The Effect of Selected RFI Variables on Steel Fabrication Performance

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The fabrication of structural steel is a critical process in the supply chain of many construction projects. An effective transfer of design information is necessary for a steel fabricator to estimate quantities, place mill orders, prepare shop drawings, and receive necessary approvals. Design documentation (i.e., plans and specifications) must be interpreted, transformed into shop drawings, and approved before the physical task of fabrication can commence. Questions seeking clarification on any aspect of the design will generate a request for information (RFI) by the steel fabricator. Although the steel fabricator may focus on other tasks while awaiting an answer, the time spent waiting for an answer represents a discontinuity in the flow of information at this point in the design-construction interface. These discontinuities may cause delays in the shop drawing production process and affect performance in subsequent fabrication activities. Since structural steel is a long lead item, fabrication performance is important to the steel supply chain as well as subsequent project activities.

Characteristics of RFI variables within a project may provide an indication of both documentation and communication quality. In order to keep the fabrication of steel on schedule, the design documentation must be sufficiently complete and, where necessary, clarified in a responsive manner. Design documentation containing a minimal number of errors, omissions and inconsistencies will typically generate a smaller number of requests by the steel fabricator. A reduced need for clarification minimizes the potential for delays in the production and approval of shop drawings. The characteristics of communication within a given project are important when clarifications are requested. Once a need for the RFI has been determined, communication between the engineer and fabricator will affect the potential for delays in the shop drawing production phase. The volume of RFIs is a function of the extent of deficiencies within the design documentation while the effectiveness of the RFI process is a function of the severity of the deficiencies and communication characteristics. Figure 1 illustrates the factors and variables involved.

Poor fabrication outcomes can affect construction productivity as well. Fabricated elements that arrive late, contain deficiencies, or are out-of-sequence have been linked to significant schedule slippage (Thomas and Sanvido, 2000) while poor shop drawings can decrease erection productivity (Thomas, Riley and Sanvido, 1999). It is crucial that structural steel be on-schedule and correctly fabricated to maintain performance objectives. High-quality shop drawings are essential in achieving this result and are dependent on the need for and processing of RFIs.

RFIS AND PERFORMANCE

It is crucial that structural steel be correctly fabricated and on-schedule to maintain performance objectives. Thomas and Sanvido (2000) analyzed three construction projects and found that problems with fabricated components caused slippage of the construction schedule by as much as 129%. The delivery of the steel to the project is affected by its predecessors, including shop drawing production and approval. The successful completion of these tasks relies on an efficient use of RFIs. Poor project performance has been linked

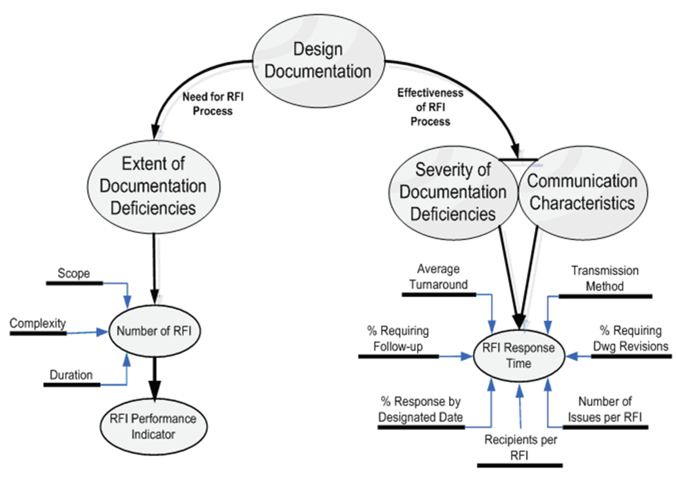

Fig. 1. Factors and variables in the RFI process.

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to higher numbers of RFIs (Pugh, 1994) while the time it takes to respond to RFIs has also been associated with project performance (Tilley, Wyatt and Mohamed, 1997; Pugh, 1994). Pugh (1994) concluded that the RFI process is a leading indicator of performance at the design-construction interface and a strong indicator for potential schedule delays. Therefore, it seems apparent that characteristics of RFI variables will influence shop drawing production, approval and fabrication of structural steel.

The time and cost consequences of RFIs and their management have been studied and found to have a significant impact on organizational resources. A 2004 study sponsored by the National Institute of Standards and Technology used interviews, surveys and focus groups to estimate the impact of inadequate interoperability in the United States capital facilities sector. Information gathered from this study revealed that specialty fabricators average 15.5 hours processing a single RFI while design firms average approximately 200 hours per month managing RFIs (Gallaher, O'Connor, Dettbarn and Gilday, 2004). This finding is similar to another study which concluded that project participants spent an average of 17 hours processing a single RFI (Mohamed, Tilley and Tucker, 1999).

Although the steel construction industry would benefit from information regarding the relationship between various RFI variables and the shop drawing production process, no such quantitative study has been performed. Similarly, there has been no quantitative study performed on the relationship between any RFI variables and subsequent steel fabrication activities. This study fills this void by investigating the relationship between selected RFI variables and performance in both the shop drawing production and fabrication phases.

DATA COLLECTION AND SAMPLE

The data used in this study was collected from 10 AISC-member steel fabricators located throughout the continental United States. Project data regarding actual and estimated milestone dates in the fabrication process were collected from the steel fabricators via a questionnaire. The fabricators were asked to submit information on projects where (1) only traditional fabrication services were provided and (2) services were procured using lump sum contracts. Traditional fabrication services were defined as those where the fabricator's role was solely that of "steel provider" as opposed to those projects where the fabricator may have been involved in design. Similarly, lump sum contracts were chosen to exclude projects where design was not substantially complete. These limitations were incorporated into the design of this study in order to reduce the effect of potential extraneous variables. The effect of fabricator involvement in design (i.e., design-assist) could provide an opportunity for a comparative follow-up study but was not included in this work.

Any research is interested in accurately measuring what it intends to measure. In the case of measuring construction performance, the use of data from completed projects is commonly used in the investigation of measures related to construction cost and duration. In construction-related research, the use of questionnaires to collect project data for performance measures is also common (Moshini and Davidson, 1992; Griffis, Hogan and Li, 1995; Pocock, Hyun, Liu and Kim, 1996; Konchar and Sanvido, 1998; Hanna, Camlic, Peterson and Nordheim, 2002). RFI documentation found in logs and other communication provides quantitative information to the outside observer. The use of RFI documentation to ascertain RFI variables relating to volume, response time, and other RFI metrics has previously been used by Pugh (1994), Tilley et al. (1997), and Hanna et al. (2002). The construct that performance within the steel fabrication process can be associated with certain RFI variables is based upon previous studies that investigated the effect of RFIs on overall construction project performance (Pugh, 1994; Tilley, 1998). Previous research found that RFI process characteristics are a leading indicator of project performance and that certain measures relative to response time and the number of clarification RFIs could allow for comparisons between projects. The theoretical constructs and operational assumptions used in this study appear consistent with other literature involving RFIs and performance.

A total of 82 project questionnaires were returned with RFI documentation. Due to incomplete information or nonconformance with the aforementioned criteria, 34 projects were rejected. This resulted in a sample consisting of 48 projects from various construction sectors (Figure 2). The size of projects, by project tonnage, included in the sample ranged from 33 to 6,500 tons. The mean value of fabricated steel weight in the sample is 572 tons per project with approximately 67% of the sample projects having fabricated elements weighing in the 100- to 1,000-ton range (Figure 3). Project size appeared related to the volume of clarification RFIs as may be expected. A trend of increasing

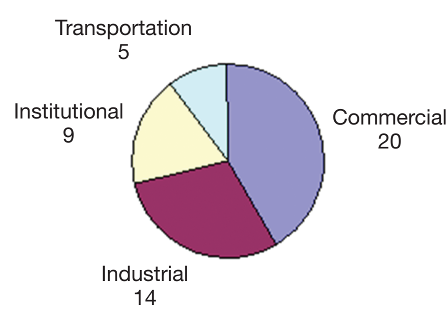

Fig. 2. Sample projects by construction sector.

average number of clarification RFIs as the average weight of fabricated elements increased was apparent in the sample. Figure 4 illustrates the average number of clarification RFI per project in each of the project weight categories.

All submitted data was checked for consistency and reviewed, if necessary, with the fabricator to increase reliability. All projects in the accepted sample were completed during the 2005 to 2006 calendar years.

PERFORMANCE MEASURES

Performance measures for construction projects commonly involve time and cost indicators. The Construction Industry Institute's (CII) Benchmarking and Metrics program has several performance indicators utilizing actual and initial (estimated) values of duration. Measurement of duration-related performance using estimated and actual calendar dates to delineate operationally defined start and stop points for project phases has similarly been used. Griffis et al. (1995), in a CII-sponsored study, investigated cost and duration performance using metrics calculated as ratios of actual-to-estimated values and noted such metrics were "the most widely used and understood."

Using estimated-to-actual duration is the basis of performance measurement in this study. The two performance measures used in this study were the shop drawing production performance (SHOPPERF) and fabrication duration performance (FABDPERF). Using the milestone dates from the fabricator's production schedule, the estimated length of time for shop drawing production and fabrication duration were calculated for each project. Shop drawing production performance was based on a timeframe that commenced with the notice to proceed and ended with the issue date of the last set of shop drawings. Fabrication duration performance was based on a timeframe starting with the issue date of the first batch of shop drawings and ending with the shipment date of the last sequence of steel for the project. The issue date was chosen as the "start" of fabrication as it may lag the actual approval date due to revisions that may be needed. These phases of shop drawing production and fabrication are illustrated in Figure 5. Since each performance measure is expressed as a ratio of estimated to actual time, higher values of each measure indicate increased performance. The formulas for both of these performance measures are as follows:

$$SHOPPERF = \frac{\text{Estimated days in shop drawing phase}}{\text{Actual days in shop drawing phase}}$$

$$FABDPERF = \frac{\text{Estimated days for fabrication duration}}{\text{Actual days for fabrication duration}}$$

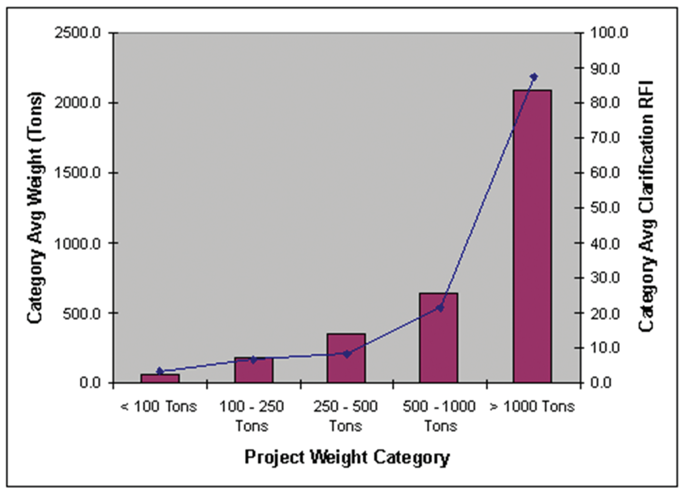

Fig. 4. Relationship of average clarification RFIs to fabricated weight.

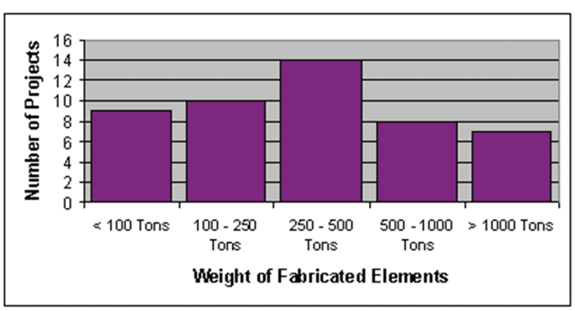

Fig. 3. Sample project categorized by fabricated weight.

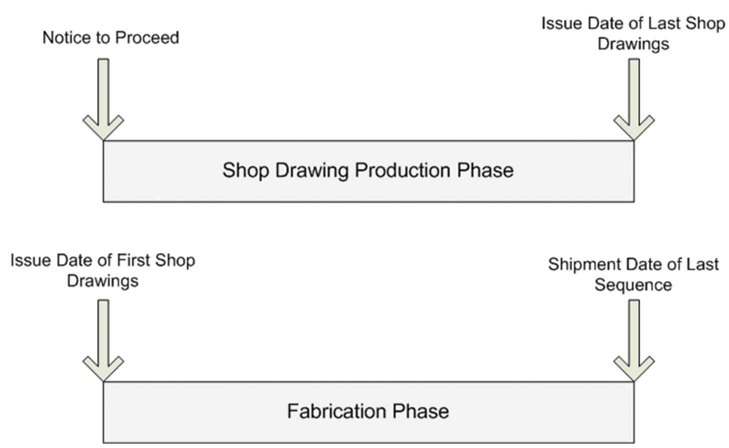

Fig. 5. Start–stop milestones for phases.

RFI VARIABLES

The RFI variables selected for this study were chosen because they were previously identified, readily accessible, and quantitative in nature. Four RFI variables were initially investigated in this study: (1) the average RFI response time, (2) the percentage of RFIs requiring follow-up, (3) the percentage of RFI responses over 7 days, and (4) the RFI performance indicator. These RFI variables comprise elements of RFI volume and timing that are considered important characteristics in a project. These were initially studied for their effect on shop drawing production performance.

RFIs can be generated for a variety of reasons. In this study, RFIs were categorized for their relation to (1) clarification of the design, (2) substitution requests, (3) erection/field issues, or (4) extraneous information/matters. While all categories require time to process, clarification-related RFIs are generally considered most relevant to documentation quality. RFI documentation from the 48 sample projects contained 1,134 RFIs categorized as shown in Figure 6.

The average RFI response time was calculated based on the fabricator's RFI logs which contained the date sent and date returned for each RFI. RFI response time is calculated as the length of time (days) between the date sent and the date returned. Average RFI response time for the project was simply the arithmetic average and outliers more than 3 standard deviations above the mean were removed from the sample project. The next RFI variable, percentage of RFIs requiring follow-up, was again calculated based on an analysis of the RFI logs. If an RFI was generated based on the original response to a previously written RFI it was deemed a "follow-up RFI." The percentage of these follow-up RFIs within a project was calculated to provide this variable. The third RFI variable investigated the effect of extended response times since longer response times could be potentially more detrimental to performance. To consider this characteristic, it was decided to investigate the percentage of RFIs in each project that required more than five working days (seven calendar days) to process. This threshold was chosen based on recommended RFI protocol (Andrews, 2005). The final RFI variable investigated for its effect on performance is termed the RFI performance indicator and is based upon previous research (Tilley et al., 1997; Tilley, 1998). This variable provides a numerical value based upon the ratio of clarification-related RFIs to the contract value and duration of fabrication. Contract value and project duration act as proxies for project size and complexity, which would influence the need for clarification. This variable allows comparisons to be made between different projects as it reflects the level of deficiency within the contract documents received by the steel fabricator. The formula for the RFI performance indicator is shown as follows:

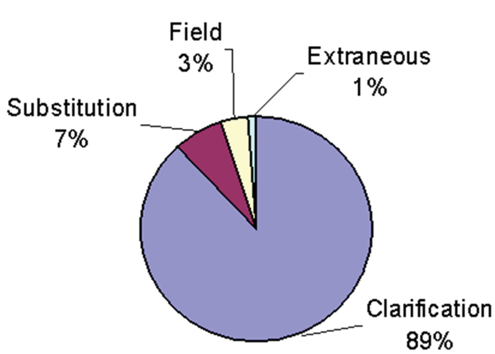

Fig. 6. Categorization of RFIs in sample.

$$PI = \left[\frac{N_c}{(CV)D}\right]$$

where

PI	=	RFI performance indicator
N_c	=	number of clarification-related RFIs
CV	=	contract value ($100,000)
D	=	initial project duration (months)

REGRESSION MODEL AND RESULTS

Multiple regression is a statistical technique that estimates the value of a dependent variable as a function of several independent variables. This analytical tool is used to determine many facets of the relationship between a dependent variable and a set of independent variables. A useful characteristic of this technique is its ability to ascertain the amount of variance in the dependent variable which is accounted for by the independent variables. The coefficient of determination, R^2, of the model ranges between 0 and 1 and represents the percentage of variability in the dependent variable explained by the regression model. Although the R^2 statistic describes the amount of explained variability, it has to be interpreted relative to other factors which comprise the model. Adding more independent variables to a regression model will always increase the R^2 statistic but may be problematic due to interaction between independent variables. Good regression models will use the smallest number of independent variables that still provide practical interpretation of the dependent variable.

The sample of 48 projects was adequate for the proposed regression technique. Determining this adequacy depends on a number of factors, including the particular statistical test, the desired power level, the significance criterion, and the effect size. To determine the proper sample size, the minimum power level for the regression analysis was set at 0.75, while a medium effect size was posited ($f^2 = 0.15$). A significance level, α, of 0.10 was chosen which is similar to other

Table 1. Correlation of Transformed RFI Variables with Shop Drawing Production Performance Variable.		
		SHOPPERF
LNRFIPER	Pearson Correlation	–0.388
	Significance (2-tailed)	0.006
	N	48
LNRESTME	Pearson Correlation	–0.282
	Significance (2-tailed)	0.052
	N	48

Table 2. Regression Statistics for Shop Drawing Production Performance Model.								
		Unstandardized Coefficients		Std. Coefficients			Colinearity Statistics	
Model		*B*	Std. Error	Beta	*t*	Significance	Tolerance	VIF
1	(Constant)	0.666	0.060	—	11.073	0.000	—	—
	LNRFIPER	−0.0913	0.029	−0.411	−3.172	0.003	0.994	1.006
	LNRESTME	−0.0735	0.031	−0.312	−2.409	0.020	0.994	1.006
VIF = variance inflation factor								

construction-related research. Using procedures outlined by Cohen (1988), the sample size of 48 exceeded the desired power level in this study.

The initial step of the research analysis sought to determine if any of the RFI variables had a significant effect on the shop drawing performance variable. Scatter plots were examined for linearity as well as outliers. Normality of the independent variables was checked using the observed values of skewness and kurtosis and found to be within a ± 2 standard error of zero. Subsequent correlation analyses revealed the RFI performance indicator and the average RFI response time variables were significantly associated with shop drawing production performance. The other two RFI variables did not have significant correlations and, therefore, were removed from further consideration. Since multiple regression is based on an assumption of linearity, the two significant RFI variables were transformed by applying the natural logarithm to each. This natural log transformation was found to strengthen this correlation between both RFI variables and the shop drawing production performance. The correlation statistics for each can be found in Table 1.

A multiple regression model to estimate the shop drawing production performance based on the RFI performance indicator and the average RFI response time variables was developed. This regression model using the transformed RFI performance indicator (LNRFIPERF) and the transformed average RFI response time (LNRESTME) was found to significantly predict shop drawing production performance ($p = 0.002$). Table 2 provides the inferential statistics for this additive model. The coefficient of determination, R^2, for this model was 0.248, indicating that these two RFI variables together explain almost 25% of the variance in shop drawing production performance for the sample. The model equation is as follows:

$$SHOPPERF = 0.666 - 0.0735(LNRESTME) - 0.0913(LNRFIPERF)$$

This model indicates that as the RFI performance indicator variable and the average RFI response time variable decrease, shop drawing production performance will increase. Although this model explains only 25% of the variance within the sample projects, it must be interpreted with respect to the nature of the shop drawing production process itself as well as the model. Shop drawing production is a complex process because of the communication characteristics involved in producing the final output. The process itself contains various lines of communication involving multiple participants including the fabricator, engineer of record, specialty engineers/designers, and possibly outside detailers. These multiple communication pathways may be exchanging information regarding RFIs using a variety of technologies,

Table 3. Regression Statistics for Fabrication Duration Performance Model.								
		Unstandardized Coefficients		Std. Coefficients			Colinearity Statistics	
Model		*B*	Std. Error	Beta	*t*	Sig.	Tolerance	VIF
1	(Constant)	0.833	0.106	—	7.829	0.000	—	—
	LNRFIPER	–0.145	0.051	–0.386	–2.839	0.007	0.994	1.006
	LNRESTME	–0.0731	0.054	–0.184	–1.355	0.182	0.994	1.006

including e-mail, fax, project management intranets, or some combination of those. Additionally, communication may be influenced by the level of familiarity that participants may have with each other as well as familiarity with the project type and the project delivery system. Instead of exploring the large number of variables that could influence the performance of shop drawing production, this model opted to investigate the aforementioned RFI variables because they were previously identified, readily accessible, and quantitative in nature. The practical nature of this model is reflected in the use of two common RFI variables, the RFI performance indicator variable and the average RFI response time variable, to estimate shop drawing production performance. This statistically significant result is particularly interesting since the sample of 48 projects was obtained from 10 different fabricators, located in various parts of the country, and using projects from various construction sectors.

Although this study quantifies the influence of only several selected RFI variables on the shop drawing production performance, these results are consistent with other studies investigating the impact of RFIs on performance. Other investigations of RFI variables with respect to project performance have concluded that RFI variables are a leading indicator of project performance (Pugh, 1994; Tilley, 1998). These studies also noted the influence of documentation deficiency on the volume of RFIs, while others have associated decreased performance measures with increased documentation deficiency (Shohet and Frydman, 2003; Tilley, McFallan and Tucker, 2000). The effect of RFI response time on steel shop drawing production is congruent with others that have found that increased RFI response time is associated with decreased performance (Mohamed et al, 1999; Tommelein and Ballard, 1997; Pugh, 1994).

The following step in this analysis investigated the association between performance of shop drawing production and the subsequent schedule performance of steel fabrication. In this study, the actual duration of the steel fabrication phase was the number of days between the issue date of the first set of shop drawings and the shipment of the last sequence of steel to the site. Since shop drawing production precedes the fabrication of structural steel, establishing an estimate of fabrication duration performance from performance in the shop drawing phase could serve as an important planning tool.

A correlation analysis was performed between the shop drawing production performance and the fabrication duration performance, that found a significant relationship between these two performance measures (r = 0.375, $\rho = 0.009$). With the finding of a positive association between duration performance in the shop drawing production phase and the subsequent fabrication phase, an additive multiple regression model was investigated to estimate fabrication duration performance using the two RFI variables found to be significant previously. This model, estimating fabrication duration performance based on the RFI performance indicator variable and the average RFI response time variable, was significant at the 0.009 level. Table 3 provides the inferential statistics for this additive model. The coefficient of determination (R^2) for this model was 0.172, indicating that these two RFI variables together explain approximately 17% of the variance in fabrication duration performance in the sample. The regression equation is as follows:

$$FABDPERF = 0.833 - 0.145(LNRFIPERF) - 0.0731(LNRESTME)$$

This model indicates that as the RFI performance indicator and the average RFI response time variable decrease, fabrication duration performance will increase. Again, this model must be again interpreted with respect to the many variables that could possibly affect the fabrication duration as well as the purpose of the model itself. It also indicates that other factors affect fabrication duration in addition to the two RFI variables studied. This should be expected since RFI variables logically share a closer association with the shop drawing production phase. When considered with regard to the number of decisions, deliveries, participants and activities that are involved in getting steel to the project site, it is noteworthy that two basic RFI variables explain roughly one-sixth of the total duration variability in the fabrication phase.

Although fabrication duration could be considered to be insulated from variables within the RFI process, this analysis indicates that fabrication duration performance shares a significant association with the same two RFI variables that were significantly associated with shop drawing production. The results are consistent with the other literature that has asserted that the pace of steel fabrication is driven by the production and approval of shop drawings (Van de Pas, Tinker and Holland, 2005). Timely fabrication of structural steel hinges upon the approval of shop drawings which has been shown to be quantitatively associated with the relative RFI volume and the characteristics of RFI response time. Increasing numbers of RFIs and longer turnaround times invariably produce discontinuities in the fabrication process. Although these discontinuities may originate in the shop drawing production phase, the previous regression equation indicates a ripple effect that occurs in the actual fabrication of the steel components.

CONCLUSION

The widely held belief that increased RFI volume and response time result in negative consequences for the fabrication of structural steel has been quantified. Relative increases in RFI volume lead to discontinuities in the production of shop drawings. Problems in the shop drawing production phase cause a ripple effect in downstream performance relative to the duration of the fabrication phase. The quantitative model developed in this study rests on the theory that shop drawing production and fabrication duration performance can be modeled based upon selected RFI variables. While there are many variables that could influence performance in various stages of steel fabrication, this study opted to investigate RFI variables that have been previously identified and are readily found using typical fabrication documentation. Statistically significant multiple regression equations were developed using two RFI variables to explain approximately 25% of the performance variance in the shop production and 17% of the performance variance in fabrication duration. This significant result occurred in a sample of 48 projects of various sizes and construction types, submitted from 10 different steel fabricators located throughout the United States.

The quality of design documentation is a major attribute of communication at the beginning of the design-fabrication interface. Documentation that is complete, consistent and unambiguous will require less clarification. In this study, the variable found to be statistically significant that reflects the extent of documentation deficiency is the RFI performance indicator (LNRFIPER). This variable, adapted from earlier research work (Tilley et al., 1997; Tilley, 1998), accounts for the number of clarification RFIs generated with respect to a project's size and duration. Higher values of the RFI performance indicator variable indicate a greater usage of RFIs within a given project and portend discontinuities in the shop drawing production process. This variable was found to have the strongest association with both shop drawing production and fabrication duration performance, which is congruent with related research.

While the quality of the design documentation is the primary determinant of the need for RFIs, communication within the process also plays a role in performance. This study has quantitatively established that the average RFI response time variable (LNRESTME) is also associated with shop drawing production performance in steel fabrication. The ability to get answers quickly when seeking clarification on design-related issues is an important factor in the timely completion of the fabricator's work. Longer RFI response times result in discontinuities that are associated with longer durations in the shop drawing production and fabrication phases.

RECOMMENDATIONS

This research identifies specific RFI variables and their statistically significant relationship with shop drawing production and fabrication duration performance. The models developed in this study found that the RFI performance indicator variable and the RFI response time variable have a substantive influence on shop drawing production and fabrication processes. Since the data used in this study represented 48 sample projects from 10 steel fabricators, generalizations to the population of steel fabricators working as steel providers in lump sum projects can be supported. The quantitative foundation of this generalized model can be applied by individual fabricators interested in performance improvement through statistical RFI management. The cataloging of RFI data on past projects could provide the steel fabricator an opportunity to develop robust models incorporating other variables pertaining to project delivery, coordination, and delegation of responsibility. The development of statistical models based on such data would allow individual fabricators to predict confidence intervals using the RFI performance indicator variable. These intervals would identify RFI ranges that would be associated with performance levels for an upcoming project. Information regarding project RFI response time could be combined with historical response time data to develop control processes, similar to control charting, which would allow quantitative, real-time recognition of performance in ongoing projects.

Engineers and designers could also benefit from a database of the RFI variables discussed herein. Such variables could be used as quality service indicators to external parties. Lower values of the RFI performance variable suggest higher levels of quality in design documentation, while lower values of the response time variable would reflect an increased commitment to prompt clarification. Both of these may be useful in documenting a design organization's commitment to quality during qualification-based selection procedures. Similar to contractor's experience modification rate (EMR), the availability of documented indices associated with good performance could be used to further enhance professional reputation.

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