# Latent Structures of the Factors Affecting Construction Labor Productivity

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**Abstract:** At any moment in time, a multitude of factors simultaneously impact construction productivity. Utilizing the knowledge of thousands of construction craft workers, the writers quantitatively analyzed the underlying structure of the factors affecting construction productivity and identified which factors the craft workers consider to be more relatively important as well. This research identified 83 factors affecting construction labor productivity through 18 focus groups with craft workers and their immediate supervisors on nine jobsites throughout the U.S. Next, a nationwide survey was administered to 1,996 craft workers to assess the impact of these factors on construction labor productivity. Principal factor analyses identified 10 latent factors to represent the underlying structure of 83 productivity factors. In addition, the relative importance of the factors' impact on construction productivity was examined based on the crafts' union status, trade, and position (craft worker versus foreman). The writers also compared their results to similar previous efforts, and more importantly, identified significant differences that may impact future productivity improvement strategies. This research will help industry and the research community better understand the factors affecting construction labor productivity and more effectively direct future efforts to improve its performance.

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## Introduction

Every construction project is directly or indirectly affected by a wide range of factors. The loss of construction productivity is usually attributed to various factors, rather than a single one. In addition, factors affecting construction labor productivity are rarely independent of the others; some factors may be the result of the same cause, or one factor may trigger the occurrence of others.

Jobsite management has different levels of control on the factors affecting construction productivity. Some factors, such as material and tool availability, can be managed and controlled. Other factors, such as the availability of skilled craft workers and extreme weather, are difficult to eliminate even though various methods are available to minimize their impact. Nevertheless, it is widely believed that the majority of the factors affecting construction productivity can be improved through the efforts of jobsite management (Olson 1982; Rojas and Aramvareekul 2003). More attention on those manageable factors is warranted. As a result, an extensive amount of research (Borcherding and Garner 1981; Diekmann and Heinz 2001; Hanna et al. 1999; Horman and Thomas 2005) has been conducted to understand the factors and prioritize them in order to help improve construction productivity. However, these studies have been conducted primarily from management's standpoint. Craft workers' input of the factors that influence their daily productivity has rarely been sought by managers or researchers either because it takes time away from craft workers' tasks that are to be done or because it is considered an infringement on management's right to control the work (Oglesby et al. 1989).

Craft workers, as the major player executing construction processes and activities, have a significant influence on construction labor productivity (Maloney 1983). In addition, craft workers are in the ideal position to know where and how much of a site's productivity is lost or could be gained. Understanding the factors influencing construction labor productivity from the craft workers' perspective will not only enable jobsite management teams to provide craft workers with better support but also enhance craft workers' motivation.

## Purpose and Scope

This paper examines the underlying structure of the factors affecting construction productivity from the craft workers' perspective. The study began with 18 focus group sessions with craft workers and their immediate supervisors on nine industry projects throughout the U.S. (Dai et al. 2005). After the focus groups identified 83 factors affecting construction labor productivity (Table 1), the research team administered a survey to 1,996 craft workers on 28 industry projects throughout the U.S. to quantify their relative importance.

In order to identify the macroview of the above productivity factors from the craft workers' perspective, the paper identifies the latent productivity factors, which represent the underlying structure of the 83 productivity factors (Table 1). Second, the

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J. Constr. Eng. Manage., 2009, 135(5): 397-406

**Table 1.** Productivity Factors

| Frequency factors (27) | Agreement factors (56) |
|---|---|
| • Inadequate instruction provided | • Receiving compliments for doing a good job |
| • Not receiving directions due to size of the project | • Being notified of mistakes when they occur |
| • Different languages spoken on a project | • Lack of goals for craft workers' qualified foremen |
| • Shortage of personal protective equipment | • Fair/just performance reviews |
| • Availability of consumables | • Foremen allowing crafts to work autonomously |
| • Restrictive project policy on consumables | • Lack of construction knowledge on behalf of foremen |
| • Availability of hand tools | • Lack of authority to discipline craft workers |
| • Availability of power tools | • Lack of proper resource allocation |
| • Lack of power source for tools | • Proper managerial and administrative support |
| • Lack of extension cords | • Excessive paperwork |
| • Inexperienced tool room attendants | • Disregard of crafts' productivity improvement suggestion |
| • Misplaced tools | • Lack of "big picture" view on behalf of the crafts |
| • Poor quality power tools | • Craft worker importance |
| • Availability of material | • Lack of communication among site management |
| • Poor material quality | • Lack of site safety resources |
| • Availability of bulk commodities | • Superintendent's people skill |
| • Errors in prefabricated material | • Qualified superintendents |
| • Drawing errors | • Lack of experience on behalf of superintendents |
| • Availability of drawings | • Respect for craft workers |
| • Slow response to questions with drawings | • Micromanagement on behalf of superintendent |
| • Availability of crane or forklift | • Political/performance competitions within company |
| • Availability of manlift | • Inconsistent safety policies established by different superintendents |
| • Waiting for people and/or equipment to move material | • Different work rules by superintendents |
| • Delay in work permits | • Different per diem rate |
| • Out of sequence work assignments | • Incentive for good performance |
| • Absenteeism | • Material storage area too far from workface |
| | • Insufficient size of material storage area |
| | • Shortage of temporary facilities |
| | • Coordination between the trades |
| | • Slow decisions |
| | • Correct crew size |
| | • Vehicle traffic routes |
| | • Weather protection |
| | • Difficulty in tracking material |
| | • Drawing legibility |
| | • Needed information not on drawings |
| | • Availability of skill training |
| | • Jobsite orientation program |
| | • Availability of health and safety training |
| | • Qualified craft workers |
| | • Craft workers' pride in their work |
| | • Craft workers' incentive |
| | • Motivated craft workers |
| | • Equal pay on projects in a geographic area |
| | • Craft workers' trust in supervisors |
| | • Poor equipment maintenance |
| | • Equipment repairs |
| | • Maintenance of power tools |
| | • Pulling people off a task before it is done |
| | • Jobsite congestion |
| | • Different pay scales for the same job on a project |
| | • Reasonable project goals and milestones |
| | • Respect for craft workers and foremen |
| | • Layoff of qualified craft workers |
| | • Awareness of on-site activities and project progress |





J. Constr. Eng. Manage., 2009, 135(5): 397-406

paper prioritizes the latent productivity factors in terms of their impact on construction labor productivity. Third, the relationship between the latent productivity factors and craft workers' perception of their respective project's productivity is examined through regression analyses. Fourth, the relative importance of the latent productivity factors is examined based on the craft workers' union status, trade, and position (foreman versus craft worker).

## Background

Numerous studies have been conducted previously to identify the multitude of individual factors that impact construction productivity. One of the first of these related efforts was a United Nations (1965) study that reported how substantial improvements in labor productivity can be achieved through repetitive site operations. Other early work was conducted by Borcherding and Oglesby (1974) and Maloney (1981), who examined the effects of craft motivation on construction labor productivity. The impact of material management practices, delivery methods, and fabricators on productivity has been examined extensively by others (Thomas et al. 1989, 1999; Thomas and Sanvido 2000; Horman and Thomas 2005). The loss of productivity as a result of scheduled overtime has also been examined repetitively (BRT 1980; Oglesby et al. 1989; Thomas and Raynar 1997). Thomas and Napolitan (1995) and Hanna et al. (1999) quantified the impact of change orders on construction productivity. Diekmann and Heinz (2001) examined the influence of support personnel, drawing, equipment, and material buffer strategies on productivity in the piping and electrical trades. This brief review of previous research on specific productivity factors is not meant to be exhaustive since such an effort would require greater liberties than can be afforded to a single manuscript. Instead, the review is meant to acknowledge that the factors addressed in our research were by and large already known, but the theoretical relationships that exist among the factors have largely been based on the opinions of either the previous researchers or a few selected industry professionals.

Multiple studies have presented construction productivity models to explain the interaction of the productivity factors (Halligan et al. 1994; Kellogg et al. 1981; Maloney 1983; Sanvido 1988; Thomas et al. 1990). However, it is extremely difficult to distinguish the influence of any single factor since jobsite productivity is simultaneously influenced by multiple factors (United Nations 1965). In the 1990s, productivity classification schemes reflected a change in project characteristics, including an increased sophistication of project design. Herbsman and Ellis (1990) grouped productivity factors into technological and administrative based on interviews with industry practitioners. Technological factors were primarily related to project design, such as specifications, design drawings, and material selection. Meanwhile, administrative factors were defined as being related to the management and construction of a project, such as equipment, labor, and social factors. Thomas and Sakarcan (1994) also defined two broad classification schemes for construction productivity: organizational and executional continuity. Organizational continuity referred to the actual work to be done, such as work scope and size of the components. Executional continuity consisted of the work environment and management components, such as weather and work sequencing. Mirroring Thomas and Sakarcan (1994), Olomolaiye et al. (1998) divided productivity factors into external and internal factors, representing those factors beyond and within the control of management, respectively. External factors included the nature of the industry, the construction clients, weather, the level of economic development, legislation, procurement policies, codes of practices, and so forth. Internal factors involved management, technology, labor, unions, and so on. While Liberda et al. (2003) also used the classification of external as one broad productivity factor classification involving 51 productivity factors, the remaining productivity factors were divided into labor and management. Based on interviews with industry experts, Liberda et al. (2003) identified management as being the most influential factor.

As discussed, there have been decades of previous efforts in modeling and classifying productivity factors. As project characteristics have changed so have the classifications, although more recent efforts have displayed more similarities than differences in their classification schemes. Unlike the writers' research, previous efforts have relied on a combination of industry and research expertise to identify the classification schemes. Furthermore, most previous efforts have not addressed the relative magnitude that different factors and their related structures have on productivity. Utilizing the perspective of thousands of craft workers across the U.S., our research identified a new classification scheme that defines the relative impact of different classes based on the knowledge of construction craft workers themselves.

## Methodology

A craft worker survey was developed to quantify the relative importance of the 83 factors identified from 18 focus group sessions with craft workers and their immediate supervisors on nine industry projects throughout the U.S. The craft worker survey consisted of three sections. Section one related to demographic information and it identified each respondent's union status, trade, and position. This research measured project productivity by using craft workers' perception, instead of measuring project productivity directly. Respondents rated their projects' productivity performance on a seven-point Likert scale, with 1 being the worst job they had ever experienced and 7 being the best job. The second section asked respondents to rate the frequency and severity of 26 factors. In order to help clarify the discussion from here on, these 26 factors investigated in the second section of the craft worker survey are referred to as the frequency factors as shown in Table 1. The frequency of these factors was rated on a seven-point Liker scale with 1 indicating as never occurring and 7 indicating as always occurring. The impact of each factor was also rated on the seven-point Likert scale, with 1 as having no impact on productivity and 7 as having an extreme impact on productivity. The third section of the survey investigated respondents' level of agreement with the other 57 factors and their perception of the factors' impact on productivity. Accordingly, these 57 factors are referred to as the agreement factors as shown in Table 1. The agreement factors tend to occur on a continual basis if they were to be an issue, such as, "My foreman is not qualified for his job." The agreement on each factor was rated by each respondent on a seven-point scale, with 1 indicating strongly disagree and 7 indicating strongly agree. The agreement factors also used a seven-point impact scale, with 1 indicating a very negative impact and 7 indicating a very positive impact, which is different than the impact rating of the frequency factors. The researchers included the bipolar impact scale since the agreement factors included both positive and negative worded issues. Therefore, if a respondent disagreed with a negative worded issue (e.g., "There is not enough room on the site for material storage"), the respondent



J. Constr. Eng. Manage., 2009, 135(5): 397-406

| | ← Less Agreement More → | | | | | | | ← Negative Impact Positive → | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Strongly Disagree | | Mildly Disagree | Neither Agree Nor Disagree | Mildly Agree | | Strongly Agree | Very Negative | | Small | No Impact | Small | | Very Positive |
| 54. The equipment on this job is not properly maintained. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 55. When the equipment on this job breaks down, it is quickly repaired. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

**Fig. 1.** Example of the survey questions



would have likely indicated that his or her experience with the issue would have been positive (i.e., having enough room on the site for material storage had a positive impact). Positive and negative worded factors were intentionally mixed to improve the quality of responses as shown in Fig. 1.

In addition, a project information form was completed by the projects' site management with the purpose of obtaining project demographic information, performance information, and project practices.

### *Factor Analysis*

Recognizing that 83 factors are likely inter-related through an underlying structure of primary factors, the research utilized factor analysis to identify and quantify this structure. Specifically, the principal axis method was chosen to extract the latent factors, which explains the common variance of the observed variables (Loehlin 1998) because the data were not statistically multivariate normal, which is required for other factor extraction methods such as maximum-likelihood method.

## Findings

### *Latent Factors*

The research performed factor analysis on the frequency and agreement factors separately, due to different rating scales as described earlier. For the frequency factors, factor analysis was performed based on the product of the frequency and severity rating for each factor. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.94 and Bartlett's test was extremely significant ($p < 0.01$); both indicating that factor analysis was appropriate in identifying the underlying structure of the frequency factors. Factor analysis extracted five latent factors, and Table 2 shows the rotated factor-loading matrix for the five latent factors. Rotation is a process of adjusting the factor axes to achieve a simpler and pragmatically more meaningful factor solution with respect to their interpretability. A factor loading is the correlation between the latent factor and the observed variable. The factor loadings less than 0.4 are suppressed to help simplify Table 2.

In total, five latent factors account for 51.3% of the total variance of the frequency factors. The variables with dominant factor loadings were used to determine the nature of the latent factors. Tools (including consumables) availability and quality, "misplaced tools," "restrictive policy on consumables," "poor tool quality," and "lack of extension cords" loaded more substantially on Latent Factor 1 than other latent factors; therefore, Latent Factor 1 is described as Tool and Consumable Factors. Latent Factor 2 is described as Direction and Coordination Factors, which refers to how supervisors direct the work and coordinate craft workers. The shortage of personal protective equipment also loaded significantly on Direction and Coordination Factors, which may be explained by the fact that a shortage of personal protective equipment can be caused by inadequate instruction provided by supervisors. Variables loading on Latent Factor 3 focus on drawing quality and availability, and slow response from engineers to the questions with drawings. Therefore, Latent Factor 3 is named Engineering Drawing Management. Latent Factor 4 is labeled Construction Equipment, which is associated with the availability and coordination of construction equipment. Material issues, which include bulk commodity availability and material quality, loaded significantly on Latent Factor 5. Four frequency factors, including different languages spoken on a project, lack of power source, inexperienced tool room attendants and errors in prefabricated materials, had relatively low correlations with the above-mentioned latent factors.

Another factor analysis was performed to identify the underlying structure of the agreement factors. For the agreement factors, factor analysis was performed by using their impact scale. Again, both the Kaiser-Meyer-Olkin measure of sampling adequacy test (0.92) and Bartlett's test of sphericity are significant ($p < 0.01$), which indicate that factor analysis is also appropriate for the agreement factors. Another five latent factors emerged from the factor analysis. Table 3 shows the rotated factor-loading matrix for the agreement factors, and once again the factor loadings less than 0.4 are suppressed.

As shown in Table 3, five latent factors explained 31.2% of the total variance of the 57 agreement factors. The latent factors of the agreement factors are named as Project Management, Foreman Competency, Superintendent Competency, Training, and Craft Worker Qualification, respectively. Among the agreement factors, 23 did not load significantly on these latent factors. Overall, a total of 10 latent factors were extracted to present the underlying structure of the factors affecting construction productivity.

### *Factor Score*

Factor scores were computed for each latent factor from the factor score coefficient matrices (Tables 2 and 3). The maximum and minimum factor scores vary for each latent factor, because each latent factor is composed of a different numbers of observed variables with different weightings making it difficult to compare the latent factors. To overcome this, the factor score of each latent factor was converted into a proportion of its corresponding latent factor's potential range using methods described by others (Maloney and McFillen 1987). For the frequency factors, the converted factor scores range from 0.0 to 1.0, with 0.0 indicating no impact on construction productivity and 1.0 indicating an ex-



J. Constr. Eng. Manage., 2009, 135(5): 397-406

**Table 2.** Factor Loading for the Frequency Factors after Varimax Rotation

| Observed variables | Latent factors: Tool and Consumable | Direction and Coordination | Engineering Drawing Management | Construction Equipment | Material |
|---|---|---|---|---|---|
| Availability of power tools | 0.80 | | | | |
| Availability of hand tools | 0.78 | | | | |
| Misplaced tools | 0.65 | | | | |
| Availability of consumables | 0.62 | | | | |
| Restrictive project policy on consumables | 0.56 | | | | |
| Poor quality of power tools | 0.55 | | | | |
| Lack of extension cords | 0.50 | | | | |
| Out of sequence work assignments | | 0.55 | | | |
| Delay in work permits | | 0.50 | | | |
| Not receiving directions due to size of the project | | 0.48 | | | |
| Inadequate instruction provided by supervisors | | 0.43 | | | |
| Absenteeism | | 0.46 | | | |
| Shortage of personal protective equipment | | 0.40 | | | |
| Drawing errors | | | 0.79 | | |
| Slow response to questions with drawings | | | 0.70 | | |
| Availability of drawings | | | 0.67 | | |
| Availability of crane or forklift | | | | 0.75 | |
| Waiting for people and/or equipment to move material | | | | 0.73 | |
| Availability of manlift | | | | 0.64 | |
| Availability of material | | | | | 0.68 |
| Availability of bulk commodities | | | | | 0.56 |
| Poor material quality | | | | | 0.50 |
| **Eigenvalues** | 4.21 | 2.58 | 2.52 | 2.22 | 1.82 |
| **Percentage of variance** | 16.18 | 9.91 | 9.69 | 8.53 | 7.01 |
| **Cumulative % of variance** | 16.18 | 26.09 | 35.78 | 44.3 | 51.31 |

tremely negative impact. For the agreement factors, the converted factor scores range from −1.0 to 1.0, with −1.0 indicating an extremely positive impact and 1.0 indicating an extremely negative impact on construction productivity. This conversion allowed the writers to identify the relative importance of the latent factors on construction productivity based on the craft workers' knowledge, which is a significant departure from previously related research. Table 4 presents the proportional minimum, mean, and maximum converted scores for the latent factors in descending order of the average factor score.

As measured by the average latent factor score, craft workers considered that Construction Equipment potentially has the most negative impact on construction labor productivity among the frequency latent factors, followed by Material, Tool and Consumable, Engineering Drawing Management, and Direction and Coordination. Among the agreement latent factors, Training, Craft Worker Qualification, Superintendent Competency, and Foremen Competency have a small positive impact on construction labor productivity from the craft workers' perspective. However, it is also noted that all of the agreement latent factors had a fairly high maximum score, which indicates that in some cases craft workers' productivity was significantly hampered by these factors.

### Demographic Difference

Demographic variables were studied to examine the difference in the latent factors' impact on construction labor productivity among different populations. The respondents were grouped by union status (union versus nonunion), trades (civil, mechanical, piping, and electrical), and positions (craft workers versus foremen). Among the participants in the survey, union and nonunion craft workers accounted for 49.5 and 50.5%, respectively. This near balance in the population may be attributed to the industrial nature of the sampled projects. Civil, piping, electrical, and mechanical trades each accounted for 42.6, 26.4, 18.2, and 12.8% of the respondents, respectively. The majority of respondents were journeymen (56.1%), followed by foremen and general foremen (26.0%), apprentices (9.6%), helpers (7.2%), and others (1.1%).

A significant difference was observed on four latent factors between union and nonunion respondents at the 95% confidence level (Table 5), although the differences were not substantial, with Craft Worker Qualification having the greatest difference between the two groups. Union respondents rated Craft Worker Qualification factors as having a small positive impact on construction productivity, while nonunion respondents reported that Craft Worker Qualification had a neutral impact on construction productivity. Craft skills could explain the difference in Craft Worker Qualifications; however, it is noted that there was no significant difference between union and nonunion respondents in regard to the impact of Training Factors on construction productivity.

Five latent factors showed statistically significant differences among four trade groups at the 95% confidence level (Table 6), but once again many of the differences were not substantial, with a few exceptions. Electrical crafts reported Engineering Drawing Management Factors being the most severe as indicated by a converted factor score of 0.44, followed by pipefitting (0.39) and mechanical crafts (0.38). Civil crafts experienced the least severe



J. Constr. Eng. Manage., 2009, 135(5): 397-406

**Table 3.** Factor Loading for the Agreement Factors after Varimax Rotation

| Observed variables | Latent factors: Project Management | Foremen Competency | Superintendent Competency | Training | Craft Worker Qualification |
|---|---|---|---|---|---|
| Reasonable project goals and milestones | 0.46 | | | | |
| Respect for craft workers and foremen | 0.53 | | | | |
| Layoff of qualified craft workers | 0.51 | | | | |
| Awareness of on-site activities and project progress | 0.47 | | | | |
| Pulling people off a task before it is done | 0.50 | | | | |
| Jobsite congestion | 0.61 | | | | |
| Different pay scales for the same job on a project | 0.37 | | | | |
| Different per diem rate | 0.40 | | | | |
| Material storage area too far from workface | 0.48 | | | | |
| Insufficient size of material storage area | 0.42 | | | | |
| Slow decisions | 0.63 | | | | |
| Receiving compliments for doing a good job | | 0.64 | | | |
| Being notified of mistakes when they occur | | 0.51 | | | |
| Disregard of crafts' productivity improvement suggestion | | 0.59 | | | |
| Qualified foremen | | 0.56 | | | |
| Fair/just performance reviews | | 0.54 | | | |
| Not being informed of the contribution of craft workers' work to the project | | 0.53 | | | |
| Foremen allowing crafts to work autonomously | | 0.52 | | | |
| Proper managerial and administrative support | | 0.45 | | | |
| Superintendent's people skill | | 0.42 | | | |
| Respect for craft workers | | 0.42 | | | |
| Different work rules by superintendents | | | 0.69 | | |
| Lack of experience on behalf of superintendents | | | 0.67 | | |
| Qualified superintendents | | | 0.65 | | |
| Political/performance competitions within company | | | 0.60 | | |
| Inconsistent safety policies established by different superintendents | | | 0.58 | | |
| Availability of health and safety training | | | | 0.49 | |
| Foremen people skill | | | | 0.48 | |
| Availability of skill training | | | | 0.47 | |
| Craft workers' incentive to seek additional training or certification | | | | 0.45 | |
| Lack of construction knowledge on behalf of foremen | | | | 0.43 | |
| Qualified craft workers | | | | | 0.65 |
| Craft workers' pride in their work | | | | | 0.59 |
| Coordination between the trades | | | | | 0.47 |
| **Eigenvalues** | 4.62 | 3.96 | 3.60 | 3.16 | 2.43 |
| **Percentage of variance** | 8.11 | 6.95 | 6.31 | 5.54 | 4.25 |
| **Cumulative % of variance** | 8.11 | 15.06 | 21.37 | 26.91 | 31.16 |

Engineering Drawing Management Factors (0.36). Project Management Factors were statistically significantly different among the four trade groups ($F=3.64$, $p=0.01$), with mechanical crafts having the highest factor score (0.09) and civil crafts having the lowest factor score (0.04). Although these differences are admittedly not dramatic, the analysis does indicate that the significance of productivity factors varies by trades, and this should be considered in an onsite productivity improvement program.

Significant differences in four latent factors were found between foremen and craft workers (Table 7). Foremen reported Engineering Drawing Management Factors being significantly more severe than craft workers did, as shown by the converted factor scores of 0.41 versus 0.38. This is most likely reflective of the fact that foremen use drawings more often than craft workers. Conversely, craft workers rated Material Factors as being significantly more severe than foremen did at the 95% confidence level. It is interesting that craft workers reported Foremen Competency and Superintendent Competency Factors as being less positive than foremen.

### *Regression Analysis*

To examine how the latent factors influenced the craft workers' perceptions about their projects' productivity, regression analyses were performed between the latent factor scores and a project productivity rating assigned by the craft workers. Fig. 2 presents the distribution of craft workers' perception of their projects' productivity. Project productivity was rated from 1 (worst project) to



J. Constr. Eng. Manage., 2009, 135(5): 397-406

**Table 4.** Converted Latent Factor Scores

| Latent productivity factor | Minimum | Mean | Maximum |
|---|---|---|---|
| **Frequency latent factors** | | | |
| Construction Equipment | 0.14 | 0.45 | 0.93 |
| Material | 0.13 | 0.43 | 0.85 |
| Tool and Consumable | 0.16 | 0.42 | 0.85 |
| Engineering Drawing Management | 0.13 | 0.39 | 0.80 |
| Direction and Coordination | 0.17 | 0.34 | 0.80 |
| **Agreement latent factors** | | | |
| Project Management | −0.53 | 0.06 | 0.76 |
| Training | −0.76 | −0.03 | 0.68 |
| Craft Worker Qualification | −0.51 | −0.05 | 0.58 |
| Superintendent Competency | −0.61 | −0.10 | 0.65 |
| Foremen Competency | −0.75 | −0.19 | 0.80 |

Note: larger mean scores indicate a greater negative impact. The range for the frequency latent factors is 0 to 1, and the range for the agreement latent factors is −1 to 1.

**Table 5.** Converted Latent Factor Scores by Union Status

| Latent productivity factors | Converted factor score | | | |
|---|---|---|---|---|
| | Nonunion | Union | $F$ | Sig. |
| **Frequency latent factors** | | | | |
| Construction Equipment | 0.46 (605) | 0.45 (560) | 1.14 | 0.29 |
| Materials | 0.43 (605) | 0.44 (560) | 10.44 | <0.01 |
| Tools and Consumables | 0.41 (605) | 0.42 (560) | 3.58 | 0.06 |
| Engineering Drawing Management | 0.38 (605) | 0.40 (560) | 7.30 | 0.01 |
| Direction and Coordination | 0.34 (605) | 0.35 (560) | 0.21 | 0.64 |
| **Agreement latent factors** | | | | |
| Project Management | 0.03 (511) | 0.09 (467) | 32.85 | <0.01 |
| Training | −0.03 (511) | −0.04 (467) | 2.03 | 0.15 |
| Craft Worker Qualification | −0.01 (511) | −0.10 (467) | 58.93 | <0.01 |
| Superintendent Competency | −0.09 (511) | −0.11 (467) | 2.29 | 0.13 |
| Foremen Competency | −0.20 (511) | −0.19 (467) | 0.89 | 0.34 |

Note: the number in the parenthesis refers to the sample size.

**Table 7.** Converted Latent Factor Scores by Positions

| Latent factors | Converted factor score | | | |
|---|---|---|---|---|
| | Foremen | Craft workers | $F$ | Sig. |
| **Frequency latent factors** | | | | |
| Construction Equipment | 0.46 (318) | 0.45 (815) | 3.23 | 0.07 |
| Materials | 0.42 (318) | 0.44 (815) | 13.80 | <0.01 |
| Tools and Consumables | 0.42 (318) | 0.41 (815) | 0.71 | 0.40 |
| Engineering Drawing Management | 0.41 (318) | 0.38 (815) | 11.77 | <0.01 |
| Direction and Management | 0.34 (318) | 0.35 (815) | 0.18 | 0.68 |
| **Agreement latent factors** | | | | |
| Project Management | 0.06 (234) | 0.07 (716) | 0.27 | 0.60 |
| Training | −0.04 (234) | −0.03 (716) | 0.48 | 0.49 |
| Craft Worker Qualification | −0.05 (234) | −0.05 (716) | 0.01 | 0.91 |
| Superintendent Competency | −0.13 (234) | −0.09 (716) | 9.50 | <0.01 |
| Foremen Competency | −0.22 (234) | −0.18 (716) | 6.83 | 0.01 |

Note: the number in the parenthesis refers to the sample size.

7 (best project). There are 1,451 valid respondents, with good productivity (5) having the highest frequency at 40.2%.

Since there were extremely weak correlations between the latent factors, the optimal model did not consider the interaction between the latent factors (Table 8). All of the regression coefficients are negative, which indicates the consistency of the craft workers' response and also indicates that craft workers perceived lower project productivity when the latent factors were more severe.

As shown in Table 8, except for Tool and Consumable (Latent Factor 1) and Superintendent Competency Factors (Latent Factor 8), all other latent factors were included in the optimal model, and had a significant impact on construction productivity from the craft workers' perspective. These eight factors explained 29% of the total variance on the craft workers' perception of their project productivity. The amount of variance explained is significant, given the fact that the sampled respondents contained a wide array of trades, each with its particular work demands, and the uniqueness of the construction projects. The variance inflation factor (VIF) of the independent variables in the regression model was also examined. All eight latent factors included in the optimal

**Table 6.** Converted Latent Factor Scores by Trades

| Latent factors | Converted factor score | | | | | |
|---|---|---|---|---|---|---|
| | Piping | Mechanical | Electrical | Civil | $F$ | Sig. |
| **Frequency latent factors** | | | | | | |
| Construction Equipment | 0.47 (315) | 0.45 (138) | 0.44 (212) | 0.45 (386) | 3.57 | 0.01 |
| Materials | 0.43 (315) | 0.42 (138) | 0.46 (212) | 0.43 (386) | 5.38 | <0.01 |
| Tools and Consumables | 0.42 (315) | 0.42 (138) | 0.43 (212) | 0.41 (386) | 2.22 | 0.08 |
| Engineering Drawing Management | 0.39 (315) | 0.38 (138) | 0.44 (212) | 0.36 (386) | 23.74 | <0.01 |
| Direction and Coordination | 0.33 (315) | 0.35 (138) | 0.34 (212) | 0.36 (386) | 11.40 | <0.01 |
| **Agreement latent factors** | | | | | | |
| Project Management | 0.07 (265) | 0.09 (125) | 0.08 (168) | 0.04 (328) | 3.64 | 0.01 |
| Training | −0.02 (265) | −0.04 (125) | −0.02 (168) | −0.05 (328) | 1.13 | 0.34 |
| Craft Worker Qualification | −0.05 (265) | −0.04 (125) | −0.03 (168) | −0.07 (328) | 2.00 | 0.11 |
| Superintendent Competency | −0.09 (265) | −0.07 (125) | −0.12 (168) | −0.10 (328) | 1.37 | 0.25 |
| Foremen Competency | −0.19 (265) | −0.19 (125) | −0.17 (168) | −0.19 (328) | 0.60 | 0.62 |

Note: the number in the parenthesis refers to the sample size.



J. Constr. Eng. Manage., 2009, 135(5): 397-406

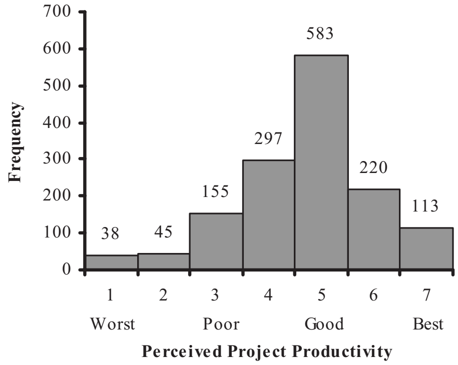


**Fig. 2.** Distribution of craft workers' perceived project productivity

**Table 9.** Standardized Correlation Coefficient

| Latent productivity factors | Standardized regression coefficient | Standard deviation |
|---|---|---|
| Construction Equipment | −0.24 | 0.12 |
| Project Management | −0.20 | 0.09 |
| Craft Worker Qualification | −0.18 | 0.09 |
| Training | −0.11 | 0.09 |
| Foremen Competency | −0.11 | 0.10 |
| Materials | −0.08 | 0.08 |
| Engineering Drawing Management | −0.08 | 0.11 |
| Direction and Coordination | −0.07 | 0.07 |

model had a VIF near 1, much less than the common cutoff point, 10. Therefore, multicollinearity was not a concern for the optimal model in Table 8.

Since the latent factors have different standard deviations (Table 9), the standardized regression coefficient was chosen to compare the latent factors' relative impact on perceived project productivity. The standardized regression coefficient refers to the predicted increase in standard deviation units of perceived project productivity per standard deviation increase in the latent factors as shown in the following formula:

$$b_i^s = \frac{b_i \times s_{x_i}}{s_y} \tag{1}$$

where $b_i^s$=standardized regression coefficient for the $i$th variable; $s_x$=corresponding standard deviation of the independent variable; and $s_y$=standard deviation of the dependent variable.

Table 9 also lists the standardized regression coefficient for the optimal regression model in Table 8. Construction Equipment Factors had the greatest influence on craft workers' perception of project productivity as evidenced by a standardized regression coefficient of −0.24, and it is also the first ranked factor with respect to its impact on construction labor productivity as measured by the converted factor score (Table 4). The next most important latent factor was Project Management with a standardized correlation coefficient of −0.20, even though it ranks low among the 10 latent factors in terms of the converted factor score. Craft Worker Qualification Factors ranks third with a standardized regression coefficient of −0.18. Although the Tool and Consumable and Material Factors significantly impacted the craft workers' ability to be productive as evidenced by their converted factor scores, their influence on the craft workers' perception of their project productivity was not substantial as found by the regression analysis. This finding may indicate that craft workers consider few improvement opportunities exist in the factors associated with materials, tools, and consumables since there was little variance in Tool and Consumable and Material Factors across projects participating in the study.

One pending question that may evolve throughout the above analyses concerns the validity of craft labor perception as a measure of construction productivity. As a result, additional analysis was conducted to compare craft workers' perception of project productivity with construction cost performance. For each project, the average score of perceived project productivity was calculated, and construction cost performance was computed as a ratio of earned value to actual construction cost. Among the projects participating in the survey, 19 projects provided their construction cost performance information. The congruency between perceived project productivity and construction cost performance is moderately high (correlation coefficient=0.44) and statistically significant at the 90% confidence level as shown in Table 10. The reason for the relatively moderate correlation coefficient could be that different measures were used by jobsite management and craft workers in the relative assessment of the projects' productivity. Earned value usually is estimated in accordance with basic cost after being adjusted for the specific project situations (such as market condition, unit price versus lump sum, etc.). Therefore, earned value fairly depends on the estimators' knowledge, experience, and information available about the specific project. Meanwhile, craft workers considered labor productivity as unit per hours (e.g., a number of bricks installed per hour). Considering these conditions and the observations, it is the writers' opinion that the craft workers, as a group, did have a reasonable sense of their projects' performance.

## Discussion

Factor analysis distilled 83 factors affecting construction productivity to 10 latent factors, which provides a macroview of the

**Table 8.** Regression of the Latent Factors on Perceived Project Productivity

| | Independent variables latent factors | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constant | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | $F$ | $R^2$ | Adjusted $R^2$ |
| 6.87 (20.42) | | −1.17 (−2.21) | −0.82 (−2.49) | −2.55 (−7.40) | −1.14 (−2.55) | −1.39 (−5.82) | −0.65 (−3.50) | | −0.84 (−3.40) | −1.28 (−5.89) | 40.92 | 0.30 | 0.29 |

Note: dependent variable: perceived project productivity; independent variable selection method: stepwise; t value shown in parenthesis: $N$=774; and Adjusted $R^2 = R^2 - (k-1)/(n^*)^*(1-R^2)$.

Latent Factors ordered as (1) Tool and Consumable; (2) Direction and Coordination; (3) Engineering Drawing Management; (4) Construction Equipment; (5) Material; (6) Project Management; (7) Foremen Competency; (8) Superintendent Competency; (9) Training; (10) Craft Worker Qualification.



J. Constr. Eng. Manage., 2009, 135(5): 397-406

**Table 10.** Comparison of Craft Workers' Perception of Project Productivity with Construction Cost Performance

| | Pearson correlation | |
|---|---|---|
| | Crafts' perceived project productivity | Construction performance ratio |
| Crafts' perceived project productivity | 1 | 0.442 (Sig.=0.058) |
| Construction performance ratio | 0.442 (Sig.=0.058) | 1 |

Note: construction cost performance=earned value/actual cost.

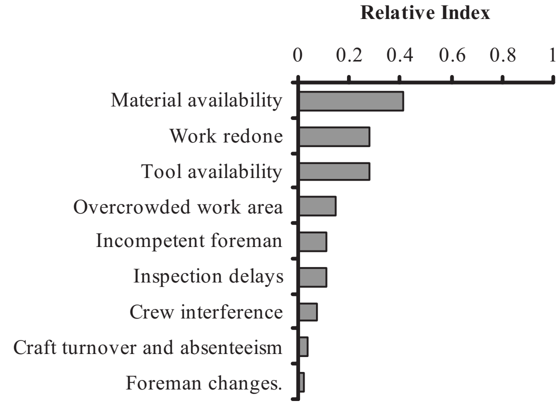


**Fig. 3.** Relative severity of the productivity factors (Borcherding and Garner 1981)

factors affecting construction productivity. Construction Equipment, Material, and Tool and Consumable Factors were found to be the major areas affecting construction productivity. However, the areas with the *greatest potential to improve project productivity* are Construction Equipment, Project Management, and Craft Worker Qualification from the craft workers' perspective. Managing a jobsite's construction productivity is extremely challenging considering the simultaneous nature of the productivity factors. However, these findings suggest that relatively greater efforts to improve factors related to construction equipment, project management, and craft worker qualifications are warranted, which the writers feel is a significant contribution to the existing body of knowledge with regard to construction productivity.

A few other research efforts have also attempted to classify the factors affecting construction productivity and comparing their results to those presented here is necessary. Rojas and Aramvareekul (2003) conducted a web-based survey of general contractors, electrical contractors, mechanical contractors, and consultants to examine the factors affecting construction productivity and their opinions on how to improve construction productivity. Management system and strategies, which refers to management skills, scheduling, material and equipment management, and quality control was ranked as having the greatest impact on construction productivity, followed by manpower, industry environment, and external conditions. The divergence between Rojas and Aramvareekul (2003) and our findings may be explained as the former identified the factors based on the literature review and their respondents were primarily individuals associated with management above the foremen level, while the writers' research identified and quantified the factors using input from craft workers who continuously work at the construction workface.

Liberda et al. (2003) identified the major factors affecting construction productivity being associated with management and human resource issues. Worker experience and skill was the second most important factor, and worker motivation, worker attitude and morale, and team spirit of the crew ranked fourth, sixth, and eighth, respectively. Therefore, Liberda et al. (2003) ranked the factors pertaining to craft worker qualifications relatively higher than our research. Once again, the difference may be attributed to the different research populations and methods of the two studies; Liberda et al. (2003) drew their conclusions based on interviews with 20 industry experts in Canada compared to craft workers and their immediate supervisors in the U.S. in the writers' research. Regardless, tool and equipment availability was ranked among the most severe factors by both studies.

Overall, the ranking of the factors in this research based on the converted factor score coincides with the ranking of previous Department of Energy (DOE) research (Borcherding and Garner 1981), which also utilized craft worker input and found material availability, tool availability, and work redone (i.e., rework) as the most significant factors affecting productivity, while the other nontangible factors, such as foremen incompetence, ranked relatively low as shown in Fig. 3 (Borcherding and Garner 1981). Although the DOE research did not single out the factors pertaining to construction equipment and engineering drawings, craft workers involved in the DOE research identified lack of cranes or trucks or both to move materials as the most frequent reason affecting material and tool availability, and work redone was attributed to poor design (Borcherding et al. 1980). In addition, material availability, incompetent personnel, communication breakdown, and project confusion were found to be major demotivators to the craft workers participating in the DOE study (Borcherding et al. 1980), which partly validates the writers' findings that craft workers consider Construction Equipment, Project Management, and Craft Worker Qualifications have the greatest potential to improve project productivity.

While both the DOE study and the writers' study described herein primarily involved construction projects of an industrial nature, the DOE projects were primarily nuclear power related, which were unique due to stringent quality control requirements and complex designs. While projects related to the writers' study reflect the current characteristics of today's typical industrial related work, this may soon change considering the impending boom in nuclear power related construction (Economist 2007). As the nature of industrial related construction changes over the next couple of decades, so may the factors impacting construction productivity on industrial jobsites change as well.

## Conclusions

The underlying structure of the productivity factors were represented by the following latent factors: Construction Equipment, Materials, Tools and Consumables, Engineering Drawing Management, Direction and Coordination, Project Management, Training, Craft Worker Qualification, Superintendent Competency, and Foreman Competency, in a descending order of their negative impact on construction productivity as measured by the converted factor score. Although there were notable differences in the latent factors between trades and between supervisors and craft workers, there were no substantial differences between union and nonunion respondents. As a result, the relative importance of the latent productivity factors can be dynamic and should be considered by both industry and academia in future efforts to improve construction productivity. Finally, regression analysis of



J. Constr. Eng. Manage., 2009, 135(5): 397-406

the latent factors on perceived project productivity indicated that Construction Equipment, Project Management, and Craft Worker's Qualification as the three areas with the greatest possibility for project productivity improvement from the craft workers' perspective

Too often, the craft worker's perception regarding construction productivity has been generally ignored by researchers and many site management teams. While sites obviously utilize the crafts workers' skills and efforts to build a project, the knowledge of the crafts have for the most part been significantly underutilized. Engaging the crafts will not only make projects more successful, but it will also make the job of working as a construction craft worker more rewarding. Moreover, the issues affecting craft workers' ability to be productive are major demotivators of craft workers. Therefore, facilitating the communication between craft workers and job site management is one path forward for the industry to better attract and retain more skilled workers into the construction industry and help resolve the craft worker shortage.

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J. Constr. Eng. Manage., 2009, 135(5): 397-406