Effect of Preconstruction Planning Effort on Sheet Metal Project Performance

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Abstract: The complexity of construction industry requires the identification of work tasks and the coordination of interactions among them. As a result, construction planning is considered to be one of the most critical steps toward success and is the main focus of past research. Consequently, little research has been performed regarding the preconstruction planning, which is the planning completed by the contractor in the period between project award and project execution. This paper focuses on sheet metal preconstruction planning, primarily that of mechanical and heating ventilations and air conditioning contractors. The research was completed in three phases: phase one gathered data on the current state of preconstruction planning, phase two developed a model sheet metal preconstruction planning process to be used by sheet metal contractors, and phase three validated the model preconstruction planning process. Based on project data collected for this research, projects that used a planning process similar to the model process performed more successfully—they achieved an average profit margin of 23% while projects that were poorly planned experienced an average profit margin of −3%.

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Introduction

Construction planning is necessary to account for all the variables and situations that may arise during a construction project. Planning for construction allows a contractor to be proactive rather than reactive to the problems as they arise. A proactive contractor controls the direction of the project while a reactive contractor allows the project outcome to change, hoping to minimize the impact of problems as they occur [Plumbing-Heating-Cooling Contractors (PHCC) National Association 2002].

Most construction industry experts believe that the earlier planning is executed, the larger impact it will have on contributing to the project outcome (Gibson et al. 1995). This relationship is shown in Fig. 1. As the project progresses and expenditures become greater, the less influence project planning will have on project outcome. Laufer has stated that it is advantageous to begin planning prior to construction execution due to management's ability to influence the project early in the project (Laufer 1987).

On the other hand, preconstruction planning is a comprehensive set of procedures initiated after contract award and prior to construction execution. Preconstruction planning has also been referred to as prejob planning, preplanning, or execution planning. The majorities of sheet metal contractors have overlooked this type of planning and, therefore, do not benefit from the advantages of early planning. The Plumbing-Heating-Cooling Contractors (PHCC) National Association lists the benefits of preconstruction planning as greater project control, increased project organization, better worker productivity, improved safety record, and increased project profitability [Plumbing-Heating-Cooling Contractors (PHCC) National Association 2002].

Definition of Preconstruction Planning

Laufer defines planning as a process of deciding (1) what activity to be completed; (2) how the activity should be completed; (3) who should complete the activity; and (4) when should the activity be completed prior to when the activity is to be performed (Laufer 1987,1990). This information is then conveyed to the project team in the form of a "plan," which can be project drawings, specifications, schedules, etc. (Laufer et al. 1993). Preconstruction planning is a comprehensive set of procedures that is completed by the contractor in the period between contract award and construction execution. Fig. 2 displays the typical project time line and the associated planning completed during each phase of the project. The output that result from preconstruction planning are schedules, estimates, budgets, manpower loading charts, coordination drawings, and safety notes.

Most research completed on planning prior to construction execution has focused on preproject planning. Preproject planning is completed by the owner and encompasses all planning completed from the initial idea of the project to the decision to proceed with the project and begin detailed design (Gibson et al. 1995, 2006;

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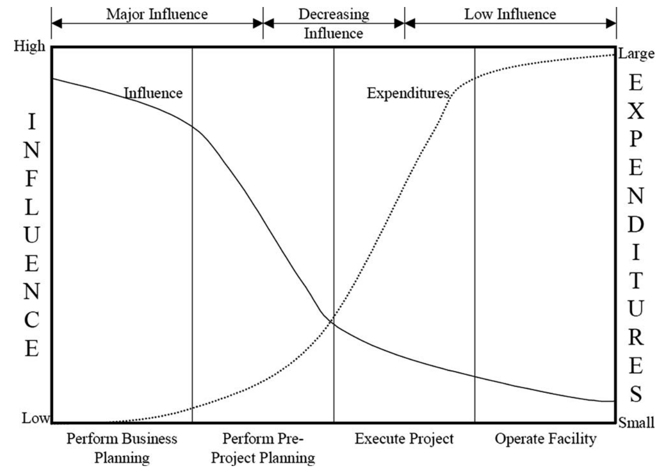

Fig. 1. Influence and expenditures curve for project life cycles (Gibson et al. 1995)

Griffith and Gibson 1999). The previous research on the topic of preconstruction planning focused on defining the current state of preconstruction planning in terms of (1) what parties are involved in preconstruction planning; (2) how much effort is invested in preconstruction planning; (3) how many types of plans are issued; and (4) which formats are used for plans (Laufer et al. 1993). This research progresses beyond Laufer's research by defining what is the appropriate preconstruction planning effort and what preconstruction planning activities should be completed to improve the contractor's probability of performing a successful project.

Research Methodology

The research methodology used a three-phase approach: (1) data collection and analysis of sheet metal preconstruction planning as it currently exists in the industry; (2) development of the model sheet metal preconstruction planning process; and (3) validation of the model sheet metal preconstruction planning process and establishing the relationship between preconstruction planning and project performance.

Phase one of the research used a survey distributed to over 1,000 SMACNA contractors located throughout the United States. The survey was created with input from several sheet metal project managers and estimators in Wisconsin and Minnesota. The survey collected data on preconstruction planning at the company level. Data were collected on (1) company attitudes toward preconstruction planning; (2) what preconstruction planning activities a company typically performed; and (3) what preconstruction planning activities were perceived to be the most important. A statistical analysis was then performed to identify what preconstruction planning activities were linked to company profit level, what were the most commonly performed activities, and what activities were identified as the most important by contractors.

Phase two used the data gathered in phase one to select preconstruction planning activities to be included in the model process. The model process was created using a four-step process to select the most commonly performed and most important planning activities. This resulted in selecting 50 of the original 108 activities. Step one selected activities that were executed by at least 60% of contractors. Step two selected activities that were identified as the 10 most important planning activities by at least 10% of contractors. Step three analyzed the activities selected in step one and step two and eliminated or combined duplicate and similar activities. Step four grouped the activities into 12 planning categories and organized the planning categories into a flowchart based on contractor interviews and checklists and flowcharts received from contractors.

Phase three validated the model process with a four-step process. Step one collected data from 19 companies on 15 "successful" projects and 12 "less-than-successful" projects. Step one used a reliability analysis to create a performance measurement index to measure project success based on project managers' definitions of success. The index allowed the researcher to compare the projects objectively on a continuous scale. Step two used a factor analysis to investigate the integrated project characteristics that affect the planning effort and also contribute to the project outcome. Step three also used a factor analysis to analyze how closely the planning effort on each project matched the model preconstruction planning process and assign a preconstruction planning score. Step four was a linear regression that regressed the project's preconstruction planning score and integrated project characteristics on the probability that the project was successful.

Data Collection Methodology

A mailed survey was used to collect data for the first phase of the research project. The mailing list for the survey was compiled from the SMACNA member directory. The member directory provided a contact and mailing address for each SMACNA member company. The mailing was completed in two rounds of approximately 500 each for a total of 1,002 surveys distributed to contractors in 44 states. This method resulted in approximately two-thirds of SMACNA member companies receiving a survey. A total of 138 surveys were returned completed; a response rate of 13.8%.

Data Collection Survey

The survey consisted of six sections. They were (1) "Company Characteristics"; (2) "Preconstruction Planning Practices"; (3) "Project Tracking"; (4) "(Their) Preconstruction Planning Program"; (5) "Net Annual Profit"; and (6) "Contact Information." Section (1) "Company Characteristics" included questions about the size of the company, number of employees, and type of work performed. Section (2) "Preconstruction Planning Practices" included questions about their planning program and their attitude toward preconstruction planning. Section (3) "Project Tracking" listed 14 items that are used to track progress on a project and asked them to identify if they track the item and how frequently they track it. Section (4) "(Their) Preconstruction Planning Program" listed 108 preconstruction planning activities and provided 14 blank spaces for write-in activities and asked respondents to identify which planning activities are typically performed at their

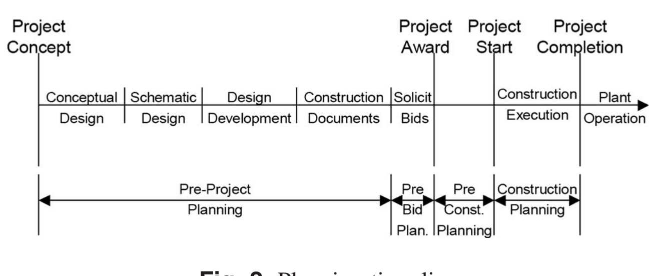

Fig. 2. Planning time line

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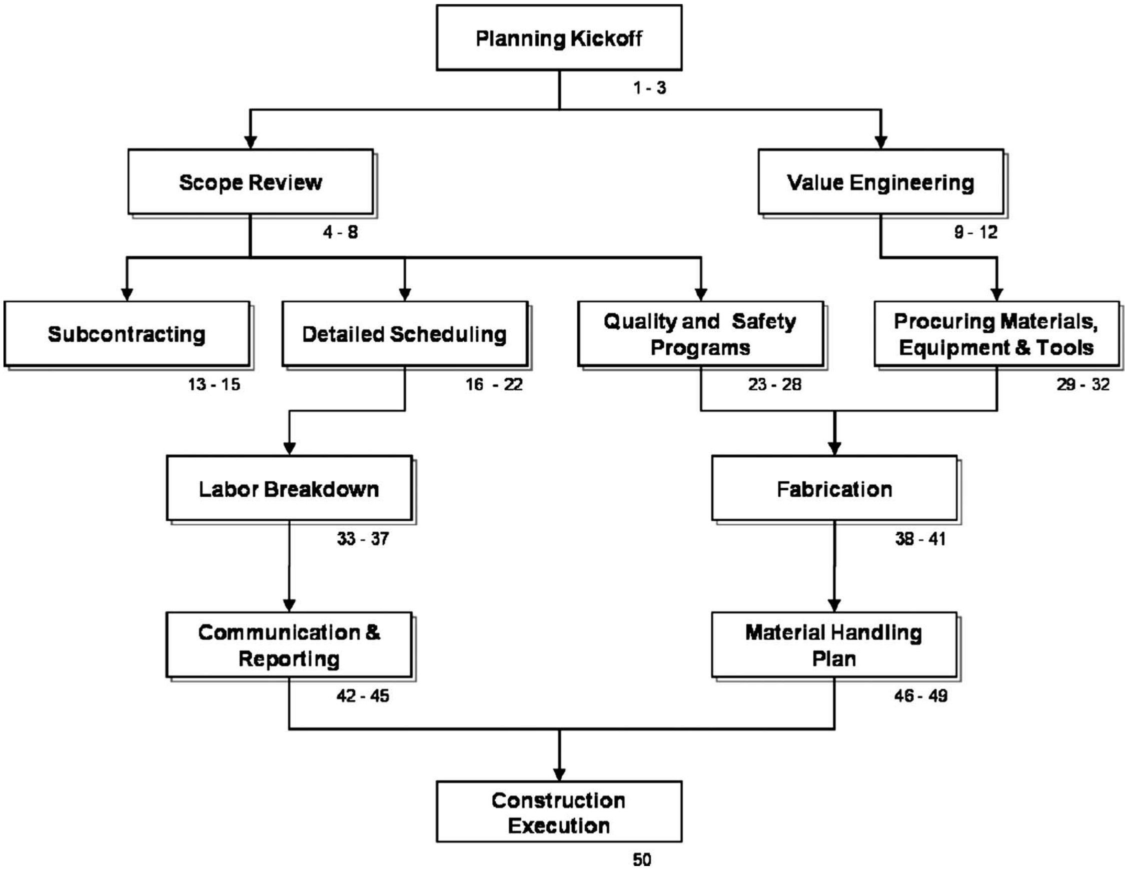

Fig. 3. Model sheet metal preconstruction planning process

company. This section also asked respondents to identify which they feel are the 10 most important planning activities. Section (5) "Net Annual Profit" provided nine profit ranges and asked respondents to identify their net annual average profit for the past 3 years. Section (6) "Contact Information" asked the respondent for contact information and if they would be interested in providing additional information in the future.

The surveys were distributed in two rounds so the first round could be reviewed for any problems with verbiage or oversights. Additionally the write-in activities in Section (4) of the survey were reviewed to identify if any planning activity was overlooked on the original survey. However, none of the offered activities was identified multiple times, thus no activities were added to the survey for the second round.

Data Analysis and Model Development

The data collected from the survey was used to create the model sheet metal preconstruction process. The model process was created using a four-step process to reduce the number of planning activities from 108 to 50. Step one selected activities that were performed by over 60% of respondent contractors. Step two selected activities indicated as one of the 10 most important activities to complete a successful project by more than 10% of respondent contractors. Step one and step two identified 60 and 29 activities, respectively. Step three analyzed the activities selected in step one and step two and eliminated or combined duplicate and similar activities to reduce the number of activities to 50. Step four organized the activities into planning categories and created a flowchart based on checklists and flowcharts received from contractors. Inputs from project interviews discussed in the next section were used to further modify the organization of the flowchart but the activities used in the model process remained the same. During the project interviews contractors were asked to "walk" the interviewer through their preconstruction planning effort. This information was used to develop the sequence and planning categories.

An overview of the model sheet metal preconstruction planning process is shown in Fig. 3. The numbers located below each planning category refer to the specific activities that should be completed, located in Table 1. Planning categories shown at the same level represent concurrent planning categories. During the interviews contractors often spoke about a planning activity being performed at the same time as another activity or the order of the activities was different depending on the characteristics of project. The idea of concurrent planning activities has been presented in research literature. Laufer states that on all but the simplest projects, planning is a nonlinear process and that it is not possible for a contractor to complete planning "in a single run through a linear process" (Laufer 1990). Additionally, the order of the planning activities may need adjustment to fit the characteristics of the project. For example, the model process has detailed scheduling occurring prior to procuring materials, equipment, and tools. On the majority of projects sufficient time will be available to review the schedule and determine when to order the equipment so that it is delivered on time; the schedule will drive when the equipment delivery is scheduled. However, on short duration projects the project schedule may be developed around when the

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Table 1. Fifty Preconstruction Planning Activities to Be Completed

Activity number	Activity description
1	Select team members
2	Conduct a formal turnover/planning kickoff meeting and site visit
3	Review lessons learned
4	Review general and supplementary conditions
5	Identify special requirements
6	Create list of unknown information and prepare RFIs to convert to known information
7	Review the signed contract
8	Review specifications for quality requirements
9	Identify and price substitute materials and equipment
10	Submit substitution request to owner/CM/GC
11	Discuss alternative duct routes
12	Identify potential cost savings
13	Review subcontractor bids, qualifications, and current work load
14	Review scope of work with subcontractors
15	Write contracts for selected subcontractors
16	Obtain and review owner/CM/CG schedule
17	Identify mobilization/demobilization dates
18	Identify and establish delivery dates for long lead time items
19	Identify construction equipment delivery dates
20	Identify work by others that directly impacts sheet metal activities
21	Develop a coordination schedule with other subcontractors
22	Establish sheet metal subcontractor start/finish date
23	Review specifications for quality requirements
24	Inform workers of required quality standards
25	Review safety lessons learned from other jobs
26	Review safety and OSHA requirements
27	Walk the site to search for hazards before construction begins
28	Inform workers of required safety standards
29	Determine log lead-time items
30	Contract material and equipment suppliers
31	Order/prepare shop drawings for long lead-time items
32	Develop purchase orders for materials and equipment
33	Review estimated work hours
34	Create a work breakdown structure and tracking record
35–36	Develop a sequence of work and create a schedule of values
37	Prepare a manpower loading chart
38	Develop CAD drawings to identify conflicts and coordinate work
39	Identify materials and systems that can be prefabricated
40	Identify shop fabrication requirements and prepare a schedule
41	Schedule delivery of prefabricated materials
42	Identify field reporting procedures and create project file
43	Review FRI and change order procedures
44–45	Review billing procedures and prepare a billing schedule
46	Receive storage approval from owner/CM/GC
47	Discuss storage, site layout, and handling of materials and systems
48	Establish procedures for receiving, storing, and handling material
49	Identify construction equipment required
50	Hold a construction execution meeting

equipment will be available for delivery; the equipment delivery will drive the creation of the schedule.

Project Interviews

Two interviews were conducted at 19 sheet metal companies located throughout the Midwest and California. One interview was used to gather information on a successful project and the other interview to gather information on a less-than-successful project. The companies were free to select which projects they wanted to discuss, however, the researcher provided the following criteria to assist in the selection of a successful project: (1) the project was profitable; (2) the project met its target work hours or was completed under the estimated work hours; and (3) the project was completed on, or before, the contract completion. The selection criteria for the less-than-successful project were the opposite of the successful project. Due to missing data only 27 of the 38 projects were used for analysis.

The company representative interviewed was the project manager, superintendent, or general manager who oversaw the project. The interview was designed to gather data on the type of project, budget performance, schedule performance, labor performance, customer satisfaction, safety performance, project uncertainty, and project complexity. Additionally, each interviewee was asked to rate their planning effort, from not performed, below average effort, average effort, and above average effort, on each of the 50 preconstruction planning activities.

Project Success Index

An effective measurement of project performance was required to investigate the effect of preconstruction planning on project performance. A project performance index was created to assign each project a performance score. The method used by Griffith in developing a project success index was followed (Griffith et al. 1999). Contractors were asked during the project interview to define a successful project and identify what criteria would lead them to consider a project successful. The data were then reviewed to determine which success criteria could be measured. This review uncovered 15 possible variables, which ranged from "actual percent profit" to "hours spent on rework," that could be used to measure project success. The statistical software SPSS was used to perform a reliability analysis on the 15 possible success variables. A reliability analysis analyzes a group of variables to determine how reliable it is to treat the group of variables as one single variable. The test statistic is Chronbach's Alpha, which can have a value ranging from zero-not reliable to one-perfect reliability (Bohrnstedt and Knoke 1988). Several reliability analyses were performed to establish the most reliable group of success variables. The final set of success variables included 10 variables which measured five of the top six most important criteria for success as listed by project managers and resulted in a Chronbach's Alpha of 0.927, a sign of high reliability. Weights were then calculated for each variable by dividing the number of times the corresponding success criterion was identified by the total number of responses. The variable weights are shown in Table 2. Eq. (1) was then created to assign each project a performance score—a positive value indicates a successful project and a negative value indicates a less-than-successful project. This method was successful in correctly classifying all projects as successful or less-than-successful.

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$$
\begin{aligned}
&\text{Performance score } Y_R \\
&= (0.231^{*}\text{Actual percent profit } z \text{ score}) + (0.185^{*}\text{How would you rate the owner's overall} \\
&\text{satisfaction with your work } z \text{ score}) + (0.038^{*}\text{How would you rate GC's overall satisfaction with your work } z \text{ score}) \\
&+ (0.108^{*}\text{Did you exceed budgeted cost } z \text{ score}) + (0.085^{*}\text{Percent change in work-hours } z \text{ score}) \\
&+ (0.131^{*}\text{Was rework a problem } z \text{ score}) + (0.131^{*}\text{Percent of hours spent on rework } z \text{ score}) \\
&+ (0.015^{*}\text{How would you rate your relationship with the owner } z \text{ score}) \\
&+ (0.046^{*}\text{How would you rate your relationship with the general contractor } z \text{ score}) \\
&+ (0.031^{*}\text{How would you rate the communication between team members } z \text{ score})
\end{aligned} \tag{1}
$$

Integrated Project Characteristics

Integrated project characteristics were identified because a project's characteristics will likely affect the level of planning. Projects that are perceived to be low risk will likely have less planning effort. However, a project with an inaccurate bid will likely have a greater preconstruction planning effort to account for the higher level of risk associated with it. A factor analysis was used to calculate integrated project characteristic scores for each project. The factor analysis was performed on 10 project variables measured during the project interview. SPSS was used to complete the factor analysis, which is a statistical method that takes a set of variables and creates a new smaller set of variables to explain the variance of the original set. The analysis identified four integrated project characteristics, which explained 81% of the variance in the original data set. SPSS was used to calculate component scores for each project, shown in Table 3 for one project. The four characteristics and the associated measurement variables are:

1. Size component
   a. Contract cost at award. (V1)
   b. Original estimated total work hours. (V2)
   c. Estimated peak number of sheet metal workers. (V3)
   d. Original estimated project duration. (V4)
2. Uncertainty component
   a. Level of uncertainty. (V5)
   b. Level of complexity. (V7)
   c. Were you the low bidder? (V10)
3. Bid component
   a. Do you think your cost estimate was accurate? (V8)
   b. Do you think your estimated work hours were accurate? (V9)
4. Design component
   a. What percentage of the sheet metal design was completed at bid time? (V6)

Table 2. Weights for Success Variables

Success criteria	Number of responses	Weight[a]
Profit	30	0.231
Customer satisfaction		
Owner satisfaction	24	0.185
GC satisfaction	5	0.038
Budget success		
Exceed budgeted cost	14	0.108
Percent change in work hours	11	0.085
Quality		
Whether rework a problem	17	0.131
Hours spent on rework	17	0.131
Good relationships		
Relationships with owner	2	0.015
Relationships with GC	6	0.046
Team communication	4	0.031
Total	130	1.000

[a]Weight equals to the individual number of responses divided by the total responses.

Project Planning Scores

A project planning score was calculated using a factor analysis similar to the one used to calculate the integrated project characteristics. The factor analysis was performed on the data recorded for the 50 preconstruction planning during the project interviews. The data for the planning activity efforts were recorded as not performed=0, below average=1, average=2, and above average =3. The factor analysis reduced the data set from the 50 activities into 13 planning components, which explained 89% of the variance in the original data set. The components were used to calculate 13 planning component scores for each project the same way as the integrated project characteristics were calculated.

Regression Analysis

The last step was to conduct a regression analysis that would quantify the relationship between planning effort and project outcome. SPSS was used to perform a linear regression with backward elimination. The dependent variable was the project performance score and the independent variables were the 13 planning component scores and four integrated project characteristics component scores. A linear regression predicts the value of the dependent variable based on the values of the given independent variables. Therefore, the model will predict the project performance based on the planning components and integrated project characteristics.

The backward elimination analysis removed six regression components. The variables remaining in the model were constant, planning components 1, 2, 3, 4, 6, 7, 8, 9, 12, and 13, and uncertainty component. Fig. 4 is a scatter plot that displays the relationship between project performance and the project's planning effort and characteristics. This model resulted in an adjusted R^2 of 0.776. The regression equation for project performance is displayed in Eq. (2) below

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Table 3. Integrated Project Characteristic Component Scores

Variable	Project variable Z score	Size component	Uncertainty component	Bid component	Design component
V1	−0.47055	−0.16392767	0.024285334	−0.004747281	0.02964657
V2	−0.52263	−0.15123842	−0.020019927	−0.012753515	0.036371159
V3	−0.32619	−0.11855363	0.056696722	−0.020683811	−0.035445065
V4	−0.61345	−0.06493925	−0.182623392	−0.090362053	−0.051368233
V5	1.52344	−0.04762459	0.555987291	−0.048800554	0.276707703
V6	−0.4102	−0.01028394	−0.0507256	0.02698081	−0.262106581
V7	1.48404	−0.28166357	0.704893519	−0.075596434	−0.251556243
V8	−0.74129	−0.02962548	−0.053181254	−0.389277075	0.078172252
V9	−0.65405	−0.04754133	0.038595364	−0.339672113	−0.037641497
V10	−0.39304	−0.04295946	−0.040775713	0.016078695	0.212794666
Total		−0.95835734	1.033132344	−0.93883333	−0.004425269

$$\begin{aligned}\text{Project Performance} = {} & 0.477 - 0.091^{*}(\text{uncertainty component})\\ & - 0.049^{*}(\text{Planning Component 1})\\ & - 0.020^{*}(\text{Planning Component 2})\\ & + 0.135^{*}(\text{Planning Component 3})\\ & + 0.073^{*}(\text{Planning Component 4})\\ & + 0.064^{*}(\text{Planning Component 6})\\ & + 0.060^{*}(\text{Planning Component 7})\\ & - 0.022^{*}(\text{Planning Component 8})\\ & + 0.047^{*}(\text{Planning Component 9})\\ & + 0.038^{*}(\text{Planning Component 12})\\ & - 0.044^{*}(\text{Planning Component 13})\end{aligned} \tag{2}$$

Recommendations for Implementation

This research resulted in the creation of "Sheet metal preconstruction planning process—Implementation manual" a document that will be published by SMACNA. The manual describes how to execute each of the 50 planning activities and includes sample documents and checklists to be used during preconstruction planning. The manual also includes a section for successful implementation that read as follows.

Preconstruction planning must become the company standard and part of the company culture. It should be mandatory for all projects regardless of size or type of construction. However, the process should be tailored to the unique characteristics of each project, including complexity, duration, and volume of work. The key conditions for successful implementation of the sheet metal preconstruction planning are:
- Supported by top management;
- Foreman takes off the job;
- It is executed early;
- It is formal and mandatory;
- Productivity is measured as estimated; and
- Effective turnover meetings.

Conclusions

Nearly all contractors perform some amount of project planning before and during the execution of their construction projects.

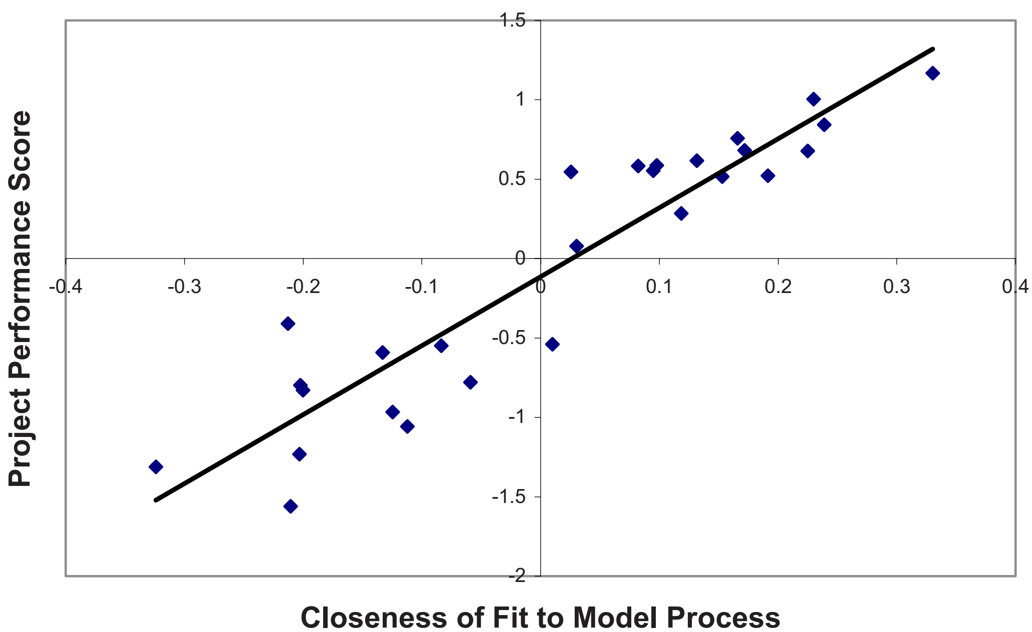

Fig. 4. Linear regression of preconstruction planning score on project performance score

Their planning may be very formal, including written instruction with checklists and delivery plans, or very informal, where the planning is done primarily in the project manager's mind. This research has resulted in the development of the model sheet metal preconstruction planning process. Based on project data collected for this research, projects that used a planning process similar to this process performed more successfully—they achieved an average profit margin of 23% while projects that were poorly planned experienced an average profit margin of -3%. Furthermore, projects that were well planned perform superior to those projects which were poorly planned in the areas of profit, general contractor satisfaction, budgeted cost, budgeted work hours, quality, relationship with the owner, relationship with the general contractor, and team member communication.

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