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ABSTRACT

Over the past decade construction expenditures for education have reached approximately $350 billion with $195 billion of that total spent on K-12 public schools. Public funding through state and local taxes is the primary source of support for construction and school districts are charged with spending these dollars wisely. Within the confines of procurement statutes school districts must select a delivery method that best suits their needs. Two commonly used delivery methods are Design-Bid-Build and Construction Manager at Risk (CM at Risk). This paper examines qualitative and quantitative data collected from one hundred thirty-seven new K-12 school projects constructed in the southeast. Eighty-six of the 137 projects in the sample were constructed utilizing the Design-Bid-Build delivery method and the remaining fifty-one projects were built using the CM at Risk delivery method. The findings are that District Managers believe that using CM at Risk will lower project cost, reduce schedule duration, and improve quality. However, improvements in quality with CM at Risk are largely based upon the perceptions of District Managers. The vast majority of District Managers using either delivery method was satisfied with both the product and service quality delivered on their projects. District Managers felt that the use of CM at Risk reduced project duration, but based on analysis of project data neither delivery method proved to be superior in reducing schedule duration or schedule growth. District Managers also believed that utilizing CM at Risk reduced project cost, but analysis of project data confirmed the opposite. The use of CM at Risk actually increased cost.

Key Words: Design-Bid-Build (DBB), Construction Manager at Risk (CM at Risk), Project delivery method, Public school construction

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INTRODUCTION

Construction spending for education in the U.S. accounted for approximately 8% of all public and private construction expenditures in 2015 (US Census). The volume of public school construction is significant and public funding at the local and state level is the primary source of support. Since 1995 states have spent more than $350 billion on the construction of K-12 public schools. Of that total expenditure, more than $195 Billion has been spent on the construction of new school facilities. Needs continue to escalate as a growing population, changing demographics, and aging facilities place increasing demand on already limited funding for public school construction (Abramson 2013, 2016).

The construction industry utilizes a number of different project delivery methods to effectively organize and manage the design and construction activities for delivery of a construction project. The criteria for selecting a particular project delivery method often includes consideration of a broad spectrum of variables such as owner preference, the need for preconstruction services, completion timeframe, budgetary constraints, project complexity, and/or procurement restrictions.

State governments and local school districts normally establish procurement policies. Within those guidelines, District Managers and public school administrators are charged with selection of a delivery method best suited for the school district on each project. Most public owners realize that the delivery method can have a significant influence on project outcome (Demkin & AIA 2009). Two project delivery methods commonly used in public school construction are Design-Bid-Build (DBB) and an alternate approach known as Construction Manager at Risk (CM at Risk). With both of these delivery methods the contractor and public owner have a direct contractual relationship.

However, these two project delivery methods have distinct differences regarding contractor involvement, pricing, coordination, and operational relationships.

Design-Bid-Build has been, and currently remains, the most widely utilized project delivery method for both private and public construction in the United States (McGraw Hill 2014). With Design-Bid-Build the owner hires an architect to establish programming and develop the design for the project. Subsequent to completion of the design documents, the project is released for competitive bidding by multiple contractors (Civitello, 2000). Minimum qualifications for consideration of a contractor’s bid typically include their ability to meet project insurance, bonding, and licensing requirements along with experience constructing projects of similar type and magnitude. Assuming the minimum qualification requirements are met, the contractor is selected based upon lowest price. The contractor is then awarded a construction contract by the owner for completion of the work. The primary factor in the selection of a contractor with Design-Bid-Build is total construction cost (AIA-AGC, 2011; Kenig 2011).

The Design-Bid-Build delivery method has been utilized since the end of the 19th century and since then has emerged as the ‘traditional’ contracting method for public construction. It is viewed as a fair and open process to award the work that reduces the chance for corruption. DBB establishes a fixed cost prior to the start of construction (Rojas & Kell 2008; Kenig 2011). Some of the perceived disadvantages of DBB include a) the lack of contractor involvement during the design phase for planning and budgeting, b) a contractual arrangement that can promote adversarial relationships with limited opportunities for collaboration, and c) the increased likelihood of contractor and/or subcontractor failure due to the competitive
nature for award of the work. In addition, because of the sequential nature of the process (design, bid, and then build) the overall project duration can be quite lengthy (Konchar 1997; O’Connor 2009; AIA-AGC 2011).

Similar to Design-Bid-Build, Construction Manager at Risk is structured to utilize two separate contracts; one between the owner and architect and another between the owner and CM at Risk. However, the selection process and criteria for award with CM at Risk varies considerably from DBB. With CM at Risk both the architect and the contractor are generally selected based primarily on their qualifications. The total construction cost is generally not factored into the final selection process for the contractor. The contractor is selected based upon their ability to perform work, rather than lowest price. In addition, the timing for selection of the contractor is advanced. The contractor is normally brought on early during the design phase to provide preconstruction services (AIA-AGC 2011; Kenig 2011).

Commonly perceived benefits of the CM at Risk delivery method include, a) contractor involvement during design enhances planning and design decisions, b) the selection process facilitates a collaborative team environment and the alignment of project goals, and c) the overall timeframe for the project can be reduced because the project can be fast-tracked with construction starting prior to design completion (Konchar 1997; O’Connor 2009; Kenig 2011). Conversely, often cited disadvantages for this contracting method include the absence of competitive pricing for contractor selection and when fast-tracked, the lack of a fixed scope and associated price prior to commencing the work (Konchar 1997; O’Connor 2009; Kenig 2011).

Twenty percent (20%) of the school districts involved in the study required utilization of a particular delivery method, but a strong majority (80%) did not. For those districts that did not mandate a delivery method a larger portion chose CM at Risk over Design-Bid-Build. Within their state’s procurement restrictions, public owners tend to gravitate toward a delivery method that they feel best meets their construction needs and project objectives. The decision is often based upon the district’s perceived effectiveness and value of the delivery method selected.

An often cited earlier study comparing Design-Bid-Build with Construction Manager at Risk concluded that CM at Risk lowers project cost and reduces the overall time for the project (Konchar 1997; Konchar and Sanvido 1998). Furthermore, the Konchar (1997) research showed that CM at Risk had significantly better quality in terms of start-up, callbacks, and interior space and layout. Observable quality improvements were shown by CM at Risk in the areas of envelope, roof, structure, foundations, and environmental systems performance. However, this study was conducted almost two decades ago, incorporated a wide variety of project types in their sample, and collected limited empirical data in defense of their findings.

A recent study by Carpenter and Bausman (2016) focused on a limited project type and relied largely on empirical data to support its findings. This study collected and analyzed data from one hundred thirty-seven K-12 public school projects in the southeast region of the United States. Its conclusions do not support the findings of the two earlier studies (Konchar 1997; Konchar and Sanvido 1998). Rather, Carpenter and Bausman (2016) found that:

- The cost performance of the Design-Bid-Build project delivery method was significantly superior to that of the CM at Risk method for the construction of public schools when comparisons were made across all cost metrics.
Evidence was not obtained to support the superiority of either of the two project delivery methods in terms of cost growth, time (schedule duration), time variance (schedule growth), claims, or warranty and callback performance.

The product [and service] quality performance of the CM at Risk project delivery method was significantly superior to that of the DBB method for the construction of public schools when comparisons were made across all product quality metrics. (Carpenter and Bausman 2016, p 9)

In this recent study the average cost/sf for schools constructed using CM at Risk was considerably higher (28.8%) than those using DBB while project duration was found to be essentially the same for both delivery methods. The benefits of CM at Risk were limited to improvements in product and service quality. In summary, this study found that public owners utilizing CM at Risk were paying a substantial premium for perceived enhancements in product and service quality.

Research Objective

The conclusions reached by Carpenter and Bausman (2016) regarding cost and schedule outcomes were based on empirical data collected from actual project records. However, most of the data to support the findings regarding the quality of the product and service was derived from qualitative surveys completed by the District Managers from the school systems involved in the study.

The findings for product and service quality outcomes were largely based on the subjective opinions of the District Managers. Also, the statistical analysis for the quality metrics typically did not evaluate satisfied versus unsatisfied or effective versus ineffective. Rather, the statistical analysis evaluated the ‘degree’ of effectiveness or satisfaction as perceived by the District Managers.

In addition to the collection and analysis of empirical project data concerning cost and schedule, this study also investigated the owner’s perception regarding the effectiveness of the delivery method for successfully controlling project cost, time and quality.

The objective of this paper is twofold: First, to expand the analysis and discussion of the qualitative data collected for the Carpenter and Bausman (2016) study addressing product and service quality to more fully understand the comparative benefits of CM at Risk. Second, to compare actual project outcomes based upon the quantitative data collected from each project with the qualitative data collected from the owners regarding their perceptions of the effectiveness concerning the project delivery method utilized on their projects.

Definitions

The operational definitions adopted for this research effort are noted below. Definitions for project delivery methods were obtained from the Associated General Contractors’ 2011 publication, Project Delivery Systems for Construction, by Michael E Kenig.

Project Delivery Method: The comprehensive process of assigning contractual responsibilities for designing and constructing a project to include definition of the project scope, contractual responsibilities, interrelationships of the parties, and the processes for managing time, cost, safety, and quality.

Design-Bid-Build (DBB): The defining characteristics of this project delivery method are a) the design and construction are separate contracts – owner-designer, owner-contractor, and b) total construction cost is a factor in the final selection of the constructor.

Construction Manager at Risk (CM at
Comparing Owner Perceptions vs. Performance Reality on Construction Management at Risk Public School Projects

**Risk:** The defining characteristics of this project delivery method are a) design and construction are separate contracts – owner to architect, owner to CM at Risk, and b) total construction cost is not a factor in final selection of the constructor.

**District Manager:** District Manager refers to the person responsible for the construction of public schools at the district level (the facility owner).

In addition, any reference to Public Schools denotes public funded schools, grades kindergarten through twelfth grade (K-12).

**METHODOLOGY**

The population for the study by Carpenter and Bausman (2016) was new K-12 school projects in Florida, Georgia, North Carolina, and South Carolina completed between January 2006 and January 2012. From this population of 829 projects, a sampling of 137 projects were selected for the study. The sample composition is shown in Figure 1. Eighty-six (63%) of the 137 projects in the sample were constructed utilizing the Design-Bid-Build delivery method. The remaining fifty-one projects (37%) were built using the CM at Risk delivery method.

*Figure 1: Sample Distribution*

Once the empirical data regarding cost and schedule was collected for a project the District Manager was then solicited for input concerning the level of service, product quality, and effectiveness of the delivery method for each of the one hundred thirty-seven school projects in the study. Questions on the survey instrument investigated perceived product and service quality, criteria for delivery method selection, and the manager’s opinion regarding the effectiveness of the delivery method utilized for that project.

Testing of survey responses was completed utilizing chi-square ($\chi^2$) distributions and significant statistical differences were noted when p-values were ≤ 0.05.

**FINDINGS AND ANALYSIS**

**Selection Criteria for Project Delivery Method**

District Managers were asked to rate the importance of ten factors concerning selection of the delivery method utilized for each project included in the study. The criteria selected as very important most often are shown in Figure 2.
The factors District Managers (DMs) utilizing both Design-Bid-Build (DBB) and Construction Manager at Risk (CMAR) selected most often as being important were to improve building (product) quality, control schedule overruns, reduce disputes & claims, control change orders, and improve service quality. Approximately 90% of DMs noted that each of these criteria were important or very important in their selection of the delivery method chosen for the project.

The five selection criteria that District Managers utilizing DBB or CM at Risk (CMAR) selected least often as being important are shown in Figure 3. This listing included to enhance control of the design process, improve team relationships, reduce project cost and schedule duration, and select a delivery method to match the experience level of the owner. While these factors were considered ‘very important’ less often when selecting a delivery method, they still were considered important or very important for 80% to 90%+ of the District Managers.
Comparing Owner Perceptions vs. Performance Reality on Construction Management at Risk Public School Projects

Statistical analysis of the responses for all ten criterion found no statistically significant differences regarding the importance of each criteria when comparing CM at Risk projects with those constructed utilizing Design-Bid-Build. Owners utilizing Design-Bid-Build and CM at Risk were selecting a delivery method for essentially the same reasons.

In summary, the findings are that: a) all ten of the criteria were considered important for selection of a delivery method, and b) all of the selection criteria were viewed as having a similar level of importance regardless of whether the delivery method is Design-Bid-Build or Construction Management at Risk.

Product Quality

The variables investigated for product quality included the quality of building exterior, building interior, building MEP systems, warranty issues, and overall project product quality. The distribution of responses for satisfied and very satisfied is summarized in Table 1. The responses were statistically analyzed for ‘very satisfied’ and overall response distribution for Design-Bid-Build (DBB) versus Construction Manager at Risk (CMAR). The findings were that product quality was perceived as superior with the CMAR delivery method for all of the metrics investigated.

Table 1 also summarizes the percentage of District Managers that were satisfied or very satisfied with product quality for both delivery methods. Even though DMs had a ‘higher level’ of satisfaction with the product quality on CM at Risk (CMAR) projects, the vast majority of managers were ‘satisfied’ (satisfied or very satisfied) with product quality on Design-Bid-Build projects. On average, ninety-two percent (92%) of District Managers on DBB projects were satisfied with product quality. A very small minority (8%) were dissatisfied.

<table>
<thead>
<tr>
<th>Product/System Quality</th>
<th>DBB Satisfied</th>
<th>DBB Very Satisfied</th>
<th>CMAR Satisfied</th>
<th>CMAR Very Satisfied</th>
<th>DDB Satisfied or Very Satisfied</th>
<th>CMAR Satisfied or Very Satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Quality</td>
<td>38%</td>
<td>55%</td>
<td>82%</td>
<td>18%</td>
<td>93%</td>
<td>100%</td>
</tr>
<tr>
<td>Building Exterior</td>
<td>29%</td>
<td>57%</td>
<td>16%</td>
<td>84%</td>
<td>86%</td>
<td>100%</td>
</tr>
<tr>
<td>Building Interior</td>
<td>34%</td>
<td>57%</td>
<td>16%</td>
<td>84%</td>
<td>91%</td>
<td>100%</td>
</tr>
<tr>
<td>HVAC system</td>
<td>36%</td>
<td>60%</td>
<td>16%</td>
<td>82%</td>
<td>96%</td>
<td>98%</td>
</tr>
<tr>
<td>Plumbing System</td>
<td>30%</td>
<td>63%</td>
<td>12%</td>
<td>88%</td>
<td>93%</td>
<td>100%</td>
</tr>
<tr>
<td>Lighting System</td>
<td>33%</td>
<td>60%</td>
<td>10%</td>
<td>88%</td>
<td>93%</td>
<td>98%</td>
</tr>
<tr>
<td>Warranty Issues</td>
<td>42%</td>
<td>51%</td>
<td>17%</td>
<td>79%</td>
<td>93%</td>
<td>96%</td>
</tr>
<tr>
<td>Overall Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>92%</td>
<td>99%</td>
</tr>
</tbody>
</table>
Survey results were similar for service quality. Statistical analysis supported the finding that District Managers were ‘more’ satisfied with the quality of the service on CM at Risk (CMAR) projects for all of the metrics listed in Table 2: Service Quality. However again, the vast majority of DMs on projects utilizing DBB were satisfied with the level of service they received. As shown in Table 2, approximately ninety percent (90%) of the District Managers were satisfied for each of the performance metrics investigated concerning the quality of service.

**Table 2: Service Quality**

<table>
<thead>
<tr>
<th>Service Quality</th>
<th>DBB Satisfied</th>
<th>DBB Very Satisfied</th>
<th>CMAR Satisfied</th>
<th>CMAR Very Satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Performance</td>
<td>39%</td>
<td>51%</td>
<td>16%</td>
<td>80%</td>
</tr>
<tr>
<td>Planning</td>
<td>40%</td>
<td>49%</td>
<td>20%</td>
<td>78%</td>
</tr>
<tr>
<td>Cost Control</td>
<td>44%</td>
<td>48%</td>
<td>18%</td>
<td>80%</td>
</tr>
<tr>
<td>Schedule Control</td>
<td>40%</td>
<td>43%</td>
<td>12%</td>
<td>82%</td>
</tr>
<tr>
<td>Quality Control</td>
<td>48%</td>
<td>43%</td>
<td>18%</td>
<td>82%</td>
</tr>
<tr>
<td>Communication</td>
<td>44%</td>
<td>49%</td>
<td>22%</td>
<td>76%</td>
</tr>
<tr>
<td>Cooperation</td>
<td>43%</td>
<td>49%</td>
<td>20%</td>
<td>76%</td>
</tr>
<tr>
<td>Overall Average</td>
<td>90%</td>
<td></td>
<td>97%</td>
<td></td>
</tr>
</tbody>
</table>

In summary, statistical analysis supports that District Managers had a ‘higher level’ of satisfaction with both the service and product quality on projects with a CM at Risk delivery method. However, the vast majority (90%+/-) of District Managers on Design-Bid-Build projects were satisfied with the quality of the product and service delivered on their project. In essence, District Managers had a high level of satisfaction regarding product and service quality for both delivery methods.

**Project Delivery Effectiveness**

District Managers were also asked to assess the effectiveness of the project delivery system for their projects included in the study. The questions in this section of the survey instrument focused on the factors that DMs indicated were important determinates for selection of a project delivery system. The intent was to gain their insight regarding the perceived effectiveness of their delivery method of choice in meeting their criteria (objectives) of the selection process. The variables investigated are shown in Figure 4. With the exception of ‘Owner Experience’, they mirror the selection criteria noted in Figures 2 & 3.

Carpenter and Bausman (2016) statistically compared the perceived effectiveness of CM at Risk versus Design-Bid-Build for each variable. The findings were that DMs believed that the CM at Risk delivery method was more effective in improving building and service quality, reducing schedule duration and schedule growth, reducing project cost, controlling change orders, and decreasing disputes/claims. The only two variables where the delivery methods were viewed as having similar effectiveness were team relationships and control of the design process.
In summary, District Managers perceived that the CM at Risk delivery method was a more effective project delivery method – it improved quality and reduced cost, schedule, and disputes. The important questions raised by these results are: “Does District Manager perception match reality? Is CM at Risk more effective at improving product and service quality, and reducing cost, schedule duration, and disputes?”

**Figure 4: Project Delivery Effectiveness**

<table>
<thead>
<tr>
<th>CMAR</th>
<th>DBB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve Building Quality</td>
<td>Improve Building Quality</td>
</tr>
<tr>
<td>Reduce Project Cost</td>
<td>Reduce Project Cost</td>
</tr>
<tr>
<td>Reduce Schedule Duration</td>
<td>Reduce Schedule Duration</td>
</tr>
<tr>
<td>Improve Service Quality</td>
<td>Improve Service Quality</td>
</tr>
<tr>
<td>Control Schedule Growth</td>
<td>Control Schedule Growth</td>
</tr>
<tr>
<td>Reduce Disputes/Claims</td>
<td>Reduce Disputes/Claims</td>
</tr>
<tr>
<td>Improve Team Relations*</td>
<td>Improve Team Relations*</td>
</tr>
<tr>
<td>Control Design Process *</td>
<td>Control Design Process *</td>
</tr>
<tr>
<td>Control Change Orders</td>
<td>Control Change Orders</td>
</tr>
</tbody>
</table>

**Perception versus Actual Project Results (Reality)**

District Managers perceive the CM at Risk delivery method as being more effective in reducing project cost, duration, and disputes while improving quality. The only performance criteria that CM at Risk is not perceived as delivering a superior outcome are improved team relationships and control of the design process. However, the District Managers’ perceptions regarding performance often do not match the findings based on the actual empirical project data that was collected for the study.

Table 3: Qualitative vs. Empirical Findings, summarizes the findings based on both the qualitative (opinion/perception) data and the quantitative (empirical) data obtained from actual project records. Table 3 identifies the delivery method found to be most effective for each project performance factor based upon each of the two data sets – qualitative and quantitative.

District Managers believe that the CM at Risk delivery method is superior in reducing project cost and change orders (cost growth). However,
Statistical analysis of the empirical data found that projects using the Design-Bid-Build delivery method had substantially lower cost and that neither delivery method was superior in reducing cost growth.

A similar disparity exists regarding project schedule. District Managers viewed CM at Risk to be more effective in reducing the duration of the project schedule and schedule growth (extension). Analysis of actual project data revealed that neither delivery method had a superior performance outcome. There was no statistical support favoring one delivery method over the other. CM at Risk projects were not completed quicker nor did they have less schedule growth.

The comparative analysis has mixed results for quality. District Managers perceive CM at Risk to be more effective at improving building quality, but project records concerning callbacks and warranty issues do not support this supposition. The qualitative data collected from the DMs indicates that the use of CM at Risk improves the quality of the service provided by the contractor. However, since ‘service quality’ is a subjective concept, confirmation or rejection of this finding with empirical data was not possible given the scope of the project records available. District Managers felt that neither delivery method was superior in improving team relationships, but again project data was not available to support or refute any finding concerning team relationships. Lastly, DMs felt that CM at Risk was more effective in reducing disputes, but analysis of litigation data and callback/warranty issues contained in the project records do not support this supposition.

### CONCLUSIONS

District Managers were asked to identify the importance of key factors that drive the choice of a delivery method for a project. The importance of each factor that influences selection is essentially the same, regardless of whether the delivery method selected is Design-Bid-Build or CM at Risk. In both cases District Managers were selecting a delivery method because they believed its use would enhance building (product) and service quality, control schedule overruns and change orders, reduce disputes & claims, increase control of the design process, improve team relations, decrease project cost, and reduce schedule duration. The selection criteria, or reasons for using a delivery method, were essentially the same for both Design-Bid-Build and CM at Risk.

Based on a statistical analysis of the response data, District Managers had a ‘higher’ level of satisfaction with the quality of the building and services provided when the CM at Risk delivery method was utilized. However, the vast majority of District Managers using the

<table>
<thead>
<tr>
<th>Performance Factor</th>
<th>Qualitative Data (District Managers)</th>
<th>Empirical Data (Project Records)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>CM at Risk</td>
<td>DBB</td>
</tr>
<tr>
<td>Reduce Project Cost</td>
<td>CM at Risk</td>
<td>Neither</td>
</tr>
<tr>
<td>Control Change Orders</td>
<td>CM at Risk</td>
<td>Neither</td>
</tr>
<tr>
<td>Time</td>
<td>CM at Risk</td>
<td>Neither</td>
</tr>
<tr>
<td>Reduce Schedule Duration</td>
<td>CM at Risk</td>
<td>Neither</td>
</tr>
<tr>
<td>Control Schedule Growth</td>
<td>CM at Risk</td>
<td>Neither</td>
</tr>
<tr>
<td>Quality</td>
<td>CM at Risk</td>
<td>Neither</td>
</tr>
<tr>
<td>Improve Building Quality</td>
<td>CM at Risk</td>
<td>Neither</td>
</tr>
<tr>
<td>Improve Service Quality</td>
<td>CM at Risk</td>
<td>---</td>
</tr>
<tr>
<td>Improve Team Relationships</td>
<td>Neither</td>
<td>---</td>
</tr>
<tr>
<td>Reduce Disputes</td>
<td>CM at Risk</td>
<td>Neither</td>
</tr>
</tbody>
</table>

1 Based on Warranty issues and Callbacks
DDB delivery method were ‘satisfied’ (satisfied or very satisfied) with product and service quality. On average, approximately 90% of DMs on DBB projects were satisfied with the quality received. Only a very small minority (8%-10%) were dissatisfied. In summary, the vast majority of District Managers, on both Design-Bid-Build and CM at Risk projects, were satisfied with the quality of the building and the quality of the services provided on their projects.

District Managers believed that the CM at Risk delivery method was more effective at improving building and service quality, reducing schedule duration and schedule growth, reducing project cost, controlling change orders, and decreasing disputes/claims. Overall, District Managers perceived that the use of the CM at Risk delivery method improves quality, reduces cost, decreases schedule duration, and reduces disputes.

**Summary**

District Managers believe that using CM at Risk will deliver the trifecta – lower cost, reduced schedule duration, and improved quality. However, their perceptions regarding the effectiveness of the Construction Management at Risk delivery method do not align with actual project results for K-12 public schools constructed in the southeast.

Improvements in quality found within this research are largely based upon District Managers beliefs and perceptions. And, even if these perceptions are valid, the evidence revealed that CM at Risk delivers only a marginal increase in product and service quality. The vast majority of District Managers using either Design-Bid-Build or Construction Management at Risk were satisfied with both the product and service quality delivered on their projects. In addition, neither delivery method proved to be superior in reducing schedule duration or schedule growth. However, empirical data concerning project cost reflects project outcomes counter to the perception of District Managers that CM at Risk reduces project cost. In fact, the converse is true. The use of Design-Build-Build lowers project cost. District Manager perception is at odds with actual project performance.

In summary, the findings of this study are that the use of Construction Management at Risk on K-12 public schools yields no reduction in schedule duration and only a marginal perceived improvement in quality at a substantially increased cost.

**FUTURE RESEARCH**

There are a number of variables that can influence project cost, schedule, and quality. The methodology employed on this research effort was designed to limit and/or mitigate several key variables by restricting the geographical area of study, construction timeframe, facility type, and contracting method. However, the scope of this research did not address project complexity or include a value analysis of project design. It is possible that the CM at Risk delivery method was more often utilized on projects with a higher level of complexity and/or projects incorporating higher-performance designs. Both of these variables could have significant influence on project cost, schedule, and quality.

To limit the impact of these variables, and others that may influence project results, it is recommended that the methodology of future research utilize in-depth case study to provide support for a more comprehensive analysis comparing the project outcomes achieved by the different delivery methods.
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Supervisor Practices for Productivity and Safety: A Hot Asphalt Roofing Case Study

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ABSTRACT

This case study investigates the production practices of a high-reliability hot asphalt roofing foreman. A “high-reliability” foreman is one who has consistent exceptional performance in both productivity and safety. The foreman studied was working for a large national roofing contractor. The researchers collected extensive data from the project through project observations, multiple interviews with the foremen, and interviews and surveys of the work crew. Practices examined include activity preparations, safety practices, material management, production and quality controls, crew management practices and uncertainty management. The findings indicate that the foreman’s practices were guided by the following greater principles: (1) Create “high quality work assignments”; (2) Prevent errors and defects; (3) Reduce workers’ exposures to hazards and excessive demands; and (4) Maintain a well-established crew for efficient coordination.

Keywords: High Reliability, Production System, Productivity, Safety, Hot Asphalt Roofing.

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INTRODUCTION

Construction operations are subject to multiple demands for productivity, quality, and safety. The high production pressure combined with dynamic and hazardous work environment creates a high likelihood for errors, which can result in production and quality defects and/or safety accidents. In the construction industry, the loosely defined work processes leave the work crews many degrees of freedom in how they organize and coordinate the work. The field supervisors typically develop the production system as they decide the task and resource allocation, task sequencing, workload, workflow, coordination, etc. Designing effective production systems that can achieve high levels of efficiency as well as safety and quality remains an important challenge for construction researchers and practitioners. This research aims at learning from the work practices of exceptional field supervisors who consistently achieve high levels of both productivity and safety. In the context of this research, such supervisors are called “High Reliability” (HR) supervisors (Mitropoulos & Cupido 2009, Memarian & Mitropoulos 2014).

This case study focuses on hot asphalt roofing operations. Hot asphalt built-up-roofing (BUR) continues to be the most widely used system for roofs with a slope less than 4:12. Roofing construction is a high-risk operation. According to the Bureau of Labor Statistics (BLS 2015), roofing construction was one of the occupations with high fatal injury rate with 46.2 per 100,000 full-time equivalent workers in 2014 (compared to the overall construction industry fatality rate of 9.5). All types of roofing construction face similar difficulties, such as risk of falling from elevation, uneven work surface, and exposure to severe climatic conditions. Construction of hot asphalt roofing involves additional challenges, such as the constant exposure to the heat and smoke from hot tar, and difficulties in quality control. This study investigates the production practices of a HR foreman in hot-asphalt roofing. Learning from the best performers, will enable the industry to design effective production systems that can meet the production requirements for efficiency, speed and quality, while at the same time protecting the health and safety of the workforce.

LITERATURE REVIEW

Production safety trade-offs

In construction, operational success requires both high production and high safety performance. On the other hand, the literature in organizational theory, occupational safety and construction has emphasized the conflict between production and safety. Rasmussen et al. (1994) explains that individuals and organizations make on-going trade-offs to satisfy multiple constraints/goals—economic performance, safety and workload. These trade-offs are an important element of the safety of production operations. Woods et al. (2010) indicate that production employees make many large and small trade-off decisions every day (a.k.a. “sacrifice decisions”). Hollnagel (2009) refers to the “Efficiency-Thoroughness Trade Off” (ETTO).

The occupational safety literature recognizes the trade-offs between production and safety outcomes (Guo et al. 2016, Stride et al. 2013, Zohar 2000, Zohar 2010, Ford and Tetrick 2008). McLain and Jarrell (2007) conceptualized the “safety-production conflict” as the perceived inability to achieve simultaneously safety and production. The construction literature provides extensive evidence that production pressures have a strong effect on safety. Hinze & Parker (1978) found that production pressures are related to
more injuries, and suggested that job practices are more important than safety policies in preventing accidents. Since then, several researchers have emphasized the negative effect of production-safety conflict on safety performance (Choudry and Fang 2008, Flin et al. 2000, Han et al. 2014, Mullen 2004).

High Reliability Organizations

Research on High Reliability Organizations (HRO) argues that it is possible to promote simultaneously both high operational performance and safety. HROs are defined as organizations that perform complex operations under extreme conditions while their rate of incidents is low (Bigley & Roberts, 2001). Such organizations include aircraft carriers, power plant operators and wildfire fighting crews. Weick and Sutcliffe (2001) found that HROs manage the unexpected through five processes: preoccupation with failures rather than successes, reluctance to simplify interpretations, sensitivity to operations, commitment to resilience and deference to expertise as exhibited by a fluid decision-making system and structure. Baker et al. (2006) identify effective teamwork as an essential component for the success of HROs.

In the context of construction, Mitropoulos & Cupido (2009) defined high reliability field supervisors as those supervisors who consistently reach and maintain high productivity and exceptional safety performance while delivering high quality of work. Studies of the production practices of exceptional foremen in framing, masonry, and concrete has provided evidence that the production control system is a critical determinant of safety performance (Mitropoulos & Cupido 2009, Memarian and Mitropoulos 2014. Mitropoulos 2014). These studies found that high reliability supervisors have a clear and strong focus on preventing errors and rework, as well as detecting and correcting problems fast. These practices prevent interruptions in the work process, and regulate task demands for the workers, (Mitropoulos and Memarian 2013, Memarian & Mitropoulos 2016).

Roofing Construction Safety

Roofing construction has received significant attention from construction safety researches. Falls from roof constitute the leading cause for work-related fall fatalities in roofing construction with about 26% of all incidents (Hsiao and Simeonov 2001; Sa et al. 2009; Fredericks et al., 2005). BLS (2014) reported that fall, trip, slip accidents accounted for about 83.1% of all fatal injuries in roofing construction. Fredericks et al. (2005) also identified fall from elevation as the leading cause of fatalities in roofing construction followed by harmful substances or environment and transportation accidents. Due to high rate of accidents and demanding work conditions, roofing construction suffers from high turnover (Hinze and Gambatese 2003). Welch et al. (2010) reported about 10% worker turnover and that about 60% of them left their job due to health-related conditions.

In an extensive review of factors contributing to fall accidents, Hsiao and Simeonov (2001) summarized these factors as environmental, task-related and personal factors that can trigger fall accidents in roofing construction. Environmental factors include visual exposure to elevation, unstable visual cues and inadequate visual information in the work environment, confined and inclined support surfaces, and unexpected changes in roof surface properties. They identified task-related factors as load handling, physical exertion, fatigue, task complexity that can result in loss of balance and fall. Individual factors include individual differences such as work experience and training, and using personal protective equipment (Hsiao and Simeonov 2001).
Hot asphalt roofing

Hot asphalt roofing involves the installation of several layers of material (insulation sheets, purlin board, base layer and cap sheet) with a layer of hot asphalt between each layer of material. It is a challenging operation, and involves significant task demands and risks for the workers. It is physical demanding and includes lifting and handling heavy rolls and tar buckets, frequent kneeling down and back bending, and constant exposure to sun and adverse climatic conditions. Knee and back pain are the most common complaints among roofers. Working with hot tar is demanding for several reasons—it is too hot and can easily burn and injure workers; it is sticky and makes it difficult for the mopping worker to move the mop; it sets quickly and workers must work fast because once it sets it is very difficult to adjust rolls and sheets. In the summer, hot tar sets faster due to high temperature that requires workers to increase their pace of work during summer time; and it has a strong smoke that exposure to that for a long time can cause respiratory problems for the workers.

The operation is performed under time pressure because the hot tar sets quickly—once the tar is mopped, the sheets or plies must be laid immediately. Installation must be fast and accurate because adjusting sheets or fixing wrinkles after the hot tar sets is difficult and can hurt the quality of work. The process is repeated in short cycles. Thus, the installation requires constant attention and close coordination. To achieve high quality waterproofing requires special attention around water drains, flashings, penetrations and terminations. Increased attention is also needed when working near the edge, or mopping the tar.

METHODOLOGY

The researchers first identified a roofing contractor to participate in the study and collected data on the organization. Next, they identified a HR foreman based on data collected from the safety and operations manager. Then, extensive field data were collected on the construction operation, the organization of the crew, and the production practices.

The Contractor

The roofing company that participated in this study was the southwest district branch of one of the major roofing contractors in the US. The company performs almost exclusively commercial and institutional projects. The size of the projects ranges from $100,000 to $10,000,000. At the time of the study, the southwest district branch operated with eight superintendents, 60 foremen, and about 800 workers. The company has above average safety performance over the previous four years, as reflected in their 0.63 Experience Modification Rate (EMR). The company’s safety director and the area superintendent were interviewed to understand the company’s safety systems, and production expectations and requirements.

Supervisor Selection

In order to select a high reliability foreman, the researchers considered four factors in assessing foremen’s performance over the previous three years: (1) productivity, (2) safety, (3) quality, and (4) project complexity. Using these four factors, the contractor’s safety director and area superintendent assessed the performance of each foreman using a 10-point rating scale where 1 was the lowest performance and 10 was the best. The performance score was calculated as the product of the four scores (Productivity × Safety × Quality × Complexity).
The selected foreman had 27 years of experience in roofing construction. He had served as a hot asphalt roofing foreman for 15 years, all with the same company. He was considered the top hot asphalt roofing foreman within the company—"the company’s top gun" according to the area superintendent. He had won the company’s “outstanding safety performance reward” more than once. At the time of the study, the HR foreman was assigned to finish a project that another foreman had started. Because of performance problems, the first foreman was terminated and the workers were sent to other jobsites. The HR foreman and his crew were called to come back from the east coast where they had just finished another project.

**OPERATION DESCRIPTION**

Field data collection involved multiple interviews with the foreman and field observations of the work practices. The interviews included structured questions regarding the foreman’s production and safety practices and open-ended questions to provide an opportunity to learn from the foreman’s past projects. The field observations helped the researchers familiarize themselves with the operations and confirmed the findings from the foreman interviews.

**Project Description**

The project was an educational complex located in a residential area in Phoenix, Arizona. It included five separate buildings, and the overall work area was about 70,000 sqft. The scope of the work included removing the top layer of the old roofing, and replacing it with a new hot-asphalt roofing. The new roof required: one layer of insulation sheet, one layer of base sheet, one layer of cover ply, and one layer of cap sheet as the final layer. The foreman assessed the level of difficulty of this project as “7 out of 10” (where 1 =very low and 10 = very high), primarily due to the limited work area with several pipe penetrations and air conditioning units.

The work was performed in the early summer. Normally, in the summer the roofers would work during the night. However, because the project was in a residential area, work was not allowed after 8:00 p.m. Furthermore, because the school was in session, the contractor was not allowed to start their work before 4:00 p.m. These restrictions limited the work schedule to a four-hour timeframe from 4:00 p.m. to 8:00 p.m during the weekdays. Over the weekends, the crew extended the work schedule to 10 hours to work from 6:00 a.m. to 4:00 p.m.

**Work Crew and Organization**

The crew consisted of the foreman and seven workers: the “Second,” one leadman, three journeyman roofers, and two laborers. All seven workers had worked with the foreman in this crew for seven years or more. The “Second” was the most experienced worker who had worked 12 years with the foreman, followed by the leadman with 10 years of experience in the crew. At the beginning of the operation, the foreman hired two additional laborers who had not worked with the crew before. These workers quit one week later, and the foreman did not replace them.

The roles and tasks of the roofing crew were the following:

- **The kettle operator** works on the ground loading bulk tar into the kettle and pumping it to the roof.
- **The material handlers** are laborers who are responsible for handling the hot tar from the pump hose to the work area and performing any other support tasks.
- **The mopper** is typically the most experienced member of the crew—usually the “second” or the leadman.
• **The liners** are responsible for measuring, cutting, and arranging sheets and boards ahead of the floppers.

• **Floppers** follow the mopper and stick cap sheets, plies, and boards on the roof surface.

• **Finisher** is a roofer or laborer who follows the floppers and covers the seams between the sheets with granule powder.

The primary materials and layers in hot asphalt roofing include:

• **Insulation sheet (4’×8’×2.5’’).** Typically, hot asphalt roofing work starts with installation of one or two layers of insulation sheets (Figure 1).  

• **Plastic cement** is a sealant material used to cover small gaps and to provide extra coverage around pipes, boxes, and metal stands.

• **Purlin boards (4’×4’×0.5’’).** One layer of purlin board is installed on top of the insulation sheets (Figure 2).

• **Bases** are rolls of roofing paper that are installed on the purlin boards and form the next layer of the roof.

• **Cap Sheet** is the final layer of BUR (Figure 3). Cap sheets are delivered in form of rolls. The dimension of cap sheet rolls is 30-33 feet long and 3.0 feet wide. Each roll weighs about 80-85 lb.

• **Tapper boards** are used to make the slope from the ridge line toward the water drains. The thickness of these boards varies at two ends.

• **Granule powder** is used to cover seams between cap sheets.

• **Hot tar (Bitumen)** is the major adhesive material used in hot asphalt roofing to stick different layer of materials.

The tar kettle is the primary equipment in hot asphalt roofing that is used to supply hot tar. It is located on the ground and pumps hot tar to the roof using a hose.
FINDINGS: PRODUCTION PRACTICES OF HR FOREMAN

The observations on the foreman’s work practices are organized under the following categories: Work preparation (including safety); material management, work flow, production control, quality control, crew management and management of unexpected situations.

Work Preparations

A few days before the starting a new project, the foreman would walk on the roof with the superintendent to understand the work layout, site condition, access points, limitations, and especially the safety hazards and fall protection requirements. The foreman would not let his crew start working on the roof before making sure that everything was 100% safe: the perimeter safety cables were installed, holes were securely covered, ladders were installed properly, and there was enough lighting if they would work overnight. Before starting the work, he also made sure that all the water drains, holes, and penetrations were securely covered to avoid clogging problem in the future due to pouring hot tar or trash into the water drains and other openings.

Material Management

The foreman’s practice was to request material a week in advance, to avoid any interruption in work. According to the foreman, since the company has limited number of drivers, it happens that they deliver materials with delay. Thus, to avoid any interruption the foreman would order materials for a week in advance and would never leave less than one work-day material in the storage. When the materials were delivered to the site, the foreman always checked their quality before using them. In one instance, he returned the delivered plies to the shop because they were old. According to the foreman, the old plies get sticky and the workers cannot easily open the rolls and lay them. They also lose their flexibility and can break when the workers lay them over the roof.

The material handling activity included carrying insulation sheets, cap sheets, rolls, and hot tar on the roof. Bulk materials were loaded on the roof by a forklift. The foreman loaded on the roof only the required material to avoid congesting the workspace and double-handling the material. Some extra material was needed for expected patches around pipes, AC, and other roof penetrations. On the roof, material handling was done manually as the limited space on the roof did not allow the crew to use any dolly or carts. Thus, to transport the hot tar from the pump to the work area, one laborer was assigned to fill two buckets at a time (each 5 gallons and weighs about 40 lb.), and take them back to the work area.

Work Method

The foreman’s work method tried to “minimize walking on the hot-fresh roof.” He used two practices to accomplish this: First, the crew started from the farthest point and moved toward the location of the ladder and the tar pump. As a result, the workers did not need to walk on the freshly laid roof. The opposite approach was used by the previous foreman who had started work exactly from the opposite point. He had started from the ladder and moved forward to the end of the work area, thus workers would be walking constantly on the fresh roof.

The second practice was the method for laying the plies and the cap sheet. The standard method requires the liners to lay the new pieces on the previous row of new roofing—then the floppers flip them and adjust them. Using this method, workers stand and work on the fresh roof which is still hot. In the summer, to avoid the heat from the fresh roof, the foreman decided to use a different approach, in which...
the sheets were not laid on the fresh row. The floppers needed to take and lay sheets one-by-one while they were standing on the old roof which was colder compared to the fresh roof. In this approach, it is more difficult to adjust side and end laps and it is slower compared to the standard method. This approach has some trade-offs between labor time and workers’ discomfort.

Production Control

The roofing work schedule is set based on the number of “man-days.” For instance, when a work is “200 man-days” and the work crew has eight workers, the work is estimated to done in about 25 work-days. However, the number of work-days is affected by several factors such as rainy days, workers’ absenteeism, and resources availability. To control the crew’s daily production, the foreman had established daily production rates for different parts of the work. The average daily production rate of a standard hot-asphalt roofing crew is about 50 squares, which is equal to 5000 sqft of sheet installation. The crew members were familiar with the production rates and the work pace as they had been with the foreman for several years.

Quality Control

In hot asphalt roofing, quality control is an ongoing process—typically it requires observing the activities closely, and walking on the roof to make sure everything has been installed properly. The foreman identified three major quality issues that required attention and are supposed to be fixed before the hot tar sets:

- **Wrinkles.** Wrinkles create an uneven surface that is susceptible against sharp objects that increases risk of water leakage. When wrinkles are noticed, the sheet must be removed and reinstalled.

- **Side & end laps.** These laps are to provide enough coverage at the seams. Typically, side laps are 5-6 inches and end laps are about four inches. In this project, since the crew was operating during the night time, there was high risk of mistake in sheets alignment.

- **Granule powder.** The granule powder must be poured immediately after laying sheets, when the tar is still hot and sticky. The foreman kept reminding the worker to pour granule powder immediately.

With regards to the work quality, the most critical point on this project was around the air conditioning (AC) units, where there is a higher risk of water leakage. To minimize the likelihood of errors, the foreman assigned his experienced workers (usually his second and leadman) to work around areas that involved more detail work. To prevent leakage, the roofers laid more layers around the AC units and penetrations than required by the specs. In addition, the foreman closely supervised the installation activities around the AC units.

Crew Management

Over the past seven years, the foreman performed all projects with the same crew members. In this crew, the roles were clear and everybody knew their tasks. The laborers in the crew were not allowed to perform installation tasks—they performed material handling, housekeeping, and support tasks like cutting sheets and helping roofers. The foreman was very sensitive about the workers being late, and everybody in the crew was aware of that. According to the foreman, the workers always call him if they have a problem and cannot go to work, and he would never fire or send anyone to the office because of absenteeism; he considers this crew as his work family.
Managing Unexpected Situations

According to the foreman, common unexpected situations that could affect the crew’s performance included (1) weather conditions, (2) work changes, (3) absenteeism, (4) unexpected material deliveries, (5) low quality of material, and (6) equipment breakdown. Adverse weather is the most common reason that slows down or stops the roofing activities. According to the foreman, rain is a major disturbance—not only it stops the work for that day, but also does not allow the crews to install anything for at least the next 48 hours until everything has dried out. If there is up to 20% chance of rain, they do everything other than tearing off the old roof (for the projects with old roofing). If the chance of rain is 30% and more the crew is not allowed to do any installation work.

Unexpected change orders can also stop the whole work process for a while. In the hot asphalt roofing, a common change order is for “materials.” According to the foreman, especially in new construction, sometimes the inspectors do not approve the type or quality of material. The foremen do not have any control over such situations, and it is between the company and inspectors. Absenteeism without advance notice was another unexpected situation identified by the foreman. The two new workers of the crew quit without advanced notice. This issue created an unexpected situation for the foreman. To compensate for the lack of workforce, the foreman participated in the physical work as the mopper.

Unexpected material deliveries (without coordinating with the foreman first) can create significant disruptions. When material is delivered to the jobsite, the priority is with off-loading the truck because they cannot hold the truck and the driver for a long time. Sometimes the foreman even needs to stop the work and assign his whole crew to off-load the truck. Low quality of material delivered is another issue that can slow down the work. The foreman would check material before letting the crew use it. If the quality of material delivered was poor, the foreman would not use it and return it to the shop, even though it would stop the work for a few work-hours or even a day.

Finally, if the tar kettle breaks down the crew cannot do any installation work, as there is no alternative. On this project, since the work schedule was four hours a day, they would not have enough time to fix the kettle or request a replacement for the same day. Even in projects with longer work-days it is not easily possible to fix or replace the broken kettle quickly, which would result in losing one or even more workdays.

DISCUSSION: IMPLICATIONS FOR PRODUCTIVITY AND SAFETY

The foreman’s practices had important implications for productivity and safety. With regards to safety, this case highlights two important practices:

1. The de-coupling of safety from production, where a different crew was setting up the perimeter fall protection. As a result, those responsible for the safety measures were not under the production pressures to install roofing, which could interfere with their safety duties. (It is however possible that the safety crew could be under other time pressures).

2. Not allowing the work to start until it was safe to do so. This practice is consistent with lean production principles, where work is “released” only when it is well prepared.

The case also illustrates three important material management practices:
1. Planning the deliveries to minimize disruptions for unloading (and productivity loss).

2. Material quality control before sending the material to the work area eliminated the risk of installing defective or poor condition sheets by roofers, and consequently reduced installation difficulty, quality problems and rework.

3. Ordering smaller batches of material and minimizing the amount of material on the roof had several benefits—it reduced work space congestion and reduced manual material handling. Both factors reduce safety risks and support productivity.

The direction of the work minimized walking on the new roof, and had two benefits: (1) It reduced the risk of damaging the newly laid sheets, since the tar is not yet set and the sheets can slide; and (2) it reduced the workers’ discomfort. The exposure to heat was already high because of the time of the year and the work hour constraints. The foreman’s revised method for installing pliers and cap sheets directly avoided additional exposure to heat (due to the roof) which could increase the risk of fatigue, errors and dehydration. The assignment of detailed work to experienced crew members (second and leadman) reduces the probability of errors.

In hot asphalt roofing quality control is an ongoing process. The foreman’s close monitoring was essential for preventing potential mistakes and for recognizing and correcting problems immediately, thus minimizing rework. Even when the crew was short of laborers, and the foreman helped with manual work, he performed a task (the mopper) that allowed him to supervise and set the pace of the crew.

Crew management practices were facilitated by the long tenure of the crew, which appears to be an important factor in the crew’s performance:

- The standardized work duties and the stable composition of the crew over the previous 7 years, ensured that all crew members knew their roles and the roles of the other crew members. This reduces the likelihood for errors and omissions.

- There was clear understanding of the production expectations and work standards.

- The crew had good understanding of the dependencies between crew members (who needs to supply what to whom and when), and had established effective coordination routines—such as, helping the mopper around difficult areas. The established routines increased the efficiency of the work.

- There was a clear understanding of the acceptable work behaviors (such as not being late, and notifying the foreman when someone could not go to work).

- There is a high degree of caring of the foreman for his crew as indicated by the foreman’s statements (who considered his crew as his “work family”) and his tolerance of absenteeism to accommodate the workers’ needs.

On the other hand, the high cohesiveness of the crew can present some disadvantages. First, it can make it difficult for new members to be accepted by the crew, and increase turnover of new employees, as noticed on this project. Second, the rigid allocation of responsibilities, limits the opportunities of the crew members to learn the different skills and roles, which can limit the flexibility of the crew (the ability to redistribute the roles under different situations). In this case, the crew had enough capacity to absorb the increased workload created by the two laborers who quit. The foreman himself performed physical work, and the crew members could pick up the pace when needed. The crew finished the project on time without the additional two laborers.
In summary, the foreman’s practices converged to systematically create (or prevent) the following work conditions:

1. **Prevented “defective work assignments.”**
   (1) If fall protection was not in place, the foreman would not start the work. (2) If the material was not of good quality, the foreman would not use it even if he had to wait for new material. (3) To prevent work interruptions, the foreman would plan the material deliveries.

2. **Prevented errors and quality defects.**
   (1) The foreman did not allow the use of old material. (2) He monitored and inspected the work very closely to immediately correct errors and prevent defects. He maintained close monitoring even when performing physical work, by taking the task of the mopper. (3) He paid more attention to areas with higher risk of quality problems, where he assigned experienced workers and (4) used additional layers of roofing material.

3. **Mitigated exposures to hazards and excessive demands on workers.** (1) The foreman would not start the work until fall protection was in place. (2) He loaded only the required material for each roof section to reduce manual handling, and keep work area as uncongested as possible. (3) He used installation practices that prevented excessive exposure to heat (even at the expense of some efficiency.) (4) His participation in the physical work mitigated the increased workload created by the absence of the two new laborers.

4. **Developed high coordination ability.** The specialization of crew roles and the long tenure supported the development of teamwork and coordination (mutual understanding of needs, effective coordination routines, close cross-monitoring and mutual support), even at the expense of individual task-skills and role flexibility. This is essential for avoiding inefficiencies and mistakes in operations with high task dependency and time pressure. The foreman’s tolerance of absenteeism contributed to building a stable crew for the long-term.

**CONCLUSIONS**

This case study highlighted the challenges of a hot asphalt roofing project and investigated the work practices and strategies that a HR foreman used to deliver the project. Qualitative analysis of the work practices found that the foreman’s practices were guided by the following greater principles/strategies: (1) **Create “high quality work assignments”** by providing safe work conditions, good quality material and minimal space congestion; (2) **Prevent errors and defects**, though good quality material, proper work assignments, and close monitoring. (3) **Reduce workers’ exposures to hazards and excessive demands** by reducing manual material handling, and minimizing walking on the new, hot roof. (4) **Maintain a well-established crew** for efficient coordination. These practices involved some trade-offs with short-term efficiency, but created a high quality work process that mitigated the task difficulty and demands on the workers, and prevented errors and defects.

The case also illustrates how the crew management practices supported the characteristics of the operation. Hot asphalt roofing is a repetitive process with activities tightly interconnected, and under high time pressure to ensure high quality of installation. Crews with standardized roles and stable composition develop close coordination patterns, mutual understanding of needs, close cross-monitoring and mutual support. Similar stable crews with long tenure appear in operations with similar characteristics, such as concrete slab pouring and paving.
This study contributes to the construction research in the area of production system design, as it answers the question of “how do exceptional foremen organize and manage their operations to consistently achieve high performance in both production and safety?” The lessons from this case provide practitioners with some principles and practices for designing effective construction operations that achieve both high production and high safety. With regards to the limitations of the study, the work practices identified are case-specific. The findings do not claim that these are the only practices and principles that lead to consistently exceptional performance. Further studies of HR foremen are needed to better understand if these practices are consistently successful and if other practices are also effective.

ACKNOWLEDGMENTS

The authors want to thank the foreman, the crews and the management of the participating company for opening their jobsite to us, and taking time to and explain their operation and challenges, and sharing their knowledge and experience. The research described in this paper was conducted with the support of NSF and the CAREER Award Grant No. 0645139.

REFERENCES


ABSTRACT

Self-consolidating concrete, (SCC) is a highly flowable, non-segregating concrete that allows for concrete placement without vibration or external consolidation. SCC also allows rapid concrete placement with reduced labor costs, resulting in vastly improved concrete surface finishes and architectural applications (RMCAO 2009). To accomplish SCC, the concrete industry has developed improvements in high-range water reducer admixtures for flowability and viscosity-modifying admixtures for stability. The current project investigated six specimens, which provided an evaluation of SCC allowed to free fall 3 m (10 ft) that filled wall formwork with different inclinations and amounts of steel reinforcement. The purpose of the investigation was to evaluate SCC free fall with formwork inclination and steel reinforcement congestion.

Keywords: construction materials/methods; construction education; industrial construction.

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INTRODUCTION

Self-consolidating concrete (SCC) technology, developed in Japan in the mid-1980s, is based on increasing the amount of fine aggregates in a conventional concrete mixture without altering the water-to-cement ratio. This modification of mixture design changes the rheological behavior of concrete, producing outstanding flow characteristics (Vachon 2002).

The most important criteria for SCC are flowability (allowing the SCC to encapsulate the reinforcement and fill formwork) and stability (preventing segregation of coarse aggregate in a concrete mixture). The most common test for SCC flowability and stability is the spread test, which utilizes a standard sheet metal cone. The SCC is placed into the cone in one non-rodded lift, the cone is raised, and the resulting diameter of the concrete spread is measured, thus indicating flowability. In addition to flowability, the spread test provides clues as to the potential for segregation indicated by the possible bleeding of water at the fringes and in pockets around the concrete spread, as shown in the ASTM Standard (ASTM C1611 2010).

Literature Review

“Self-Consolidating concrete is a highly flowable concrete that can spread into place under its own weigh.” (Khayat 1999). SCC was created to fill congested areas of formwork that was unable to be filled by conventional concrete because of high viscosity and lack of fluidity. SCC also improves working conditions and on-site productivity, making SCC more efficient than conventional concrete. Because SCC technology is being developed and improved, no one SCC mixture has proved consistently dominant.

SCC is most distinguished by its unusual fluidity because it is able to spread into tight spaces and consolidate, or form a unified mass, under its own weight, unlike conventional concrete which requires vibration in order to compact (Khayat 1999). This fluidity can be attributed to a few components of a SCC mixture, specifically chemical admixtures. The most common admixture is a high-range water reducer admixture (HRWRA), which often works as a superplasticizer. This admixture increases mixture fluidity, but has little effect on viscosity. If water is used in place of HRWRA, fluidity increases but viscosity decreases drastically, causing a huge loss of strength and stability. The second admixture, a viscosity-modifying admixture (VMA), is added to thicken the mixture and increase viscosity.

Previous research (El-Chabib & Nehdi 2006) described the effect of these chemical admixtures on SCC mixture strength and its tendency to segregate. The authors investigated dosage effects of HRWRAs and VMAs and, by establishing two segregation index (SI) values, modeled them with respect to transportation, casting, and settling. The first value, SI-Static, or segregation under normal settling conditions, was modeled by leaving the mixtures in cylindrical molds for 30 min and then examining them. The second value, SI-Dynamic, or segregation under transportation and pouring conditions, was modeled by using SI-Static and SI-Dynamic criteria, two sets of mixtures were prepared. The first set of mixtures investigated dosage effects of HRWRAs; the second set investigated the dosage effects of VMAs. All mixtures contained both admixtures, but the non-variable admixture was maintained at constant dosage throughout its set. After the casting was conducted and data was gathered, the determination was made that as the HRWRA dosage increased, the concrete
Free Fall of Self-Consolidating Concrete in Walls Three Meters High

became more likely to segregate, regardless of which type of SI was used. However, an increased dosage of VMAs increased concrete mixture stability and decreased its tendency to segregate. The authors determined that chemical admixture dosages largely affected the concrete’s tendency to segregate (El-Chabib and Nehdi 2006).

Although chemical admixtures play a large role in the success of a SCC mixture, its physical components are just as crucial. Other mixture components include water, cement, and fine and coarse aggregates. To ensure a strong and fluid mixture, the concrete must have a balanced water-to-cement ratio so the concrete can flow under its own weight but be strong enough to resist bleeding or segregating (Khayat 1999). The amount of coarse aggregates in the mixture varies from project to project; however, coarse aggregate quantity should be reduced to less than 50% of the mixture. Friction inside the mixture increases when aggregates frequently come into contact with each other, consequently requiring more energy in order to increase fluidity and overcome the strength. As a result, SCC’s most-known property of high-fluidity decreases (Azamirad & Beheshti zadeh 2005).

Testing procedures, such as the slump test, test SCC mixture workability, and consistency. The SCC is placed into a sheet-metal cone located on a flat surface, the cone is lifted and the diameter of the greatest circular SCC spread and the diameter perpendicular to that spread is recorded. The diameter average is considered the spread of the SCC mixture (ASTM C1611 2014).

Another SCC test, the penetration test, provides an estimation of the mixture’s tendency to segregate due to static friction. Materials used in the procedure include a standard slump cone and a penetration apparatus, consisting of a hollow cylinder with a rod bolted vertically to the top and held together by a cubical support frame. First, the cone is placed on a flat base plate, with the smaller end of the cone facing down. The mixture is then poured into the cone. After excess concrete has been removed, the penetration apparatus is positioned on top of the cone. The hollow cylinder is then released from its position and allowed to rest directly on top of the concrete. Penetration depth of the cone is measured and used to predict segregation resistance of the mixture. If penetration depth is below 10 mm, the concrete will be resistant to static segregation. If penetration depth ranges between 10 and 25 mm, the mixture will be moderately resistant. If penetration depth is greater than 25 mm, the mixture will most likely not be resistant to segregation. This test is not practiced as common as the slump test, but it provides vital information regarding whether or not the mixture will segregate (ASTM C1712 2014).

A recent dynamic testing method, which estimates the tendency of the SCC mixture to segregate, utilizes rapid penetration as part of the test (Esmaeikhanian et al. 2014). This dynamic stability test involves the tilting of a rectangular box numerous times to simulate concrete flow and evaluate concrete homogeneity with increasing flow distance. In the test, dynamic segregation of the coarse aggregate increases with flow distance.

Segregation in SCC mixtures could also be attributed to the lateral pressure exerted by the mixture. The weight of this fluid cement results in a greater pressure exerted on the formwork than that of normal concrete. Although concrete solids remain in place, liquids spread, fill, and exert pressure on the surrounding formwork. The greater the quantity of fluid, the greater the pressure on the formwork will be. This could
lead to uneven flocculation and shear thinning because of unpredicted mixture agitation on the formwork. In addition, casting rate could affect the pressure exerted by the concrete. In order to understand the how the fluidity of the concrete affects the lateral pressure on the forms, two terms are defined. The first term, hydrostatic pressure, is pressure exerted in both downward and lateral directions by the weight of the concrete when the concrete is in a purely liquid form. The second term, lateral pressure, refers specifically to pressure exerted by the concrete on the sides of the formwork. The lateral pressure equals the hydrostatic pressure minus the vertical support reaction provided by solidifying concrete. When the casting rate of SCC is high, solidification of the SCC has not yet occurred, and increased lateral pressures result. This increase in lateral pressure must be resisted by the formwork. Decreasing the casting rate allows more time for the mixture to solidify, the concrete vertically supports more of the weight and the lateral pressure on the formwork is reduced (Ovarlez & Roussel 2006).

Additional information for SCC can be found in the ACI publication Self-Consolidating Concrete (ACI 237R-07 2007) and National Cooperation Highway Research Program, Report 628 (NCHRP 2008).

**Motivation**

In 2009, two identical, one-third scale bridge bent specimens were constructed, including free fall placement of SCC to form hollow, slanted 3 m tall columns with a large amount of congested steel reinforcement (see cross-section in Figure 1). SCC was expected to fill the forms and encapsulate the steel reinforcement, but after the forms were removed, coarse aggregate segregation had occurred at various locations around the columns in both specimens (see Figure 2). The segregation occurred in the lowest 1 m of the columns and included about 15 percent of the surface area.

**HOLLOW COLUMN**

*Figure 1: 2009 Specimen Cross-Section*
Since 2009, improvements in admixtures and SCC composition have occurred. Based on the assumption that the 2009 experiment segregation occurred due to the wall angles and/or the amount of steel reinforcement, the current project was designed to construct specimens using SCC with new admixtures and composition, walls at an angle similar to the 2009 specimens, vertical control walls, and varying quantities of steel reinforcement.

**Objective**

The objective of this project was to empirically assess 3 m (10 ft) free fall placement of SCC into wall forms with varying amounts of steel reinforcement. The assessment included surface quality, segregation resistance and bond with the steel reinforcement. The goal was to determine if the cause of SCC coarse aggregate segregation in the 2009 specimens was related to:

1) steel reinforcement congestion,
2) incline of the formwork and steel reinforcement,
3) a combination of steel reinforcement congestion and inclination of the formwork, or
4) an antiquated mixture design for which new admixtures and/or mixture designs for SCC construction have eliminated coarse aggregate segregation.

Six specimens were constructed; three specimens were constructed vertically; three specimens were constructed at a 1:10 horizontal-to-vertical ratio. In both types of specimens, each specimen had one of three different levels of steel reinforcement. The three steel reinforcements levels ranged from no reinforcement (0), to minor reinforcement (Level 1) to augmented reinforcement (Level 2).

**Research Significance**

In walls or columns, concrete cannot always be easily placed due to steel reinforcement congestion and/or narrow formwork. In those instances, SCC may be used advantageously to free fall into the formwork, but a maximum allowed distance of free fall has not yet been defined. In this research project, six specimens were filled with SCC at a height of 3 m (10 ft) in order to determine if SCC segregation would occur due to free fall. In this experimental work, coarse aggregate segregation of the SCC did not occur in the six specimens except at initial placement.

**METHODOLOGY**

This project includes the SCC mixture design, specimen configuration types, test setup, testing protocols, and expected results. Test specimen designs were primarily governed by the need to simulate SCC placement in inclined or vertical walls 3 m (10 ft) in height with a varying quantities of steel reinforcement. Initial priming of the pump and elephant trunk was omitted in order to examine the effects of lack of priming on coarse aggregate segregation of SCC.
SCC Mixture Design

Compressive strength of the SCC was selected to be at least 35 MPa (5000 psi) at 28 days to simulate construction of walls and columns. Following construction practice, the maximum size of coarse aggregate was limited to 19 mm (0.75 in) diameter (BASF 2012). The manufacturer recommended amount of HRWRA ranged from 2 to 10 ounces per 100 lbs of cement used, with 8.61 ounces included in the test mixture. For VMA, the manufacturer recommended range was from 10 to 40 ounces per cubic yard of SCC, with 48 ounces used in the test mixture. Lastly, a concrete retarder was used to increase the time for the SCC mixture to harden. The manufacturer recommended amount of retarder was from 2 to 6 ounces per 100 lbs of cement used. The actual amount of retarder used was 3.69 ounces per 100 lbs of cement. The water-to-cement ratio for the SCC mixture was 0.46, and no mechanical vibration of the concrete was used. A summary of the mixture design is provided in Table 1.

Table 1: SCC Mix Design

<table>
<thead>
<tr>
<th>Material</th>
<th>lbs./cubic yard</th>
<th>lbs./cubic foot</th>
<th>Admixture</th>
<th>Ounce/cubic yard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine aggregate</td>
<td>1637</td>
<td>60.6</td>
<td>Retarder</td>
<td>24</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>1163</td>
<td>43.1</td>
<td>HRWRA</td>
<td>56</td>
</tr>
<tr>
<td>Fly ash</td>
<td>150</td>
<td>5.6</td>
<td>VMA</td>
<td>48</td>
</tr>
<tr>
<td>Cement</td>
<td>650</td>
<td>24.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>300</td>
<td>11.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit Weight</td>
<td>3900</td>
<td>144.4</td>
<td>W/C Ratio</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Compression test cylinders for standard concrete are filled in three layers wherein each layer is compacted by rodding. Due to inherent flowability of SCC, compression test cylinders are filled in one lift without rodding. In fact, rodding is likely to cause coarse aggregate segregation sending coarse aggregate to the bottom of the mold (RMCAO 2009). Ultimate compression tests for the SCC mixture were conducted at 4, 7, 21, and 28 days from when the concrete was placed. For each day, three test cylinders were tested; compressive strength averages are graphed in Figure 3.

On the day of the test, a SCC slump flow test was conducted; average diameter of the slump flow was measured to be 22 in. Average slump flows for walls range from 20 – 30 in for lightly reinforced and 24 – 30 in for densely reinforced (BASF 2012).
Specimen Types

In the specimen notation, the first character noted indicates “V” for vertical or “N” for inclined. The second character noted in the specimen notation indicates “0” for a specimen without steel reinforcement, “1” for Level 1 reinforcement, or “2” for Level 2 reinforcement. Level 1 reinforcement includes a gross vertical steel ratio of 0.0042 with an out-of-plane wall reinforcement ratio of 0.0011 (including 2 legs of the hoop tie and 1 cross-tie). Level 2 reinforcement includes a gross vertical steel ratio of 0.0069 with an out-of-plane wall reinforcement ratio of 0.0038 (including 2 legs of the hoop tie and 3 cross-ties). Cross-sections of reinforcement types are shown in Figure 4.

![Cross-Section of SCC Specimen Types](image)

Test Setup

Setup for the experiment included 2.4 m high (8 ft) prefabricated formwork in 0.6 meter (24 inch) wide sections to create a continuous wall that was 6 m (20 ft) long, subdivided using 38 mm (1.5 in) thick wood dividers nailed to the prefabricated formwork. As labeled according to specimen type in Figure 5, installed dividers created six distinct specimens: three vertical and three inclined. Prior to steel reinforcement installation, the formwork and dividers were coated with form release oil and formwork ties were installed (Figure 6). Two steel reinforcement spacers (or plastic chairs) were installed on the ends and sides of the specimens, as indicated as black circles in Figure 5. Above the 2.4 m (8 ft) prefabricated formwork, 0.6 m (2 ft) high plywood side panels were used to funnel SCC from the required 3 m (10 ft) height to the bottom of the formwork.
Test Protocol

SCC was poured from the top of the longitudinal reinforcement at 3 m (10 ft) above the bottom of the formwork and allowed to free fall, as shown in Figure 7. SCC was placed up to a height of 2.4 meters from the bottom since coarse aggregate segregation was unlikely at the top 0.6 m (2 ft) of the walls. Because SCC in the top portion of the walls was not placed, increased hydrostatic pressure and the need for high pressure resistant formwork were avoided.

SCC was placed in two lifts approximately 1.2 m (4 ft) high in order to minimize wood divider movement in the in-plane direction of the formwork, as shown in Figure 8.

In most concrete projects, the pump and elephant trunk are primed to ensure a consistent concrete mixture. Since this project involved SCC, a portion of the experiment included not priming the pump and elephant trunk to determine if priming should be required with SCC.
Expected Results

Expected results included coarse aggregate segregation possibly due to steel reinforcement congestion, inclination of the formwork and steel reinforcement, or a combination of steel reinforcement congestion and inclined formwork. In addition, advances in admixtures and SCC mixture design could have resulted in a stable mixture without coarse aggregate segregation.

FINDINGS

The slump spread is shown in Figure 9 and is designated as a VSI – 1 rating indicating a stable mixture. The slump flow for the SCC averaged 22 inches. Therefore, slump flow was within the range for lightly reinforced walls. Similar to the 2009 tests, passing ability, typically included in the testing of SCC, was omitted.

Figure 9: Stable Mixture VSI = 1 per ASTM C1611

The surface quality at the base of specimen V-2, coarse aggregate segregation was noted when the formwork was removed, as is shown in Figure 10. Additional coarse aggregate segregation areas were limited to joints between prefabricated formwork and were considered insignificant. The bottom of specimens V-0, V-1, and V-2 are shown in Figure 11 for comparison. As compared to the 2009 specimens (Figure 2), the segregated surface area of the V-2 specimen (the portion that had been placed without priming the elephant trunk) was about 2 percent and located at the bottom 0.3 m of the specimen. With the exception of the initial concrete placement at V-2, the SCC mixture resisted segregation.
As mentioned previously, the pump and elephant trunk were not primed prior to SCC placement. According to the Ready Mix Concrete Association of Ontario, segregation of coarse aggregate may occur due to lack of priming because SCC was placed “through an un-primed pump hose or elephant trunk” (RMCAO 2009).

With the exception of initial placement into the formwork, SCC filled the formwork and encapsulated the steel reinforcement. Specimens were reviewed on all sides to visually inspect the surfaces, and specimen N-2 (inclined specimen with maximum steel reinforcement) was cut to examine the cross-section and interface of the SCC with the steel reinforcement. As shown in Figure 12, the steel reinforcement was encapsulated by the SCC. This is contrary to the steel reinforcement in the 2009 specimens, which was not entirely encapsulated by the SCC in the areas of segregation.

The compressive strength average at 28 days was 61.4 MPa (8900 psi). Compressive strength averages at 7, 14, 21, and 28 days are illustrated in Figure 3. The 28 day compressive strength of 61.4 MPa (8900 psi) far exceeded the specified 35 MPa (5000 psi) compressive strength.

CONCLUSION AND RECOMMENDATIONS

Experimental research conducted on six specimens, provided an assessment of SCC allowed to free fall 3 m (10 ft) in order to fill wall formwork with various inclinations and amounts of steel reinforcement. The purpose of the
research was to evaluate the effect of formwork inclinations with varying steel reinforcement congestion and compare it to previous specimens constructed in 2009. The following are the conclusions drawn by the research:

• The new SCC mixture filled the formwork and encapsulated the steel reinforcement. The encapsulation of the steel reinforcement did not fully occur in the 2009 specimens (due to an antiquated SCC design mixture). The successful placement of the SCC in this project indicate that advancements have been made in VMA admixtures. The VMA effectively thickened the cement paste of the SCC, while still allowing the SCC to be free flowing and fill the forms.

• The research SCC was stable and led to a more homogenous in-situ property that resisted segregation of the coarse aggregate.

• The inclined forms and steel reinforcement, which effectively blocked a direct vertical path to the bottom of the walls, did not cause SCC segregation.

• Priming of the pump and elephant trunk is recommended for SCC in order to prevent coarse aggregate segregation during initial placement.

Future Work

The work in this project was based on one specific SCC mixture from one ready-mix concrete company. While the mixture performed well for the specimens, other SCC mixtures may not function as well. Other complex formwork configurations with congested steel reinforcement, including cages in which horizontal reinforcement is installed less than 100 mm (4 in) on center, should be tested to determine if SCC placed in a free fall manner would yield similar results.
REFERENCES


ABSTRACT

A relationship between time and cost has been found to be valid for different construction types by many researchers. The purpose of this study is to validate this relationship, based on a model developed by Bromilow et al., for highway construction in Florida. Along with time and cost factors, the modified model included contract types to determine whether this variable also has an effect on project duration. Data related to 235 roads and highways construction projects was obtained for the study. SPSS® program was used for analysis of the data. The statistical technique used for the analysis was multiple regression. The results indicate that both actual construction cost and contract type have got a statistically significant relationship with construction time for highway construction projects, at the level of significance (p-value) of <0.0001. A prediction model of construction time has been developed based on the results of the study. This model will be useful to both graduate and undergraduate students taking courses related to cost estimating and construction project scheduling, and also to professionals involved with the construction industry.

Keywords: Construction Time, Construction Cost, Contract Type, Road Construction, Regression Analysis

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INTRODUCTION

General

Construction time for any type of project is related to a wide range of variables including construction cost. Time and cost have been typically used as important criteria for determining project performance globally. A relationship exists between the time taken for construction of a project and the cost incurred to complete it. Project cost has been identified as a correlate of construction time in many regions of the world (Bromilow et al., 1980; Choudhury & Rajan, 2008). In the construction industry, contractors usually use previous experiences to estimate the project duration and cost of a new project. In general, the more time it takes to complete an activity, the more human resources have to be engaged for the task, resulting in a higher project cost.

A correlation between completed construction cost and the time taken to complete a construction project was first mathematically ascertained by Bromilow et al. (1980). The authors analyzed the time-cost data for a total of 419 building projects in Australia to develop the model. The equation defining the mean construction time as a function of project cost was found to be:

\[ T = K \cdot CB \]  

(1)

Where

- \( T \) = total construction time from the date of start to substantial completion, in working days
- \( C \) = final cost of project in millions of dollars, adjusted to constant labor and material prices
- \( K \) = a constant indicating the general level of time performance per million dollar
- \( B \) = a constant describing how the time performance is affected by the size of the construction project measured by its cost.

Total construction time of a project is described by the model as a function of the final project cost. It provides a basis for all the stakeholders concerned with the construction procedure to establish a fairly accurate probable time for construction of a project in days, when the estimated cost of the project is known. The authors also took into consideration the overruns on cost and time that provided a measure on the accuracy of the industry's time and cost prediction.

The model also reveals that relationship between the cost of a construction project and time required to complete it is non-linear (Figure 1). In order to perform data analysis using a linear model, the variables need to be transformed into their natural logarithms.

Figure 1. Non-linear relationship between construction cost and time

Several other studies have been performed around the world to make similar predictions for either a specific sector of construction or construction industries, in general. Ireland (1985) replicated the study to predict construction time for high-rise buildings in Australia; Kaka & Price (1991) conducted a similar survey both for buildings and road...
works in the United Kingdom; Chan (1999) investigated the effect of construction cost on time with particular reference to Hong Kong; and Choudhury & Rajan (2008) conducted a study on residential construction projects in Texas; Choudhury (2013) also replicated the study to develop a model for prediction of construction time of school buildings in Texas. Hoffman et al. (2007) used Bromilow et al.’s (1980) time-cost model to analyze data collected for 856 facility projects. They, however, included certain other variables such as project location, building type, and delivery method in the model.

Gritzka & Labi (2008) conducted a study on factors of time delay, specifically for road construction projects. Findings of their study indicate a statistically significant relationship between longer-duration projects and cost overrun.

All these studies found that the mathematical model developed by Bromilow et al. (1980) holds good for prediction of construction time when the cost of construction is known.

Other Possible Predictors of Road Construction

A critical issue in road construction that affect project delivery, experienced almost worldwide, is cost overrun (Bhargava et al., 2010). It generally results from factors that occur during various stages of life-cycle of a project. Studies on highway projects have been conducted by quite a few researchers to seek the extent of this particular problem.

Findings by several authors indicate that it is associated with project design, project environment, and project size (Akincı & Fisher, 1998; Hinze et al., 1992); project size, of course, is directly related to overall construction time.

Construction procurement is the process of obtaining services and supplies for efficient and timely delivery of the end product. The major project delivery methods include (1) Design-Bid-Build, (2) Design-Build, and (3) Construction Management at Risk. Studies indicate that project performance is affected by project delivery method (Choudhury & Pitkar, 2007; Ling et al., 2004; Chan et al., 2002).

The trend in the use of project delivery system is changing rapidly. Project delivery system has evolved over the years. The medieval master builder was hired by an owner to design, engineer, and construct an entire facility. This system was common until the early 20th century. With changing technologies, it was necessary to change the type of delivery system that gave way to the Design-Bid-Build method. As the specialization of services increased, it was found that the interaction during design phase was extremely poor which resulted in inefficient designs, increased errors and disputes, higher costs, and ultimately longer schedule. This led to the Construction Management at Risk delivery system to improve the interaction among parties concerned and to overlap the design and the construction phases. Eventually, it was found necessary for owners to resort to a single source Design-Build contracting (El-Wardani et al., 2006). There is an increasing trend toward the use of the Design-Build delivery method in the public sector (Choudhury & Pitkar, 2007; Tulacz, 2006; Yakowenko, 2004).

It is thus possible that project delivery method could play a role in construction performance time. The likelihood of an impact of delivery method on construction time of road projects was ascertained by including it in the time-cost relationship model.
Hypotheses

From a review of literature, it is hypothesized that

1. The actual completion time of road construction projects in Florida is affected by actual construction cost.

2. The actual completion time of road construction projects in Florida is affected by estimated construction cost.

3. The actual completion time of road construction projects in Florida is affected by contract type or delivery method.

METHODOLOGY

Data Collection

The study was conducted using a database of 235 completed road construction projects undertaken by Florida Department of Transportation (FDOT). It was obtained from secondary sources.

Variables

Actual Construction Time (TIME): It is the actual time measured for the completion of a road construction project. It was measured in days. This variable was labeled as LNTIME after being transformed into its natural logarithm.

Actual Project Cost (ACOST): It is the total cost of construction works of a road construction project. It was measured in units of 1000 US Dollars. This variable was labeled as LNACOST after being transformed into its natural logarithm.

Estimated Project Cost (ECOST): It is the total cost of construction works of a road construction project, estimated by FDOT prior to construction. It was measured in units of 1000 US Dollars. This variable was labeled as LNECOST after being transformed into its natural logarithm.

Contract Type (CONT): It is the type of contracting used for delivering a road construction project. This was a dummy variable consisting of two categories: (1) Design-Build (DB), and (2) Others. This variable was labeled as LNCONT after being transformed into its natural logarithm. It was assigned a value of 1, if the contracting method was DB; if not, a value of 0 was assigned.

RESULTS

Analysis

The time-cost relationship model developed by Bromilow et al. (1980) defines only the relationship between construction time and actual construction cost. Since the present study hypothesizes relationships to exist also between (1) construction time and estimated construction cost and (2) construction time and contract type, the model had to be modified. Following model encompasses both the variables that may have an effect on construction time performance:

\[
\text{TIME} = K \times \text{ACOST}^{\beta_1} \times \text{ECOST}^{\beta_2} \times \text{CONT}^{\beta_3}
\]

A stepwise linear regression analysis was used to perform the first step of analysis (see eqn. 3). It is a semi-automated process of building a model by successively adding or removing variables based on the t-statistics of their estimated coefficients. Therefore, the variables had to be transformed into their natural logarithms.

\[
\ln(\text{TIME}) = \ln(K) + \beta_1 \ln(\text{ACOST}) + \beta_2 \ln(\text{ECOST}) + \beta_3 \ln(\text{CONT}) + \epsilon
\]

Where \(\ln(K)\) = natural logarithm of \(K\); \(\beta_1, \beta_2, \beta_3\) = regression coefficients; and \(\epsilon\) = error term.

The results show that two independent variables were retained by the model: actual construction cost (LNACOST) and contract type (LNCONT). Estimated contract cost (LNECOST), not being significant at the level of 0.5, was excluded. The results are shown in Table 1.
Table 1: Stepwise Linear Regression Analysis for LNTIME

| Variable Retained | Intercept (LNK) | Regression Coefficient | t     | p<|t|          | Critical Value of |t| |
|-------------------|----------------|------------------------|-------|-------------|-------------------|------------------|
| Intercept         | 1.827          |                        | 15.976| <0.0001     | 1.96              |
| LNACOST           | 0.529          |                        | 29.976| <0.0001     |                   |
| LNCONT            | -0.131         |                        | -2.234| 0.026       |                   |
| F-value of the Model | p > Model | F=<0.0001             | Model R2 = 0.89 | Adjusted model R2 = 0.80 |

Interpretations

The $F$-value of the model used for multiple regression analysis was found to be statistically significant at less than the 0.0001 level. This provides evidence that a relationship exists between construction time and at least one of the independent variables used in the model. The results, however, indicate that the actual construction cost and contract type are correlated to construction time at a very high level of significance with a $p$-value 0.0001 and 0.026 respectively. Estimated construction cost was not found to be significant at level of significance of 0.05; hence, it was automatically excluded by the statistical program from the model.

An important aspect of a statistical procedure that derives model from empirical data is to indicate how well the model predicts results. A widely used measure the predictive efficacy of a model is its coefficient of determination, or $R^2$ value. If there is a perfect relation between the dependent and independent variables, $R^2$ is 1. In case of no relationship between the dependent and independent variables, $R^2$ is 0. Predictive efficacy of this particular model was found to be moderately high with an $R^2$ of 0.89, and an adjusted $R^2$ of 0.80. It means that at least 80 percent of the variances in construction time of projects are explained by actual construction cost and contract type.

Based on the findings, research hypotheses indicating relationships between (1) actual completion time and cost of road construction projects (Figure 2) and (2) actual completion time and contract types for road construction projects in Florida could not to be rejected. However, the other hypothesis indicating a relationship between actual completion time and estimated construction cost for road projects in Florida had to be rejected.

Figure 2. Relationship between LNTIME and LNCOSt
The relationship between time and cost was found to statistically significant at the level of less than 0.0001. The relationship between time and contract type was found to be inverse at the level of less than 0.026. Least Significant Difference (LSD) statistic of General Linear Model was utilized to find out the direction of the difference in actual construction time. The results are shown in Table 2. It means that mean construction duration was lower when design-build type of contract was used. Difference in actual construction time between the two categories of construction type is presented in Figure 3.

Table 2: Pairwise comparison of LNTIME

<table>
<thead>
<tr>
<th>Contract Type</th>
<th>LNTIME</th>
<th>Mean Difference</th>
<th>Significance (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTHERS</td>
<td>5.112</td>
<td>0.131</td>
<td>0.026</td>
</tr>
<tr>
<td>DB</td>
<td>4.980</td>
<td>-0.131</td>
<td></td>
</tr>
</tbody>
</table>

In case the contract type is not DB, the following version of the model may be used:

\[ \text{TIME} = 6.215 \times \text{ACOST}^{0.529} \times \exp(0) - 0.131 \]  

(6)

**RELEVANCE OF THE STUDY TO CONSTRUCTION EDUCATION**

Statistical models enable empirically-observed measurements, that is, data from the real world, to be interpreted in terms of theory. In many courses in Construction Management, particularly at the graduate level, there is a marked emphasis on collection and interpretation of data. The courses include Advanced Project Management, Construction Economics, Construction Information Systems, and many others. Model management has evolved as an area of emphasis in Construction Information Systems. It involves the methods of storing, modifying, and manipulating models. The domain is composed of dynamic, temporal relationships between variables. With a comprehensive understanding of the data, the students can truly position their works to be viable. Finally, after graduation, they may sometimes be working on large projects with significant costs, technical complexity, and risks. Under such circumstances, statistical methods will allow them to make a consistent product, detect problems, minimize waste, and predict project success. A study such
CONCLUSIONS

The results of the statistical analysis indicate that for a road construction project in Florida, an increase in construction results in an increase in total construction time. The results also indicate that contract type has a statistically significant effect on actual construction time of the projects. It takes less time for completion of a road project in Florida using design-build method of delivery.

The model will be useful for students of construction science, taking courses in construction project scheduling. It will also be useful for all parties associated with the construction industry to predict the mean time required for the delivery of a road project. It provides an alternative and logical method for estimating construction time, both by bidders and clients, to supplement the prevailing practice of estimation predominantly on individual experience.

This study has been conducted using data for construction of road projects in Florida. The construction industry can benefit from the results of the study by applying the model in predicting construction time for similar projects. Such models may be developed by collecting historical data either from the owners or the constructors. However, the model documented in this study applies only for road construction projects in Florida and cannot be generalized beyond the sample size.

REFERENCES


ABSTRACT

Research has shown that the construction industry will face workforce shortages that will increase delivery cost and completion time. The purpose of this paper is to first identify and synthesize the fundamental factors impacting recruitment and retention of the potential construction workforce. A qualitative approach was employed in order to collect and synthesize known factors related to workforce development and capacity building for the construction industry. The paper then presents a conceptual framework for conducting research on capacity generation of a sustainable construction workforce—by considering the impact of family unit and cultural values, career path perceptions, higher educational attainment, and professional career advancement. In addition, the paper proposes some directions for future study to bridge and, in particular, reduce the skills gap in the construction industry.

Key Words: Capacity Building, Family Unit Cultural Impact, Construction Industry Perceptions, Career Advancement, Educational Attainment

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INTRODUCTION

The construction industry has suffered from a shortage of skilled laborers (Fiori 2003; Borcherding et al. 2004; McGrath-Champ et al. 2011; Olsen et al. 2012; Vereen 2013; Oseghale et al. 2015). As defined, this lack is “a shortage of adequately trained, skilled, and productive workers available for certain jobs” (Institute of Management and Administration (IOMA) 2005, p. 6). Reasons for the shortage of skilled workers include ongoing retirement of baby boomers (Toosi 2006; Levanon et al. 2014), industry image problem (Tarnoki 2002; Dainty, Ison, & Root 2004), decline in union membership (Gilbert 2012), fewer new laborers entering the industry (Heimbach et al. 2006; McGraw-Hill Construction 2013), lack of training (Olsen et al. 2012), and lack of organizational and promotion opportunities by construction companies (Carley et al. 2003). This shortage of skilled labor can negatively impact construction productivity (Teicholz 2004; Elkeles & Phillips 2007; Huang et al. 2009) and so must be addressed.

In order to decrease the burden on the construction industry due to lack of workforce, more men and women must be attracted to its careers; however, research shows that the industry has a poor image in general, which makes both men and women reluctant to join careers in the construction industry (Swoboda & Cieslik 1997; Fielden et al. 2000; Kashiwagi & Massner 2002; Bilbo et al. 2009a; Escamilla et al. 2016). Jobs Rated reports preferences for employment based on a rating system that measures factors such as work environment, stress, physical demands, and hiring outlook: in 2011, construction laborers ranked 191st while civil, mechanical, and electrical engineers ranked 33rd, 62nd, and 78th, respectively (Jobs Rated 2011). In addition, a study titled Sources of High School Juniors’ and Seniors’ Perceptions of the Construction Industry showed that families do not support career paths in the construction industry. For example, when students were asked if they thought their families would support them pursuing a construction vocation, only 29% of both males and females responded with a positive answer, while the other 71% reflected a neutral or negative feeling (Bilbo et al. 2009a). In addition, the typical career path for advancement in the construction industry includes years of experience, in addition to taking classes in the field or attaining higher education degrees that include; associates, bachelors, and masters construction focused majors. To attract more students into construction education programs across the country, students must first be made aware of the career opportunities in the construction industry. This has to be followed by shattering the negative perceptions of the construction industry and educating the family unit, students, and high school counselors—while the prospective students are currently juniors and seniors in high school (Escamilla et al. 2016).

In a sustainability report prepared by Balfour Beatty Construction defining why ethnicity matters, it is stated that culture, ethnicity, education level, and use of language vary considerably across the construction industry. The report concludes that embracing this diversity can help appeal to a wider range of customers, suppliers, and local people within the communities of operation (Balfour Beatty 2009). In spite of the cultural diversity, gender diversity has been slow to show progress in the construction industry, especially on site (de Graft-Johnson et al. 2009). The Davies report Women on Boards showed that companies with more women on their boards were found to outperform their rivals, with a 42% higher return in sales, 66% higher return
on invested capital, and 53% higher return on equity (Department for Business Innovation & Skills [BIS] 2011). Moreover, in an inquiry into race discrimination in the construction industry, the Equality and Human Rights Commission found that visible ethnic minorities are still persistently under-represented in construction training and employment and in the procurement supply chain (Equality and Human Rights Commission 2009). Gender inequality and race discrimination must be addressed in the construction industry, as they have created a negative cultural perception among women and ethnic minorities. Negative perceptions held by college-bound students choosing to major in a given area—especially perceptions of bias regarding future employment opportunities—must be researched, and strategies must be adjusted to encourage potential workers to enter careers in the US construction industry.

America’s demographics have transformed at a rapid pace and reflect one of the most diverse countries in the world. In fact, today, more than 30% of Americans belong to racial and ethnic minority groups, and midway through this century, minorities will constitute almost 50% of the American population (US Census Bureau 2011). However, construction companies and construction education programs have not followed suit and are not prepared to cultivate, promote, and retain a diverse group of employees. This study will begin to address the lack of diversity found in the construction industry through a comprehensive program of awareness and education.

PURPOSE

The purpose of this study is to review pertinent and current literature focused specifically on increasing recruitment of the potential construction workforce in the US. This will be accomplished by exploring a review of peer reviewed studies looking into the issue of educational attainment for construction workers and developing a capacity-building model to serve as a blueprint for further research focused on increasing the recruitment of potential construction workforce. The investigation delves into literature that includes family-unit cultural impact on decision-making for potential career path and opportunities in construction education, explains the perception of students toward construction vocations, describes issues faced by students during construction education, and, finally, expresses issues faced by workers in the construction industry. In addition, this study aims to develop a research process model that serves as conceptual framework for capacity building of construction workers in construction careers.

METHODOLOGY

A qualitative approach was employed in order to collect and synthesize known factors related to workforce development and capacity building for the construction industry. According to Holliday (2007) qualitative studies gather data from different sources and assess them in a hierarchy to create new concepts (Ostadalimakhalbaf & Simmons 2015). Wilscolt (2001) stated that the nature of this type of research is exploratory and open-ended. For this study research papers published after 2000 were extracted from databases such as Web of Science, Scopus, Engineering Village, and ASCE Library. Search results were narrowed by language, text availability, article type, and publication date. Articles in peer-reviewed journals and conference papers form a main part of reviewed materials. In addition, technical reports from famous effective local
and national research institutes, government documents, and other literary sources were also gathered through Google Scholar in order to obtain a holistic literature review. The key words used in search engines include Shortage of Skilled Labor, Skills Development, Workforce Development, Construction Career Awareness, and Construction Education and Career.

Data interpretation was performed employing the concept of triangulation, which involves cross-referencing various sources of information about the same phenomenon (Dixit et al. 2010). To do this, the study refers to different literature sources in order to identify factors impacting recruitment and retention of the potential construction workforce. After identifying factors, the information was arranged using a table, and recommendations were identified for improving the skills gap in the construction industry.

FINDINGS

Family Unit Cultural Impact

Family unit plays a pivotal role in young adult vocational development (Brown 2002; Beauregard 2007; Wong & Liu 2010; Schroder et al. 2011; Jones 2012; Kisi 2013; Ostadalimakhmalbaf 2014). A study on 809 high school juniors and seniors in the US demonstrated that 78% of students identified one or both parents as being mainly in charge of helping them find an occupation (Hurley & Thorp 2002). Gostein (2000) demonstrated that parents impact the career choice of their children in different ways, including direct inheritance, the provision of apprenticeship, and role modeling (Bossman 2014). Hargrove et al. (2005) indicated that family environment, especially quality of family relationships, plays a remarkable role in determining the vocational choices of young adults. Whiston and Keller (2004) emphasized that family plays a key role in ethnic minorities' occupational choice and showed that “the influence of family of origin factors on career development cannot be examined effectively independent from socio-contextual factors such as socioeconomic status and race” (Brown 2004). Similarly, a study on rural high school seniors indicated that the cultural and social context of family and community can significantly impact the youth career-choice process (Ferry 2006). Moreover, Borchert (2002) asserted that parental educational background can influence a student’s awareness of the importance of education and may persuade students to a certain path. Likewise, Ferreira et al. (2006) indicated that parental educational attainment is one of the major factors affecting the occupational choice-making process of young people. Family members’ own work experiences can considerably affect students' career decision-making (Porfeli, Wang, & Hartung 2008). A study on high school students in southern Nevada indicated that a family member’s employment in the construction industry impacts a student’s decision to choose construction as an area of study in high school (Kisi 2010).

At the same time that literature shows parents having a dominant effect on career decisions, research reveals that family unit perception of the construction industry is not positive. Research by Erlich and Grabelsky (2005) expressed that no parent wants their child to be a construction laborer. In addition, a study by Escamilla et al. (2016) on 250 Hispanic high school students found that careers in the construction industry don’t have a positive reputation among most Hispanic family units. Obtaining a better understanding of family unit perceptions toward the construction industry, as well as identifying the cultural
complexities associated with the decision-making process, can reveal practices that would lead to successful recruitment of high school students into construction education programs in the US.

**Career Path Perceptions**

The public has limited knowledge of construction careers (Barthorpe et al. 2000; Kashiwagi & Massner 2002; Ling & Ho 2013), young adults' knowledge is inaccurate regarding what jobs can be pursued with a degree in construction science (Bilbo et al. 2009a), and fewer youth are viewing construction as a vocation choice (Escamilla et al. 2016). Recent research on high school students showed that when asked, “Do you believe the public has a positive perception of the construction industry?” a majority of students (76.7%) reported negative or neutral perceptions (Escamilla et al. 2016). A survey administered for 215 Hispanic high school students in Texas found that low wages, dangerous and dirty conditions, and family unit disapproval are the fundamental perceived barriers preventing students from entering construction vocations (Escamilla et al. 2016). Ling and Ho (2013) stated that “the significant negative perceptions about construction jobs are that they are harsh, dangerous, stressful, demanding, and masculine in nature.”

Alongside these factors, a perceived integrity deficiency in construction careers is another obstacle. A study by Clarke and Boyd (2011) on youths between 15 and 18 years old shows that they consider construction workers to be untrustworthy and dishonest, which results in a negative perception toward the industry.

Students are generally indecisive about career choices (Bandura 2006), so career counselors are a crucial resource during the vocational exploration process and are central to the process of assisting students achieve their career plans (Gati & Asher 2001; Francis & Prosser 2012). But research has demonstrated that construction management students consider these high school counselors to have had the least impact on their choice of construction career (Koch 2007). High school counselors have lacked the essential information to be able to lead high school students toward construction careers (Bilbo et al. 2009b). In addition, Barthorpe et al. (2000) stated that school teachers consider construction vocations more suitable for those with a lower educational attainment. Along with the problem of high-school-counselor deficiency, Schleifer (2002) reported that inappropriate perception of blue-collar workers is the primary factor constituting a barrier to the construction industry. Similarly, Troianovski (2008) confirmed that the public perceives blue-collar careers as offering less money and less advancement opportunity compared with white-collar vocations (Clarke & Boyd 2011). Therefore, it is imperative to investigate these negative perception issues and find methods that change potential future workforce participant’s perception of the construction industry. Additionally, in order to reach high school students, we must improve the perception of construction professionals at the junior and senior high school level.

**Educational Attainment**

Educational attainment of production workers within the construction industry, such as blue collars, is lower than production workers in other industries. In 2010, about 24% of construction production workers had less than a high school diploma, in comparison to 17% of production workers in all other industries combined (CPWR 2013). And while Hispanics are the construction industry’s largest minority group (BLS, 2013a)—and actually are over-represented in the construction industry
(National Council of La Raza (NCLR) 2013)—they are much less likely to attain a high school diploma or post-secondary education than non-Hispanic workers in the industry.

On the other hand, the number of middle-skill jobs requiring moderate academic skills and solid non-academic skills (without a bachelor’s degree) is on the rise (Holzer & Lerman 2007; Lerman 2009; Carnevale et al. 2010). Attending an apprenticeship program or vocational school is an effective way for obtaining the aforementioned skills (Lerman 2008; Boucher 2013; John 2013). According to Kochan et al. (2012) “Apprenticeships—the vast majority of which are at unionized companies and are jointly run by unions and management—are the most trial-tested way for firms to address their current and future skills needs” (p. 85).

There are advantages to apprenticeship programs, including receiving a paycheck, technical instruction, hands-on training, and building a career foundation (Tropey 2013). Common construction apprenticeships include electricians (four years), carpenters (four years), plumbers (three or four years), construction craft laborers (two years), and pipefitters (four or five years) (Tropey 2013). Despite the growing number of apprentices in these programs in recent years, apprentices still accounted for only about 0.3% of the total US labor force in 2015. In particular, construction apprentices constituted about 0.1% of the total US labor force (U.S. Department of Labor (DOL) 2015; BLS 2016).

One of the major problems encountered by the construction industry is decreased attrition rate of apprentices before or after completion of the training program. An assessment study on the construction workforce in Arizona demonstrated that the apprentices who completed training programs constituted 33% to 50% of the number of competent workers required for the next decade (Poole et al. 2005). Literature has stated numerous barriers affecting the dropout rate, such as cultural barriers, being first-generation, lack of applicant prequalification assessment, economic burdens due to the long-term commitment, and lack of consistency in training program curriculum from the view of educators and industry members (Choy 2001; Poole et al. 2005; Ishitani 2006; Bartlett 2007; Thomas et al. 2009; Ward, Siegel, & Davenport 2012). A mentoring program is a useful method to provide apprentices with resources, counseling, and encouragement in order to reach their objectives (Putshe et al. 2008, Crisp & Cruz 2009; Del Puerto et al. 2011; Coles 2011), but lack of mentorship can decrease retention and completion rates in training programs (Lerman 2008). Therefore, it becomes essential to take steps to prepare potential workers for effective participation in the construction industry by enhancing their educational attainment level and removing obstacles from their education and training programs.

Career Advancement

Escamilla et al. (2016) reported a variety of factors that serve as barriers for workers in construction careers: dangerous conditions, gender inequality, race discrimination, and a lack of integrity in the industry, which will be discussed in the following paragraphs.

One of the serious barriers preventing workers from entering the construction industry is safety.

The construction industry has the highest fatality rate across various industries, accounting for 18% of fatal injury cases (BLS 2013b). In particular, Hispanic workers represent the highest number of injuries in the construction industry (Dong & Platner 2004; Farooqui, Ahmed & Saleem 2007; O’Neal,
Shaffer & Rummer 2007; Seixas et al. 2008; Dong et al. 2009; Irizarry 2009; Lavy, Aggarwal & Porwal 2010; Menzel & Gutierrez 2010; Roelofs et al. 2011; Menzel & Shrestha 2012; Arcury et al. 2014). In 2012, 222 Hispanic construction laborers were killed on job sites, a 12.7% increase from 2011 as compared with an 8.7% increase for the overall construction industry (Dong et al. 2014). In addition to the considerable number of fatal injuries, the construction industry also suffers from a high rate of non-fatal injuries (Levin 2008). In 2010, there were 74,950 non-fatal injuries resulting in days away from work in construction; being struck by an object was the leading cause of non-fatal injury in construction. Moreover, according to Build a Better Texas (2012), despite the existence of a considerable number of young workers available to the construction industry, dangerous and risky conditions was cited as one of the major factors keeping them from pursuing a career in the construction industry (Escamilla et al. 2016).

The construction industry does not reflect the growing demographic of women in the labor force; therefore, women are under-represented in all construction jobs (Sang & Powell 2012; Wangle 2009; Hawkes & Iversen 2008), comprising less than 25% of total employees in the industry (Dabke et al. 2008). In particular, according to the National Association of Women in Construction (NAWIC) (2010), women comprise only 9.0% of workforce in the construction industry (Kamranzadeh 2012). Data collected by the National Women’s Law Center (2012) demonstrated that women’s participation in US construction careers did not show any growth from 1983 to 2010, while the percentage of women in other dirty, dangerous, and male-dominated vocations increased from 1983 to 2010. Menches and Abraham (2007) stated that the major barriers for women’s career advancement in construction careers include a male-dominant environment and masculine culture, the conflict between work and family responsibilities, and slow career progression.

For ethnic minorities, racial and ethnic discrimination has been reported as a barrier to entering the construction industry (American Sociological Association 2005). Wong and Lin (2014) pointed out that “being called insulting names; racist joke telling; racist comments; offensive graffiti; harassment; being forced to eat in separate locations; longer working hours and being cheated out of legal rights to employment benefits and compensation” are prevalent forms of race discrimination faced by ethnic minority laborers in construction workplaces. Brown et al. (2011) stated that hostile psychosocial workplaces consisting of aggressive and disruptive acts lead to emotional and mental stress. In addition, the existence of racism on construction sites adversely influences productivity. In these environments, the level of collaboration and open communication decreases as discrimination continues to exist, forcing ethnic minorities to interact with laborers of their same cultural group and eventually forming a socially fragmented workplace (Loosemore & Chau 2002).

One of the primary challenges facing the construction industry is its lack of integrity (Stansbury 2005; Zou 2006; Ayodele 2008; Sohail & Cavill 2008; Jong et al. 2009; Ayodele et al. 2011; Bowen et al. 2012; Nordin et al. 2013). A survey conducted by Doran (2004) of 270 owners, architects, construction managers, contractors, and subcontractors showed 84% of respondents having experienced or confronted unethical performances associated with construction industry activities (Escamilla et al. 2016). According to Global Fraud Commentary (2013), there are various forms of fraud that
occur in the construction industry, such as billing fraud and tax avoidance. In particular, wage theft is a serious and pervasive problem in construction careers (Ochsner et al. 2012). For instance, wage theft and payroll fraud has been considerable expense for Texas, with an estimated $117 million in lost wages and $8.8 million in absent sales tax leading to a lack of sufficient money for state and local governments (BBT 2012).

**Conclusion**

The cited sources in the Findings section are consolidated in Table 1. Table 1 will provide a way that makes them easily accessible to scholars and construction professionals.

### Table 1

**Cited Sources in the Findings Section**

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Description</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family Unit Cultural Impact</td>
<td>Family unit perception of construction industry: family unit impacts youth career choice process (cultural identity, decision-making)</td>
<td>Gostein (2000); Borchert (2002); Brown (2002); Hurley &amp; Thorp (2002); Brown (2004); Whiston &amp; Keller (2004); Erlich &amp; Grabelsky (2005); Hargrove et al. (2005); Ferreira et al. (2006); Ferry (2006); Beauregard (2007); Porfeli, Wang, &amp; Hartung (2008); Kisi (2010); Wong &amp; Liu (2010); Schroder et al. (2011); Jones (2012); Kisi (2013); Bossman (2014); Ostadalimakmalbaf (2014); Escamilla et al. (2016)</td>
</tr>
<tr>
<td>Career Path Perceptions</td>
<td>Poor public perception: identify barriers that prevent a student from pursuing construction careers, including counselor impact on student vocational exploration process</td>
<td>Barhorpe et al. (2000); Gati &amp; Asher (2001); Schleifer (2002); Kashiwagi &amp; Massner (2002); Bandura (2006); Koch (2007); Trojanovski (2008); Bilbo et al. (2009a); Bilbo et al. (2009b); Clarke &amp; Boyd (2011); Francis &amp; Prosser (2012); Ling &amp; Ho (2013); Escamilla et al. (2016)</td>
</tr>
<tr>
<td>Educational Attainment</td>
<td>Lower educational attainment than production workers in other industries; apprenticeship program advantages (paycheck, technical instruction, hands-on training, and building a career foundation); barriers (cultural barriers, economic burdens, mentoring)</td>
<td>Choy (2001); Poole et al. (2005); Ishitani (2006); Bartlett (2007); Holzer &amp; Lerman (2007); Lerman (2008); Putse et al. (2008); Crisp &amp; Cruz (2009); Lerman (2009); Thomas et al. (2009); Carnevale et al. (2010); Coles (2011); Del Puerto et al. (2011); Kochan et al. (2012); Ward, Siegel, &amp; Davenport (2012); BLS(2013a); Boucher (2013); CPWR (2013); NCLR (2013); John (2013); Tropey (2013); DOL (2015); BLS (2016)</td>
</tr>
<tr>
<td>Career Advancement</td>
<td>Safety (highest fatality rate, high rate of non-fatal injuries); racial and ethnic discrimination; gender inequality; lack of integrity (payroll fraud, wage theft)</td>
<td>Loosemore &amp; Chau (2002); Dong &amp; Platner (2004); Doran (2004); American Sociological Association (2005); Stansbury (2005); Zou (2006); Faroqui et al. (2007); Menches &amp; Abraham (2007); O’Neal et al. (2007); Ayodele (2008); Dabke et al. (2008); Hawkes &amp; Iversen (2008); Levin (2008); Seixas et al. (2008); Sohail &amp; Cavill, 2008; Dong et al. (2009); Irizarry (2009); Jong et al. (2009); Lavy et al. (2010); Menzel &amp; Gutierrez (2010); Ayodele et al. (2011); Brown et al. (2011); Roelofs et al. (2011); Bowen et al. (2012); Build a Better Texas (2012); Kamranadeh (2012); Ochsner et al. (2012); Menzel &amp; Shrestha (2012); National Women’s Law Center (2012); Sang &amp; Powell (2012); BLS (2013b); Global Fraud Commentary (2013); Nordin et al. (2013); Arcury et al. (2014); Dong et al. (2014); Wong &amp; Lin (2014); Escamilla et al. (2016)</td>
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</table>
DEVELOPMENT OF THE CAPACITY-BUILDING MODEL

In the interest of developing a coherent and consistent conceptual framework for addressing the growing need for a sustainable construction workforce, the Mobilization 2 Completion (Fig. 1) initiative was created. This model provides a research process recommended for capacity building of construction workers in the construction industry. This model should not be viewed as a solution for how to increase the construction workforce; it should be used as a conceptual framework for conducting research on increasing capacity for the construction industry.

The initiative name, Mobilization 2 Completion, was created from construction terms that reflect the research focus. Mobilization is defined as the activation of manpower and resources. Completion is defined as the transition from meeting the scope objectives to operability. The number 2 represents direction from beginning to end.

The research model at its most creative is conceptualized in the form of an ever-evolving flower and is inclusive of those research domains in the most current literature. While the overarching goal of the model is to provide a basis for further insight into what research efforts are required by researchers to bridge the workforce gap in construction careers, it therefore provides only the core information required, uncluttered by irrelevant details. The model's four domains are Family Unit Cultural Impact, Career Path Perceptions, Educational Attainment, and Career Advancement. There are also four action words used to link the domains: Guidance, Recruitment, Core Competencies, and Career Development.

The Family Unit Cultural Impact domain includes areas of research focused on those issues where the family unit impacts the decision-making. These focus areas include but are not limited to

- cultural identity,
- decision-making,
- values/morals, and
- demographics.

The Career Path Perceptions domain includes areas of research focused on career path decision-making from both students and schools. The focus areas include but are not limited to

- career choice,
- counselor impact,
- mentoring,
- outreach, and
- college readiness.

Both Family Unit Cultural Impact and Career Path Perceptions act as the Guidance for the future construction workforce. The Guidance becomes integral to the supply of those students that will serve to meet the industry workforce needs. This workforce will shrink because of those leaving as they age, while the demand for this workforce will increase with the growth of work needed to sustain a growing population.

The Educational Attainment domain includes areas of research focused on preparing students for a career in the construction industry. The focus areas include but are not limited to

- capture and retention,
- campus climate,
- mentoring,
- pedagogy, and
- a path to graduation.

Both Career Path Perceptions and Educational Attainment act as Recruitment for the future construction workforce. Recruitment becomes the strategies to increase the construction education student population.
The Career Advancement domain includes areas of research focused on climbing the career ladder as students transition into a career. The focus areas include but are not limited to:

- job readiness,
- diversity,
- mentoring,
- safety, and
- workforce development.

Both Educational Attainment and Career Advancement act as Core Competencies for the potential workforce. Core Competencies are those skills, both hard and soft, needed to succeed in a construction career.

Both Career Advancement and Family Unit Cultural Impact act as Professional Development for both the workforce and the impact that family unit has on career.

Each study completed within these domains acts as a new petal within the conceptual research model process flower. The domains are exclusive, but the research and cross-pollination among the domains are unlimited. There are many ways for the capacity generation research to be conducted. As a result, the research process model can be viewed from different perspectives by a variety of research fields. For example, some researchers might be interested in aspects of the research process model associated with social and economic perceptions of high school students toward the construction industry. While others may be interested in the safety and leadership aspects of the research process model that impact career advancement progression through a construction company’s promotion process. Although research can be conducted in one domain, there are also opportunities for a more comprehensive research methodology that might require a view of the research process model focused on identifying potential points of linkage of two or more dimensions, resulting in broadening the capacity of the construction workforce pool. Specifically, while the domains look to be exclusive to four areas (family unit/cultural unit, career path perception, educational attainment, and career advancement), there are unlimited research opportunities for interaction and cross-pollination among the domains.

Overall, it is important that the integrity of the research process model is maintained by ensuring that all perspectives are consistent with each other so that those findings and conclusions enable future research to establish grounded methodologies that increase capacity in the construction industry.
CONCLUSION AND RECOMMENDATIONS

This paper looks at the factors that serve as barriers to increasing recruitment of skilled construction laborers and consolidates research results in a way that makes them easily accessible to scholars and construction professionals. It reviews the content of journal and conference papers published in the construction field and combines their factors to develop a unique model to promote recruitment and retention of skilled workforce in construction careers. The capacity-building model describes the impact that family unit and cultural values, career path perceptions, higher educational attainment, and professional career advancement have on capacity generation of a sustainable skilled construction workforce. With the information gathered and the model developed, we hope to initiate a new area of discussion associated with the development of skilled workers in construction vocations.

This paper suggests some directions for future study. Areas worthy of exploration include (but are not limited to) the following:

Family Unit/ Cultural Impact domain;

- Address family unit perceptions of the construction industry
  - Identify the family unit for students who are juniors and seniors in targeted high schools
  - Conduct family unit and student prestudy assessment
  - Develop education modules focused on effectively presenting opportunities to the family unit for careers in and education requirements for construction

Career Path Perceptions domain;

- Compare construction education enrollment demographics to state profiles
- Target high schools with a large enrollment of under-represented students
  - Conduct a junior and senior student prestudy assessment
  - Identify efforts needed to increase awareness of construction careers and foster outreach to students and K-12 school counselors

Educational Attainment domain;

- Present educational modules focused on careers and education requirements for construction management
  - Deliver counseling modules to family unit and students
  - Conduct family unit and student poststudy assessment
- Address factors of recruitment and retention for skilled-trade construction education students
  - Identify the perceptions of construction education students toward construction education and the construction industry and determine which, if any, of these perceptions are significant indicators of career path decisions
  - Identify factors affecting matriculation, attrition, and retention of vocational and construction management education students
  - Use an asset-based mentoring program for construction education students
- Identify effective methods for mentoring women and under-represented minority groups that foster success through construction education
  - Understand the function of new technology as a learning tool to transform educational outcomes and improve productivity and efficiency of teaching construction curriculum to students
  - Identify leadership and role models from faculty in construction schools as crucial in attracting more students into construction vocations
Career Advancement domain;

- Study lack of gender diversity and race discrimination in construction careers
  
  o Investigate how recruiting more women into construction careers will help the construction industry diversify and improve leadership skills for women
  
  o Identify factors that impact the attraction of female and under-represented minority students to pathways into the construction industry
- Address safety and health concerns to decrease fatal and non-fatal injuries
  
  o Develop construction safety training modules featuring new technologies (ex. BIM-enabled 3D visualization, email, SMS, and Facebook) to improve safety training for construction workers
  
  o Conduct community-based practice research (CBPR) to enhance knowledge, hazard identification, and self-efficacy of construction workers
- Address the lack of integrity perception in construction trades
  
  o Identify strategies to prevent occurrences of wage theft, and propose the means to improve integrity within the construction industry

Future scholarly work in these areas will help develop a clearer understanding of strategies needed to improve the shortage of competent labors in the construction industry. In addition, future research will inform construction professionals on how to allocate their resources to address the needs of their business with a competent and sustainable workforce.
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