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The Relationship between the Components of the Construction Industry Institute Zero Accident Techniques Best Practice and Safety Performance

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Abstract: Worker safety is a major concern for both the workers and employers in construction. The Construction Industry Institute (CII) has addressed worker safety in its Zero Accident Techniques (ZAT). The ZAT is composed of thirteen components (e.g., near miss investigations, safety audits, risk identification, etc.). This paper attempts to identify an effective strategy to focus efforts on the most effective ZAT elements. It is thought that some ZAT implementation strategies result in better safety performance than others. This paper evaluates the components of the ZAT by clustering them into logical groups and then analyzing them to measure their correlation and relationship to safety performance. The Zero Inflated Poisson Regression is used to identify the impacts and causal relationships that exist between the groups of safety actions and the safety performance achieved on construction projects. This paper shows that the ZAT components related to Worker Selection lead to better safety performance.

1 Introduction

The Construction Industry Institute (CII) is an organization of member companies who share the objective of performing or assisting in research to benefit the productivity and safety of the industry. There have been many efforts by CII to capture the causes of project successes and failures in the areas of cost growth, schedule growth and safety performance (B&MCommittee 2003). The framework for the improvements is the CII Best Practices. They are the metrics by which CII measures the quality, productivity, and safety of construction projects. There are fifteen best practices, which CII has defined, refined, and validated as a result of implementation (B&MCommittee 2010). The fifteen CII Best Practices are:

1. Alignment
2. Benchmarking and Metrics
3. Change Management
4. Constructability
5. Disputes Prevention & Resolution
6. Front End Planning
7. Implementation of CII Research
8. Lessons Learned
9. Materials Management
10. Partnering
11. Planning for Start-up
12. Project Risk Assessment
13. Quality Management
14. Team Building
15. Zero Accident Techniques

2 Scope and Objectives

The scope of this paper is limited to the analysis of CII's Zero Accident Techniques (ZAT) Best Practice. Through regression analysis, the objective of this paper is to explore the impact of implementing ZAT on the Recordable Incident Rate (RIR). ZAT is composed of thirteen components which have been grouped according to three common themes (i.e., Initial Safety Plan, Safety Maintenance, and Worker Selection). The idea is to determine the group, i.e., theme, which shows the best relationship with safety performance.

3 Data

The data used is an excerpt of the database created by the Benchmarking and Metrics division of CII. 226 Large Industrial projects were extracted. Large projects are defined by CII as any project having the following four criteria (Mulva 2012):

1. Total Installed Cost > $5 million
2. Duration > 14 months
3. Site work hours > 100K
4. Full time PM resources required

Each project was assessed to identify corresponding information regarding project characteristics as well as the ZAT Best Practice implementation information. The data organization and cleaning step involved analyzing the 226 projects and filtering them down to the 59 projects that had complete information in the data fields required for this study, i.e., project characteristics and ZAT information; projects with missing information were discarded.

The thirteen components that make up ZAT are:

1. Plan Implementation – Was there a site-specific safety plan for this project?
2. Safety Supervisor Commitment – What is the time commitment of the safety supervisor?
3. Safety Workers – How many workers per safety person on average were on site?
4. Safety Orientation – How extensive was the site-specific safety orientation for new contractor and subcontractor employees?
5. Formal Safety Training - On average how much ongoing formal safety training did workers receive each month?
6. Toolbox Meetings – On average, how often were safety toolbox meetings held?
7. Safety Audits – How often were safety audits performed by corporate safety personnel?
8. Pre-Employment Drug Screenings - To what extent were pre-employment substance abuse tests conducted for contractor employees?
9. Drug Screening - How frequently were contractor employees randomly screened for alcohol and drugs?
10. Near-Miss Investigations - How often were near-misses formally (i.e., written documentation) investigated?
11. Safety Incentive Use - To what extent were safety incentives used that were based upon zero injury objectives?
12. Safety Performance Criteria - to what extent was safety performance utilized as a criterion for contractor /subcontractor selection?
13. Risk Identification - To what extent were safety risks systematically identified in the pre-construction phases of this project?

4 Zero Inflated Poisson Regression

The Poisson (or log-linear) regression was chosen for this application because it is designed to be used when the dependent variable (total recordable incidents) consists of only natural, integer values and it is assumed to have a Poisson distribution (Cameron et al. 1998). The total number of recorded incidents is a “counted” variable because the only possible values are integers from 0 to infinity. The Poisson regression equation does normalize the total number of recordable incidents for the length of the project by defining the dependent variable in Equation 1 as the log(count/time). This is important so that longer projects are not penalized for having more time in which incidents can possibly occur. The full Poisson regression equation used for this analysis is:

$$\text{Log(count/time)} = b_0 + b_1X_1 + \ldots + b_bX_n \qquad \text{Eq. 1}$$

Where,

count	= number of recordable incidents for the project
time	= number of work hours for the project
b	= coefficient of independent variables
X_i	= independent variables, i.e., project characteristics

The Zero Inflated Poisson Regression analysis accounts for the extreme frequency of zero observations (i.e., zero safety recordables) by separating the data into two groups, the data that falls under a normal Poisson function, and the data that lies outside of this normal Poisson function. In Figure 1, the frequency of incidents in the data is represented by the histogram, and the line shows an estimate of a normal Poisson function fitted to this data. The data that falls outside of a normal Poisson function represents the additional zero observations, or the inflated zeroes.

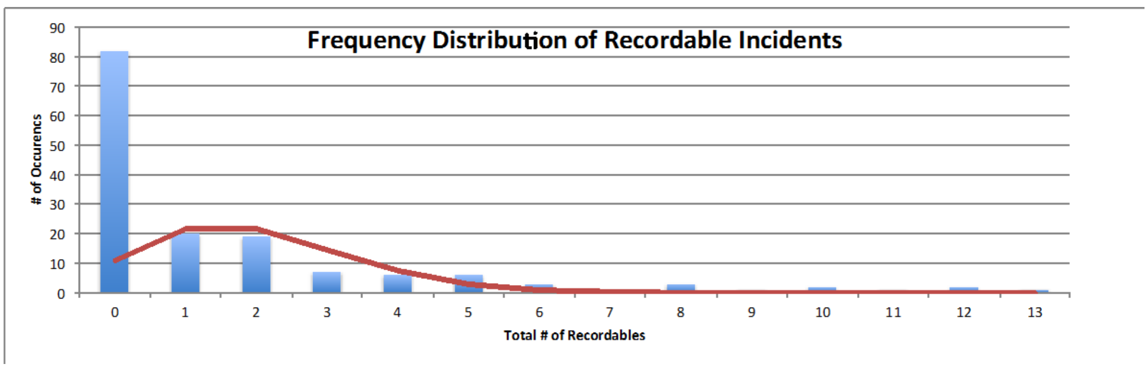

Figure 1: Frequency Distribution of Incident Data Fitted to a Normal Poisson Function

Figure 1 shows that the frequency of zero recordable incidents breaks the shape of the function. The log-linear nature of the data, as well as the dependent variable occurring only in values of natural numbers lends itself to the Poisson distribution. Therefore, each of the project characteristics fields is used as inputs against the total number of recordable incidents in a Zero Inflated Poisson's Distribution Regression model.

A Zero Inflated Poisson regression calculates two components simultaneously. The first component is the regression equation for the data that is under the normal Poisson distribution function; the second is the regression equation for the data that is above the normal Poisson distribution function. These two equations are solved simultaneously and changes in one equation affect the other. However, the resulting independent variables that are significant to each data grouping can be different. The results from a Zero Inflated Poisson regression analysis would include the variables that significantly impact the dependent variable for the group under the normal Poisson distribution and a separate list of variables that impact the dependent variable for the group above the Poisson distribution.

A Bayesian Information Criteria (BIC) score can be used in Poisson regression models to compare one model against another. Bayesian Information Criteria is a method of model selection where smaller values represent a better fit (Weakliem 1999). BIC was developed for use with log linear regression models (Raftery 1985) and therefore, is an appropriate criteria to use in selecting the best regression model when using a Zero Inflated Poisson regression model. The BIC is defined by an equation based upon the Bayes theorem.

The BIC score can be used when there are multiple models to be tested. For example, if a researcher is unsure whether the inclusion of an additional variable will be beneficial or not, both models can be run and the BIC scores can then be compared. Whichever has a lower BIC score is a better fit for the data in use. This BIC score also adjusts itself according to the size of the model, this means that a new variable must show a greater improvement to be determined beneficial to a model with more variables than a model with fewer variables (Raftery 1985). This makes this BIC score a useful tool for models of any size and also allows a model with fewer variables to be compared to a model with a greater number of variables.

5 Clustering ZAT Components

Grouping each of the ZAT components is the first step in designing an experiment to test different aspects of the Zero Accident Techniques. First, the components were studied to identify any commonalities among them. Looking at the thirteen ZAT components, it was observed that multiple components pertain to the initial construction of the safety plan. Second, five of the ZAT components share the fact that they require upkeep throughout the entire construction phase. This makes safety maintenance a second logical category. The third grouping of components dictate how workers or subcontractors are assessed for employment. Using these three traits as criteria for grouping, the final groupings are shown in Figure 2.

Once the three groups of ZAT components were defined, an un-weighted Best Practice Implementation Score (BPIS) for each group was calculated for each of the 59 projects in the data set. The thirteen component scores have been translated to a 0 to 1 scale during the process of calculating the BPIS. Because the purpose of this study is to use statistical methods to determine if one group of ZAT components has more effect on the overall safety performance than others, the CII defined weightings for each of the components will not be used. Imposing such weightings on these components would cause the results to be skewed towards the CII weighting scheme and our objective is to independently determine the most important factors of the ZAT.

Referring to Figure 2 and noting the number of components in each group, ZAT Group #1 will have a maximum possible score of 5; ZAT Group #2 will have also a maximum possible score of 5; and ZAT Group #3 will have a maximum possible score of 3.

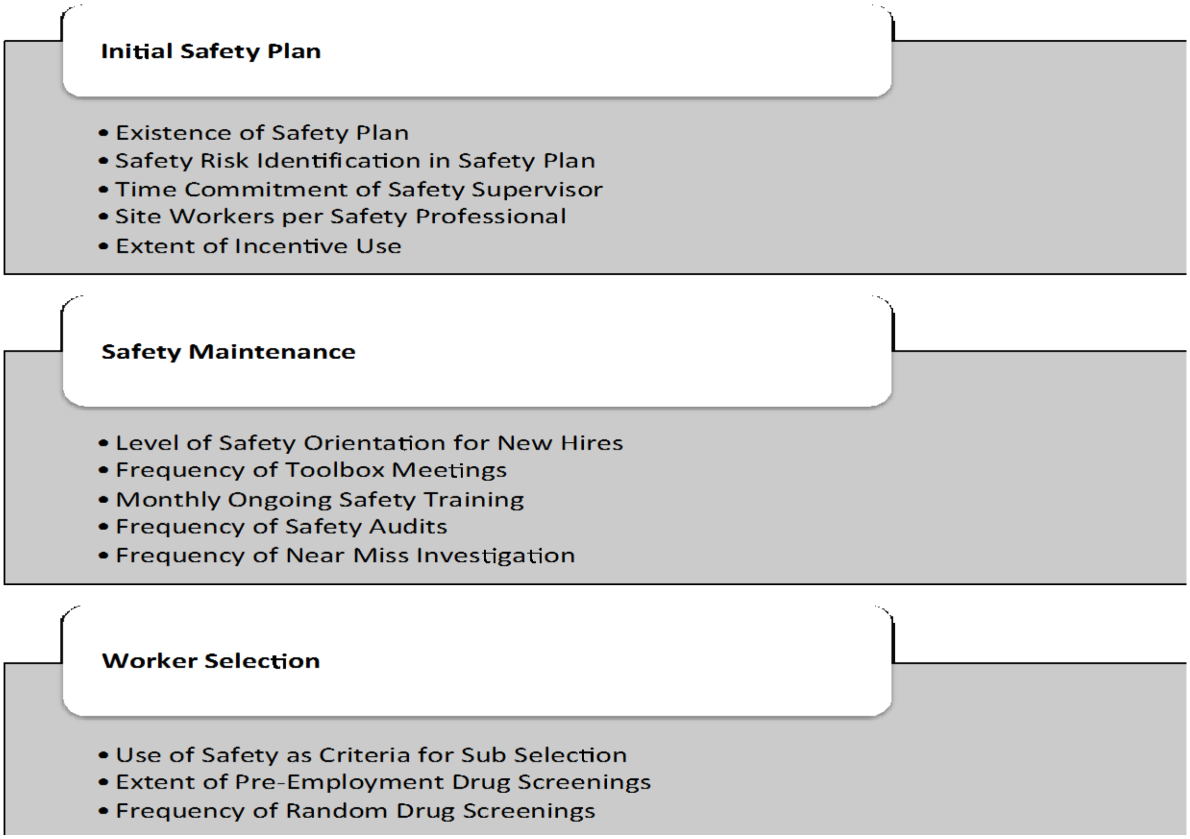

Figure 2: Final Grouping of the ZAT Components

6 Regression Modeling

Regression analysis can be used to determine if some components of the ZAT impact safety performance more than others. The regression model has the following variables:

Dependent Variable:

- Total Number of Recordable Incidents / Total Work Hours

Independent Variables:

- Location
- Major Classification
- Characteristic
- Project Cost
- ZAT Group #1 BPIS: Initial Safety Plan
- ZAT Group #2 BPIS: Safety Maintenance
- ZAT Group #3 BPIS: Worker Selection

The regression model was used to determine the extent to which any of the three ZAT groups impact the Recordable Incident Rate in the presence of the other factors, like Location, Major Classification, etc.

7 Poisson Regression Results

The results obtained from the regression analysis are shown in Table 1, 2, and 3.

Table 1: Regression Results Including All Variables

Full Log Likelihood		-171.8168	
AIC (smaller is better)		363.6337	
AICC (smaller is better)		368.2170	
BIC (smaller is better)		384.4090	

Table 2: Analysis of Maximum Likelihood Parameter Estimates

Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept		1	-11.2024	0.6178	-12.4133	-9.9915	328.77	<.0001
Group1_Sum		1	-0.2829	0.1177	-0.5135	-0.0523	5.78	0.0162
Group2_Sum		1	0.2107	0.1107	-0.0064	0.4277	3.62	0.0571
Group3_Sum		1	-0.5728	0.1171	-0.8022	-0.3433	23.94	<.0001

Table 3: LR Statistics for Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
Group1_Sum	1	5.58	0.0182
Group2_Sum	1	3.64	0.0564
Group3_Sum	1	23.18	<.0001
Bin_Location	1	32.81	<.0001
Major Classification	1	2.74	0.0981
Characteristic	3	22.53	<.0001
Project Cost	1	88.74	<.0001

The main observation comes from Table 3. In this table, an aggregate Chi Squared value is shown for each independent variable combining the significance of all levels of the variable. It is shown here that all variables meet a Pr>ChiSq cutoff level of 0.1, meaning that they are all significant using a 90% confidence interval and used as an indicator to predict the recordable incidents. If an Alpha, or cutoff level for the Chi Squared value, is set to 0.05, the variable Major Classification (Light Industrial versus Heavy Industrial) would not be considered a good predictor of safety performance.

Another important aspect of the regression results is the estimate of the parameter coefficient. Table 2 shows the results that were determined by the hypothesis test to be the most representative of the data, this value can be found in the portion of the table under the heading “Estimate”. The estimates of the parameter coefficient for the ZAT Groups from Table 2 are:

1. ZAT Group #1 Coefficient = -0.2829
2. ZAT Group #2 Coefficient = 0.2107
3. ZAT Group #3 Coefficient = -0.5728

These coefficients indicate the direction and magnitude of the relationship they hold with the dependent variable. The coefficient for ZAT Group #1 indicated that for every unit the ZAT Group #1 score increases, the log of the rate of recordable incidents will decrease by 0.2829 units, thus the rate will decrease by exp(0.2829) = 1.329. Note that the dependent response variable in a Poisson regression analysis is a form of an incident rate (not the OSHA defined Recordable Incident Rate) and is equal to Log(Number of Recordable Incidents/Total Work Hours).

Group #3 ZAT Score is the largest driving factor among the groups of ZAT components because the magnitude of the coefficient is the largest.

The coefficient estimate for ZAT Group #2 is positive which seems illogical from a safety standpoint. The coefficient for Group #2 indicates that for every point the ZAT Group #2 Score increases, the log of the rate of recordable incidents increases by 0.2107 points. To test this regression coefficient for validity, the ZAT Group #1 Score was combined with the ZAT Group #3 Score in an attempt to isolate ZAT Group #2 and test for any complex co-linearity issues between the three ZAT Groups. When ZAT Groups #1 and #3 are combined and a regression analysis is conducted, Table 4 shows the pertinent result values.

Table 4 shows the coefficient estimate for ZAT Group #2 is 0.2312. This coefficient is still positive and has a similar magnitude to the results from Table 2. It can be statistically concluded that it is, in fact, appropriate for this variable to have a positive coefficient. A plausible speculation regarding the direction of the coefficient for this group could be attributed to the nature of some of the tasks included in this group, e.g., safety audits and near miss investigations. This is certainly an area for future research.

Table 4: Regression Results to Isolate ZAT Group #2

Analysis Of Maximum Likelihood Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept		1	-10.8292	0.5755	-11.9572	-9.7012	354.04	<.0001
Groups 1 & 3		1	-0.4256	0.0730	-0.5687	-0.2826	34.00	<.0001
Group2_Sum		1	0.2312	0.1111	0.0134	0.4489	4.33	0.0375

8 Conclusions

The conclusion that can be drawn from the regression analysis indicates that it is likely that some of the ZAT Groups are more able to impact the safety performance of construction projects than others. The ZAT Group #3 showed the greatest significance in the regression equation as well as having a negative coefficient with the greatest magnitude. The ZAT Group #3 is the Worker Selection group. The data suggests that when the ZAT components of Group #3 are implemented more thoroughly, the recordable incident rate will decrease. This implies that the safety reputation of a subcontractor is a good indicator of future safety performance.

The ZAT Group #2 showed statistical significance in the regression analysis but was also showing that an increased implementation worsened safety performance. The ZAT Group #2 is the Safety Maintenance group and includes actions that need to be continually repeated throughout a construction project. This aspect of safety maintenance, however, shows a positive correlation to safety performance and it is the subject of further research.

The ZAT Group #1 is the group of ZAT components related to developing a site-specific safety plan. This group showed a strong statistical significance in the regression analysis. The ZAT Group #1 also has a negative coefficient in the regression model indicating that an increased implementation of Group #1 components results in an improvement in safety performance.

The pre-construction safety-planning activities and the worker selection process have the strongest correlation to improved safety performance on a project. The research indicates that pre-construction planning and prioritization of safety are the most important considerations when seeking to maximize safety performance. These results also indicate that past safety performance of contractors can be used to predict future safety performance. This could be due to the fact that safety is often a part of a company's deep-rooted culture and it is not a fluctuating priority. It can be noted that worker selection is also a group of safety actions that take place during pre-construction also. This means that safety planning processes are more significant in creating a project with better safety performance than attempting to implement ad hoc safety actions after construction has started. Safety professionals need to understand that focusing on safety planning from the inception of the project is critical to ongoing safety performance throughout the project.

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