

Engineer Manual 385 Effectiveness: A Study of Predictive Analytics

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This study looks for causation between the use of the EM 385 and the number and the severity of mishaps using three multiple regression analysis. Under the guidance of the United States Army Corps of Engineering Manual 385 (EM385), the federal government has taken a stringent stance on construction safety. This manual prescribes the safety and health requirements for all Corps of Engineers activities and operations. The research population studied included construction contractors who performed work within various federal government agencies. The data was compiled using 2008 data that was merged using the federal construction spending data with mishap rates obtained from the OSHA Data Initiative (ODI). Based upon the collection and collation of sample data, by random sampling and manual matching database, establishes a model for determining the validity of EM385, and adjusted the experimental model several times. However, analysis of this data revealed that there were no conclusive results showing a causal relationship between the EM 385 and a reduction in the number and severity of mishaps.

Keywords: Safety, EM385, Predictive Analytics, Regression Analysis

Introduction

Insurance costs are rising and workers are dying. Construction in the United States has consistently experienced higher fatality and injury/illness rates. The post-accident cost of safety is significant. Research utilizing 2004 mishap data reveals that disabling injuries had an annual cost of $15.64 billion (Rajendran, 2006). This fact clearly illustrates that worker safety effects business viability. Both productivity and the costs incurred resulting from worker injuries makes performing work safely a key characteristic of a profitable company. A study done in 2009 supports this idea that the more a firm spends on workplace safety, the lower its worker's compensation rates (Huang, 2009). The EM 385 is composed of extensive safety planning guidelines that have cost millions of dollars to develop and implement over its 73 year history.

The EM 385 has become a vital part of construction operations on all Department of Defense (DOD) construction projects, with the objective of creating a safer work environment. The use of the EM 385 attempts to bridge the gap left from the lengthy safety mandates and the actual construction that takes place on the jobsite. The "print architecture and nomenclature of the manual are similar to that of the OSHA regulations, with a few variations" (Decoopman, 2011). "While the OSHA standards say little about safety management, the EM 385 addresses this issue in some detail" (Rekus, 2003). Safety management as defined by the EM 385 takes the form of the accident prevention plan, which encompasses a detailed activity hazard analysis. It is important to understand that these safety management mechanisms are project and activity specific outlining the precautions necessary to mitigate the hazards that are inherent in every construction task. This is supported by a study in which safety management was linked to improved safety performance (Bradbury, 2006). In a 2008's study it was found that most safety management programs were being applied in an informal fashion rather than using a safety management model

(Hallowell, 2008). Looking at ways to learn from mishaps that have occurred, construction research has attempted to study precautionary techniques to mitigate hazards and prevent accidents. The EM 385 "provides important management information through qualitative post-hazard analysis. This allows project participants to take precautions accordingly against eventual accident reoccurrence"(Wang, 2010). The EM 385 safety planning requirements are meant to initiate and cultivate a safer construction safety and health program. "Teo et al. (Teo, Ling, & Chong, 2005) argued that insufficient safety knowledge of workers is one of the major causes of site accidents"(Wang, 2010). Given the content of behavioral based safety research it can be concluded that controlling behavior is essential to better safety performance. For this reason, development of safety programs, that institute pre-hazard assessment, is becoming more prominent in the construction industry.

Essentially the EM 385 defines the planning processes that will be used to prevent mishaps, ensure compliance and accountability, in an attempt to foster a positive safety culture. The difference between OSHA regulations and the EM 385 is that OSHA develops the rules for safety and the EM 385 implements them through on-site safety management. After an extensive review of all of the extant research and literature on the subject, it became apparent that there is a lack of quantitative research on the relationship between safety performance and the use of the Engineering Manual 385 (EM 385). For this reason this research could be critical to the construction industry at large. The following two research questions were posed to determine if a relationship exists between the number and severity of mishaps and the use of the EM 385: #1: What was the effect of the EM 385 on reducing the number of mishaps? #2: What was the effect of the EM 385 on reducing the severity of mishaps? To assess the EM 385, this research examined three common safety metrics. These metrics are created, collected and actively tracked by OSHA. The metrics include the total number of recordable cases rate (TCR), the days away, restricted, and transferred (DART) rate, and the days away from work (DAFWII) rate. The research used a structural equation modeling technique, specifically multiple regression, to estimate and assess the number (TCR) and severity of mishaps (DART and DAFWII), to gauge the effectiveness of the EM 385 guidelines. Causation between the EM 385 and a reduction in mishap quantity and severity was this research's objective, while considering other explanatory variables that could affect this predictive model. The following influence factors tie safety research to the variable selection utilized in this study.

Safety Metrics: The TCR, DART and DAFWII rates were founded on a theoretical basis known as the Parkinson Law. By establishing these standard metrics and publishing the averages each year, standards are set for the industry to manage procurement, assess performance and dictate changes. Using these principles, research conducted in 1998 showed that there was a correlation between mishap reduction and keeping records on incident rates(Garza & Hancher, 1998). **Safety by Region:** In a 2008 survey of occupational injuries and illnesses, 22 states were found to have a higher number of mishaps than national average, with 14 states experiencing lower than national average rates. It is with this reality that the region where the work takes place must be considered as a factor in the assessment of mishap rates. **Safety by Size:** The size of the project is the primary factor that companies use to determine the necessary crew size that would be required to complete the job. Foundational research done with project superintendents has revealed that smaller organizations in construction tend to have better communication (Hinze, 1976). Through this improved communication, safety becomes much more vital to the crew, project and/or company. The close-knit dynamics of smaller organizations tend to result in fewer mishaps, even when there is an absence of a project and/or organizational safety program. **Safety by Industry**: The Bureau of Labor and Statistics report the sectors that had the highest annual average employment were contained in the building construction sector. By the normalized number and severity of mishaps, commercial construction was a more hazardous industry than residential construction. **Safety by Contract Type**: The motives behind contractors working under lump-sum and unit-price contracts varied greatly. Contractors working under a lump-sum contract were driven by higher profitability to complete the project more quickly, which resulted in less general requirement costs. Inversely unit-price contracts were driven by the time and cost that were incurred. These contract methods can drive contractors working under lump-sum contracts to assume more safety risks, since the faster a project gets completed, the fewer project overhead costs are incurred. More risk can equate to more mishaps, and for that reason contract type was considered as a variable in this research. **Safety by Solicitation**: In an article on prequalification importance in a tough economy, Douglas Mcleod stated that in a tough economy such as the one in 2008, lowest bid procurement in the competitive bid world could result in working with contractors with poor safety performance (Mcleod, 2012). Under the negotiated solicitation model, safety can be a key factor in selection, since selection can be based on intangibles, such as past safety performance, rather than on the lowest price. On the other hand, competition could breed better safety performance. An understanding of this variation in safety performance resulted in this research utilizing solicitation procedures as one of its explanatory variables. **Safety by Business Type:** Disadvantaged business entities (DBE) under Federal acquisition regulations (FAR, 1991) are required to set aside work for performance in almost every procurement sector. Construction is particularly affected by this requirement due to the large volumes of money involved in the work. For that reason, this research considered DBEs and the set-asides they were given as a factor in its statistical assessment of the EM 385 and its contribution to a reduction in mishaps.

Methodology

In order to predict the impact of EM385 on the accident rate, it is necessary to accurately analyze and identify the factors that affect the construction accident rate. On this basis, constructing a multivariate regression model that is reasonable and effective can improve the accuracy of prediction and provide strong evidence for determining the effectiveness of EM385. The target population studied in this paper is a building contractor operating in the federal construction sector. The effectiveness of EM385 was assessed by using post-accident analysis using a population of randomly selected ODIs. The source of this research data is OSHA Data Initiative and the Federal Spending database. The OSHA Data Initiative (ODI) collected four parts of the NAICS (North American Industry Classification System) 236220, 236210, 236116, and 236115 from 2008. Includes residential (236115 and 236116) and commercial (236220 and 236210). A random selection of 190 building contractors from the consolidated database was combined with the federal database after sampling.

Modeling

The Initial Multiple Regression Model is established to estimate the causation between the number and severity of mishaps and the use of the EM 385, while partitioning several other key explanatory variables. The predictive analytics dictate the following.

$$+\beta_p(PTYPE_p) + \beta_q(CTYPE_q) + \beta_r(SOLIC_r) + \beta_s(DIS_s) + \beta_t(SET_t) + \varepsilon_0$$

Process.

Step 1. Stated a substantive research question. Research Question #1: What was the effect of the EM 385 on reducing the number of mishaps? Research Question #2: What was the effect of the EM 385 on reducing the severity of mishaps?
Step 2. Stated a null and alternate hypothesis: <u>Null Hypothesis:</u> The use of the EM 385 does not reduce mishap rates. <u>Alternate Hypothesis</u>: The use of EM 385 does reduce mishap rates.
Step 3. Set alpha (Type I error) and described why it was selected: An initial alpha was set at 0.1percent as this is often standard practice. A two tailed methodology was employed as some of the explanatory variables have unknown positive or negative impacts on the ODI safety metrics.
Step 4. Stated the statistical technique(s) that will be used: A structural multiple regression equation modeling the

effects on the three dependent variables was used.

Step 5 . Data Preparation:

The data listed below required no preparation for statistical analysis:

Total case rate (TCR); The days away, restricted, and transfer (DART); The days away from work (DAFWII)
Contractor Size by Revenue; Contractor Size by Employees; Project Size

The data listed below required preparation for statistical analysis. Dummy Variables were used as follows:

Use of the EM 385: 1=EM385 Use, 0= EM385 Non-Use _=Not Identified;
Project Type: 1=Commercial Construction, 0=Residential, _= Not Identified
Contract Type: 1=Fixed Price, 0=Variable Cost, _= Not Identified
Solicitation: 1= Competitive Bid (<1 Bidder),0=Negotiated (1 Bidder), _= Not Identified
Disadvantaged Business:1=DBE Used, 0=No DBE Used, _No DBE identified

Step 7.Calculate and interpret the results: Multiple regression was utilized to test the causation between the 3 dependent and 10 explanatory variables.

Results

1. Significant test of the variables of the original model. Following several stepwise regression analysis of the explanatory variables， retaining both explanatory variables with a significant p-value. Explanatory variables such as EM 385, OSHA Region, Contractor Size and Solicitation in the model had an insignificant p-value, but were retained due to the importance of the variable in the final regression model.
2. Multi-collinearity Analysis. In the initial research model explanatory variables with a Pearson Correlation of <0.6 were assessed. After this assessment the highly correlated explanatory variables were analyzed individually. Disadvantaged Business are divided into ten categories for separate analysis, and the final analysis will be combined into one explanatory variable, so its multi-collinearity is not considered. In addition federal set-aside projects were highly correlated with a Pearson correlation of 0.642 with disadvantaged businesses, since set-asides are aimed at providing disadvantaged business entities with exclusive opportunities to win and perform federal projects. In the final model the set-aside variable was removed.
3. Multiple Regression Analysis. The following is the final structural equation that estimate the causation between the number and severity of mishaps and the use of the EM 385 and other explanatory variables that are significant and/or essential to this research. The final model is as follows:

$$Y_i = \beta_0 + \beta_j(EM385_j) + \beta_k(REGION_k) + \beta_m(EMPL_m) + \beta_r(SOLIC_r) + \beta_s(DIS_s) + \varepsilon_0$$

The R Square from this model was 0.22 for the TCR estimation, 0.13 for DART estimation, and a 0.12 for DAFWII estimation. This indicates a very low individual independent variables in the final model of the predictive ability of the explanatory variables.

4. Re-modeling after EM385 extraction for multiple regression analysis:

$$Y_i = \beta_0 + \beta_k(REGION_k) + \beta_m(EMPL_m) + \beta_r(SOLIC_r) + \beta_s(DIS_s) + \varepsilon_0$$

Listed below is a show of the coefficients in the EM385 Extracted research model for the three structural equation models as seen in Table 1, 2, and 3:

Table 1 EM385 Extracted TCR Model Coefficient Table

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std.Error	Beta		
(Constant)	3.133	1.185		2.645	0.009
Contractor # Of Employees	-0.001	0.003	-0.30	-0.440	0.660
OSHA Region 1	5.997	2.186	1.198	2.734	0.007
OSHA Region 2	-0.577	1.881	-0.023	-0.307	0.759

OSHA Region 3	-1.460	1.413	-0.082	-1.033	0.303
OSHA Region 4	-1.293	1.166	-0.096	-1.109	0.269
OSHA Region 5	1.982	1.380	0.115	1.435	0.153
OSHA Region 7	1.288	1.767	0.055	0.729	0.467
OSHA Region 8	6.654	1.750	0.284	3.802	0.000
OSHA Region 9	-0.806	1.812	-0.033	-0.445	0.657
OSHA Region 10	9.854	3.849	0.177	2.560	0.011
Solicitation Procedures	0.560	0.934	0.042	0.599	0.550
Disadvantage Business	1.849	0.816	1.157	2.265	0.025

Table 2 EM385 Extracted DART Model Coefficient Table

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std.Error	Beta		
(Constant)	1.781	0.768		2.320	0.022
Contractor # Of Employees	0.000	0.002	-0.008	-0.112	0.911
OSHA Region 1	2.514	1.417	0.136	1.774	0.078
OSHA Region 2	0.120	1.219	0.008	0.099	0.922
OSHA Region 3	-1.197	0.916	-0.110	-1.307	0.193
OSHA Region 4	-1.156	0.755	-0.140	-1.530	0.128
OSHA Region 5	0.624	0.895	0.059	0.697	0.487
OSHA Region 7	0.160	1.145	0.011	0.140	0.889
OSHA Region 8	2.402	1.134	0.167	2.117	0.036
OSHA Region 9	-1.029	1.175	-0.069	-0.876	0.382
OSHA Region 10	-2.586	2.495	-0.076	-1.037	0.301
Solicitation Procedures	0.479	0.605	-0.58	0.792	0.429
Disadvantage Business	1.131	0.529	0.156	2.137	0.034

Table 3 EM385 Extracted DAFWII Model Coefficient Table

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std.Error	Beta		
(Constant)	0.603	0.499		1.207	0.229
Contractor # Of Employees	0.000	0.001	-0.026	-0.361	0.719
OSHA Region 1	2.112	0.921	0.176	2.292	0.023
OSHA Region 2	1.493	0.793	0.147	1.883	0.061
OSHA Region 3	-0.208	0.596	-0.029	-0.348	0.728
OSHA Region 4	-0.293	0.491	-0.055	-0.596	0.552
OSHA Region 5	0.728	0.582	0.107	1.252	0.212
OSHA Region 7	0.413	0.745	0.044	0.554	0.580
OSHA Region 8	0.582	0.738	0.063	0.789	0.431
OSHA Region 9	-0.606	0.764	-0.063	-0.793	0.429
OSHA Region 10	-1.222	1.622	-0.055	-0.753	0.452
Solicitation Procedures	0.278	0.394	0.052	0.706	0.481
Disadvantage Business	0.962	0.344	0.205	2.796	0.006

A multivariate regression analysis was performed on the model for extracting EM385. The results showed that R^2 of TCR was 0.22, R^2 of DART was 0.13, and R^2 of DAFWII was 0.12. After removing the EM385 from the research model the results reflect that the EM385's effect on the number and severity of mishaps is inconclusive. In the two models, the presence or absence of EM385, R^2 has almost no change, so there is reason to believe that the impact of EM385 on the model is indeed uncertain or insignificant. Basically, there is no change in the model with or without the EM385. A significant test was performed to compare the results of the two models. EM385 had little effect on other explanatory variables. All variables have a P-value change that is less than a few percent, and all coefficient symbols remain the same. This again confirms the fact that EM385's contribution to the research model is uncertain.

Discussions

The final model multiple regression analysis results coefficient and significant results are summarized as follows:

Table 4 Final Model Multiple Regression Analysis

	Regional unionization	expected			actual			sig.
		TCR	DART	DAFWII	TCR	DART	DAFWII	
EM385 Proxy		-	-	-	+	+	+	no
Contractor # of Employees		-	-	-	-	+	+	no
OSHA Region 1	Strong	-	-	-	+	+	+	sig.
OSHA Region 2	medium				-	+	+	DAFWII sig.
OSHA Region 3	medium				-	-	-	no
OSHA Region 4	weak	+	+	+	-	-	-	no
OSHA Region 5	Strong	-	-	-	-	-	-	no
OSHA Region 6	weak	+	+	+				
OSHA Region 7	no	+	+	+	+	+	+	no
OSHA Region 8	no	+	+	+	+	+	+	TCR、DART sig.
OSHA Region 9	no	+	+	+	-	-	-	no
OSHA Region 10	weak	+	+	+	+	-	-	TCR sig.
Solication Procedures		-	-	-	+	+	+	no
Disadvantaged Binsiness		+	+	+	+	+	+	sig.

***EM385 Proxy*:** The EM385 proxy coefficient is expected to be negative, there should be fewer mishaps, not more. This however is not the result determined in the regression results for all three structural equation models, which is reflected in a positive sign on the coefficient. This result could be due to missing observations, little variation in the data, and behavioral issues with respect to reporting. The limited sample size, the fact this data is only from one calendar year, only a few non-EM385 data points, possible misspecification of the explanatory variable and any omitted variable problems are all possible explanations for the incorrect sign and lack of significance. While the EM385 intent is to reduce mishaps, it may just encourage proper reporting, while businesses outside the control of the EM385 could be underreporting and/or misreporting, whether intentional or not.

***Contractor Size by Employees*:** The contractor size coefficient is expected to be negative, however the regression result reflects a positive sign on the severity of mishap coefficients (DART and DAFWII), while there is a negative sign on the number of mishaps (TCR). The contractor size is a key variable to consider since the more employees, results in more resources that can be attributed to safety. Larger contractors have formal safety policies and procedures, along with designated safety professionals to oversee and monitor safety.

***OSHA Region*:** The OSHA Regions coefficients are expected to be half negative and half positive, which is a reflection of the mathematics associated with regression techniques used. This is attributed to the research that has shown safety having a causal link to safety education, worker knowledge, management focus and training. With organized labor focus on apprenticeships, having dedicated safety personnel on the project site and continuous safety training and oversight, the focus on unions in this research is warranted.

***Solicitation Procedures*:** The solicitation procedures coefficient is expected to be negative; however the regression results reflect a positive coefficient. The theory behind the hypothesis is that competition breeds better results, in this case fewer and less severe mishaps. While the results did not show this theory to be true, the sample size and validity of the dependent variables could be questionable. These results, however, lack significance with a p-value greater than .10, so the solicitation procedures used by the government could not be a factor that affects mishap rates.

***Disadvantaged Business*:** Disadvantaged Business' coefficient is expected to be positive. This is due to the fact that disadvantaged businesses tend to be smaller, have less experience and lack the professional knowledge gained through experience and formal education. This is shown in the regression results reflecting a positive coefficient.

***Evaluation the EM385 Extraction Model*:** After comparing the final regression model's explanatory coefficients to the coefficients where the EM385 was extracted from the model, it was apparent that the EM385 retained or extracted from the model had little to no effect on the other explanatory variables. In all cases the variation was less than a few percent in significance, while all the coefficient signs remained the same. This again confirms the fact that the EM385 contribution to the research model is inconclusive.

Conclusions

In summary, this research has, through detailed analysis, revealed that the EM 385modeling presented does not quantitatively prove or disapprove the EM385's effectiveness at reducing mishaps. While this research has not exhausted the efforts to prove the effect the EM 385 has on reducing mishaps, it does however serve as a start in identifying an issue where future research and policy changes that can help determine the effectiveness of the EM385. With the time, money and resources used by the federal government to utilize this safety guide, it is worth additional evaluation to continue the research in this subject area. The question on whether or not the EM385 provides any value for project safety is critical to the construction industry at large. All of the results point to one conclusion and that is the ability to determine a quantitative relationship between mishap rates and the EM 385 at this point in time, with the available data at hand, is indeterminate. That said, the model originally presented has a strong theoretical basis and changes in data collection and auditing policies may be able to correct the inability of this model to define a significant quantitative relationship.

References

Bradbury, J. C. (2006). Regulatory Federalism and Workplace Safety: Evidence from OSHA Enforcement, 1981–1995. *Journal of Regulatory Economics, 29*(2), 211-224.

Broderick, T., & Murphy, D. (2001). Construction safety: a cruel oxymoron? *Occupational Health & Safety, 70*(10), 68.

Decoopman, D. L. (2011). The Silver Bullet: U.S. Army Corps of Engineers EM 385-1-1 Construction Standard. *American Society of Safety Engineers*.

Garza, J. M. D. L., & Hancher, D. E. (1998). Analysis of safety indicators in construction. *Journal of Construction Engineering & Management, 124*(4), 312-314.

Hallowell, M. R. (2008). A formal model for construction safety and health risk management. *Dissertations & Theses - Gradworks*.

Hinze, J. (1976). The Effect of Middle Management on Safety in Construction.

Huang, Y. H. (2009). Financial decision-makers' views on safety: What SH&E professionals should know. *Professional Safety(April)*, 36-42.

Mcleod, D. (2012). Prequalification important in tough economy.

Rajendran, S. (2006). Sustainable Construction Safety and Health Rating system. *Dissertations & Theses - Gradworks*.

Rekus, J. F. (2003). EM385 you guide to safty on DoD construction projects. *Occupational Hazards, 65*(2), 35-40.

Teo, E., Ling, F., & Chong, A. (2005). Framework for project managers to manage construction safety. *International Journal of Project Management, 23*(4), 329-341.

Wang, H. H. (2010). A context-based representation and reasoning formalism to support construction safety planning. *Dissertations & Theses - Gradworks*.