A Critical Review of Methods Used to Determine Productivity of Mechanical, Electrical, and Plumbing Systems Coordination

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ABSTRACT

Mechanical, Electrical, and Plumbing (MEP) systems coordination is a process during the pre-construction phase through which the proposed location and route of each system components are specified. The MEP coordination process has significantly changed due to utilization of Building Information Modeling (BIM). There is a gap in knowledge regarding productivity measurement of MEP coordination team. Moreover, there is a need for research to enhance our understanding about important factors affecting productivity of MEP coordination. The main objectives of this research are: (i) to document approaches for conducting MEP coordination using BIM, (ii) to identify metrics for measuring productivity of MEP coordination; and (iii) to identify factors affecting MEP coordination productivity. A questionnaire survey was conducted to achieve these objectives. The survey show that the most frequently used metric for conducting MEP coordination using BIM is square feet of coordinated area per total coordination hour. Moreover, experience level of MEP coordination team members is the top factor that significantly affects MEP coordination productivity. The findings of this study indicate that construction industry lacks a systematic procedure to record information to track, measure, and compare MEP coordination productivity across different coordination projects.

INTRODUCTION

Mechanical, Electrical, and Plumbing (MEP) systems coordination is a challenging task during the pre-construction phase of complex building projects (Riley et al. 2001; Korman 2009). In general, coordination is conducted after engineers complete MEP systems design including equipment requirements, system components’ location, and component routes in the building (Korman and Tatum 2001). After completing the designs, the coordination process begins by holding meetings between the representatives of the general contractor and specialty trades (e.g., HVAC dry, HVAC wet, plumbing, fire protection). Through these meetings, the 2D drawings of different MEP systems, developed by engineers, are sequentially compared and overlaid on a light table to detect spatial conflicts and interferences. To
avoid these interferences, MEP systems components are re-routed or relocated. Moreover, the coordination process might also result in the structural and architectural design modifications. Finally, upon the completion of coordination, specialty trades prepare shop drawings that are later used to fabricate different systems’ components. This process is manual, error-prone, time-consuming, expensive, and is perceived as one of the major challenges in the delivery process for construction projects (Tatum and Korman 2000).

MEP coordination process has changed by the utilization of BIM tools in design processes (Korman et al. 2008). Korman stated that three-dimensional building models enable engineers and constructors to visualize the size, location, and routing of different MEP systems. Moreover, software integration tools such as NavisWorks provide a platform to merge the 3D models into one common model and conduct automated clash detection. Automated clash detection not only expedites detection of physical interferences, but also increases the precision of coordination task. In addition to the effects utilization of BIM technology has on the MEP work coordination processes, it also has significantly magnified the benefits of conducting coordination prior to construction. Increased design and field productivity are some of the reported benefits of the use of BIM tools in coordination (Staub-French and Khanzode 2007; Khanzode et al. 2008; Hartmann et al. 2008). These studies mostly investigated the engineering productivity gain considering design process in its entirety. However, little research has been reported that particularly discuss productivity analysis of MEP coordination.

There is little literature on documentation of the different MEP coordination using BIM technology. There are legitimate questions regarding the difference of the current coordination approaches in term of their means and methods. There is a need to identify the metrics construction firms use to measure the productivity of their coordination teams. There is also additional need to identify major factors that affect the productivity of coordination efforts. This study was initiated with the goal of enhancing the existing knowledge regarding productivity analysis of MEP coordination. The objectives of this study were: (I) to document current approaches of conducting MEP coordination using BIM technology (II) to identify the metrics companies use to measure productivity of their MEP coordination teams (III) to identify the information items companies collect to monitor the coordination process (IV) to identify factors that affect MEP coordination productivity. This research project contributes to the body of knowledge in engineering design productivity through identification of major factors affecting MEP coordination and metrics used to measure productivity of MEP coordination. In addition, this research contributes to the state of practice through providing information needed to establish a systematic procedure to track, measure, and compare MEP coordination productivity across different construction projects.

**DESIGN PRODUCTIVITY**

MEP coordination is a task that is conducted as a part of engineering design process of construction projects. Thus, MEP coordination productivity analysis should be conducted in accordance to principals of engineering productivity studies. Different studies have been conducted concerning engineering and design
productivity. Productivity metrics suggested by the studies can be categorized as follows:

- **Design hours per construction document**: metrics that consider design hours as input and construction documents (e.g., drawings, specifications, contract forms) as output.
- **Design hours per installed/built quantities**: metrics that consider design hours as input and installed/built quantities (e.g., number of installed equipment, concrete volume, building floor area) as output.
- **Normalized design hours**: Metrics that consider design hours as input and are normalized through dividing the input by basis design hours.

A summary of the existing literature on engineering productivity is presented in this section. In addition, the metrics that are used to measure engineering productivity are further discussed.

**Design Hours per Construction Documents**

Thomas et al. (1999) developed a model to measure engineering and design productivity during the contract documents phase. Thomas et al. considered construction documents (e.g., drawings, specifications, contract forms) as design outputs; Accordingly, productivity unit rates were defined as design work hours per drawing sheet, design work hours per specification section, and design work hours per each contract documents. Chang and Ibbs (2006) also used design work hours per drawing sheet unit rate in a study to find the major factor that affect design productivity. Productivity metrics that consider construction documents as the tangible outputs of design require less effort to estimate design productivity. However, consideration of tangible construction documents as the outputs is arguable since the real output of engineering firms is the design information; construction documents are the means to convey this information to other project stakeholders and are not the actual outputs. Moreover, the described metrics do not take project characteristics into account. Therefore, these metrics can only be used to compare projects with similar characteristics.

**Design Hours per Installed/Built Quantities**:

Construction Industry Institute (CII) (2001) conducted an extensive study to define industry standard metrics to measure engineering productivity. Through this study, a framework to measure productivity in ten different engineering disciplines was developed. Application of this framework was also illustrated by conducting productivity analysis in piping industry. This framework was later modified and improved in another CII’s supported project to benchmark engineering productivity (Kim 2007). Both studies incorporate the effects of project characteristics and design quality in developing proper engineering productivity metrics. Consequently, the developed metrics can be used to compare engineering productivity across different projects. Another example of considering installed/built quantities as the outputs of engineering is a study conducted by Sacks and Barak (2008) to quantify the impact of 3D parametric modeling on productivity in structural engineering practice. Sacks and Barak deemed total volume of concrete and gross floor area as output measures of structural engineering practices. Unlike the approach discussed in the previous...
section, these studies measure the output of engineering practices using installed/built quantities.

**Normalized Design Hours**

CII (2004) conducted a study in continuation of its efforts to establish consistent standards to measure engineering productivity. To measure engineering productivity, the study proposed “productivity index” that is calculated by dividing actual design hours by “basis hours”. Basis hours can be predicted using regression models developed for different engineering discipline. The models were developed based on design component quantity data. The advantage of this approach is that productivity index can be used to compare engineering productivity not only across different projects, but also across different engineering disciplines. However, the predictive regression models have large estimation errors and are therefore unreliable (Kim 2007).

An important observation is that the information items that were collected vary based on the metrics used to calculate engineering productivity. Table 1 shows a summary of these metrics and corresponding information items for different studies. Overall, studies that use number of construction documents to measure design output require information items that can be simply obtained. While, more detailed information should be collected to estimate engineering productivity if productivity is measured by considering construction quantities as design output. Unlike engineering productivity, MEP coordination productivity analysis has received limited attention in the existing body of literature. The presented study is part of a larger effort in progress at the Georgia Institute of Technology to define proper metrics to measure MEP coordination productivity considering major affecting factors. This paper presents results of a survey conducted among construction industry professional to document MEP coordination approaches, identify metrics that are used to measure MEP coordination productivity, and identify major factors that affect productivity of MEP coordination teams.

**SURVEY OF INDUSTRY PROFESSIONALS**

In order to fulfill the objectives of this study, a questionnaire survey was conducted among construction industry professionals. The questionnaire was designed in two parts based on a wide scope review of existing literature. The first part collected respondent’s information such as respondent’s role in the company, company name, and company type. The second part focused on obtaining information regarding the means and methods of conducting MEP coordination using BIM, and MEP coordination productivity measurement. The questionnaire was sent out in summer 2013 to a total of 72 construction industry professional with experience in MEP coordination. A summary of survey results is presented in the following section.

**DISCUSSION OF SURVEY RESULTS**

Forty-five complete responses from 28 different companies were received. Thirty-five respondents were BIM/VDC managers and the rest consisted of coordinators, project managers, and owners. Figure 1 shows the count of respondents
based on their company types. The majority of respondents were contractors, which was expected since general contractors and specialty trades are usually responsible for coordination.

![Figure 1. Count of respondents based on company](image)

In the second part of the questionnaire, respondents were asked to answer nine questions regarding the means and methods of conducting MEP coordination using BIM and MEP coordination productivity measurement. The results obtained from each question are discussed in the rest of this section.

1. Utilization Frequency of Different MEP Coordination Approaches

The respondents were asked to specify, on a scale of one (never) to four (often), how frequently they observe the use of different coordination approaches by their firms. Six specific MEP coordination approaches were defined and provided in the questionnaire:

- **Regular coordination:** All trades conduct four days of drafting and one day of coordination per week.
- **Parallel coordination:** Multiple coordination teams conduct coordination simultaneously on different zones of the project.
- **Coordination meetings as needed:** All trades draft separately and coordination meetings will be scheduled when needed.
- **Remote coordination:** Team members remotely attend coordination meetings.
- **Coordination conducted by specialty trades:** General contractor transfers responsibility of conducting coordination to specialty trades.
- **Cloud computing-based coordination:** Coordination is conducted using cloud-computing technologies.

In addition, respondents were asked to indicate whether they have seen any other coordination approaches. Figure 2 shows the average usage frequency of the defined coordination approaches. It is shown that remote coordination and regular coordination are the two most commonly used approaches for MEP coordination. One respondent specified another coordination approach called “Staging Coordination”. In this approach, coordination is scheduled in a way that only one trade works in an area at a time. Next trade starts working on the area when the first trade is finished. Coordination of each area starts with trades with “the least movable items” and then other trades model around those who modeled before. After all trades finish modeling major pieces, the coordination process continues through regular meetings. Some respondents specified that in “fast-track projects” collocation of trades meet in one location and conduct modeling and coordination simultaneously.
Table 1. Metrics and Collected Information Items Used to Measure Design Productivity

<table>
<thead>
<tr>
<th>Information Items</th>
<th>Productivity Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Hours</td>
<td>✓</td>
</tr>
<tr>
<td>Number of Drawings</td>
<td>✓</td>
</tr>
<tr>
<td>Number of Contractual Documents</td>
<td>✓</td>
</tr>
<tr>
<td>Project Size</td>
<td>✓</td>
</tr>
<tr>
<td>Project Type</td>
<td>✓</td>
</tr>
<tr>
<td>Project Cost</td>
<td>✓</td>
</tr>
<tr>
<td>Client/Owner</td>
<td>✓</td>
</tr>
<tr>
<td>Number of Installed Pieces</td>
<td>✓</td>
</tr>
<tr>
<td>Volume of Structural Concrete</td>
<td>✓</td>
</tr>
<tr>
<td>Project Delivery System</td>
<td>✓</td>
</tr>
<tr>
<td>Project Profit</td>
<td>✓</td>
</tr>
<tr>
<td>QA/QC</td>
<td>✓</td>
</tr>
</tbody>
</table>

* “Direct Work Hours” or “Direct Design Hours” refers to the work hours associated with activities such as deliverable production, site investigations, meetings, and engineering rework; indirect engineering work hours, such as document control and quality management, are excluded from productivity calculation.

**“Basis hours” were calculated using regression models for each design discipline.
2. Involvement of Trades in Coordination Process

Thirty-two respondents indicated that all trades are involved from the beginning to the end of coordination. One respondent specified the following order for trade involvement: 1) HVAC wet, 2) HVAC dry, 3) electrical, 4) plumbing, 5) fire protection. Another respondent stated a different order: 1) HVAC wet, 2) HVAC dry, 3) Plumbing, 4) Fire Protection, 5) Electrical.

3. Numbers and Titles of Personnel Assigned to Coordination by General Contractor and Trades

Respondents indicated that in the majority of projects only one personnel is assigned to coordination by the general contractor and each trade. The following are the top three personnel titles that were reported:

- **General Contractor**: BIM coordinator, BIM manager, BIM engineer
- **HVAC Dry**: drafter, detailer, BIM coordinator
- **HVAC Wet**: drafter, detailer, BIM coordinator
- **Plumbing**: drafter, detailer, BIM coordinator
- **Electrical**: drafter, detailer, BIM coordinator
- **Fire Protection**: drafter, detailer, BIM coordinator, designer, MEP engineer

4. Software Packages Used by Coordination Teams

According to survey results, NavisWorks, AutoCAD, Revit, and Tekla are the top four software packages that coordination teams use. Synchro, BIM 360 Glue, Pneumatic Tube, BlueBIM, and PD3D are among other software packages that were mentioned by respondent.

5. Metrics Construction Firms Use to Measure Productivity of MEP Coordination

Fifteen out of 45 respondents indicated that their firms do not measure MEP coordination productivity. The top five metrics are as follows (the numbers in parentheses show the number of companies that use the corresponding metric):

1. Coordination hours/SF of building zones (3)
2. SF coordinated/number of meetings (2)
3. Coordination hours/number of coordinated discipline components (1)
4. SF coordinated/coordination hours/trades (1)
5. Clashes/1000 SF of building area (1)

6. Separate Productivity Measurement for Each Trade

Twenty-three out of 45 respondents specified that their firms measure coordination productivity separately for different trades. One respondent stated that his firm estimates trades’ coordination productivity based on reduced labor and fabrication times. Another respondent indicated “we track the clash batches between trades to assign fixes and look at productivity”.

![Figure 2. Average usage frequency of defined MEP coordination approaches](image-url)
7. Trade Rankings Based on the Time It Takes to Coordinate

Respondents were asked to rank trades in terms of the time it takes them to coordinate. They were also asked to specify which trades have been perceived as the bottlenecks of MEP coordination. Respondents were allowed to choose more than one answer. Figure 3 shows the results. It is shown that HVAC dry is the most time consuming trade in MEP coordination process. An important observation is that although fire protection is the fastest trade to coordinate, it ranked second among trades perceived as bottleneck of coordination process.

8. Information Items Collected to Monitor MEP Coordination Progress

Twenty-six respondents specified their firms monitor MEP coordination progress. Figure 4 shows the results. Number of clashes resolved in each meeting, BIM competency of team members, number of trades attending meetings, experience level of team members, and number of clashes resolved in each meeting per trade are among the information items that are more commonly collected. “Number of drawings” is another information item mentioned by one of the respondents.

9. Major Factors that Affect MEP Coordination Productivity

Thirteen factors that could possibly affect MEP coordination productivity were identified through literature review. Respondents were asked to specify the impact of these factors on a scale of one to four. Figure 5 shows the rankings of these factors according to survey results. It is shown that coordination team experience level, preliminary design quality, and project schedule are the major factors that affect productivity of MEP coordination.
CONCLUSIONS

This study was initiated with the goal of enhancing the existing knowledge regarding productivity analysis of MEP coordination. The objectives of this study were to identify the metrics companies use to measure productivity of their MEP coordination teams and identify factors that affect MEP coordination productivity. In order to fulfill the objectives of this study, a questionnaire survey was conducted among construction industry professionals with experience in MEP coordination. The survey results indicate that “remote coordination” and “regular coordination” are the top two most common approaches of conducting coordination. Coordination team experience level, preliminary design quality, and project schedule were identified as the top three major factors that affect MEP coordination productivity. It was shown that there is no established metric to measure MEP coordination productivity across construction industry. Moreover, construction companies do not have a systematic procedure to record information to track and measure MEP coordination productivity.

This research contributes to the body of knowledge in engineering design productivity through identification of metrics companies use to measure MEP coordination productivity and major factors that affect it. In addition, this study contributes to the state of practice through identifying information needed to establish a systematic procedure to measure, track, and compare MEP coordination productivity across different construction projects. This research makes step toward acquiring a better understanding of MEP coordination productivity measurement; however, more research is necessary to quantitatively investigate the relationship between MEP coordination productivity and factors that affect it. Moreover, development of a methodic approach to measure and benchmark MEP coordination productivity is recommended for future studies.

ACKNOWLEDGEMENT

The writers thank Professor Charles M. Eastman, who leads Digital Building Laboratory (DBL) at the Georgia Institute of Technology, for supporting this research project. In addition, we are grateful to Turner Construction Company, in particular Mr. James P Barrett, Ms. Jennifer Downey, Mr. Pushkar Mahabaleshwarkar, Mr. Omar Martinez, and Mr. Chad C Bacote who kindly helped us throughout the progress of this study.
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