Analyzing the Distribution and Variations

in Construction Costs for

Commercial Tenant Improvement Projects

by

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ABSTRACT

In this era of high-tech computer advancements and tremendous programmable computer capabilities, construction cost estimation still remains a knowledge-intensive and experience driven task. High reliance on human expertise, and less accuracy in the decision support tools render cost estimation error prone. Arriving at accurate cost estimates is of paramount importance because it forms the basis of most of the financial, design, and executive decisions concerning the project at subsequent stages. As its unique contribution to the body of knowledge, this paper analyzes the deviations and behavior of costs associated with different construction activities involved in commercial office tenant improvement (TI) projects. The aim of this study is to obtain useful micro-level cost information of various construction activities that make up for the total construction cost of projects. Standardization and classification of construction activities have been carried out based on Construction Specifications Institute's (CSI) MasterFormat® division items. Construction costs from 51 office TI projects completed during 2015 and 2016 are analyzed statistically to understand the trends among various construction activities involved. It was found that the interior finishes activities showed a much higher cost of construction, and a comparatively higher variation than the mechanical, electrical, and plumbing (MEP) trades. The statistical analysis also revealed a huge scope of energy saving measures that could be achieved in such TI projects because of the absence of energy management systems (EMS) found in 66% of the projects.

DEDICATION

Dedicated to my parents, Sumitra and Amitava Ghosh.

ACKNOWLEDGMENTS

I wish to thank Dr. David Grau Torrent for his continuous support in my pursuit of reaching where I am today. His belief in me, and the shared wisdom, has enabled me to gain precious knowledge and have a wonderful outlook towards life and towards this great field of construction.

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CHAPTER 1

INTRODUCTION

This chapter presents an introduction to construction cost estimation and describes the need

for analyzing historical construction costs in order to obtain accurate project estimates.

BACKGROUND

Estimating project costs are vital to project success right from the conceptual stages of

project to its completion. While conceptual cost estimate forms a benchmark for all

further project decisions, major changes in detailed project estimates during construction

(also called as cost overruns) could be detrimental to project completion and its success.

Construction cost estimation is one of the best examples of knowledge-intensive

engineering tasks. The accuracy and comprehensiveness in cost estimation are delicate

issues and can be easily affected by many different parameters. These cost influential

parameters can be broadly classified into estimator-specific, and design-specific factors

(Akinci et al.,1998). While the former can be controlled with the help of proper decision-

support tools and computer based algorithms, the latter is more indirect in nature, and is

highly dependent upon project specific factors.

Analysis of construction costs to support the estimator-specific factors can be broadly

divided into two categories, a) statistical and model analysis techniques, and b) artificial

intelligence techniques (Elfaki et al., 2016). The former consists of analyzing costs using

traditional statistical methods such as by calculating mean, median, standard deviation,

and variance, etc. It also consists of complex analysis of multi-variate project conditions

using linear and multiple regression analysis techniques. Artificial intelligence techniques

consist of machine learning, artificial neural networks, and case-based reasoning techniques, to name a few. Due to the complexity of developing algorithms and hidden processes involved in artificial intelligence approaches (Elfaki et al., 2014), traditional statistical methods are still used to analyze the trends in construction cost.

Most of the researches have considered macro cost factors (eg. total project cost) and have neglected the micro-level costs associated with the construction tasks that make up for total cost of construction (Newton, 1991). For the purpose of understanding micro-level construction activities which constitutes the total project cost, the statistical analysis performed in this study follows a specification based outline in order to generalize and categorize construction costs into easily identifiable construction activities for better understanding.

RESEARCH OBJECTIVES

The objective of this study is to analyze the behavior of construction costs for office tenant improvement projects in terms of CSI MasterFormat® based specification system. Commercial tenant improvements, minor renovations, or rebuilding of existing office space for a new tenant accounts for approximately 98% of the total commercial building stock. The other 2% of the building stock undergo major retrofit and renovations (Miller et al., 2015). This shows that a substantially major proportion of investment and activities are associated with office tenant improvement projects that constitute 98% of the building stock. Also, in today's era, more organizations are inclined towards establishing a workplace which is conducive to better employee performance and collaboration within the team. In this pursuit, achieving the right balance between investment, architectural

layout, and energy efficiency is one of the most challenging tasks faced by owners and architects alike (Karhu et al., 2012). Therefore, it is important to understand the behavior and variations of construction costs that drives the total project cost. Understanding those construction trades which have shown a high deviation or fluctuation in past will indeed help owners, architects, and engineers plan for better usage of space in order to find the right balance between cost, energy efficiency, and improved functionality of the space.

METHODOLOGY

In order to perform a specification based construction cost analysis, 51 project samples are selected that belong to office tenant improvement project type. The total costs associated with these projects are divided into various construction activities in order to perform statistical analysis. Construction costs are formalized into unit costs (cost per square foot) based on total project area for analysis purposes. This will enable in understanding the micro-level construction cost behavior in terms of cost deviations and magnitude of costs for each construction activity. Statistical analysis is performed by calculating the mean, quartile numbers, and standard deviations which are then compared across the construction activities to determine high variance activities. Understanding the behavior and variation in costs among different construction activities which together make up for the total construction cost, will help in knowing the trades which constitute the highest portion of project cost. Also, the results of this analysis will enable the readers to focus more towards the high variance and high cost construction activities involved in an office tenant improvement project during estimating stages.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

In an experience based industry, such as construction, understanding and assessing

previous projects are essential for resolving reoccurring problems (Ji et al., 2011). Cost

estimation can be regarded as one of the most knowledge-intensive engineering task that

renders it error prone (Elfaki et al., 2014). While the word estimate itself does not

guarantee an accurate number, construction costs are dynamic and change over time

(Bromilow, 1988; Elfaki et al., 2014). Considering its dynamic nature, efforts are made to

arrive at accurate cost figures with the help of available information at any given time

and circumstances. This chapter covers the findings of a thorough literature review of the

prior studies that have been performed in the field of construction cost analysis, and the

support tools that are being developed to assist in construction cost estimation. These

tools and techniques will be analyzed in terms of its broad analysis type and the results

obtained from those researches will be observed.

PRIOR STUDIES

According to Akinci et al., in 1998, there are two group of factors that can highly

influence the estimated cost of a project, a) estimator-specific factors, and b) design and

project-specific factors. While the first group of factors can be controlled by providing

various levels of information and decision support tools to an estimator, the second group

of factors always tends to indirectly affect the project cost. These factors could be the

ambiguity in project scope definition, and improper risk assessment of projects.

In order to reduce the human error (targeting the first group of factors as mentioned above), many decision-support tools have been suggested which could considerably reduce human error, and enable estimators to predict costs more accurately based on the historical knowledge gained from previously performed projects. Based on the intensive literature review performed, the support tools were found to be mainly representing two broad categories, viz., a) statistical analysis and modelling approaches, and b) artificial intelligence techniques (Elfaki et al., 2016). While it can be argued that statistical analysis is an integral part of cost modelling and artificial intelligence approaches, statistical analysis by itself can serve as an effective decision support tool to an estimator (Choi et. al., 2015).

The significance of analyzing construction costs can be gauged by the importance which the United States government puts on construction statistics. As per the Census Bureau and Bureau of Economic Analysis, requests for national economic statistics grew by 5.7% ($10.5 million) from the approved amount for 2016 fiscal year (FY) to $194.7 million for FY2017. Out of the total requested amount for the nation's economic statistics for FY2017, $16.8 million or 8.6% of the amount has been allocated for construction statistics. The growth in construction statistics budget was recorded to be the highest at 31.6% when compared with FY2016 allocation towards the same (Williams, 2016). This signifies the need for development of better statistical analysis techniques and decision-support tools which could provide a clear picture of the variations, deviations, and behavior of construction costs at a micro project levels.

As for the research that has been done in past, Table 1 provides a summary of the various cost modelling techniques which have been divided into two broad categories of (statistical analysis and artificial intelligence techniques) for better understanding.

Table 1

Summary of Cost Estimating Decision-Support Tools & Techniques (Elfaki et al., 2014).

Approach	Method/Technique Adopted	Proposed by
STATISTICAL ANALYSIS	Variability Analysis	Choi et. al., 2015; Khosrowshahi et al., 1996; Kouskoulas et al., 1974
	Single-step Ahead Approach	Mahamid, 2011; Petroutsatou et al., 2011; Sonmez, 2008
	Multi-step Ahead Approach Linear Regression	Dursun et. al., 2016 Sonmez, 2008
	Multiple Regression	Mahamid, 2011; Dursun et al., 2016
ARTIFICIAL INTELLIGENCE	ML: Artificial Neural Networks	Jafarzadeh et al., 2013; Petroutsatou et al., 2011
	ML: Support Vector Machines	Cheng and Hoang, 2014; Son et al., 2012
(ML - Machine Learning, KBS - Knowledge Based System)	KBS: Case-Based Reasoning	Ji et al., 2012; Choi et al., 2014
	KBS: Ontology	Ma et al., 2016

Apart from machine learning and knowledge-based systems that enables to develop cost prediction algorithms and models, several other artificial intelligence techniques such as genetic algorithm, ant colony systems, and hybrid systems (combination of one or more of the above mentioned approaches) are also being tried and tested by the researchers. While such artificial intelligence techniques show the ability to deal with uncertain situations and work with incomplete data, it also recognizes new project instances based on its acquired experience. At the same time, many researchers and industry practitioners

have argued against the use of these techniques because of its hidden processes (also termed as a *"Black-box"* type approach), difficulty and error in self-learning, and the problem of controlling the training iterations in order to prevent from over/under-training (Elfaki et al., 2014).

Also, there have been several discrepancies found with respect to the representation of construction costs during these analyses. Several studies (Emsley et al., 2002; Lowe et al., 2006) have rejected the use of absolute costs during analysis because of violations in model assumptions and inaccurate representation of the results. Hence, many researchers (Stoy et al., 2008; Gunaydm et al., 2004) have adopted the unit construction cost (cost/sf) approach. The same unit cost approach is therefore being adopted in this study as well.

KNOWLEDGE GAP

Developing cost estimates has long been a conspicuous topic in the domain of construction (Elfaki et al., 2014; Newton, 1991). Up until now, there has been no consensus among researchers in regards to the supremacy of one analysis technique over another. Accuracy of results were found to be depending upon the type of data sets being used, level of detail being adopted in the study (eg. – single-step or multi-step layered approaches), initial project conditions, and geographical conditions. The inconclusive evidence of the supremacy of any particular cost modelling approach has been explained with the help of data presented in Table 2. This table shows the results of previous research in various cost modelling techniques in comparison with other techniques, and also in terms of the prediction errors observed in those studies. The percentages of error are in terms of mean absolute percentage error (MAPE), or root mean squared error (RMSE).

Table 2

Summary of the Results of Cost Modelling Research

Method	Prediction Error	Superior to,	Reference
Regression Analysis	12 - 13%	Not compared	Stoy et al., 2008
Regression Analysis	12%	Not Compared	Sonmez, 2008
Artificial Neural Networks (ANN)	18-23%	Linear Regression (19-21%)	Emsley et al., 2002
Hybrid (Principal Component Analysis & Support Vector Regression-SVR)	9.01%	SVR (9.1%), ANN (10%), Decision Tree-DT (10.2%), Machine Learning (34.6%)	Son et al., 2012
Multistep Ahead Approach	16 - 26%	Conventional Single-Step approach (% not calculated)	Dursun et al., 2016
Case-based Reasoning (CBR)	7.5 – 12.9%	Multiple Regression Analysis	Ji et al., 2011
CBR	5.5 - 7.5%	Not compared	Ji et al., 2012
CBR	4.81%	Neural Networks (2.97%, 5.6%, 5.8%, 5.5%), Multiple Regression (6.95%)	Kim et al., 2004
Artificial Neural Networks (ANN)	8.1% (RMSE)	Linear Regression (RMSE-8.6%)	Wang et al., 2010

Such high percentage of prediction errors (per Table 2) among various cost estimation techniques highlights the need for developing better techniques to analyze and assess historical data to develop effective decision-support tools for estimators and decision-makers in the construction industry.

Newton in 1991 had highlighted a common trend in cost modelling research by suggesting that the emphasis was more towards analyzing non-specific and macro cost models, that use abstract units of measurements. Over the years, it is still seen that the cost models are developed based on total project costs, and by considering macro-project

variables (Dursun et al., 2016; Wang et al., 2010; Stoy et al., 2008; Kim et al., 2004), instead of analyzing the costs associated within a project.

SUMMARY

The importance of accurate construction cost estimation and its reason for being error prone was observed from the reviewed literatures. This literature review also highlights the high prediction error percentages (per Table 2) of existing cost models, and the need to analyze construction costs at a more detailed level, rather than considering the macro-level project costs for analysis purposes. This emphasizes on the need to select similar construction project types and analyze the behavior of the costs associated within the trades involved in such projects. In view of the same, a detailed methodology to perform such analysis has been presented in the following chapter.

CHAPTER 3

RESEARCH METHODOLOGY

INTRODUCTION

This chapter covers the approach towards analyzing the behavior of micro-level

construction costs by performing statistical analysis. This is done by obtaining a sample

of similar projects and statistically analyzing the variation in costs associated with

various construction activities. The steps involved in analyzing the distribution and

variations in construction costs based on CSI MasterFormat® division items are as

follows:

1. Perform cost breakdown of each project based on CSI MasterFormat® division
   items.

2. Determine the scope of work for each division item for maintaining a
   homogeneous set of data.

3. Formalize construction costs for each activity based on gross project area.

4. Perform descriptive statistical analysis of each division item (can also be called as
   construction activity).

PROJECT SELECTION & DATA SAMPLING

Selection of projects that are similar in nature with respect to occupancy type, location,

construction type, and nature of construction activity is important in order to perform

statistical analysis of a homogeneous set of project sample. In any construction project,

there are a multitude of independent variables such as gross area, project duration,

location, number of floors, occupancy type, topographic and demographic conditions,

construction type, and delivery method, etc. (Elfaki et al., 2014). These independent variables make the projects unique. It is because of the presence of so many independent variables in a project which makes it difficult to compare the project costs. Therefore, to minimize the deviation in the nature of such construction projects, most of the independent variables has been kept constant except for the gross project area. To summarize the nature of independent variables, projects that are considered for this study fall under the category of office tenant improvement projects. While at the same time, joisted masonry is the construction type, and design-bid-build is the delivery method for all of the projects. In terms of topographical conditions, all projects are located in major cities across Phoenix, Arizona.

Once the projects are selected based on the above mentioned constant independent variables, the next step is to breakdown the total project cost into identifiable set of construction activities. For this purpose, specifications based on CSI MasterFormat-2016 was chosen.

"MasterFormat is the specifications-writing standard for most commercial building design and construction projects in North America. It lists titles and section numbers for organizing data about construction requirements, products, and activities. By standardizing such information, MasterFormat facilitates communication among architects, specifiers, contractors and suppliers, which helps them meet building owners' requirements, timelines and budgets" (CSI MasterFormat® Numbers & Titles, 2016). It is important to note that the targeted office tenant improvement projects for this study were obtained from a single organization (which prefers remaining anonymous) based in Arizona.

As a result of the above mentioned steps, 51 projects were selected involving a total of 28 different construction and pre-construction activities as mentioned in Appendix A. These projects belong to the category of commercial tenant improvement projects involving no scope of new exterior build up, and only consists of interior remodel. The construction activities involved in the project samples have a definitive scope of work, which helps in minimizing sudden increase or decrease in the cost of construction. For example, the scope of activity involved in Heating, Ventilation and Air Conditioning (HVAC) division consists reworking of the ductwork to suite new office layout. This involves installation of new insulated ductwork as required, and installation of new or reused registers, grills, and diffusers as well. Final test and balance certification of the HVAC system is included in this cost. New air conditioning (AC) systems, packaged rooftop units, split systems, new condensate piping, and any related work that involves installation of new AC units are not considered in this case for any project.

The nature of scope of activities involved in each division item has been selected based on the majority of similar nature of activities performed in most of the tenant improvement projects. A cost breakdown of 51 projects were performed based on 28 construction activities within the defined scope of work (mentioned in Appendix A). Cost per square foot (cost/sf) data for each of these division items were calculated by dividing the cost of each division item with the gross project area. These cost/sf numbers are further used to carry out descriptive statistical analysis of each construction activity involved in a typical office T.I. project.
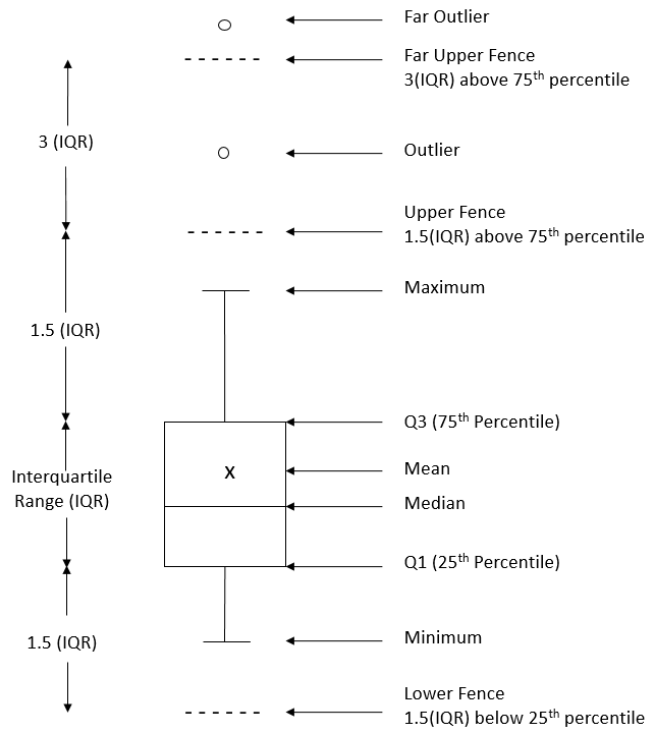
ANALYSIS OF COST VARIATIONS

With the help of cost/sf data for each division item corresponding to the 51 projects, the range, average, median, upper and lower quartile numbers, variance, and standard deviations were calculated using Microsoft Excel™ program. Each of the construction activity's cost/sf numbers were also represented graphically using the Box and Whisker plot (called as a boxplot hereafter) in Microsoft Excel™. A boxplot is generally used in explanatory data analysis. It helps in understanding the spread of data with respect to its central value (median), average, and also depicts the variability of the data. The boxplot also helps in analyzing the distribution of data with respect to its skewness and shows the unusual outliers in the data set (Statistics Canada, 2013). It should be noted that when a sample consists a large set of data, there exists a presence of outliers within the sample. Presence of outliers influences standard deviation to a great extent. Therefore, the variations in cost for each construction activity has been analyzed in terms of standard deviation under three conditions:

1. Standard Deviation-1 (SD-1): All values in a data set (including outliers) are considered while calculating the standard deviation.

2. Standard Deviation-2 (SD-2): In this case, extreme outliers are excluded while calculating the standard deviation. Extreme outliers are usually greater than three times the interquartile range (IQR) which are shown as dots beyond the whiskers in a boxplot as shown in Figure 1 below. Eliminating the extreme outliers will help in understanding the distribution of construction costs that generally occur in a typical office T.I. project.

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Figure 1

Presence of Outliers and Extreme Outliers in a Boxplot (adapted from Cross Validated, 2016).

Far Outlier

Far Upper Fence
3(IQR) above 75th percentile

3 (IQR)

Outlier

Upper Fence
1.5(IQR) above 75th percentile

Maximum

1.5 (IQR)

Q3 (75th Percentile)

Interquartile
Range (IQR)

X   Mean

Median

Q1 (25th Percentile)

1.5 (IQR)   Minimum

Lower Fence
1.5(IQR) below 25th percentile

3. Standard Deviation-3 (SD-3): To further analyze the central tendency of the data

set, statistically significant data points that are within mean plus or minus three

times the standard deviation (mean ± 3*SD) are considered for this standard

deviation calculations. Based on the probability distribution graph shown in

Figure 2, the range of data within mean ± 3*SD constitutes 99.7% of statistically

significant values. It is also observed in large data sets, such as in this case, there

are instances that has null probability of occurrence. Generally, only 5% of the

data is considered to show a deviation that is mean plus twice as much of SD, and

between 0.3% to 0.1% chances of occurrence for values beyond mean plus three

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times the SD. The standard deviation calculations for this data set will neglect the values that have almost a null probability of occurrence and is believed to represent 99.7% of the overall sample size.

Figure 2

Distribution of a Data Set Based on Standard Deviation (STAT 200, 2016).
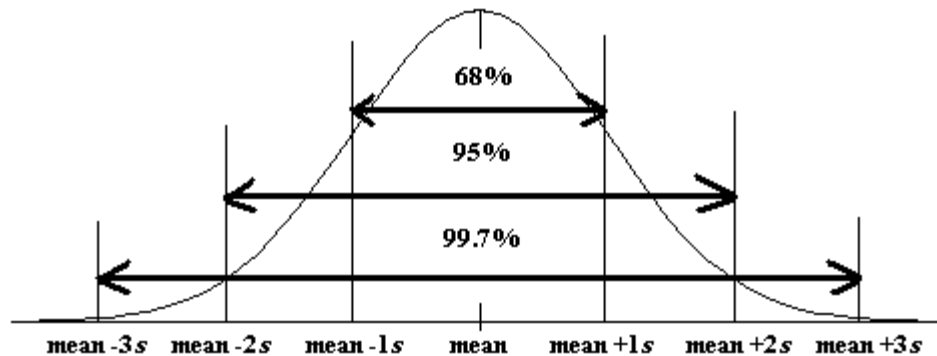
SUMMARY

In this section, a sequential description of the analysis being performed to understand the variation in construction costs is mentioned as follows:

1. For all of the 28 activities that were found to be performed in one or many of the 51 sample projects, the sample size for each construction activity was obtained.

2. Construction activities that were not performed in less than 16 projects (out of the total 51 projects) are considered to be less relevant for further in-depth analysis and are not considered for further perusal.

3. Statistical data like the minimum (min.), maximum (max.), average (avg.), median (med.), quartile-1 (Q1), quartile-3 (Q3), variance (var.), and standard deviation (SD) for the remaining construction activities throughout the 51 project

samples are calculated in terms of their cost/sf numbers with the help of following Excel™ formulas:

a) Minimum – "=min (range of values)"

b) Maximum – "=max (range of values)"

c) Average – "=average (range of values)"

d) Median – "median (range of values)"

e) First Quartile (Q1) – "quartile(range of values,1)"

f) Third Quartile (Q3) – "quartile(range of values,3)"

g) Variance – "var (range of values)"

h) Standard deviation – "stdev (range of values)"

4. A box plot is then plotted using Microsoft Excel™ for each of these construction activities which depicts the spread of data, the interquartile range, mean, median, and the presence of outliers corresponding to each division item.

5. To understand the variations in construction cost for each construction activity, standard deviations (SD) are calculated for three data sets:

$$\text{i.} \quad SD-1 \; (\sigma_1) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\bar{x}-x_i)^2} \qquad\qquad (1)$$

$$\text{ii.} \quad SD-2 \; (\sigma_2) = \sigma(\forall x \; [x \leq \{Mean + (3*SD)\}]) \qquad\qquad (2)$$

$$\text{iii.} \quad SD-3 \; (\sigma_3) = \sigma(\forall \; x \; [x \leq 3*IQR]) \qquad\qquad (3)$$

Where 'x' are the data samples in cost/sf, and 'IQR' is the interquartile range. The findings from the above step will be further used for discussions and qualitative analysis of the behavior of each construction activity.

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CHAPTER 4

DATA COLLECTION AND ANALYSIS

INTRODUCTION

This chapter presents the approach towards data collection and sampling, its analysis, and thus present the results of the analysis being performed. Variations and the spread of construction activity costs in terms of gross project area has been shown with the help of a boxplot, and the statistical findings have been presented in subsequent tables. A final table showing the standard deviations (SD-1, SD-2, and SD-3) for three set of data samples has been further presented. As a result of this analysis, variations in construction costs (as a function of gross project area, represented in terms of cost/sf) for CSI division items (or construction activities) has been presented with the help of bar graphs and is a result of this research. Furthermore, a qualitative analysis of the variations observed in construction costs has been has been presented, and is thus a supplemental submission to this thesis.

PROJECT SELECTION

This research considers 51 office tenant improvement projects carried out by a single organization located in the southwest region of the United States. These 51 projects were carried out during the period of late 2015 till September 2016. These projects cover a total construction area of 909,514 square feet, and involves construction costs worth $25.2 million. Each of the project samples selected for this research comprised of the construction activities that are listed in Appendix A. It is important to note that the above mentioned construction cost does not involve markup costs such as overheads & profits,

supervision, insurance, performance, and bond costs. Considering these markup costs, the total cost of completing these projects comes to around $31.2 million.

With the help of CSI MasterFormat® divisions, construction activities were categorized into 28 division items, whose costs/sf data has been used for statistical analysis for this study.

STUDY OF CONSTRUCTION ACTIVITIES

Once the construction costs were divided for each construction activity (which were within the preview of the scope of work as described in Appendix A), next steps involved the selection of construction activities that were performed in at least 16 projects from the sample of 51 projects under consideration for this study. A result of this analysis is shown in Table 3.

The reason for omitting construction activities performed in less than 16 projects for a statistical analysis is based on the reasons described below, which is also as per information obtained from industry sources during the data collection period. The construction activities that are not considered for further analysis have been described as follows:

1. Permits/Development Fees/Utility Charges (CSI Division – 1215.20): Costs pertaining to obtaining permits form the city officials are generally carried out by the owner. The costs associated with this CSI division item is solely dependent upon state and federal regulations. Deviations in interior design, or construction type does not negate the need of obtaining permits for construction, demolition, installation of fire protection systems, utility connections, and other city related taxes and costs. It is also

evident form the fact that out of 51 projects under consideration, only 11 projects

(21.6% of total sample size) involved the general contractor to obtain permits on

behalf of the owner.

Table 3

Sample Size of Construction Activities from a Total of 51 Projects

Sl. No	CSI Code	Description	Sample Size	
1	1002.50	Reimbursables, Plans & Specs	51	100.0%
2	1215.20	Permits/Development Fees/Utility Charges	11	21.6%
3	1714.00	Construction Clean-up	51	100.0%
4	2411.60	Site Construction/Demolition	49	96.1%
5	32130.00	Site Concrete (Pavements & Sidewalks)	1	2.0%
6	3001.00	Building Concrete	28	54.9%
7	4001.00	Masonry	3	5.9%
8	5400.00	Metals/Structural Steel	15	29.4%
9	6400.00	Woods, Plastics & Composites	47	92.2%
10	7210.00	Thermal & Moisture Protection	51	100.0%
11	8110.00	Openings (Doors, Glass, & Frames)	48	94.1%
12	9200.00	Finishes (Framing & Drywall)	50	98.0%
13	9500.00	Ceiling Tile and Grid	47	92.2%
14	9680.00	Flooring	50	98.0%
15	9900.00	Painting	51	100.0%
16	10440.00	Specialties	42	82.4%
17	11130.00	Equipment	4	7.8%
18	12200.00	Furnishings (Window Treatments)	26	51.0%
19	21100.00	Fire Protection (Sprinklers and Piping)	50	98.0%
20	22100.00	Plumbing	47	92.2%
21	23050.00	HVAC	50	98.0%
22	23090.00	Energy Management System	17	33.3%
23	26050.00	Electrical	50	98.0%
24	28310.00	Fire Life Safety Systems	42	82.4%

2. Site Concrete (CSI Division – 32130.00): This division generally covers concrete used in pavement, sidewalks, sidewalk ramps, pipe bollards, housekeeping pads, and other miscellaneous concreting. Only one of the projects had the scope of constructing a concrete pad for resting a heavy specialized equipment to be used by the tenant. Pavement and sidewalk constructions are often considered in infrastructure development and hence this line item can be disregarded.

3. Masonry (CSI Division – 4001.00): At times it is required that the exterior masonry façade of a tenant space needs to be demolished or reworked. Reworking of the exterior façade consisting of stone, stone veneer, and/or simulated/manufactures stone is also included in this scope of work. It was observed that 3 out of 51 projects (5.9%) involved reworking of masonry walls in its scope. Due to less relevance of this line item among the sample under analysis, this construction activity has been omitted from further analysis.

4. Metals/Structural Steel (CSI Division – 5400.00): Out of the 51 projects under consideration, 15 projects (29.4%) involved some kind of metal or structural steel rework, fabrication, and installation in existing space. This type of work is usually required when there is a new roof opening for HVAC unit/s or condenser platforms. Projects involving this scope of work comprised the construction of water heater (and other such heavy equipment) stands, pipe bollards, and chain link fencing inside the office space. Structural steel rework for roof structure repair, ornamental steel panels for better aesthetics, and the aforementioned scope of work are required in special cases and cannot be generalized for all tenant improvement type projects.

5. Equipment (CSI Division – 11130.00): Office TI projects seldom require the general contractor (GC) to provide for equipment such as bank and vault, vending machines, dock equipment, racking and shelving, appliances such as dishwasher, refrigerator, oven unit, ice maker, etc. Such equipment and appliances are usually covered by the tenant themselves and the contractor has to make arrangements for providing water lines, and fixing it in place. Among the sample of projects under consideration, 4 projects (7.8%) required the GC to purchase and install such equipment. Also because of the standardized costs of such equipment that are readily available in the market, this is not considered for further analysis.

STATISTICAL ANALYSIS OF CONSTRUCTION COSTS

This section consists of analyzing the distribution and variations in cost/sf data pertaining to 19 construction activities from a total of 51 project samples. These activities are selected based on its occurrence among the sample of projects under consideration. A summary of the statistical analysis for selected construction activities are presented in Table 4. Data (in terms of cost/sf) pertaining to each construction activity across all 51 project samples has been analyzed for the minimum (Min.), maximum (Max.), average (Avg.), first quartile (Q1), third quartile (Q3), variance (Var.), and standard deviation (SD). In order to graphically understand the variations in construction costs, a box and whisker plot is plotted for all 19 construction activities. This boxplot is depicted in Figure 3. A boxplot helps in better understanding of the spread of data which is one of the objectives of this research.

Table 4

Results of Descriptive Statistical Analysis of Construction Activity Costs.

Sl. No.	CSI Code	Description	Min	Max	Avg.	Med.	Q1	Q3	Var.	S.D.
1	1002.50	Reinbursables, Plans & Specs	0.005	0.272	0.064	0.054	0.025	0.079	0.003	0.057
2	1714.00	Construction Clean-up	0.085	1.832	0.511	0.355	0.281	0.693	0.133	0.364
3	2411.60	Site Construction/Demolition	0.026	6.230	1.418	1.065	0.481	1.765	1.942	1.394
4	3001.00	Building Concrete	0.038	1.355	0.326	0.215	0.138	0.338	0.095	0.309
5	6400.00	Woods, Plastics & Composites	0.148	25.047	2.655	1.601	0.798	2.896	14.877	3.857
6	7210.00	Thermal & Moisture Protection	0.033	8.788	1.232	0.615	0.309	1.724	2.469	1.571
7	8110.00	Openings (Doors, Glass, & Frames)	0.035	18.206	4.181	3.453	1.570	5.302	14.023	3.745
8	9200.00	Finishes (Framing & Drywall)	0.935	19.143	4.892	4.126	2.780	5.310	13.631	3.692
9	9500.00	Ceiling Tile and Grid	0.076	7.426	1.735	1.534	0.956	2.308	1.556	1.247
10	9680.00	Flooring	0.345	6.314	3.479	3.590	2.776	4.300	1.760	1.327
11	9900.00	Painting	0.182	8.894	1.388	1.008	0.698	1.448	1.873	1.369
12	10440.00	Specialties	0.023	2.327	0.431	0.230	0.084	0.585	0.273	0.522
13	12200.00	Furnishings (Window Treatments)	0.026	1.889	0.640	0.471	0.245	0.849	0.324	0.569
14	21100.00	Fire Protection	0.155	3.406	0.946	0.904	0.596	1.143	0.302	0.550
15	22100.00	Plumbing	0.087	10.710	2.264	1.392	0.746	2.282	6.227	2.495
16	23050.00	HVAC	0.321	9.043	3.790	3.491	2.330	5.405	5.298	2.302
17	23090.00	Energy Management Systems	0.172	1.833	0.757	0.640	0.443	1.057	0.219	0.468
18	26050.00	Electrical	1.550	13.481	4.935	4.183	2.750	6.355	6.724	2.593
19	28310.00	Fire Life Safety Systems	0.208	4.761	1.093	0.916	0.524	1.276	0.868	0.932

Note: All Data in Cost/SF

Figure 3

Boxplot Showing the Spread of Data for Construction Activities.
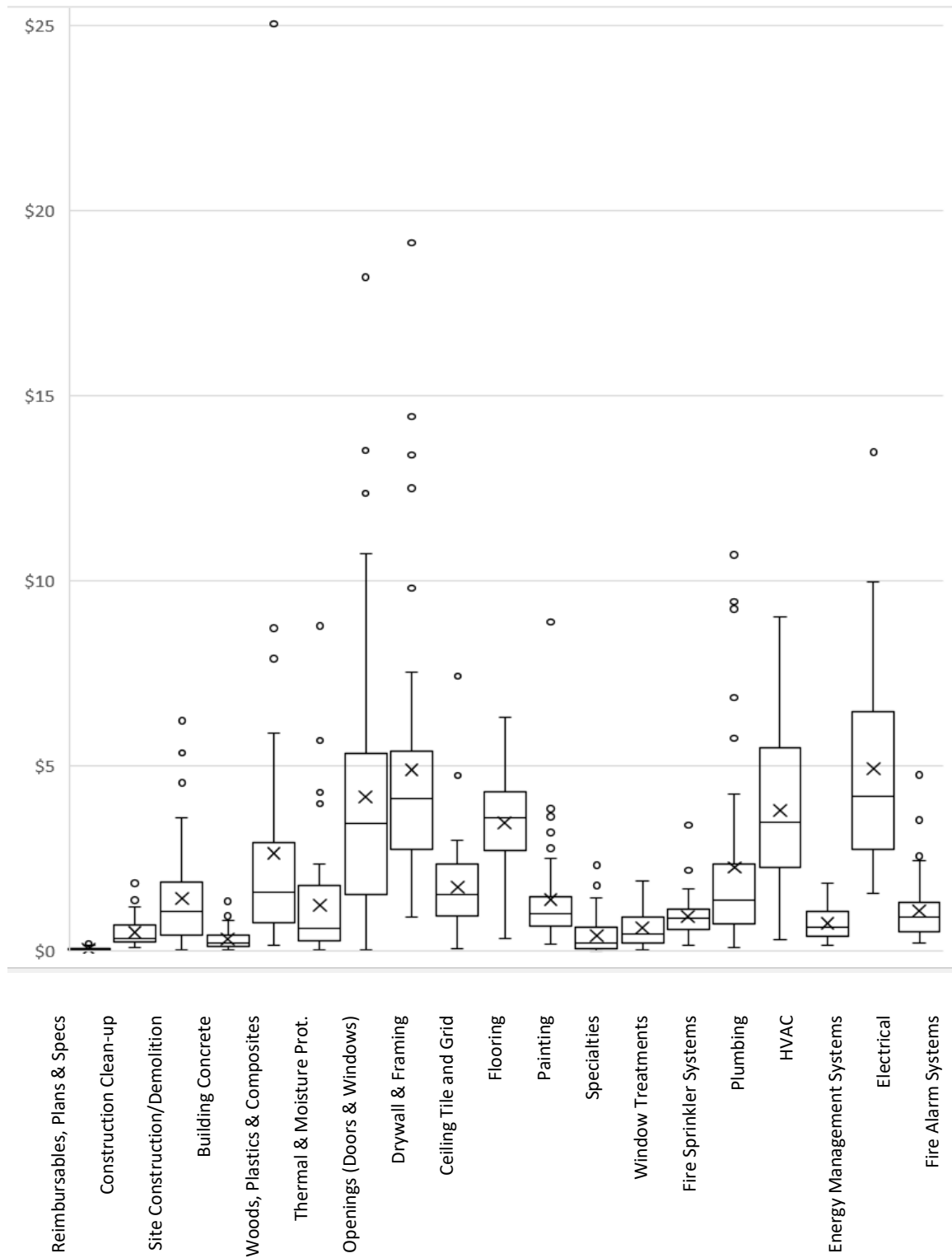
It can be seen in Figure 3 that there are several outliers and extreme outliers are present in most of the construction activities. In order to better understand the variations in construction costs, standard deviations for each construction activity excluding these extreme outliers and statistically insignificant data samples as mentioned in equations (1), (2), and (3) are calculated further.

Based on the probability distribution of data samples for a normally distributed range, data samples that are greater than mean plus or minus three times the standard deviation (mean ± 3*SD) are typically considered statically insignificant. There is almost a null probability of occurrence of such events. This is also shown in Figure 2 that the probability of occurrence of values greater than the mean plus/minus two times the SD (mean ± 2*SD) has less than 5% chances of occurring, and the chances for values beyond (mean ± 3*SD) is less than 0.3%. In view of the same, a second set of standard deviations (SD-2) has been calculated that analyzes the deviation in construction activity costs considering the most statistically significant data set only (i.e. within mean plus/minus three times the SD).

Extreme outliers, as depicted in Figure 1 above, significantly affect the standard deviation of a data set. These values usually do not represent the true nature of a data set, and hence are shown outside the whiskers away from the interquartile range of a data set. To analyze the behavior of construction costs without considering these extreme outliers, SD-3 is calculated which will provide a more accurate variation analysis of the construction costs.

A result of the above mentioned standard deviations has been presented in Table 3 which depicts the standard deviations for a) all values including extreme outliers and

statistically insignificant data samples (represented by Equation 1), b) all values except

the statistically insignificant data samples (represented by Equation 2), and c) all values

except the extreme outlies (represented by Equation 3).

Table 5

Observed Standard Deviations for Construction Activities

Sl. No.	CSI Div.	Description	SD-1 (all values)	SD-2 (x ≤ Mean + [3*IQR])	SD-3 (x≤[3*IQR])
1	1002.50	Reinbursables, Plans & Specs	0.057	0.040	0.035
2	1714.00	Construction Clean-up	0.364	0.315	0.290
3	2411.60	Site Construction/Demolition	1.394	1.072	0.962
4	3001.00	Building Concrete	0.309	0.202	0.111
5	6400.00	Woods, Plastics & Composites	3.857	1.955	1.469
6	7210.00	Thermal & Moisture Protection	1.571	0.952	0.829
7	8110.00	Openings (Doors, Glass, & Frames)	3.745	3.156	2.549
8	9200.00	Finishes (Framing & Drywall)	3.692	2.153	1.792
9	9500.00	Ceiling Tile and Grid	1.247	0.925	0.804
10	9680.00	Flooring	1.327	1.327	1.087
11	9900.00	Painting	1.369	0.780	0.428
12	10440.00	Specialties	0.522	0.433	0.376
13	12200.00	Furnishings (Window Treatments)	0.569	0.569	0.458
14	21100.00	Fire Protection	0.550	0.424	0.368
15	22100.00	Plumbing	2.495	1.550	1.015
16	23050.00	HVAC	2.302	2.302	2.302
17	23090.00	Energy Management Systems	0.468	0.468	0.468
18	26050.00	Electrical	2.593	2.593	2.305
19	28310.00	Fire Life Safety Systems	0.932	0.624	0.431

NOTE: All data in Cost/sf. IQR - Interquartile Range

RESULTS

To understand the deviations in construction cost for 19 construction activities as shown

in Table 5, a bar chart has been plotted. Figure 4 represents three different standard

deviations of cost/sf data for 19 construction activities that are typically involved in

office tenant improvement projects. These three standard deviations for each construction

activity depicts the nature of fluctuations in cost among different projects.

Figure 4

Bar Chart Showing Variation in Standard Deviations.
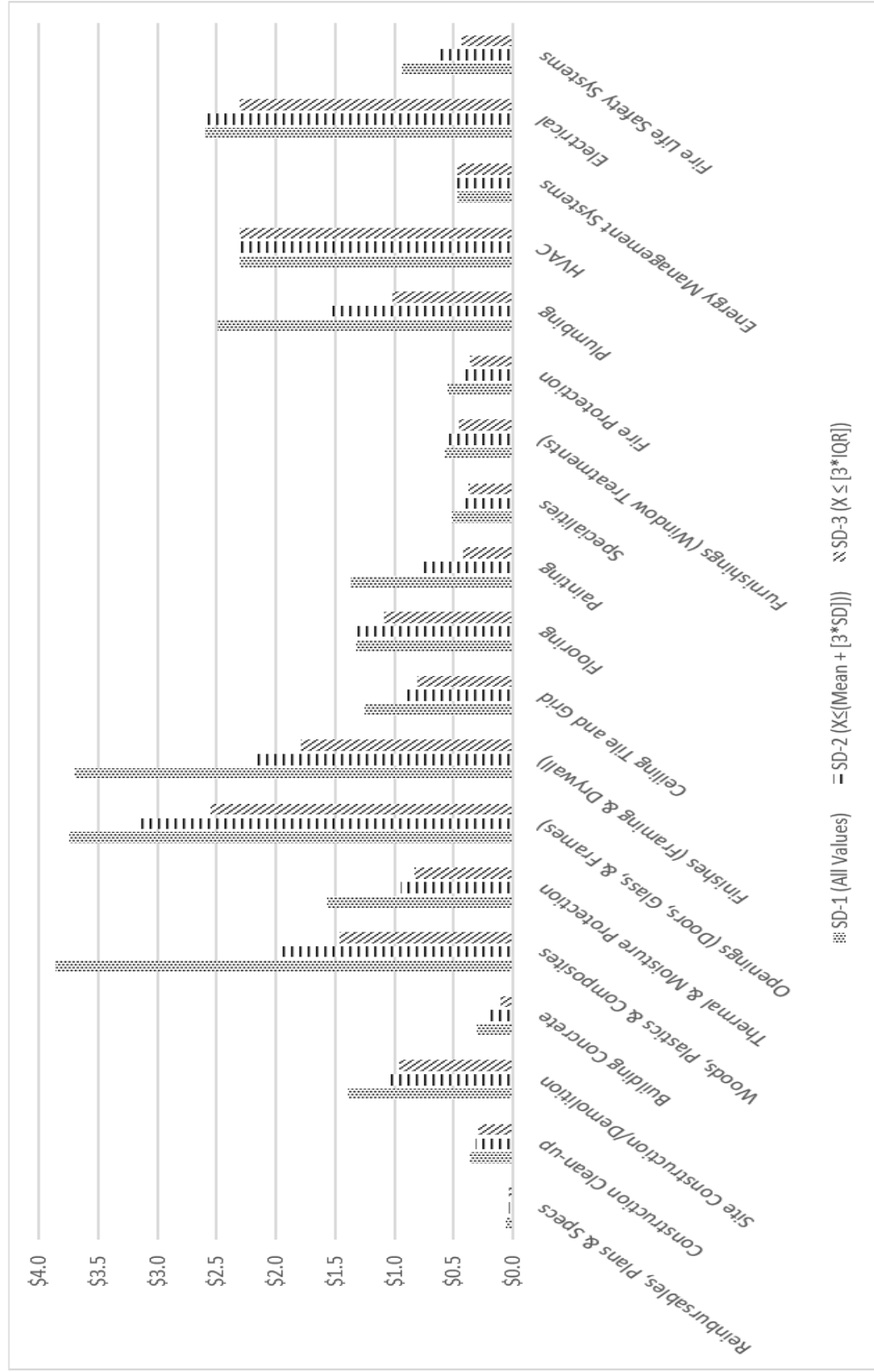
As per the boxplot and bar chart shown in Figure 3 and Figure 4 respectively, it is observed that interior finishing activities such as Woods/Plastics & Composites (also called as Millwork), Openings (door, frames, & windows), and Finishes (drywall & framing) activities show the greatest cost deviation at $3.86/sf, $3.75/sf, and 3.69/sf respectively, when considered for all values in the data set.

When statistically insignificant data are excluded from standard deviation calculations (SD-2), Openings, Electrical, and HVAC trades show the highest deviation in cost/sf values at $3.16/sf, $2.59/sf, and $2.30/sf respectively.

And when extreme outliers are excluded for standard deviation calculations (SD-3), once again Openings, Electrical and HVAC trades show the highest deviations at $2.55/sf, $2.305/sf, and $2.301/sf respectively.

This shows that Openings, Electrical, and HVAC trades generally have a high deviation in its costs, along with high cost of construction as well. At the same time, the interior finishing trades (such as Millwork, Openings, and Drywall construction activities) show a high range of variation in its costs.

The least amount of cost/sf deviations across the three SD calculations were observed for Reimbursables, Plans and Specifications (between $0.06/sf to $0.03/sf), Building Concrete ($0.31/sf to $0.11/sf), Clean-up ($0.36/sf to $0.29/sf), Energy Management Systems (EMS) ($0.47/sf), Specialties ($0.52/sf to $0.37/sf), Sprinkler systems ($0.55/sf to $0.37/sf), Window treatments ($0.57/sf to $0.46/sf), Fire Alarm Systems ($0.93/sf to $0.43/sf), Ceilings ($1.24/sf to $0.80/sf), Flooring ($1.33/sf to 1.08/sf), Painting ($1.37/sf to $0.43/sf), Demolition ($1.39/sf to $0.96/sf), Insulation ($1.57/sf to $0.83/sf), and Plumbing ($2.49/sf to $1.01/sf) when arranged in ascending order of standard deviations.

SUMMARY

Based on the statistical findings, a summary of the results has been summarized as follows:

1. The cost of construction for carrying out interior finishes (which includes millwork, insulation, doors & windows, drywall & framing, ceiling, flooring, and painting) collectively cost over 50% of the total project cost. While the lower division items such as sprinkler systems, plumbing, HVAC, electrical, energy management systems, and fire alarm systems cost around 42% of the total construction cost for all the projects considered for this study.

2. The highest deviation in construction costs along with the highest number of extreme outliers were observed for Openings (doors, frames, & windows), and Flooring construction activities.

3. The highest average cost of construction for a single construction activity were observed for HVAC and Electrical trades at 11% and 15% respectively.

4. Overall, the trades representing interior finishing activities showed a greater variation in its cost when compared to the mechanical, electrical, and plumbing (MEP) trades. This indicates the possibility of a higher predictability index during conceptual estimating stages for MEP trades rather than the interior finishing trades.

5. Only 33% of the projects observed in this study had an Energy Management System (EMS) in its space. This indicates the vast opportunity for energy savings in the remaining 66% of the projects which do not have these systems in place.

CHAPTER 5

DISCUSSIONS

INTRODUCTION

As evident from the results that out of 19 construction activities involved in office tenant

improvement projects, only 5 construction activities (Openings, Electrical, HVAC,

Millwork, and Drywall construction) were found to be showing the highest range of

standard deviations and cost/sf values. While there are other trades such as Plumbing,

Flooring, Interior Demolition, and Insulation that involve a significant high amount of

construction costs, the deviations are comparatively less and can be predicted with

accuracy while estimating for such projects.

ASSESSMENT OF HIGH VARIANCE CONSTRUCTION ACTIVITIES

A qualitative analysis of the high variance construction activity has been presented below

which will help readers to understand the cause of such high deviations, and enable for

better planning during design and estimation stages.

1. Openings (Doors, Glass, & Frames): One of the main findings of this research is

    realizing the nature of high variation in the cost of doors, glass, and frames

    involved in office TI projects. This construction activity has shown the highest

    value of IQR ($3.7/sf), standard deviations ($3.75/sf, $3.2/sf, and $2.5/sf for SD-

    1, 2 & 3 respectively), and the largest range of values as evident form the boxplot

    as well. Unlike other ground-up and new construction projects, where mechanical,

    electrical, and plumbing trades cost the highest among other construction

    activities, it is seen that the cost of providing and fixing doors, windows, and

frames in office TI projects cost an average of 9% to 10% of the total construction cost.

One of the main reasons for such high deviation in its cost can be attributed to the vast variety of door, frame, and glass types which can be used in an office. With specialized glass wall systems, and hollow metal frames installed in an office, the cost of material procurement and installation goes up when compared to other regularly used door and frame types. Hence, it should be important during conceptual stages of design development to specify the type of doors, frames, and glass that are intended to be used in the project in order to estimate its cost accurately.

2. Electrical: Electrical jobs are regarded as one of the most expensive construction activities. The same was observed in this study that an average of 15% of the total construction cost is required for reworking the light fixtures, installing power and data connections, and associated wiring for the same. The deviations measured in its costs were also observed to be the second highest with a range of $2.6/sf to $2.3/sf with a presence of only one outlier. Although the cost associated with electrical activities in office TI projects were found to be the highest, the presence of only one extreme outlier and no statistically insignificant data samples indicate that there is a definitive range of cost/sf that can be predicted with high accuracy while preparing cost estimates during conceptual stages of a project. The limited purchase of new electrical fixtures and materials, and more reuse of existing materials leaves only one variable (i.e. labor costs) to be determined with higher accuracy. This in turn depends upon the schedule and duration of the projects.

Hence, it can be also said that the duration of TI projects affects the cost of electrical activities.

3. HVAC: Generally, office TI projects need reworking of existing air handling ducts, registers, grills, and diffusers by relocating and rearranging them to suite the new office layout. To maintain a similar and homogeneous scope of work for this trade, projects were selected based on similar scope of work across all construction activities involved in tenant improvement projects. Hence, it should be noted that, although some tenant improvement projects need new air conditioning systems, or at times need a complete retrofit of their existing HVAC system, the projects under observation for this research does not involves any new HVAC system installation or retrofitting.

Based on the scope of work mentioned for this trade, the average and the total cost of construction for this division item were observed to be 11% and 16% respectively. This trade showed the second highest amount of cost involved when compared with other construction activities. At the same time, it is important to note that there were no extreme outliers and no statistically insignificant data samples for this trade. Deviations in construction costs were same for all three standard deviations at $2.3/sf. This deviation in its cost is only next to openings, electrical, and millwork trades, implying a significantly higher range of cost values. It is observed that the absence of extreme outliers indicates an ease in determining the range of cost/sf during estimation at pre-construction stages. The average cost of construction was observed to be $3.80/sf, which is fourth highest when compared to other construction activities. Such high cost of construction, a

definitive range of cost/sf data, and no presence of extreme outliers, implies that HVAC trade involves the one of the highest proportion of construction cost that needs more time and efforts during estimation. It also suggests that HVAC trade can possibly show a lesser prediction accuracy in cost modelling approaches and hence its scope and specification needs to be well defined during estimating stages.

4. Woods, Plastics, and Composites: Also termed as 'millwork' in the industry, the presence of one extreme outlier ($25.05/sf), which is also the highest cost/sf data among the entire data set, has resulted in the highest standard deviation when considered for all the values. When this extreme outlier is neglected, the standard deviation varies between $1.5/sf to $1.95/sf for statistically significant samples and within the limits of the boxplot. This also has a good spread of data within an IQR of $2.1/sf. This IQR is the 5th largest value observed among the 19 construction activities being analyzed. It has been learned from the industry sources that such high variations in cost for this activity is due to a gap in the demand and supply. Manufacturers tend to quote high prices when there is a lot of demand in the market. This phenomenon is seen only for this trade during the recent days as per the industry sources, which has resulted in such high variations in construction cost for millwork. This is an excellent example of how external market and economic factors affect the construction costs.

5. Finishes (framing and drywall construction): With a significant amount of deviation in costs/sf data ($3.7, $3.2, and $2.5/sf for SD-1, 2, & 3 respectively) as compared to other construction activities, and around 12% (6 out of 50) of the

data being extreme outliers, the construction of interior partition walls, and other constructions using drywall comprised of around 13% of total construction cost for the observed projects. This was the second highest construction cost observed only after the cost of Electrical trade. It is important to note that in terms of pre-project planning and estimation, this construction activity would take one of the highest priorities to determine its cost considering the vast variations observed for this trade.

6. Flooring: It was observed from the boxplot that 20% (10 out of 50) projects have shown extreme outlier values, while at the same time none of its values were statistically insignificant. The only other construction activities that have all its values statistically significant are the HVAC and Electrical trades. Cost for providing new flooring ranges between 10% to 12% of the total construction cost which is the fourth highest among other activities mentioned above. It is also important to note that the deviations shown in cost/sf values is less when compared to other interior finishing trades. This leads to the conclusion that the knowledge of the specifications of flooring material to be used in a project should be well defined during estimation, and the costs of flooring materials, although being less variant, constitute a large proportion of total construction cost.

7. Energy Management Systems (EMS): This construction activity is important to be analyzed for two main reasons, viz., a) this study shows that over 66% of the projects considered for this study did not have an energy management system, and b) the cost of re-programming and maintenance of EMS is among the least observed when compared to other trades.

Observations made in this study indicate a low cost of maintenance and re-programming of EMS for an office space. With an average cost of $0.75/sf, and no presence of extreme outliers or any statistically insignificant data, the cost of maintaining an EMS for an office space is one of the least expensive and less cost variant ($0.46/sf) activity. Despite of such low costs involved, there were only 33.3% (17 projects) of the total 51 projects which had an energy management system in its space. This indicates a vast scope for energy efficiency measures which could be taken in order to reduce energy costs in commercial office buildings.

PRACTICAL IMPLEMENTATIONS

This research is intended to provide valuable feedback and information to the construction industry and also to the organizations which are involved in performing commercial tenant improvement projects. Through this research, the high variance construction activities are analyzed and their deviations in cost per square foot data is obtained from a sample of 51 office TI projects. Construction activities such as Openings (Doors, Frames, and Windows), Electrical, HVAC, and Finishes (Drywall & Framing) trades show the highest variance in its costs. Also, the data analysis indicates that on an average, 55.25% of the total construction costs are generally consumed by these four construction activities in office TI projects. In view of these findings, and also considering the lack of cost modelling technologies available in the market, these findings were shared with a few industry mentors from whom the data was obtained. A summary of their

observations and comments pertaining to the data analysis and research findings are mentioned as follows:

1. Importance of Obtaining Material Specifications during Conceptual Stages: Due to deviations ranging from $3.86/sf to $2.30/sf for the four construction activities mentioned above, the importance of obtaining material specifications for interior finishing trades, and other specific requirements for Electrical and HVAC trades were emphasized by the industry mentors. These specifications, if provided during the early conceptual estimation stages, should help in obtaining realistic conceptual estimates which could be helpful to form decisions regarding the project. With the help of material specifications for interior finishing trades, the estimate data which is saved over a period of time would help in budgeting future projects with a higher accuracy.

   In addition to this, it was also commented by the mentors that providing specifications for flooring material during early conceptual estimating stages is already in practice. It was told that there is a common practice adopted by the architects to provide a list of building standard materials along with the conceptual plans to the general contractors or vendors to obtain pricing. A list of building standard materials help in providing detailed information about the specifications of materials and equipment that are used in the building either during the time of construction, or by other tenants using the same space, or indicates the specification of materials used in another building managed by the same owner. Hence, the importance of asking for building standard

material specifications, or a preferred list of materials from the owner/tenant for interior finishing activities, and also asking about specific requirements regarding Electrical and HVAC trades were mutually agreed by the industry mentors.

2. Retrieving a Few but All Construction Activity Costs from Historical Cost Database: Considering the huge quantum of raw historic estimating data accumulated over the past many years, retrieving cost figures for all construction activities is indeed a time and labor intensive task. Moreover, retrieving historic costs from each of the previously performed projects, and sorting the costs for each construction activity needs skill and knowledge by the person performing the activity. According to the industry mentors, retrieving historic costs from their database and storing them in new cost modelling software was the single most important and challenging task which kept them from purchasing new estimating tools. Such tools have a common requirement of defining construction activities, and providing historic cost figures in their systems in order to provide useful information about similar projects to be performed in future.

When it was observed that a few construction activities constitute over 50% of the total construction costs, and the same activities (openings, electrical, HVAC, finishes, and flooring) also show a high deviation in their cost/sf data, it was felt that instead of retrieving costs for all construction activities, if costs for specific high-variance construction activities are retrieved along with corresponding material specifications, the transition towards using a cost

estimation software would be much more quicker and require less skilled man-hours.

3. Using Only High-Variance Construction Activity Costs for In-House Development of In-House Cost Models: Considering the dynamic nature of the construction industry, and also by considering the fact that no two construction projects are same, a common cost modelling platform becomes very difficult to be used for a broad range of construction projects and organizations. Like the dynamic nature of various independent variables in construction projects, construction organizations adopt various different approaches towards arriving at cost figures for project estimation. The variability involved in independent variables such as project type, delivery method, project duration, geographical conditions, etc. makes a single cost modelling approach error prone. This can also be attributed to various different specification based systems (such as MasterFormat®, UniFormat®, etc.) that are adopted by different organizations to arrive at construction costs. This variability in defining project scope and subsequently its construction activities make the historical cost data unique for each organization. Upon discussions with industry mentors, it was felt that an in-house cost modelling tool could be developed using single/multiple regression analysis, case-based reasoning, or other artificial intelligent techniques (depending upon the budget of the organization, and skills of the estimators to use these models) which targets one construction type at a time (like commercial tenant improvement projects, commercial ground-up projects, infrastructure

redevelopment, multi-family residential township development, etc.). This could eliminate the variability of independent variables, and help in forming a uniform scope of construction variables to develop the appropriate cost model. Along with this, identifying high-variance construction activities for different project types, and using the same to retrieve specific historic construction activity costs form a company's database could help in minimizing time and efforts for implementing new cost modelling software in an organization.

SUMMARY

Out of the 28 construction activities that were recognized in the sample of commercial tenant improvement projects used for this research, five construction activities were neglected for further analysis because of its least occurrence in the overall sample of projects. From the final nineteen construction activities that were selected for statistical analysis, four construction activities showed the highest deviations in its cost and also constituted over 50% of the total construction costs. These four construction activities were Openings, Electrical, HVAC, and Finishes.

Feedback and reviews were obtained from industry mentors (from whom these construction costs were obtained) to understand the practical implementations of these research findings. It was mutually agreed by the industry mentors that only the high-variance construction activity costs can be used (neglecting other construction costs which showed lesser deviations) to retrieve historic costs and feed them into a cost modelling software, or it can also be used to develop an in-house cost model. Such statistical analysis approach to identify high-variance construction activity costs (that are

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based on a well-defined project scope) can be implemented for other project types as well. Identifying high-variance construction activities and using them to develop cost models, or using them as a benchmark for future cost estimates, could reduce the time and efforts put by estimators in arriving at conceptual cost estimates. These few valuable feedbacks obtained from the industry mentors indeed shows the significance of the research methodology being adopted to develop a decision-support tool for construction cost estimation.

CHAPTER 6

CONCLUSIONS

This research presents a specification-based, micro-level statistical analysis of construction activity costs involved in commercial tenant improvement projects. Costs pertaining to construction activities performed in 51 commercial tenant improvement projects were compared with each other, and analyzed in terms of their standard deviations. This analysis resulted in finding four major construction activities (viz. Openings, Electrical, HVAC, and Finishes) which comprised over 50% of the total construction cost, and also showed the highest deviations among other construction activities.

To analyze construction costs at such level of detail is a complicated task and requires huge amount of time in data collection and sampling. This can be regarded as one of the limitations of this approach. Apart from this, data collected from a single organization, and difficulty in implementing this technique for conceptual cost estimation, where specifications are not fully developed, can be considered to be a few other limitations of this research. However, this research successfully demonstrates the use of a specification based, micro-level construction cost analysis technique that could be used for other types of construction projects, and in various different artificial intelligent cost modelling approaches as well. With the help of reviews obtained from industry mentors on the research findings, it was realized that only the high variance construction activity costs could be retrieved form historical cost database rather than having to retrieve costs for all construction activities. This could lead to savings in time and efforts, and also lead to quicker adaptation of cost modelling tools for construction organizations.

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APPENDIX A

SCOPE DEFINITION FOR CSI DIVISION ITEMS

Sl. No.	CSI Code	Description	Scope of Work
1	1310.00	Design & Engineering	Fees for architectural design, structural design, and consultation during preconstruction stages. Mostly in case of Design-Build projects.
2	1002.50	Reimbursables, Plans & Specs	Cost for reproduction (printing) of plans and specifications.
3	1215.20	Permits/Development Fees/Utility Charges	Cost of obtaining permits from City offices. Consists of plan review fees, building permit fees, sewer & water development, & tap fee, demolition permit, asbestos removal permits, etc.
4	1714.00	Construction Clean-up	Cost for maintaining a clean and safe workplace throughout project duration. Includes cost for final clean at project completion.
5	2411.60	Site Construction/Demolition	Cost for interior demolition to accommodate new layout and finishes. Includes demo of partition walls, removal of flooring, ceiling, millwork, and other interior finishes. Also includes termite pretreat in trenches.
6	33100.10	Utilities & SWPPP	Cost for laying utilities (water, waste water, and electricity). Includes bringing in power, and water connection from nearby source.
7	32130.30	Site Concrete	Consists of concreting sidewalks, ramps, curbs, and other site related concreting activities.
8	3001.00	Building Concrete	Cost of concrete pourback in plumbing trenches. Usually required for new plumbing connections for new sinks or restroom layouts.
9	4001.00	Masonry	Cost for repairs and construction of building masonry.
10	5400.00	Metals/Structural Steel	Consists of ornamental steel panels at building interior, stainless steel railings, steel for overhead doors, creating new roof openings, bollards, water heater stand, etc.

11	6400.00	Woods, Plastics & Composites	Consists of cost for rough and finished carpentry. Rough carpentry includes mount boards for television, creating new roof opening or roof patchwork. Finish carpentry includes custom made plastic laminate or solid surface countertops, caseworks, and cabinets. Includes Fiber-Reinforced Plastic (FRP) at restroom walls.
12	7210.00	Thermal & Moisture Protection	Cost for insulating interior partition walls, ceilings, and/or roof with fiberglass batt insulation as per specifications.
13	8110.00	Openings (Doors, Glass, & Frames)	Cost for purchase and installing new door, hardware, and frames. Includes glass for sidelites, windows and door vision panels.
14	9200.00	Finishes (Framing & Drywall)	Consists of framing and drywall fixing for interior partition walls, demising walls, wall furring, and gypsum board ceilings in restroom (typically), or as per plans and specs.
15	9500.00	Ceiling Tile and Grid	Rework or replacement of acoustical ceiling grid and/or tiles. Includes 2x2 and 2x4 grids with regular or tegular style tiles. Also includes cost for hanging steel wires for light fixtures and other ceiling mount devices.
16	9680.00	Flooring	New flooring throughout office space. This generally consists of carpet tiles in offices and conferences, vinyl flooring in kitchen, breakroom, storage, and other wet areas, ceramic tiles in reception area & restroom. Includes wall base (rubber or wood - as per plans).
17	9900.00	Painting	Cost for painting entire space with the level of finish as mentioned in drawings and specifications.
18	10440.00	Specialties	Cost for providing fire extinguishers with cabinets, and restroom partitions & accessories.

19	11130.00	Equipment	Includes cost for providing and fixing appliances like dishwashers, refrigerators, oven, ice maker, etc. in new office space.
20	12200.00	Furnishings (Window Treatments)	Cost for new blinds in office windows.
21	13340.00	Special Construction	Consists of costs for providing and fixing water features, misting systems, covered parking structures, and clean room construction.
22	14200.00	Conveying Systems	Cost of elevators, material handling systems, pneumatic tube systems, and hoists & cranes.
23	21100.00	Fire Protection (Sprinklers and Piping)	Rework existing fire sprinklers and piping to suit new office layout.
24	22100.00	Plumbing	Cost for providing and fixing new sinks, restroom accessories, capping of plumbing lines from previously located sink areas etc.
25	23050.00	HVAC	Consists of cost for reworking and providing new ductwork according to new office layout. Excludes any new air conditioning units.
26	23090.00	Energy Management System	Rework existing energy management system of the space to suite new office layout.
27	26050.00	Electrical	Consists of providing and fixing new power/data outlets, switches, circuits and connection, associated wiring, and reusing existing light fixtures to suite new office layout. Includes 20% replacement of damaged light fixtures. Excludes any major lighting retrofit and new lighting fixtures throughout office space.
28	28310.00	Fire Life Safety Systems	Cost for re-programming existing fire alarm system panel to suite new office layout.