PREDICTIVE MODELING OF PREFABRICATION FEASIBILITY FOR THE UNITED STATES ELECTRICAL CONTRACTING FIRMS

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Abstract: Electrical contractors have promoted offsite prefabrication after experiencing its potential in improving their operations. However, prefabrication is not a one solution that fits all. Accordingly, there is a need to develop better understanding of prefabrication feasibility for electrical contractors by analyzing its operational requirements and surrounding industry factors. The objective of this paper is to identify and model the determinants of electrical contractors' prefabrication feasibility within the U.S. industry context, which can be used to predict the viability of prefabrication as a production approach for individual electrical contracting firms. The methodology of this study included four main phases. First, a qualitative analysis was performed to initially understand current prefabrication operations and practices of electrical contractors through a set of semi-structured interviews, site visits of prefabrication facilities, and prefabrication case studies. Second, a quantitative data collection task was performed by: 1) acquiring the internal business variables of a sample of electrical contractors using an online questionnaire; 2) complementing the questionnaire data with location-based economic data to represent external industry-related variables. Third, the collected data was used to develop and validate a binary logistic regression model that relates the prefabrication feasibility to its significant determinants. Fourth, a sensitivity analysis was performed for the developed model to provide a larger understanding of electrical construction prefabrication feasibility beyond the collected data. The developed predictive model provides useful insights about prefabrication feasibility dependency on union relations, labor conditions, market competition, supply chain relations, and building information modeling.

1 INTRODUCTION

Offsite prefabrication has been practiced in the construction industry for decades due to its clear benefits in reducing project duration and cost. Offsite prefabrication was identified as one of promising breakthroughs that can greatly improve the productivity of the construction industry (NRC 2009). Prefabrication can be applied with different extents for the typical systems and components of building projects. Building electrical systems provide great prefabrication opportunities due to their modular decomposition into standardized components and subsystems. For example, electrical systems are typically decomposed into panels, ducts, cables, receptacles, and rough-in supports. Due to their standardized modular structure, electrical and mechanical systems were reported to be as the most building components that can be constructed using offsite prefabrication operations (MHC 2012).
Electrical construction has been the subject of several previous research studies, but with little attention to prefabrication. Previous electrical construction research included: 1) schedule coordination between mechanical, electrical, and plumping (MEP) trades (Korman et al. 2003, Hormann et al. 2006); 2) management of contract changes by electrical contractors (Hanna et al. 2004); 3) utilization of Building Information Modeling (BIM) in electrical construction (Khanzode et al. 2008, Hanna et al. 2014); 4) design-build considerations for electrical contractors (EC) (Rowings 2000); and 5) financial analysis of electrical contractors (Jaselskis et al. 2002). Few research studies were performed to analyze prefabrication practices of electrical contractors. First, Bogus et al. (2009) performed an industry study to identify the best practices of electrical construction prefabrication, through observing the prefabrication facilities of a sample of electrical contractors. Second, Mikhail (2014) performed a survey-based study of prefabrication practices of electrical contractors. The major findings of this study include: 1) the use of electrical prefabrication has increased by 9% over the period 2004 – 2014; 2) the majority of survey respondents still limit their prefab operations between 1% – 9% of their work volume (measured in labor hours); 3) electrical contractors experienced cost reductions in 97% of their projects; and 4) electrical prefabrication helped to achieve time savings in 94% of the projects.

The findings of the previous research studies documented the best practices and benefits of prefabrication, but did not analyze its determinants to be a feasible production approach for electrical contractors. Prefabrication is not a one solution that fits all electrical contractors, and its successful implementation is dependent on internal and external factors that influence its economic feasibility. A previous study (Mikhail 2014) investigated the internal and external drivers/impediments of electrical construction prefabrication. However, there is no quantitative tool that can predict for electrical contractors the feasibility of adopting prefabrication operations considering firm’s internal and external variables.

2 RESEARCH OBJECTIVE AND METHODOLOGY

The objective of this paper is to develop a data-driven predictive model of prefabrication feasibility of electrical contractors. To achieve this objective, the research methodology included four main phases. First, qualitative data of electrical construction was collected by interviewing industry professionals, visiting prefabrication facilities, and acquiring case studies of prefabrication work. Second, electrical construction prefabrication was qualitatively analyzed by interviewing a sample of electrical contractors, visiting their prefabrication facilities, and collecting case studies of prefabrication assemblies and projects. Third, the collected data is used to develop and validate a logistic regression predictive model of prefabrication feasibility that considers electrical contractor’s internal and external attributes. Fourth, the behavior of the proposed system is evaluated using multi-variable sensitivity analysis to better understand the impact of the model’s selected variables on the prediction of prefabrication feasibility.

3 QUALITATIVE ANALYSIS OF ELECTRICAL PREFABRICATION

Qualitative analysis of electrical construction prefabrication was performed using interviews, site visits, and case studies to obtain an in-depth understanding of prefabrication operations and drivers. The outcome of the qualitative analysis is the development of initial list of potential drivers/determinants of electrical prefabrication feasibility that will be considered in the next phase of collecting their quantitative values and developing the predictive model. The qualitative analysis was facilitated by a taskforce of electrical construction professional, which was formed by ELECTRI International Foundation to support this research study.

First, the taskforce members and other industry professionals were interviewed in a semi-structural setting to answer a set of open-ended questions (Patton 2002) about the impact of project supply chain stakeholders (designer, general contractor, vendor, manufacturer) on electrical construction prefabrication; as well as the impact of firm’s external environment on its prefabrication operations (i.e. union relations, labour hourly rates, etc.). The interviews were performed with 7 operation managers of different electrical construction companies, 1 vendor representative, 3 manufacturer sale managers and 1 executive director of a local chapter of the National Electrical Contractors Association (NECA). Second, the prefabrication facilities of a large and small electrical contractor were visited to observe on the ground their operations and document the interfaces between the facility, site work, and vendors. Third, case
studies were collected for electrical prefabrication coordination in construction projects, layout and equipment of prefabrication facilities, and samples of prefabricated electrical assemblies.

4 QUANTITATIVE DATA COLLECTION

Considering the observations and findings of the previous phase, prefabrication-related internal and external quantitative data of a sample of electrical contractors was collected using web-based questionnaire and available online governmental economic databases.

4.1 Web-based Questionnaire

A web-based questionnaire was designed and disseminated to NECA’s electrical contractors with the objective of identifying the level of their prefabrication operations, firm business attributes, and external industry parameters. The questionnaire included 26 questions, including the following that were utilized in this study:

1) Which of the following percentages represent the prefab facility contribution to the total work volume? (N/A, <5%, 5%-10%, 10%-20%, 20%-40%, >40%)
2) What is the annual volume of your work? ($<5M, $5M-$10M, $10M-$50M, $50M-$100M, $100M-$200M, >$200M)
3) What is the zip code of your FARTHEST project?
4) Which of the following services are provided by your company? (Engineering, BIM, Prefab, Maintenance)
5) Which of the following lean principles do you apply in your operations (either onsite or offsite)? (Last Planner System, Look-ahead schedules, Kanban, Value Stream Mapping, Kaizen, 5 S’s, none.)
6) Do you have a vendor partnership in place? (Yes, No.)
7) Which of the following value-added services have you obtained from your vendor(s)? (provided 11 possible services, like Managing material/tools inventory, Using vendor warehouse to store in-transit assemblies/material deliveries, material Packaging/kitting, and others)
8) How do you classify your vendor/distributor? (Local 1 state, Regional 4 states, National 10 states)
9) How frequent did you have your vendor involved early in an Integrated Project Delivery (IPD) setting? (>50%, 30%-50%, 10%-30%, <10%, Never)
10) Select from the following list the manufacturer’s services/programs that your firm used before, if any. (Training workshops, Products customization, Custom Packaging, Materials Logistics.)
11) What is the zip code of your main office?
12) In your opinion, how much flexibility do current electrical specification writers provide for electrical contractors to perform offsite work and achieve construction industrialization? (Very flexible, Flexible, No effect, Inflexible, Very inflexible)
13) How much resistance did/would your company experience with IBEW local for offsite work in your current/future prefab facility? (High resistance, Moderate resistance, Neutral, Encouraging, Very encouraging)
14) How much resistance did/would your company experience with IBEW local for outsourcing prefab work to either vendors or manufacturers? (same answer options of question 13)

The first question was used to identify the existence and size of the electrical contractor prefabrication operations. The second to the tenth questions were designed to collect firm-related business information related to the geographic spread of the company, type of services, adoption of lean principles, and supply chain relations with vendors and manufacturers. The last four questions (11 to 14) were included to collect relevant external industry-related attributes, such as the contractor location, union resistance to prefabrication, and flexibility of design and code requirements to prefabrication. The zip code is used to retrieve other industry economic data through available federal online databases, as explained later in section 4.2.

After a 5-month period of questionnaire online dissemination, 78 valid responses were received on a voluntary basis from a diverse sample of electrical contractors. The questionnaire was disseminated through NECA’s email list that included 2925 electrical contracting firms. 78 valid responses were
received with a response rate of 2.7%, which is similar to other previous study surveys that are based on voluntary participation (Galloway 2006, Rasdorf et al. 2010). There is no reliable source to identify the total population of electrical contractors and its ratio to the collected sample. As shown in Figure 1, the questionnaire sample is considered to be diverse and representative of the electrical construction industry. First, the sampled contractors are geographically dispersed as the responses were received from 32 states. Second, the sample included electrical contractors of diverse backgrounds in terms of company size (measured in work volume) and amount of prefabrication. For example, 54% of the respondents perform prefabrication with varying capacities (between 5% to 40% of the total work volume), which closely matches a recent industry survey (FMI 2013).

4.2 Industry Economic Data

The data of each questionnaire response was complementing by retrieving the values of its location-based industry economic attributes from available online federal databases. As shown in Figure 2, online databases of the U.S. Census Bureau (USCB) and Bureau of Labor Statistics (USBLS) were used to retrieve the local industry economic data of every response in two main steps. First, the zip code value of the response (provided in the eleventh question of the questionnaire) is used to identify the county of the electrical contractor and then its metropolitan area. It is proposed here that the economic metrics of the larger metropolitan areas are more accurate regional indicators of the industry-related determinants of electrical contractor prefabrication feasibility, compared to the localized metrics in the city or county levels. Second, the identified metropolitan area is used to retrieve the following data from the online databases: 1) the unemployment rate from the USBLS local area unemployment statistics (LAUS) database (USBLS 2014-a); 2) the number, total annual payroll, and average employees of electrical construction firms in the metropolitan area, which are retrieved from the USCB’s County and Metropolitan Areas Business Patterns database (USCB 2014-b); and 3) the number and average hourly wage of electricians in the metropolitan area, which are obtained from USBLS’s Occupational Employment Statistics (OES) database (USBLS 2014-b).
The collected economic data was utilized as indicators of the demand for construction projects, industry competition, and supply of electrical workers. Unemployment rate was proposed as indicator of the economic growth and demand for construction services around electrical contractors. Economic data of electrical contracting firms (number, total payroll and average number of employees) was used to gauge the size and level of competition around the electrical contractor. Finally, electricians’ occupational data (number and hourly wage) was used to indicate the supply and demand of electrical construction workforce. All these industry parameters (construction demand, competition, labor availability) were proposed based on the performed qualitative analysis of electrical construction prefabrication and suggestions of the study taskforce.

5 DEVELOPMENT AND VALIDATION OF PREFABRICATION FEASIBILITY BINARY LOGISTIC MODEL

Logistic binary regression analysis was utilized to model the dependency of electrical construction prefabrication feasibility on its firm-related and industry-related determinants. As shown in Equation 1, prefabrication feasibility \( PF \) is modeled as a binary dichotomous variable (Tung 1985, Kleinbaum 1994) that can be one of either values: 1 (true, meaning that prefabrication is a viable operations approach for the electrical contractor) or 0 (false, meaning that there are no enough drivers to justify the feasibility of performing prefabrication operations). The \( PF \) value is determined based on the prefabrication feasibility probability \( p \) that ranges between 0 and 1. As shown in Equation 1, prefabrication feasibility is declared \( (PF = 1) \) if \( p \) is less than a threshold value of 0.5 (as suggested by previous studies, Cheung et al. 2010, Moon et al. 2011), and is declared infeasible \( (PF = 0) \) if \( p \) is more than or equal to 0.5. As shown in Equation 2, prefabrication feasibility probability \( p \) has an exponential relation with its determinants \( X_1 \) to \( X_n \). A determinate \( X_i \) will be a driver of the prefabrication feasibility (i.e. increasing its probability \( p \)) if its coefficient \( C_i \) is found to be positive. Otherwise, a determinant will be impediment to prefabrication feasibility with a negative coefficient. In order to estimate these coefficients using linear regression techniques, the prefabrication feasibility probability is transformed into its logit value and with a linear relation with its determinants, as shown in Equation 3. The logit function facilitates transforming the prefabrication feasibility probability \( p \) (with exponential values between 0 and 1) into a linear variable that ranges between \(-\infty\) and \(+\infty\) (Kleinbaum 1994).

\[
P_F = \begin{cases} 
0 & \text{if } p < 0.5 \\
1 & \text{if } p \geq 0.5 
\end{cases}
\]

\[
p = \frac{1}{1 + e^{-(C_0 + C_1 X_1 + C_2 X_2 + \ldots + C_n X_n)}}
\]

\[
\text{logit}(p) = \ln\left(\frac{p}{1-p}\right) = C_0 + C_1 X_1 + C_2 X_2 + \ldots + C_n X_n
\]

Twenty electrical prefabrication determinants were initially considered in the development of the logistic regression model, based on the performed qualitative analysis and collected data. The initially considered determinants included 11 firm-related variables and 9 industry related variables, which include:

1) Volume of Firm’s Annual Work (\textit{workVolume}, firm-related): this variable represents the EC size that may financially justify owning and running a prefabrication facility, which ranges between 1 (work volume is less than $5M) and 6 (more than $200M).

2) Business Territory Coverage Distance (\textit{coverDistance}, firm-related): it is calculated as the driving distance between the firm’s main office and farthest project.

3) Engineering/Design Services (\textit{engDesign}, firm-related): it is a binary variable that refers to the existence of electrical engineering/design capabilities within the company (i.e. 1) or otherwise (i.e. 0).

4) BIM Capabilities (\textit{BIM}, firm-related): it is a binary variable that can take a value of 1 to refer to the existence of firm’s BIM capability, or 0 for otherwise.

5) Level of Lean Operations (\textit{lean}, firm-related): it represents the number of lean management principles used by the EC. The value of lean level ranges from 0 to 6.
6) **Vendor Partnership Existence** (*vendorPartner*, firm-related): it is a binary variable that can be 1 when a vendor partnership exists; or 0 otherwise.

7) **Strength of Vendor Relationship** (*vendorRel*, firm-related): it refers to the number of value-added services offered by the vendor to the electrical contractor, which can range between 0 and 11.

8) **Existence of Material Blanket Prices** (*blanketPrice*, firm-related): it is a binary variable to indicate the existence of material blanket prices (i.e. its value equals 1) or none (i.e. 0).

9) **Vendor Size** (*vendorSize*, firm-related), it is modeled to take three values: 1 for local vendors, 2 for regional, and 3 for national.

10) **Vendor Early Involvement** (*vendorEarly*, firm-related): it ranges from 0 to 4, where 0 refers to no involvement and 4 refers to vendor’s early involvement in more than 50% of the projects.

11) **Strength of Manufacturer Relation** (*ManufRel*, firm-related): it refers to the number of services and programs offered by the manufacturer to the electrical contractor, which can range between 0 and 4.

12) **Prefabrication Flexibility of Electrical Specifications** (*specsFlex*, industry-related): it ranges between -2 and +2, where the lowest value (-2) refers to the greatest inflexibility of electrical specification writers to prefabrication changes.

13) **Metropolitan Unemployment** (*unemploy*, industry-related): it is the ratio of unemployed workforce across all industries, which is utilized as an indicator of the overall economic progress of the metropolitan area where the electrical contractor is located.

14) **Annual Payroll of Electrical Contracting Firms** (*payroll*, industry-related): it is used to indicate the volume of the electrical contracting industry (in $1,000) in the local metropolitan area.

15) **Number of Electrical Contracting Firms** (*nFirms*, industry-related): it is utilized to indicate the volume and competition level of the local electrical contracting industry.

16) **Average Number of Employees per Firm** (*nEmp*, industry-related): it is used to indicate the average size of electrical companies and competition in the local metropolitan area.

17) **Electricians Employment** (*electricEmp*, industry-related): it is proposed as an indicator of labor supply and availability in the metropolitan area.

18) **Electricians Average Hourly Wage** (*electricWage*, industry-related): it is utilized to reflect the labor cost as a major driver for prefabrication, per the performed interviews.

19) **Union Acceptance of Prefabrication** (*unionPrefab*, industry-related): it refers to the electrician union (IBEW) position towards contractors performing offsite work in prefabrication facilities, which ranges between -2 (high resistance) to +2 (very encouraging).

20) **Union Acceptance of Outsourcing** (*unionOutsource*, industry-related): it refers to the electrician union position towards contractors outsourcing some of the project work to vendors and manufacturers in the form of prefabricated assemblies.

Before performing the logistic regression analysis, the proposed variables were tested for multicollinearity to remove any strongly-correlated variables that may affect the quality of developed predictive model. Multicollinearity in the collected data can be detected considering the following two tests (Pallant 2010): 1) variables are significantly correlated with a Pearson correlation factor (R) more than 0.7; and 2) variables with large Variance Inflation Factor (VIF) more than 5. As such, the *Payroll* and *nFirms* variables were found to be a source of multicollinearity in the collected data, as they were significantly correlated (R = 0.981) and they had very high VIF value, 64 for *Payroll* and 54 for *nFirms*. Accordingly, the number of variables considered for the regression analysis was reduced to be 18.

The 78 valid responses collected by the questionnaire were divided into two groups (Yiu et al. 2006, Cheung et al. 2010): 1) an estimation data group of 70 responses, which was used to estimate the logistic regression model coefficients; and 2) a validation data group of 8 responses, which was used to test the prediction accuracy of the developed model. IBM SPSS Statistics 22 package was used to apply a forward step-wise binary logistic regression analysis on the estimation data group. As shown in Table 1, only 6 variables were included in the SPSS results with their coefficient values, standard error (S.E.), Wald statistic, and its significance level p-value. The two variables with the strongest significance (i.e. smallest significance p-value) in the model were found to be BIM and *unionOutsource*. The other variables had a medium significance of p-values between 0.05 and 0.07. In general, the model fits the collected data with an acceptable quality that is illustrated by its very low P-value, high pseudo Nagelkerke R-squares, and high correct classification rate (CCR%). Figure 3 illustrates the histogram of the the correct/incorrect classifications of prefabrication feasibility (showed as 1) and infeasibility (shown as 0),
calculated by the developed model. Equations 4 and 5 illustrate the prefabrication feasibility probability \( p \) in its final form.

\[
[4] \quad p = \frac{1}{1 + e^{-\logit(p)}}
\]

\[
[5] \quad \logit(p) = -6.821 + 6.5916 \cdot (BIM) + 2.577 \cdot (vendorPartner) - 0.784 \cdot (unemploy) + 0.3914 \cdot (nEmploy) + 0.2407 \cdot (electWage) + 1.9687 \cdot (unionOutsource) + \]

Table 1: Coefficients and Statistics of the Developed Logistic Regression Model

<table>
<thead>
<tr>
<th>Variables</th>
<th>Sample Average</th>
<th>Value</th>
<th>S.E.</th>
<th>Wald</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant ((C_0))</td>
<td>--</td>
<td>-6.821</td>
<td>5.529</td>
<td>1.5220</td>
<td>0.2173</td>
</tr>
<tr>
<td>BIM</td>
<td>0.46</td>
<td>6.5916</td>
<td>1.8075</td>
<td>13.3</td>
<td>0.0003</td>
</tr>
<tr>
<td>vendorPartner</td>
<td>0.397</td>
<td>2.5773</td>
<td>1.3891</td>
<td>3.4425</td>
<td>0.0635</td>
</tr>
<tr>
<td>unemploy</td>
<td>7.16</td>
<td>-0.784</td>
<td>0.4225</td>
<td>3.4474</td>
<td>0.0633</td>
</tr>
<tr>
<td>nEmploy</td>
<td>12.77</td>
<td>0.3914</td>
<td>0.2107</td>
<td>3.4515</td>
<td>0.0632</td>
</tr>
<tr>
<td>electWage</td>
<td>26.28</td>
<td>0.2407</td>
<td>0.1247</td>
<td>3.7243</td>
<td>0.0536</td>
</tr>
<tr>
<td>unionOutsource</td>
<td>-1.128</td>
<td>1.9687</td>
<td>0.988</td>
<td>3.9686</td>
<td>0.0464</td>
</tr>
<tr>
<td>Model Overall P-value</td>
<td>2.6E-13 (≈ 0.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nagelkerke R²</td>
<td>0.851</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCR%</td>
<td>90.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Histogram and Classification of Estimated Probabilities

The prediction accuracy of the developed modeled was validated by calculating the electrical prefabrication feasibility values of the validation group data and comparing them to the observed values. Table 2 lists the validation values of the model variables, observed prefabrication state, calculated prefabrication probability and resulting prefabrication feasibility for the 8 cases of the validation data group. The shown medium prediction accuracy (CCR% ≈ 75%) is considered within the acceptable range of 50% - 100% correct classifications (Pampel 2000). The validity and prediction accuracy of the model can be improved by collecting a bigger sample of electrical contractors, which is planned in future research studies.
### Table 2: Validation Results of the Developed Logistic Regression Model

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIM</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>vendorPartner</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>unemploy</td>
<td>9</td>
<td>3.4</td>
<td>4.5</td>
<td>8.3</td>
<td>6.1</td>
<td>3.5</td>
<td>8.1</td>
<td>5.4</td>
</tr>
<tr>
<td>nEmploy</td>
<td>14.7</td>
<td>13.27</td>
<td>13.5</td>
<td>14.74</td>
<td>9.4</td>
<td>11.25</td>
<td>13.17</td>
<td>11.8217</td>
</tr>
<tr>
<td>electWage</td>
<td>30.48</td>
<td>20.71</td>
<td>22.41</td>
<td>24.23</td>
<td>19.37</td>
<td>22.04</td>
<td>30.17</td>
<td>40.01</td>
</tr>
<tr>
<td>unionOutsource</td>
<td>0</td>
<td>0</td>
<td>-2</td>
<td>-1</td>
<td>-1</td>
<td>-2</td>
<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td>Observed Prefabration State</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Calculated Probability</td>
<td>0.312</td>
<td>0.999</td>
<td>0.952</td>
<td>0.996</td>
<td>0.0053</td>
<td>0.9425</td>
<td>0.869</td>
<td>0.774</td>
</tr>
<tr>
<td>Predicted Prefabration Feasibility</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CCR%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75%</td>
</tr>
</tbody>
</table>

### 6 SENSITIVITY ANALYSIS

The behavior of the developed model was analyzed to obtain more insights about electrical construction prefabrication beyond the collected cases and data. As shown in Figure 4, two-way sensitivity analyses (Clemen and Reilly 2001, pp. 174) were performed to study the impact magnitude of the following example variables on the prefabrication feasibility prediction output of the proposed model: BIM, vendorPartner, nEmploy, and electWage. The other variables are assumed to take the value of a base case, which is modeled as the average value of the observed variables. The sensitivity analyses provided the following useful insights about electrical prefabrication feasibility:

1) Prefabrication feasibility increases with the escalation of the average local electrician wage (electWage) as indication of scarce labor supply and the need to deliver the projects with less labor hours using offsite prefabrication;

2) Prefabrication feasibility increases with the increase of local competition in the form of average employees per electrical construction companies (nEmploy), due the need to outperform the competitors in terms of project cost and time savings achieved by prefabrication; and

3) The contribution of BIM capabilities of increasing the feasibility of electrical prefabrication operation (i.e., the difference between cases A and C) is bigger than the contribution of having a vendor partnership (i.e., the difference between cases A and B).

![Figure 4: Sensitivity Analyses of the Developed Model for four of its Variables](image)

150-8
7 CONCLUSION AND FUTURE RESEARCH

This paper presents the development of a new predictive model of the prefabrication feasibility for electrical contractors. The development of the model was accomplished through four main phases. First, a qualitative analysis of electrical construction prefabrication is performed using interviews, site visit, and case studies to develop a better understanding of the drivers and impediments of electrical prefabrication. Second, quantitative data of the proposed prefabrication determinants were collected using a web-based questionnaire and online federal economic and occupation databases. Third, a binary logistic regression model was developed and validated using the data collected of a sample of electrical contractors. The logistic regression is designed to estimate the probability of prefabrication feasibility for electrical contractors, based on six identified significant determinants: BIM, existence of vendor partnership, local unemployment rate, average number of employees in local electrical construction companies (i.e. local competition), the local hourly pay rate of electricians, and the acceptance/resistance of electrical local union to outsourcing prefabrication services. Fourth, two-way sensitivity analyses were performed to analyze the impact of some of the identified determinants on the prediction outcome of the developed model.

The developed model should prove useful to both academic researchers and electrical construction professionals. The model supports the previous research on construction prefabrication in general and electrical prefabrication in specific by assessing the dependence of construction prefabrication feasibility on the contractor’s internal and external parameters. In addition, the developed model provides a data-driven tool to assess the feasibility of adopting prefabrication operations in comparison to their peers in the industry.

This research can be expanded in future studies to: 1) collected a larger data sample of electrical contractors to further validate and improve the prediction accuracy of the developed model; 2) apply the same methodology to other building construction trades (like mechanical, plumbing, etc.) and analyze their differences and unique attributes; and 3) develop a web-based tool that facilitates the dissemination and use of the developed model by both academics and practitioners.

References


