EXPLORING THE RELATIONSHIP BETWEEN PROJECT INTEGRATION AND SAFETY PERFORMANCE

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Abstract: While recent studies suggest that there is a relationship between indicators of project integration—such as early involvement of constructors—and the quality of project health and safety outcomes, there is no study that empirically investigates this relationship. To address this limitation in the current body of knowledge, the purpose of this paper is to explore the relationship between several characteristics of the integrated projects and construction safety performance. To achieve this objective, the following activities were conducted. First, to collect detailed information regarding recently completed building projects, a survey questionnaire was developed in which, safety performance metrics—such as the number of accidents—were considered as dependent variables, and project organization, team integration, and using emerging processes and technologies were included in the questionnaire as independent variables. Second, the questionnaire was distributed to reach a diverse set of respondents, and a database of 204 building projects was created. The collected data was validated by conducting follow-up phone interviews with respondents. Finally, the database was analyzed using various statistical techniques to investigate the relationship between project integration indicators and safety performance. The results of this study provide preliminary evidence that early decisions of owners and contractors to move towards more integrated projects can impact the safety performance of projects.

1 INTRODUCTION

Using more integrated project delivery systems are gaining traction in the construction industry. The integrated projects are usually characterized with usage of alternative delivery methods such as integrated project delivery method (IPD), team integration techniques such as partnering and col-location, and emerging processes and technologies such as building information modeling (BIM), prefabrication, and lean tools. There is an interest among both owners and contractors to understand the relationships among these new variables and typical definitions of project success such as cost, time, and safety outcomes (El-Asmar et al. 2013).

Considering its importance, several studies attempted to find empirical relationships between safety performance and other project related factors. Most significant studies conducted by researchers focused on using empirical evidence provided in accident reports in national databases such as the Occupational Safety and Health Administration (OSHA) Integrated Management Information System (IMIS) (Hinze et al. 1998, Huang and Hinze 2003, Goh and Chua 2013, and Esmaeili et al. 2015a, Esmaeili et al. 2015b).
Although these studies provide significant contribution to educate project managers regarding factors that contribute to accident occurrence, they provide limited knowledge about the impact of project integration on safety performance. In fact, national databases provide a little information about the type of delivery method used, time of involvement of a contractor in the design process, existence of a partnering statement, or using building information modeling in a project.

To address this growing knowledge gap, the objective of this study is to determine the role of project integration in terms of project organization, team integration, and application of emerging processes and technologies on safety performance. To achieve this objective, a comprehensive questionnaire was developed and distributed into the U.S. construction industry to create a large empirical database of building projects. Then, the database was analyzed using various statistical analysis. This study departs from the current body of knowledge by empirically measuring the impact of project integration—such as project organization, team integration, and using emerging processes and technologies—on the safety performance of building projects. It is expected that the results of this study will provide a guideline for both owners and contractors to understand the impact of their early decisions on safety performance.

2 BACKGROUND

In this section, the research team aimed to identify a dependent variable that measures safety performance and to identify several independent variables that explain project integration. The notable results of the literature review and discussion of dependent and independent variables are provided below.

2.1 Dependent variables

The dependent variables are safety outcomes that reflect the measured safety performance or number of accidents in the project. However, as worker-hours increase, the possibility that workers will get exposed to hazards and get injured will also increase. Rather than collect the number of worker-hours, which is a difficult undertaking, to consider the impact of project size and worker-hours, the number of recordable incidents were divided by the area of the building. Thus, the safety performance was calculated using the following equation:

\[
[1] \text{Safety Performance} = \frac{\text{Number of Recordable Incidents}}{\text{Area (ft}^2)} \times 100,000
\]

2.2 Independent Variables

The independent variables are those factors that can impact performance outcomes. A comprehensive literature review was conducted to identify independent variables that define project integration. Four variables were selected to be included in the questionnaire for further analysis: (1) project complexity; (2) project organization; (3) team integration; and (4) using emerging processes and technologies. These variables are explained in more details in the following sections.

2.2.1 Project Complexity

One of the project characteristics that can influence project performance is complexity. Previous studies investigated the impact of complexity in design (Glavan and Tucker 1991) and scheduling (Nasser and Hegab 2006) of projects. In one of the recent studies, Puddicombe (2011) investigated the cost and schedule performance of 1,300 projects and found that complexity is an important characteristic of a project that has a crucial impact on project performance. However, there is no previous study that has empirically investigated the impact of project complexity on safety performance.
2.2.2 Project Organization

The construction industry is highly fragmented mainly due to the lack of communication among designers and contractors. The traditional delivery practices such as design-bid-build also exacerbate separation of design and construction process. Separation between different parties negatively impacts the potential for innovation as this division makes knowledge exchange more difficult. There are several empirical studies that investigated the impact of project organization on project performance (Konchar and Sanvido 1998, Molenaar and Songer 1998, Ibbs et al. 2003, Hale et al. 2009). Most of these studies had consensus that as ones moves towards more integrated delivery methods, the possibility of cost and schedule growth decrease (Konchar and Sanvido 1998, Molenaar et al. 1999, Gransberg et al. 1999, El-Asmar et al. 2013). While the contribution of these studies are significant, none of them has considered the impact of different delivery method on safety performance of a project.

In addition to project delivery types, the project organization determines the time of involvement for different stakeholders. Song et al. (2009) studied the early involvement of contractors in design and its impact on construction schedule performance. They found that constructability input provided by contractor can improve drawing quality, material supply, information flow, and can indirectly impact construction schedule performance. One of the major limitations of previous studies in this domain is that they did not consider the impact of early involvement of project stakeholders on safety performance.

2.2.3 Team Integration

Three major characteristics of team integration that are investigated in this study are: partnering, co-location, and collaborative goal setting. The complexity, uncertainty, and time pressure existed in construction industry has increased the need for cooperation, flexibility, integration (Eriksson and Pesamaa 2007). One of the concept that can affect project performance through improving team behavior of project participants is partnering. Partnering facilitates knowledge and resource sharing, and improves collaborative relationships that are necessary for successful project completion (Cacamis and El -Asmar 2014). Some studies measured the impact of partnering on project performance. In one of the seminal studies, Gransberg et al. (1999) found that partnering could help to control cost and time growth on projects greater than five million dollar. Nevertheless, there are limited number of studies looked at the relationship between project’s safety performances and partnering.

One of the most notable differences between integrated and less integrated delivery methods is co-location in an environment, which encourages informal collaboration and face-to-face communication among stakeholders (Raisbeck et al. 2010). Within an open floorplan office, known as the “Big Room,” a team of the contractors, architects, and owners work in a collaborative environment during the design and construction of a project. According to Hall et al. (2014), co-location facilitates collaborative decision making, innovation, and transparency. In this study, the research team decided to assess impact of using co-location on safety performance of a project.

The third characteristics of team integration that was investigated by the research team was collaborative goal setting. According to the OSHA act, the employers or contractors are responsible for the safety of their employees, and the standard form of contracts in the construction industry—such as AIA A201 and EJCDC E-500—explicitly transfers responsibility of safety to general contractors. However, if the contractor or builder is participating in goal settings, he or she can inform owners and designers regarding the impact of various decisions on safety performance. In other words, as far as the contractor is concerned regarding safety of his or her employees, the contractor can convince other project stakeholders to consider safety as one of the objectives. A minimal number of studies have investigated the impact of team integration on safety performance.

2.2.4 Using Emerging Processes and Technologies

Three emerging processes and technologies that seem to have a significant impact on enhancing safety performance are offsite prefabrication, using lean construction tools, and using building information modeling (BIM). As prefabrication provides several benefits to the project in terms of cost, time, and
productivity, its usage has been steadily increased in past decades (CII 2002, Eastman and Sacks 2008). Previous studies claimed that prefabrication has the potential to enhance safety performance by reducing the hazard levels of a task (Gambatese et al. 1997, Toole and Gambatese 2008). For example, to reduce risk of fall accidents, work can be shifted from a high elevation to the ground; to avoid the risk of cave-in, work can be shifted from inside an excavation to grade; or to reduce the risk of suffocation, work can be moved from inside a confined space to an open space (Toole and Gambatese 2008). In addition, when work is shifted from the field to the factory, work can be conducted in an environment where the majority of risks are under control and equipment is in better condition.

Toole and Gambatese (2008) highlighted the importance of prefabrication in facilitating hazard prevention through design practices. They found that one of the main pathways that hazard prevention through design will progress in the future is in using prefabricated elements. Using prefabrication elements in design help designers to improve construction safety without fear of liability. In another study, Tanabe and Miyake (2010) proposed a safety design approach for an onshore modularization liquefied natural gas liquefaction plant. Their innovative design showed the feasibility of considering prefabrication elements in the design phase to enhance safety in downstream operations. While there is a common perception that prefabrication can enhance safety, there is no study that empirically supports this hypothesis.

Another independent variables that was identified from the literature is using lean construction tools. Lean production originated in the manufacturing and automotive industries, and after its successful contribution to the manufacturing industry, it has been used in the construction industry (Salem et al. 2006). Previous studies in the construction industry indicated that using lean tools has a positive impact of safety performance (Ohno 1988, Thomassen et al. 2003, Salem et al. 2006, Nahmens and Ikuma 2009, Wong et al. 2009, Womack et al. 2009). The research team decided to consider the impact of using lean construction tools beside other independent variables on safety performance.

Previous studies indicated that using building information modeling (BIM) has a great potential to improve safety performance in a project. Some of the potential applications are: (1) hazard identification; (2) design for safety; (3) site safety planning; and (4) training and education. First, BIM can be used to effectively enhance hazard identification by creating a 3D model of a project. Park and Kim (2013) developed a framework to integrate BIM, augmented reality, location tracking, and game engine technologies into a comprehensive site safety planning process. According to the framework, safety risk factors can be identified in the planning stage by visualizing 3D design and the required site safety facilities for project activities. Second, BIM enables designers to modify designs by considering safety constraints in early stages of a project (Rajendran and Clarke2011). To provide proof of concept, Qi et al. (2013) developed prevention through design (PtD) tools to provide feedback to designers about the hazards created by different design alternatives. Third, BIM-based site planning can improve safety performance by providing detailed spatial information of construction environments as well as dynamic planning and 4D model (Sulankivi et al. 2009). For example, the visualization of a crane’s reach was carried out to examine the risk of load fall or the objects the crane’s rib could hit (Sulankivi et al. 2009). Finally, Rajendran and Clarke (2011) stated that 3D model of a building can be used in orientation sessions to enhance situational awareness of workers new to the working environment. Although previous studies stated that BIM can help to solve some of the safety issues on the site, a limited number of studies have empirically investigated the relationship between using BIM and safety performance.

3 RESEARCH METHODOLOGY

The purpose of this study was to explore the impact project integration measures—such as delivery method, team selection, and other behavioral and technological factors—have on project safety performance. The objective of the study was achieved by conducting the following activities: (1) questionnaire development; (2) data collection; (3) data compilation and validation; and (4) data analysis. First, a survey questionnaire was developed to collect the required data from owners and contractors with an industry advisory board (Esmaeili et al. 2013, Franz et al. 2014). Recordable accidents per square foot of a project were collected as a dependent variable to measure safety performance, and several independent variables were collected including: project complexity; project delivery method (i.e., design-
bid-build, construction manager at risk, design-build, integrated project delivery method); time of involvement of different parties; co-location; collaborative goal setting; and using offsite prefabrication, lean construction tools, and building information modeling.

Second, the survey was distributed by e-mail and postal mail to professional organizations in the U.S. construction industry. During the data collection process, more than 8500 project managers were contacted in the two years. A cover letter, set of instructions, and glossary of terms were attached to the survey in order to illustrate the project objectives and to explain the key terms. The diverse group of respondents was asked to answer the survey according to the most recent project that their organization completed (Franz 2014).

Third, the data collected via e-mail and postal mail were compiled and validated by conducting follow-up phone interviews. In total, 331 surveys were received and reviewed and compiled into a single database in Microsoft Access® with unique identification codes. The reviewing procedure included: verifying the project information to check for possible missing data, scrutinizing the consistency in given values, excluding out-of-scope projects, eliminating unverified projects, and resolving multiple response discrepancies. The reviewing procedure resulted in a database of 204 building projects (Franz 2014).

Forth, the descriptive statistics were examined for each variable and each distribution was checked for normality in the screening procedure. Then, correlations between variables were analyzed. Because all variables were non-normally distributed, correlations between them were analyzed using Spearman's rank-based correlation coefficient (Schumacker 2015). Correlation between recordable accidents were measured against other project performance measures such as cost, schedule, and delivery speed.

Kruskal-Wallis test was used for the group comparisons for recordable accidents per square foot area, because each of the response variables was significantly non-normal and the group sizes within could be relatively small for some categories. The Kruskal-Wallis test is a common nonparametric test that compares the overall population distribution for any number of groups. Since there are lots of “ties” in the data (observations with the same number of incidents) and in some cases quite a few groups, a chi-square approximation was used to calculate the p-value (Schumacker 2015). Post-hoc analyses were also conducted on significant groupings using pairwise Wilcoxon-Mann-Whitney tests with a Bonferroni adjustment. Since there were multiple comparisons in this data set, the Bonferroni adjustment kept the Type 1 error probability controlled. All analyses were done using R, which is an open-source statistical program (R Development Core Team 2011).

4 RESULTS AND DISCUSSION

From 204 projects, 124 projects provided information about recordable accidents with a range of 62 and median of 1. Fifty-two percent of projects had at least one recordable accidents. These results indicate that, on average, safety performance of projects in the database was higher than the industry average. As mentioned earlier, in the questionnaire, several questions were asked related to independent variables such as project organization, team integration, and using emerging processes and technologies. The recordable incidents per square foot of a building for each of these independent variables are calculated and summarized in Table 1.

The results of the correlation analysis are summarized in Table 2. As is shown, only unit cost, project delivery speed, and construction delivery speed are significantly correlated with safety performance measures. This can be justified by considering that safety performance was calculated by dividing the number of accidents by area of the building; unit cost, project delivery speed, and construction delivery speed are also related to the total area of the building. Another project performance metric that is marginally correlated to the safety performance is construction cost growth.
Table 1: The recordable accident per square foot of a building for each independent variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Data</td>
<td>1.230</td>
<td>1.776</td>
<td>124</td>
</tr>
</tbody>
</table>

**Project Complexity**
- Likert value 1-4: 1.058, 1.996, 41
- Likert value 5: 1.068, 1.387, 41
- Likert value 6: 2.241, 1.929, 23

**Delivery Method**
- CM at risk: 1.320, 1.466, 43
- Design-bid-build: 0.507, 1.254, 25
- Design-build: 1.433, 2.112, 54
- IPD: 2.821, 1.606, 2

**Time of Builder Involvement**
- Pre-design: 1.022, 1.741, 45
- Conceptual: 1.927, 2.186, 27
- Schematic: 1.388, 1.452, 14
- Development: 2.513, 2.087, 5
- Documents: 0.880, 1.176, 10
- Bidding: 0.594, 1.329, 23

**Time of Mechanical, Electrical, and Plumbing (MEP) Contractor Involvement**
- Pre-design: 0.738, 0.942, 12
- Conceptual: 2.007, 2.339, 11
- Schematic: 1.859, 1.827, 15
- Development: 1.732, 2.109, 12
- Documents: 1.220, 1.259, 18
- Bidding: 0.944, 1.778, 48

**Time of Structural Contractor Involvement**
- Pre-design: 0.496, 0.653, 12
- Conceptual: 1.093, 1.757, 11
- Schematic: 1.596, 1.598, 9
- Development: 1.943, 1.919, 14
- Documents: 1.547, 1.603, 16
- Bidding: 1.158, 1.937, 54

**Team Integration**

**Using Partnering**
- Yes: 1.244, 1.732, 32
- No: 1.224, 1.800, 92

**Builder Participated in Co-Location**
- Yes: 1.588, 1.771, 19
- No: 1.083, 1.766, 61

**MEP Contractor Participated in Co-Location**
- Yes: 1.920, 1.842, 9
- No: 1.064, 1.728, 71

**Structural Contractor Participated in Co-Location**
- Yes: 1.916, 1.875, 6
- No: 1.081, 1.727, 74

**Builder Participated in Goal Setting**
- Yes: 1.447, 1.895, 92
- No: 0.629, 1.243, 28

**Emerging Proc. & Tech.**

**Using BIM in a Project**
- Yes: 1.516, 1.874, 90
- No: 0.472, 1.209, 34

**Using Prefabrication in a Project**
- Low: 1.037, 1.747, 62
- High: 1.441, 1.817, 59

**Using Lean Scheduling Tools in a Project**
- Yes: 2.078, 2.100, 20
- No: 1.137, 1.669, 104
Table 2: Correlation between recordable accidents per square foot of area and other success measures

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correlation</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Cost Growth (%)</td>
<td>-0.055</td>
<td>0.557</td>
</tr>
<tr>
<td>Project Schedule Growth (%)</td>
<td>-0.044</td>
<td>0.627</td>
</tr>
<tr>
<td>Construction Cost Growth (%)</td>
<td>0.180</td>
<td>0.064</td>
</tr>
<tr>
<td>Construction Schedule Growth (%)</td>
<td>-0.004</td>
<td>0.973</td>
</tr>
<tr>
<td>Unit Cost (log)</td>
<td>0.314</td>
<td>0.001</td>
</tr>
<tr>
<td>Project Delivery Speed (sf/month of project duration; log)</td>
<td>0.298</td>
<td>0.008</td>
</tr>
<tr>
<td>Construction Delivery Speed (sf/month of construction duration; log)</td>
<td>0.259</td>
<td>0.004</td>
</tr>
</tbody>
</table>

According to the results, the project complexity has a statistically significant impact on safety performance. This is understandable since in more complex projects, contractors might have to use unfamiliar means and methods that expose workers to unknown hazards. The post hoc analysis revealed that very complex projects (Likert value=6) have lower safety performance than projects with medium (Likert value=5, p-value=0.005) and low complexity (Likert value=1~4, p-value=0.037).

Table 3: Group comparison between independent variables using Kruskal-Wallis test

<table>
<thead>
<tr>
<th>Grouping variable</th>
<th>Test stat (chi-square)</th>
<th>p-value</th>
<th>DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Complexity</td>
<td>15.56</td>
<td>0.001</td>
<td>3</td>
</tr>
<tr>
<td>Delivery Methods</td>
<td>9.75</td>
<td>0.021</td>
<td>3</td>
</tr>
<tr>
<td>Time of Builder Involvement</td>
<td>12.95</td>
<td>0.024</td>
<td>5</td>
</tr>
<tr>
<td>MEP Contractor Participated in Co-Location</td>
<td>6.84</td>
<td>0.009</td>
<td>1</td>
</tr>
<tr>
<td>Struct. Contractor Participated in Co-Location</td>
<td>5.49</td>
<td>0.019</td>
<td>1</td>
</tr>
<tr>
<td>Using BIM in a Project</td>
<td>13.58</td>
<td>0.000</td>
<td>1</td>
</tr>
<tr>
<td>Using Lean Scheduling Tools in Project</td>
<td>5.12</td>
<td>0.024</td>
<td>1</td>
</tr>
</tbody>
</table>

As far as project organization is concerned, the type of delivery method and time of builder involvement in a project design had significant impacts on safety performance. The post hoc analysis showed that projects delivered by design-bid-build method had a better safety performance than projects delivered by construction manager-at-risk (p-value=0.032). This is a surprise finding as it is a common belief that constructability input provided by a CMR agent in design phase can have a positive impact on safety performance. To understand the underlying reasons for such a difference, one needs to conduct follow up interviews with project personnel. Conducting post hoc analysis for the time of builder involvement showed marginally significant difference between the safety performances of projects that the builder involved in design development phase versus projects that the builder involved in bidding phase (p-value=0.096). Because the number of projects in which the builders were involved in design development phase was only five and the results of Wilcox-Mann-Whitney test was marginally significant, the research team believes that the time of builder involvement should not be considered as a significant factor.

Although previous studies indicated that BIM can help to improve safety performance, the results of the study show that projects that did not use BIM had better safety performance. There are several other confounding factors that might have contributed to this finding. Empirical evidence provided in this study encourages further analysis to objectively measure impact of using various BIM functions on safety performance. Previous studies also claimed that using lean tools has a positive impact on safety performance; however, the findings of the current study imply that projects that used lean scheduling tools had more accident per square foot of a building (2.078) than projects that did not use any lean tools.
Further analysis of database revealed that projects that use lean tools, on average, had larger square foot area (335,431 SF) than the ones that did not use lean tools (151,457 SF). As discussed earlier, square foot area of a building plays a significant role in determining number of accidents.

The results of the study indicated that co-location of MEP and structural subcontractors have a significant impact on safety performance of projects; however, the post hoc analysis did not show any significant difference. The statistical analysis of results also could not find any significant relationship between safety performance and following independent variables: time of involvement of MEP and structural subcontractors; using partnering; builder participated in co-location; builder participated in goal setting; and using prefabrication in a project.

5 CONCLUSION

This study assessed the factors contributing to safety performance by looking at project integration measures. The safety performance was defined as the recordable incidents per square foot of a building and several independent variables were considered related to project organization, team integration, and using emerging processes and technologies. The study has practical implications for both academia and practice. The large database of 204 building projects created in this study can be used to answer numerous questions defined by academia and the results of the study can also provide empirical evidence for both owners and contractors to understand the impact of their early decisions regarding project integration on safety performance.

While this study is unique in its kind and provides significant contributions to the body of knowledge, there are several limitations that need to be addressed in future studies. First, one of the limitations of the current study is to use lagging indicators (e.g., number of accidents) as safety performance metrics. One should note that recordable and lost time work incidents are rare events in projects and do not capture unsafe behaviors that do not lead to an incident. Further studies should be conducted to explore the impact of project delivery decisions on leading indicators such as near-misses. Second, we could not collect the number of worker-hours in projects, which inhibited us from calculating some of the standard safety measures such as total recordable incidence rate (TRIR) and days away, restricted or transferred (DART). Future studies should be conducted to address this limitation. Third, most of the independent variables in this study were simplified so we could measure them using a Likert scale. For example, complexity has several definitions in the construction industry and future studies should be conducted to investigate the relationship between complexity in design and construction activities and safety performance. Finally, as safety performance depends on people, more qualitative studies should be conducted to understand the drivers of unsafe behavior in worksites. Nevertheless, the research reported in this paper is a pioneer study in establishing the relationship between safety performance and independent variables that define integrated projects.

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