 4th floor	2/27/08 2:00 PM	2/27/08 2:10 PM	2/27/08 3:00 PM	2/27/08 3:50 PM	2/27/08 4:00 PM	2.00	0.25	64.00	SCH-03
3	Wood	Wood roof trusses	3/4/08 1:00 PM	3/4/08 1:15 PM	3/6/08 4:45 PM	3/6/08 6:00 PM	3/7/08 9:00 AM	68.00	8.50	0.50	CP
4	Concrete	Mix designs	3/8/08 10:00 AM	3/8/08 10:30 AM	3/8/08 4:00 PM	3/8/08 4:55 PM	3/9/08 9:00 AM	23.00	2.88	-	-
5	Wood	TJI landing & LVL stair beams	3/12/08 11:00 AM	3/12/08 11:15 AM	3/12/08 1:00 PM	3/12/08 3:45 PM	3/12/08 4:15 PM	5.25	0.66	0.50	CP
6	Steel	Steel stair post	3/18/08 11:00 AM	3/18/08 12:00 PM	3/18/08 1:00 PM	3/18/08 1:45 PM	3/18/08 1:50 PM	2.83	0.35	208.00	PC-01, Others
7	Steel	Steel grating for area wall	3/18/08 11:00 AM	3/18/08 12:00 PM	3/18/08 1:55 PM	3/18/08 2:10 PM	3/18/08 2:15 PM	3.25	0.41	336.00	PC-01, Others
8	Wood	Wood roof trusses & west wing of GWL	4/1/08 1:50 PM	4/1/08 1:50 PM	4/2/08 8:00 AM	4/3/08 11:00 AM	4/3/08 1:00 PM	47.17	5.90	1.00	CP
9	Steel	Lightage parapet shops	4/2/08 9:00 AM	4/2/08 9:00 AM	4/2/08 3:00 PM	4/2/08 3:15 PM	4/2/08 3:20 PM	6.33	0.79	-	-
10	Lightage steel	Lightage sud wall shops	4/7/08 10:30 AM	4/7/08 10:30 AM	4/7/08 2:30 PM	4/9/08 8:30 AM	4/9/08 8:45 AM	46.25	5.78	-	-
11	Wood	Wood roof truss shops	4/11/08 12:00 PM	4/11/08 12:15 PM	4/15/08 9:30 AM	4/16/08 2:00 PM	4/16/08 3:30 PM	123.50	15.44	-	-
12	Lightage	Roof truss shops	4/17/08 10:45 AM	4/17/08 11:00 AM	4/18/08 12:30 PM	4/21/08 10:30 AM	4/21/08 1:00 PM	98.25	12.28	-	-
13	Steel	Partition wall support beams and columns	4/30/08 2:30 PM	4/30/08 2:30 PM	5/1/08 8:30 AM	5/2/08 10:00 AM	5/2/08 10:15 AM	43.75	5.47	-	SCH-03
14	Steel	Entry canopy framing (HSS channel & angle members)	5/9/08 9:00 AM	5/9/08 9:10 AM	5/9/08 9:30 AM	5/9/08 4:30 PM	5/9/08 4:50 PM	7.83	0.98	2.00	PC-03
15	Lightage	Lightage stud wall (1-FL load bearing & 3-FL non-load bearing)	5/5/08 2:00 PM	5/5/08 2:00 PM	5/7/08 10:00 AM	5/13/08 1:15 PM	5/13/08 2:00 PM	192.00	24.00	12.00	PC-02, PC-03
16	Rebar	Fdn wall rebar	5/10/08 8:00 AM	5/10/08 8:30 AM	5/11/08 8:00 AM	5/12/08 9:30 AM	5/12/08 11:00 AM	51.00	6.38	0.50	CP, SCH-02
17	Rebar	Fdn wall rebar	5/13/08 9:30 AM	5/13/08 10:15 AM	5/13/08 11:00 AM	5/13/08 1:30 PM	5/13/08 3:00 PM	5.50	0.69	1.00	CP
18	Rebar	Fdn rebar (frost wall & footing)	7/30/08 10:00 AM	7/30/08 10:30 AM	7/31/08 8:00 AM	8/1/08 12:30 PM	8/1/08 2:00 PM	52.00	6.50	0.50	CP
19	Rebar	Fdn rebar (frost wall & footing)	7/31/08 10:15 AM	7/31/08 10:30 AM	8/4/08 11:00 AM	8/5/08 1:00 PM	8/5/08 3:00 PM	124.75	15.59	2.00	CP
20	Concrete	Concrete mix designs	8/1/08 1:00 PM	8/1/08 1:15 PM	8/1/08 2:00 PM	8/1/08 3:00 PM	8/1/08 3:30 PM	2.50	0.31	-	-
21	Steel	Anchor bolt	8/5/08 9:00 AM	8/5/08 9:15 AM	8/5/08 4:00 PM	8/6/08 9:00 AM	8/6/08 10:00 AM	25.00	3.12	2.00	CP, PC-03
22	Steel	Structural steel (WF beam, column & misc.)	8/6/08 2:00 PM	8/6/08 2:30 PM	8/7/08 8:00 AM	8/14/08 8:30 AM	8/14/08 4:00 PM	194.00	24.25	32.00	CP, Others
23	Steel	Structural steel (WF beam, column & misc.)	8/19/08 9:15 AM	8/19/08 9:45 AM	8/19/08 11:00 AM	8/20/08 3:30 PM	8/21/08 9:00 AM	47.75	5.97	3.00	CP
24	Precast	PC plank, beams & columns	8/20/08 10:30 AM	8/20/08 11:00 AM	8/23/08 9:00 AM	8/27/08 10:00 AM	8/27/08 2:00 PM	171.50	21.44	8.00	PC-01, PC-03, CP
25	Wood	Wall panel (1st floor)	8/29/08 10:00 AM	8/29/08 10:30 AM	8/29/08 1:00 PM	8/30/08 8:45 AM	8/30/08 10:00 AM	24.00	3.00	-	-
26	Wood	I-Joist	8/29/08 9:30 AM	8/29/08 9:40 AM	8/30/08 11:00 AM	8/31/08 9:30 AM	8/31/08 10:00 AM	48.50	6.06	-	-
27	Wood	Wall panel (2nd & 3rd floors)	9/9/08 9:15 AM	9/9/08 9:30 AM	9/11/08 1:30 PM	9/12/08 9:45 AM	9/12/08 1:00 PM	75.75	9.47	-	-
28	Wood	Wall panel (4th floor) & Roof truss	9/15/08 12:45 PM	9/15/08 1:00 PM	9/18/08 8:15 AM	9/20/08 9:30 AM	9/20/08 10:45 AM	118.00	14.75	-	-
29	Wood	Floor truss shops (2nd - 4th FL) & roof truss shops	10/2/08 8:45 AM	10/2/08 8:45 AM	10/2/08 9:30 AM	10/2/08 4:00 PM	10/2/08 4:30 PM	7.75	0.97	-	-
		Max						194.00	24.25		
		Average						55.82	6.98		
		Min						1.25	0.16		
		StdDev						58.71	7.34		

1st-level possible causes	2nd-level possible causes	Code
Schedule	Tight schedule (resulting in insufficient time)	SCH-01
	Submittals after the fact	SCH-02
	Poor planning by GC	SCH-03
Project coordination	Architectural revisions during the engineering review process	PC-01
	Lack of architectural information	PC-02
	Coordination items with architect	PC-03
	Unclear items in Request For Information (RFI) not addressed	PC-04
Procedure	Copying red marks	CP
Others	Delay caused by late input from GC and suppliers	Others

APPENDIX 3: 1st- AND 2nd-LEVEL CAUSES AND EXAMPLES

1st-level possible causes	2nd-level possible causes	Examples
Schedule	Tight schedule (resulting in insufficient time)	GC requests immediate reviews and approvals.
	Submittals after the fact	Having poured concrete, GC requests reviews of rebar detailing.
	Poor planning by GC	GC sets an unrealistic plan.
Project coordination	Architectural revisions during the engineering review process	• Fast-track projects usually have revisions after the structural package has been released. If engineers know of the changes during review, engineers mark it accordingly. If they don't, it usually means field revisions. • On a recent project that an engineer was working on, wall locations were revised, door locations revised, a mechanical pit added, a trash enclosure added, exterior grading was adjusted, etc. All of these items required revisions to the foundation plan or framing plans, which affected rebar shop drawings, PC plank shop drawings, and steel shop drawings.
	Lack of architectural information	Missing dimension and location (e.g., openings and partitions)
	Coordination items with architect	• Architectural input is required for certain item, e.g., hoist beam elevations, partition wall support beams. • Engineers have issues with top of beam elevations that need to be determined by the architect. Mechanical penetrations and openings can also be a coordination issue. • Sometimes doors will move on the architectural plans, prompting the move of a column location. • Architectural dimensions and structural dimensions did not match on one project.
	Unclear items in Request For Information (RFI) not addressed	Prior to reviewing the shop drawing, unclear items should be clarified, but any clarifications are not requested until the engineering review starts.
Procedure	Copying red marks	• Once the engineering review is finished, engineers make 5 additional copies. This job is done by hand writing And usually takes 1-2 days. • In general, one project has 3-60 submittals submitted near the same time. Each submittal takes two days to copy the marks.
Other Causes	Delay caused by late input from GC	• Steel post details left out of initial submittal by GC.
	Delay caused by late supplier's input	• Steel stair post details left out of original submittal by supplier. • Steel grating details left out of original submittal by supplier.