Pre-Design Methodology for Establishing Scope-Budget and Scope-Duration Alignment for Capital Projects

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Dedication

The author dedicates this to the memory of his parents Paul F. and Mary Ann Holmlin.

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Abstract of Praxis

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It is well established that projects do not meet their cost, schedule and scope objectives and often fail to deliver the benefits that were hoped for. Part of the challenge is that at the conceptual/pre-design stage, the level of scope definition is often only 1-2% and the resulting pre-design cost estimates typically have an accuracy range of -50% to +100%. Project teams may not feel confident providing this information to the designers as design-to-cost targets and overall project cost management suffers as a result. The proposed methodology was developed to assist with pre-design estimating on a new student health center at a college in the mid-Atlantic region of the United States. Development of a preliminary work breakdown structure allowed development of a cost model targeted at the major cost elements of a capital project by removing cost elements such as sitework and general conditions that have greater variability that is often concealed in cost/SF historical data used for modeling. The regression equation developed, based on five data points of comparable projects ranging in size from 20,000SF to 72,714 SF , with a zero intercept, has an R^2 of 0.9925, a P Value <0.0001 and a F test score of 661.63. 63. Using the model to validate the cost of the comparable projects resulted in a cost forecast range of -10.3% to + 39.4% as compared to industry standard expected cost range in the pre-design period of -50% to+100%. Using the forecast cost and Bromilow equations to forecast project duration resulted in duration forecasts within approximately +/-18% of the contracted durations.

The need for vigorous cost management over the life of a project remains, but this methodology offers an approach to (1) develop design-to-cost targets and (2) for the project team to have greater confidence they have scope-budget and scope-duration matches as the project enters design.

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List of Symbols / Nomenclature

Ce	cost estimate; the estimate for the entity we are developing
C_e	Cost of the existing project being used as a comparable for the project being estimated
Cml	the most likely cost
Co	the optimistic cost estimate
Co	Cost at time 0; typically the time period the comparable project was constructed in
Cp	cost pessimistic; the highest cost expected
Ct	Cost at time t; typically the time period the estimate is being prepared in
Floor	Number of floors in the building
GFA	Gross Floor Area $(000\ m^2)$
I_e	Geographic cost indice for the comparable project
I_0	the value of the cost indice at the time the comparable construction contract was
I_l	Local geographic cost indice for the locality where the project being estimated is located
I_t	the value of the cost indice at time t when the project is being estimated to

Glossary of Terms

Estimate. A quantitative assessment of the likely amount or outcome (Project Management Institute, 2011).

Estimate Costs. The process of developing an approximation of the monetary resources needed to complete project activities. (Project Management Institute, 2011)

Pre-programming estimate. An estimate of the probable magnitude of total construction cost, usually based on single unit costs (such as dollars per gross floor area) for use in the earliest planning phases of a project. (National Research Council, 1990)

Program Estimate. An expression of probable total construction cost, usually based on a combination of single unit costs and theoretical costs as related to the functional program requirements of the facility and the general design concepts to which budget and the program of requirements relate. (National Research Council, 1990)

Project Estimating. The Act of creating a quantitative assessment of the likely amount or outcome. Project estimating is typically applied to project costs, resources, effort and durations. (Project Management Institute 2011).

Chapter 1 – Introduction

Projects are a widely used mechanism to allow organizations to execute their strategies. Unfortunately, projects also have a long history of being unsuccessful (Matta 2003). The most widely used criteria for success (to meeting scope, cost and schedule objectives) was identified by Steiner in 1969. More recently other success criteria have been identified (Williams, 2016). However, scope, cost and schedule continue to be widely used (and are often known as the "triple constraint" or the "iron triangle") (PMI, 2013; Williams, 2016). A recent McKinsey study observed that projects take 20% longer to be complete than was planned and exceed budget targets by 80% (Agarwal, 2016). More discouraging, the Project Management Institute, one of the leading project management professional associations, reported that on average organizations loose $109MM (US) for every billion dollars spent on projects (PMI 2014). Research on projects in Europe suggests that 24% of projects fail, 57% experience cost overruns and the average overrun is 30.5% (Holgeid 2013).

A silver bullet that will assure organizations of project success does not exist. However, project teams may be able to help set themselves up for success by implementing cost and schedule controls in the early phases of a project. Developing approaches to allow a project team to better estimate cost and duration prior to the start of design will start the project cost management effort at the earliest possible time and help set the project up for success by allowing the project team to give more complete instructions to the design team as they begin their work. This is particularly difficult to do because the level of scope definition is very limited in the early phases of a project. Historically, pre-design cost estimate have a very wide range of potential accuracy.

Sometimes known as order-of-magnitude estimates, the accuracy of these early phase estimate may range from -50% to +100% (AACEI, 2011). Estimates of project duration often rely on expert judgment which may be in short on supply some project teams.

Improved cost estimating and duration forecasting would allow a team to know they have a scope-budget and scope-duration match prior to beginning design. This will allow them to focus on managing variances from cost and schedule targets beginning early in the design phase. Better pre-design cost estimates and duration forecasts would also allow project teams to provide better guidance and direction to the architects and engineers (particularly in the area of design-to-cost targets).

One approach to this problem involves developing a preliminary work breakdown structure (WBS). Historical data from comparable projects would be used to develop a regression model for forecasting cost of the building element of the WBS. Sitework and general conditions vary widely project to project, so isolating those costs to be estimated locally (as opposed to incorporated into a cost model) may eliminate a source of variation in cost estimates.

The vehicle to try this approach is the planned design and construction of a new Student Health Center at the College of William and Mary. The objective of this project is twofold; first, to develop a cost model to allow the pre-design cost estimate of a new 23,000SF[1] student health center at the College of William and Mary. Second, to estimate the duration of construction of this project.

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[1] Initial information in the Request for Proposal for Architects set the gross floor area for the project at 23,000SF. During programming additional space requirements were identified and additional financial resources were obtained. The Praxis project was done based on the initial space needs in the RFP.

The project involves the identification and collection of data on four (4) comparable student health center projects (California State University San Marcos, Pennsylvania State University, San Jose State University and University of Kentucky) as well as one project well under construction that can be used to validate the model based on the guaranteed maximum price at contract (Duke University). These comparable projects, appropriately normalized to account for price level and geographic cost differences, will be used to develop a regression equation for cost forecasting.

Duration will be estimated base on several cost-duration models including Bromilow Models, Love-Tse Edwards formula and the Duration Square Root Rule as opposed to expert judgement.

Chapter 2: Literature Review

There are three bodies of literature important to this project; they include (a) project scope definition particularly through breakdown structures such as Work Breakdown Structures (WBS) or Cost Breakdown Structures (CBS), (b) cost estimating and (c) project time-cost relationships to help determine project duration.

2.1 Project Scope Definition

The Project Management Institute’s “Guide to the Project Management Body of Knowledge” defines project scope as “the work performed to deliver a product, service, or result with the specified features and functions” (PMI 2013). The PMBOK identifies six (6) processes that projects should undertake to develop and define a project’s scope. These include (1) Plan Scope Management, (2) Collect Requirements, (3) Define Scope, (4) Create WBS, (5) Validate Scope and (6) Control Scope (PMI 2013). For capital projects, the collection (identification) of requirements, defining of project scope and the creation of a Work Breakdown Structure (WBS) typically occurs during the design phase. By the completion of the design phase of the project, the construction documents (plans and specifications and other supporting materials) fully define the project.

The PMBOK identifies three (3) key documents that a project team develops to fully define the project scope baseline. The baseline include the Project Scope Statement, the Work Breakdown Structure and the Work Breakdown Structure Dictionary (PMI 2013). The central document is the Work Breakdown Structure (WBS) which identifies the deliverables that will need to be designed during the design phase of the project and constructed during the construction phase. The WBS, which often has the appearance of an organization chart, is defined as:

“A deliverable oriented hierarchical decomposition of the work to be executed by the project to accomplish the project objectives and create the required deliverables. It organizes and defines the total scope of the project. The purpose of a WBS is to serve as both a communicating tool and a method for coordination of the work (NASA 2012). Each descending level represents an increasingly detailed definition of the project work.... (PMI, 2006). Figure 1 depicts a generic Work Breakdown Structure.

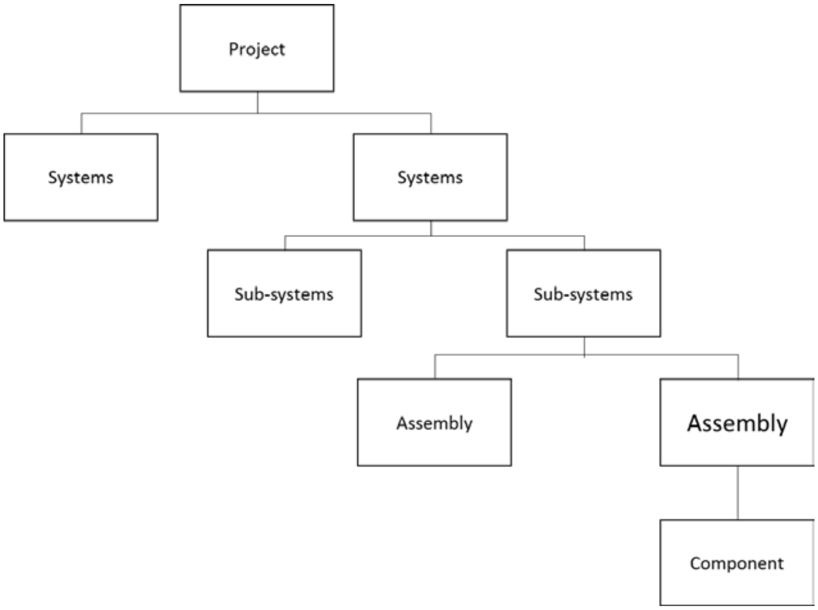

Figure 1 Generic Work Breakdown Structure

A complete WBS will allow for the aggregation of cost, schedule and performance information (DOE 2012). To achieve a “complete” WBS, the 100% rule is often applied to WBS. The lower level elements (sometimes call the children or child level) should represent all of the level above (sometimes called the parent level). The 100% rule states that “the next level of decomposition of a WBS element (child level) must represent 100% of the work applicable to the next higher level (parent)" (DOE 2012).

The benefits of developing a WBS include (1) the segregation/identification of a project into components, (2) facilitation of effective project planning and assignment of responsibilities to the project team, (3) serves as a basis for master schedules, (4) provides visibility of work for management, and (5) aids in the tracking and statusing of work (DOE 2012).

The upper levels of a WBS can be organized in several ways. The high level elements may be organized by product, phase or geographically (PMI 2013, DOE 2012). While some organizations prescribe the organizing principle, other organizations say specifically that there is no one correct approach to prepare and utilize a WBS (DOE 2012, NASA 2013). However it is organized, as noted in the Department of Energy's Work Breakdown Structure Handbook, "the WBS defines the products to be developed and /or produced. It relates the elements of work to be accomplished to each other and the overall project end product" (DOE 2012). The WBS should include both the various products (deliverables) that the project is charged with creating as well as common or support elements such as project management, safety, training, and systems engineering (NASA 2013).

For larger projects there are often three categories of WBS that nest together. These include the Project Work Breakdown Structure (PWBS) which includes all of the work of the entire project, the Contract Work Breakdown Structure (CWBS)[2] which

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[2] There are well over a dozen different "breakdown structures" used in project management. Several share the same sets of initial. For instance, the Cost Work Breakdown Structure (CWBS) and the Contract WBS. Or the Risk Breakdown Structure (RBS) and the Resource Breakdown Structure RBS). The project team must be careful in identifying which breakdown structure they are talking about.

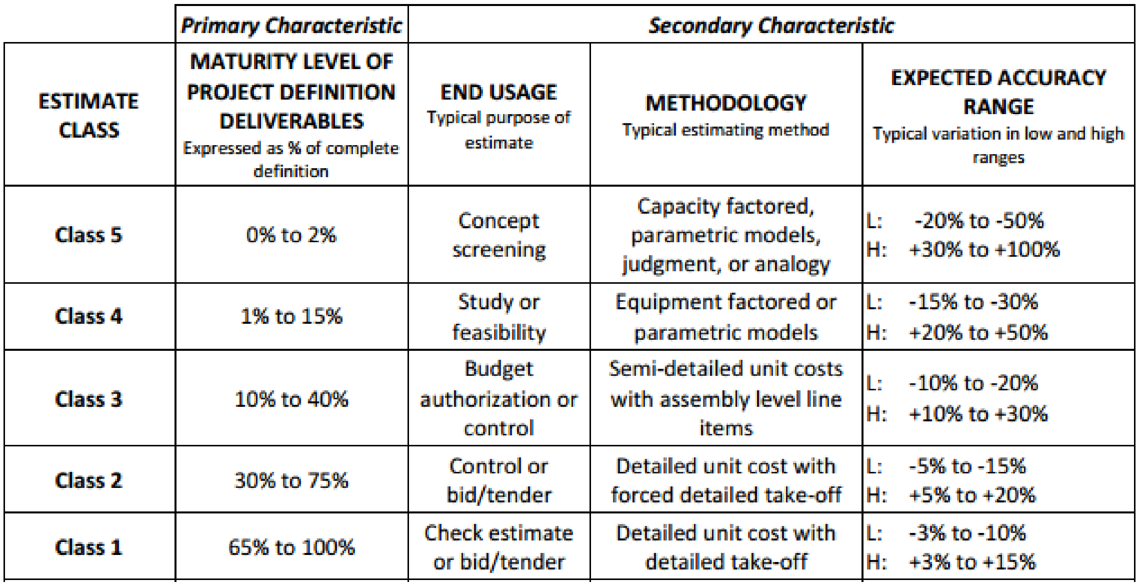
depicts the work by contract and the Sub-contract Work Breakdown Structure (SWBS) which allows key subcontractors to meet reporting requirements (typically for earned value reporting in federal government projects) (DOE 2012).

The lowest level of a WBS are work packages. These work packages are later (further) decomposed into tasks which become the basis for project cost estimating and scheduling as well as risk analysis and staffing (PMI 2013). In later project phases, a complete WBS becomes crucial to developing cost estimates that are complete, as well as project schedules and staffing and risk management plans.

However, prior to the start of design, a project team will not be in a position to develop a complete WBS because understanding of, and knowledge about, the project is low. While development of a *complete* WBS may need to wait for better definition of the project, a preliminary WBS can be of great help to the project. The NASA Work Breakdown Structure Handbook notes that WBS are developed at different levels of detail and that the number of levels depend on several factors including the project's size, degree of definition and complexity (NASA 2012). NASA recommends development of a preliminary WBS early in the project formulation (feasibility) stage to identify and define the top levels of the project. The objective is to reflect the entire scope of work for the project life cycle (NASA 2013).

2.2 Cost Estimating

Over the life of a project, cost estimating occurs in four stages (Project Management Institute 2011). These include (1) Preparation to Estimate, (2) Create Estimates, (3) Manage Estimates and (4) Improve Estimating Process (Project Management Institute, 2011). At the pre-design stage the level of project definition is quite low. Figure 2, from AACEI 18R-97 notes that early project estimates have a level of project definition of 0% to 2%.



	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Figure 2 Cost Classification Matrix from AACEI Recommended Practice 18R-97

With this low level of project knowledge, developing a structured approach to estimating takes on additional importance. Of particular importance at this point in the project is the Preparation to Estimate and the actual Creation of the Estimates. Key points in preparing to make a project cost estimate include (1) clear identification of the task (purpose of the estimate), (2) as broad a participation in making the estimate as is practical, (3) availability of data, (4) a standardized structure for the estimate, (4) making provision for uncertainties and risk and (5) recognition of excluded costs (Oberlander 2001; Serpell 2004; GAO 2009; Serpell 2011; Department of Energy 2011).

The creation of the estimate provides optimum results if it utilizes a structured estimating process; Figure 3 depicts a generic cost estimating process designated as best practice by the Government Accountability Office (GAO 2009).

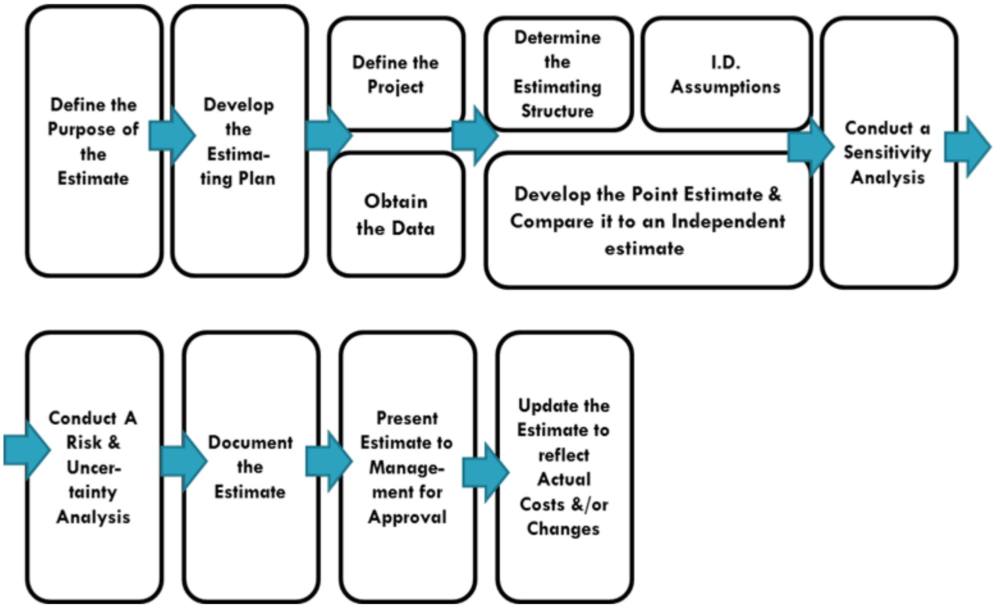


Figure 3 Generic Cost Estimating Process

This process is applicable to estimating at all stage of a project, but steps 1-6 are most applicable to a pre-design estimate. Step 1, Define the Estimates Purpose, similar to Clear Identification of the Task, starts the Create the estimate process. The second step, “Develop the estimating plan” involves selection of the appropriate estimating methodology.

2.3 Estimating Processes.

The Project Management Institute’s Practice Standard on Project Cost Estimating defines an estimate as “a quantitative assessment of the likely outcome or amount. Usually applied to project costs, resources, effort, and durations and is usually preceded by a modifier (i.e., preliminary, conceptual, feasibility, order of-magnitude, definitive). It should always include some kind of indication of accuracy (e.g., +/- x percent) (PMI 2011). However, there is not widespread agreement on this definition. The U.S. Department of Energy defines a cost estimate as "a statement of costs estimated to be incurred in the conduct of an activity, such as a program, or the acquisition of a project or system (DOE 1997). The 2008 NASA Cost Estimating Handbook defines a cost estimate as "the result of applying quantitative techniques to calculate and forecast development, production, operation, and disposal costs within a scheduled timeframe and defined scope for a given project" (NASA 2008). The Association for Cost Engineering, International, A leading professional association defines a cost estimate as, "a compilation of all of the probable costs of elements of a project or effort included within an agreed upon scope" (AACEI 2016).

These differences in definitions by highly knowledgeable parties may help explain some of the difficulty participants in capital projects experience particularly when trying to develop estimates of what a project will cost. While there has not been a concerted effort to arrive at a common definition, several authors have focused energies on overall approaches to estimating as well as estimating methodologies in the hope that more discipline in the overall approach to estimating may lead to better estimates.

The Government Accounting Office has developed a twelve step process for developing a high quality estimate (GAO, 2009). The National Aeronautics and Space Administration (NASA) has developed a twelve step process in three parts that is largely consistent with the GAO process but tailored to NASA's needs (NASA 2015).

2.4 Estimating Methodologies.

There are three broad categories of estimating approaches. These include Analogous techniques, (2) Parametric techniques and (3) Bottom up techniques. (NASA 2008, PMI 2011). Within each of these methodologies, there are a number of estimating tools or techniques (Carr 1989; Hegazy 1991; Layer 2002; Gibson 2003: Akintola 2016.)

2.5 Analogous Estimating.

The analogous estimating method, also known as top down estimating, looks to estimate the project of interest (current project) with a completed project that is similar (PMI 2012, NASA 2008). Analogous estimating is considered the simplest form of estimating (PMI, 2012). They are often used for conceptual or long range planning studies, architectural studies, for cross checking estimates at later stages in a project, whenever there is a scarcity of information about a project or in the very early stages of design (NASA 2008). The estimate developed using the analogous approach is sometimes as an order of magnitude, conceptual or preliminary estimate (PMI 2012). The AACEI notes that project definition at this stage of a project is 1-2% (AACEI 1997). Given the low level of project scope definition, estimates at this stage of a project range from -50% below to 100% above the actual cost of the project (AACEI 1997).

A similar project is used as the basis for the estimate after any adjustments for differences in the project are made as well as normalization of the data to account for geographical and inflation differences (NASA 2008). It is important that the project selected as analogous be as similar as possible to the project of interest.

Analogous techniques, sometimes known as top down techniques, are often used when there is little information about the project available (PMI 2011; There are four types of analogous estimating methodologies. These include (1) ratio estimating, (2) power series estimating, (3) range estimating and (4) three point estimating (PMI 2011). It should be noted that not all sources consider these techniques to be analogous estimates; Dysert (2008) includes ratio and capacity factor estimating as a parametric technique. Ratio estimating, sometimes called equipment ratio or capacity factor estimating, is predicated on the notion that there is a linear relationship between the cost of a project with one, or more similar basic features. These features can be either physical characteristics or performance characteristics. This approach is often used in estimating the costs of equipment such as pumps, compressors or large vessels in chemical process plants. The ratios or factors used come from industry data, enterprise or industry data or personal experience. Lists of factors may be found in a number of sources on cost estimating including Clark and Hackney.

Power series estimating assumes that there is a linear relationship between both capacity and cost. The assumption is that the ratio of the capacities is the same as the ratio of costs. It is considered an enhancement of the ratio estimating technique. In ratio estimating the relationship can be depicted as a straight line on a linear scale and in power series estimating the relationship can be depicted as a straight line on a semi-logarithm (PMI 2012).

Range estimating provides the full range of potential costs of a project instead of a point estimate. Range estimating is often defined as “estimating a variable in the form of a probabilistic range (Curan 1989, Evrenosoglu 2010).

Three point estimating is considered to be more sophisticated approach than range estimating (PMI, 2011). Three point estimates are developed based on a pessimistic, most likely and optimistic cost estimate. These estimates can be developed from historical data, but may also be developed as expert knowledge/information. Two formulas are used. One is a triangular distribution and the other is based on the PERT formula. An estimate based on the triangular estimate is based on the following formula:

$Ce = (Co+Cml+Cp)/3$

Where:

Ce= cost estimate; the estimate for the entity we are developing

Co=the optimistic cost estimate

Cml= the most likely cost

Cp=cost pessimistic; the highest cost expected

The other three point estimate is the PERT formula and place greater weight on the most likely cost. This formula is:

$Ce=(co+4Cml+cp)/6$

Where:

Ce = the estimated cost of the item we are estimating

Co=the optimistic cost

Cml=the most likely cost

Cp= the pessimistic cost

Ratio estimating is predicated on the premise that there is a linear relationship between the cost of one project and the cost of another project that have one, or more, similar attributes or performance characteristics (Clark 1997, Humphreys 1991, PMI 2011). Ratio estimating has several different names including equipment ratio, Lang Factor estimating, percentage estimating, parameter estimating, module estimating, capacity factor or factor estimating (Chilton 1950; Humphries 1991, PMI 2011). The ratios or factors that are used in this method are developed from industry data, historical records of the organization or the individual experience (s) of the project team (PMI 2011). While this method takes economy of scale into account, it does not consider location or timing of the work (DOE 2011). Advantages of this method include (1) the estimate reflects a specific design, (2) it takes much less time than making a definitive estimate, is felt to be more accurate than curve estimating (Clark 1997). Disadvantages for this method include (1) the need to include all items, (2) a tendency not to adjust and (3) a lack of details for bulk materials (Clark 1997).

Power series estimating is generally considered to be an enhancement of the ratio methodology. It is based on the notion that the final cost of a project is related to a value that is developed by raising the ratio of a characteristic, such as capacity or size, to a certain power. The power series relationship can be depicted as a straight line on semi-logarithm scale. The slope of the line varies by project type (PMI 2011). Typical exponents range from 0.6 to 0.75.

Analogous estimates have the advantage of being (1) based on historical data, (2) relatively fast to complete, (3) are easily understood and (4) can be accurate for the minor deviations from the similar (analog)) project (NASA 2008). Weaknesses of this approach include (1) the reliance on a single data point (the analogous project), (2) the difficulty in identifying and selecting an analogous project, (3) the need to normalize the data for inflation and geographic location to be accurate and (4) the reliance on either extrapolation or expert judgement to make the adjustments from the analog project to the project of interest (NASA 2008).

2.6 Parametric Estimating

Parametric cost estimates are based on an approach that incorporates statistical, or other mathematical relationships, between historical project data and key characteristics of the project of interest (NASA 2008, PMI 2012. These relationships are known as Cost Estimating Relationships (CERs). An important assumption in parametric estimating is that the drivers/forces that drove the cost relationship(s) in the past will continue to do so in the future (Mileham 1993; NASA 2008).

Development of a CER is a multiple step process. The NASA Cost Estimating Handbook lists those as (1) Define an estimating hypothesis, (2) Collect Relationship Data, (3) Evaluate and normalize data, (4) Analyze data for candidate relationships, (5) Perform Statistical Analysis, (6) Test Relationships and (7) Select Estimating Relationship (NASA 2008). The International Society of Parametric Analysts document an eleven (11) step process for developing a CER in their Parametric Handbook. These steps include (1) Opportunity Identification, (2) Data Collection, (3) Data Evaluation and Normalization, (4) Selection of Variables, (5) Test Relationships, (6) Regression and Curve Fitting, (7) Data Analysis and Correlation, (8) Select CERs, (9) Validation, (10) Approval and (11) CER Database (ISPA 2008).

Parametric estimating methodology is advantageous because of (1) the CERs provide an excellent tool for responding to “what if” inquiries, (2) can provide information regarding confidence intervals, (3) are based on information (data) and not opinions, (4) are defensible based on the research into the data and the use a scientific methodology (NASA 2008).

Weaknesses of the parametric approach include (1) the decrease in predictive ability and credibility outside the range of the data, (2) collecting the appropriate data is time-consuming and potentially expensive, (3) the need to fully document and describe the selection of the data as well as development of equations, conclusions, and validations and (4) it may be difficult for people not involved in the estimating process to understand the relationships (NASA 2008).

2.7 Build-Up Estimating

The third broad category of cost estimates are built-up estimates sometimes referred to as engineering built-up or bottom up estimates (NASA 2008, PMI 2012). The basis of the estimate for this type of estimate are typically highly developed, if not completed, plans and specifications. As a result, bottom up or built-up estimates are generally considered to be the most accurate and reliable type of estimates (PMI 2011).The estimates often are based on detailed takeoffs of quantities and/or bills of materials or the elements from a Work Breakdown Structure (WBS). The cost of every quantity in the take-off or the cost of every element in the WBS are summed and appropriate overhead and indirect costs are added (NASA 2008).

The estimates have the advantages of (1) being defensible, (2) intuitive, (3) credible based on the back-up documentation of quantity take-offs or WBS, (3) transparent in that they allow for insight into the key cost contributors, (4) are severable in that a mistake in one portion of the estimate does not compromise or render invalid the entire estimate and (5) they are re-usable in that they can be transferred for use into other project budgets and or schedules (NASA 2008).

Disadvantages of the parametric approach include (1) the significant amount of time and effort it takes to develop an estimate, (2) they are not quickly/easily responsive to “what if” scenarios, (3) a new estimate must be prepared or “built-up” for any new scenarios, (4) the built-up methodology cannot provide a statistical confidence interval, (5) the lack of insight into key cost drivers and (6) any relationships between cost elements must be established, or programmed, by the estimator (NASA 2008).

2.8 Data Normalization

Central to the estimation process is normalization of the data. GAO, ISPA and DOE estimating processes all include normalization of the estimating data. Typically, the data to be normalized is historical cost data. There are several potential areas for normalizing data including differences in accounting between historical projects, recurring and non-recurring costs, physical and performance factors, price level changes and geographic/reginal differences. The most common normalizations are for price level changes and geographic differences (DOE 1997, Hendrickson 2008).

2.9 Time-Cost Modeling

One challenge project team’s face, particularly at the early stages of a project is estimating the duration of the project. Since the scope is, typically, 0-2% defined, it is quite difficult to develop a schedule or estimate task durations. Typically, expert judgement is used to develop duration forecasts. Another tool available are time-cost models. These models forecast duration based on estimated project cost (which is also not reliably known at the earliest stages of a project).

A number of researchers have examined this problem. Best known is the work of F.J. Bromilow (Bromilow 1977, 1988). Based on ten years of data from Australian construction projects, Dr. Bromilow developed equations, typically referred to as Bromilow equations, which allow a project team to develop duration forecasts or check other duration estimates later in the project. Kumaraswarmy (1995), Ng (2001), Love (2005) and Ogunsemi (2006) have all developed methods to estimate project duration based on extensions of Bromilow's work. More recently Czarnigowska (2013) has developed a method for forecasting duration, but concludes "calculations presented above confirm the universal nature of Bromilow's Time-Cost Model......noting it is too inaccurate to find any practical application". Other models such as the square root rule (PMI2011) also suffer from accuracy as well as documentation issues. Like other key project management issues at the early stage of a project, the lack of information prevents the development of reliable duration estimates.

Chapter 3 Methods

Four separate methodologies are important to this project. The first, discussed in the following section, involves the cost estimation process. The second involves normalization of the cost data on comparable projects. (The results of this are an input into step 7 of the cost estimation methodology.) The third methodology involves development of a point estimate using linear regression analysis. The results of which are also an input (step 8) of the cost estimation process above. The final methodology involves estimation of the project duration. Three different approaches are used for this including (a) Bromilow models (Bromilow 1977, Bromilow 1988), a Time-Cost model developed by Love, Tse and Edwards (Love 2005) and (3) application of the Square Root rule (PMI, 2011).

3.1 Cost Estimation Methodology

The basic framework for this research project is the cost estimating process identified in the GAO's Best Practices for Cost Estimating (GAO 2008). This is a twelve step process includes the following steps:

1. **Receive Customer Request and understand project**. This project developed based on a conversation with the College of William and Mary's Facilities Planning, Design and Construction (FPDC) section. Part of the Colleges Facilities Department, FPDC had been tasked to manage the design and construction of a new Student Health Facility. As part of a pre-design exercise, the project manager was interested in determining if the project could be built for the budget that had been assigned.

For purposes of this project, the focus would be on developing an estimate for the building (only). Estimates for other parts of the project would remain the responsibility of the FPDC project team.

2. **Obtain, or build, a Work Breakdown Structure (WBS)**. For purposes of developing an estimate for the building, a three level WBS was developed. Figure 4 depicts the preliminary WBS. Level 1 of the WBS is the project level depicted in the model as a single rectangle labeled “W&M Student Health Center Project”. Level 2 of a WBS typically represents Systems or Phases. For the purposes of this project, Level 2 consists of five (5) elements that depict key phases the project will go through. These include (1) Design, (2) Project Management, (3) Building, (4) Furniture, Fixtures and Equipment (FF&E) [3] and (4) Commissioning and Move In (“spinning up” and testing of mechanical and other building systems as well as the actual occupancy of the building).

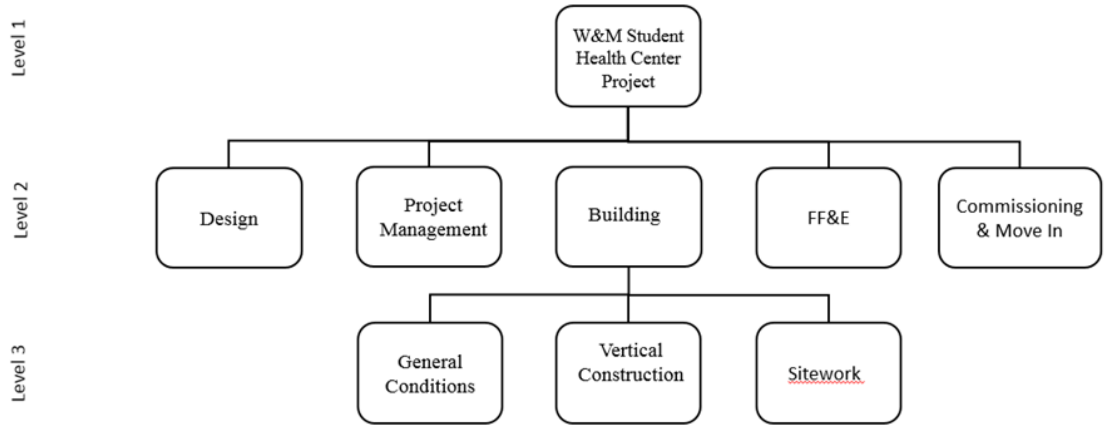


Figure 4 Preliminary WBS New Student Health Center

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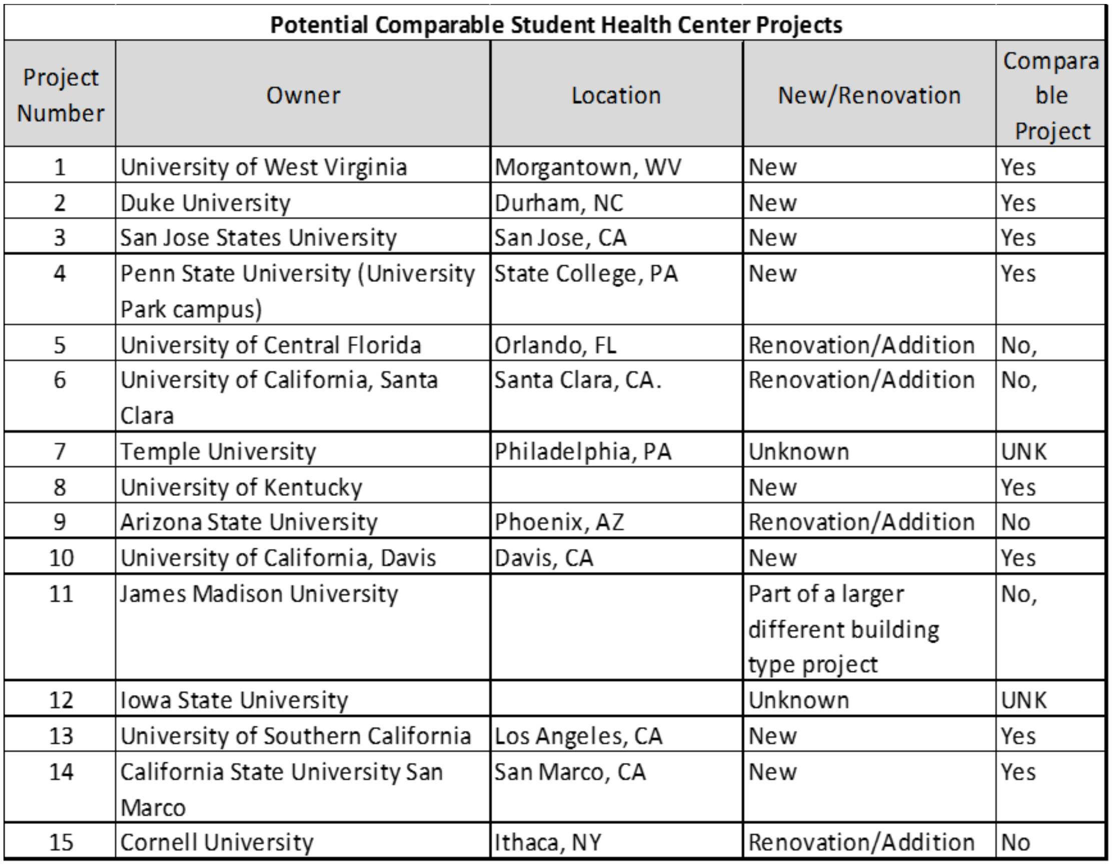
[3] FF&E is often included in the building element of a WBS. However, identifying it as a separate element helps fence off the funds needed to purchase the FF&E. Additionally, and perhaps more importantly, modern FF&E is often complicated and the logistics of purchase and installation argue for increased visibility from a management perspective and listing as a phase in Level 2 of the WBS.

Level 3 is a decomposition of the Building element into key components. These three elements included (1) general conditions, (2) the “vertical construction” that makes up the building and (3) sitework (including associated utilities). Since every site is different, it was hypothesized that the sitework element of the cost of comparable projects would have more variability than the vertical construction. This argument was also extended to general conditions since the project delivery method and/or general conditions will be unique to the individual project or contractor executing the work.

3. **Obtain, or participate in Development of Project Technical Description.** Preliminary information about the project was provided by the FPDC project manager. A Basis of Estimate for the New Student Health Center is included in Appendix A based on those discussions.
4. **Develop Ground Rules and Assumptions.** For the purposes of the Praxis it was assumed that:
   a. historical cost data would be normalized to February 2016
   b. geographic data would be normalized to Williamsburg, Virginia which was the location of the ‘to be built’ student health center.
   c. That cost data on comparable projects would be limited in terms of the number of comparable projects that data would be available on.
5. **Select Cost Estimating Methodology.** As discussed in the Literature Review, there are a number of estimating techniques. However, at the beginning of a project information about the scope of a project is minimal. Additionally, not every project team has members who have background and experience in some of the more

sophisticated analysis techniques such as case based reasoning or neural networks, nor is there necessarily the time to develop more detailed estimates. Based on this, it was determined that a parametric estimate methodology would be most appropriate approach for this project.

6. **Select & Build Cost Model**. This step involves selection of the estimating technique and developing a regression analysis model.
7. **Gather and Normalize Data.** In order to gather information on comparable projects to use as historical data, the term “Student Health Center Construction Projects” was searched on Google. A total of fifteen projects were identified as potential comparable projects. Table 1 lists the potential comparable projects.



Potential Comparable Student Health Center Projects

Project Number	Owner	Location	New/Renovation	Comparable Project
1	University of West Virginia	Morgantown, WV	New	Yes
2	Duke University	Durham, NC	New	Yes
3	San Jose States University	San Jose, CA	New	Yes
4	Penn State University (University Park campus)	State College, PA	New	Yes
5	University of Central Florida	Orlando, FL	Renovation/Addition	No,
6	University of California, Santa Clara	Santa Clara, CA.	Renovation/Addition	No,
7	Temple University	Philadelphia, PA	Unknown	UNK
8	University of Kentucky		New	Yes
9	Arizona State University	Phoenix, AZ	Renovation/Addition	No
10	University of California, Davis	Davis, CA	New	Yes
11	James Madison University		Part of a larger different building type project	No,
12	Iowa State University		Unknown	UNK
13	University of Southern California	Los Angeles, CA	New	Yes
14	California State University San Marco	San Marco, CA	New	Yes
15	Cornell University	Ithaca, NY	Renovation/Addition	No

Table 1 Potential Comparable Projects

The target project, the proposed William and Mary Student Health Center (WMSHC) is, new construction. Each of the potential comparable projects was research on the internet to identify basic characteristics such as size, location, date of completion, and whether the project was new construction or a renovation. Four of the fifteen projects were renovation projects and were judged not to be similar to the proposed project which is new construction. In one project, the student health center was a very small part of a much larger project; in two others, information on web sites on whether the projects were new or renovations could not be determined. All seven of these projects were judged to not be comparable projects for use in cost modeling for the proposed W&M Student Health Center.

Eight (8) of the projects were judged to be potential comparable. E-mails and phones calls were made to the project managers for each of the projects with requests for a (brief) project scope statement as well as a copy of a final pay application. These pay applications had total project costs for each of the elements in the preliminary WBS in sufficient detail allowing aggregation of building, general conditions and site costs. Five of the eight projects provided cost information and project scope information for use in the project (D. Collins, Personal Communication January 15, 2016; S. Doan personal communication on January 15, 2016; P. Manning, personal communications on January 15, 2016; B. Ozlin, personal communications October 21, 2015; C. Parker, personal communications January 15, 2016 and S. Watters, personal communications, January 15, 2016).

8. **Develop Point Estimate.** A point estimate was developed using regression analysis. A description of the process/methodology for this is included in the following section.
9. **Develop and Incorporate Cost Risk Assessment.** For purposes of the Praxis, this was considered outside the scope of work.
10. **Document Probabilistic Cost Estimate**. For purposes of the Praxis, this was considered outside the scope of work.
11. **Present Estimate Results.** This step would involve sharing the cost forecast with the William and Mary project management staff.
12. **Update Cost estimate on a regular basis**. Typically, the estimated cost of a project will be updated at several points during the design and just before construction. For purposes of the Praxis, this was considered outside the scope of work.

3.2 Data

As noted above, cost data on five (5) projects was gathered. Those projects include the student health centers at (1) the California State University at San Marcos (CSU at San Marcos), (2) Duke University, (3) Pennsylvania State University (PSU), (4) San Jose State University (SJSU) and (5) the University of Kentucky.

A summary of the non-normalized cost data for each project is summarized in Table 2. Project Data Sheets and supplemental cost information for each of the five comparable projects is included in Appendices B through F.

Table 2 Comparable Project Data –Not Normalized

Project Name	Floor Area (SF)	Building Cost ($)	Site Cost ($)	General Conditions ($)
CSU at San Marcos	20,000	$4,625,009	$475,191	$1,144,005
Duke University	71,770	$20,241,390	$3,179,473	$3,690,215
Pennsylvania State University	63,300	$16,655,662	$1,650,000	$1,769,338
San Jose State University	53,000	$17,598,294	$2,459,026	$8,769,147
University of Kentucky	72,714	$16,485,937	$685,126	$43,200

Table 2 Comparable Project Data – Not Normalized

3.3 Data Normalization

Part of step 7 (Gather and Normalize Data) involves data normalization. This involves two adjustments. The first involves making adjustments for general price levels over time (inflation). Between the time a construction contract was signed on a comparable project and the time a cost estimate is being prepared for on the project of interest. This adjustment is typically accomplished by use of cost indices of the time periods of interest.

$$C_t = C_0 \left({}^{I_t}/_{I_0} \right)$$

$Ct =$ Cost at time t; typically the time period the estimate is being prepared in

Co =Cost at time 0; typically the time period the comparable project was completed

I_t = the value of the cost indice at time t when the project is being estimated to

I_0 = the value of the cost indice at the time the comparable construction contract was executed

Appendices B, C, D, E and F include Project Data Sheets for each of the comparable projects as well as the cost indices used for the data normalization. As an example, the Student Health Center at the California State University at San Marcos has a non-normalized cost of the building of $4,625,009. The project was completed in October of 2014. The ENR Cost Index at the time construction was completed was 9545. The project analysis was performed in February of 2016. The ENR Index at that time was 10,182.92. To adjust the cost for time (2014 to 2016):

$$C_t = C_0 \left({}^{I_t}/_{I_0} \right)$$

$$C_{2016} = C_{2014} \left({}^{10182.92_{2016}}/_{9545_{2014}} \right)$$

C_{2016}=$4,625,009 (1.0667) = $4,933,627 (See Appendix B)

There are several sources of cost indices for making these adjustments. These include the Engineering News Record Construction Cost Index, The U.S. Department of Commerce GNP Deflater or the Tuner Construction Company Cost Index (ENR 2016, Hendrickson 2008, US Department of Energy 1997).

The other area of normalization for this project involves adjusting for geographic cost differences. Building codes, weather, geology and similar differences will cause differences in the cost of construction. These differences are adjusted in a process similar to the price level adjustment.

$$C_l = C_e \left({}^{I_l}/_{I_e} \right)$$

C_l = Cost local; adjusted cost for the project being estimated

C_e = Cost of the existing project being used as a comparable for the project being estimated

I_l= Local geographic cost indice for the locality where the project being estimated is located

I_e = Geographic cost indice for the comparable project

Popular sources of geographic cost indices include RS Means estimating guides.

Appendices B, C, D, E and F also include the Geographic Index adjustment factors and results for each of the comparable projects.

As an example, Appendix B for the Student Health Center project at California State University at San Marcos shows a cost after normalization for time of $4,933,627. The location index for San Diego (where the CSU at San Marcos project was constructed) is 104.5. The location index for the Newport News, VA. Area (near where the subject project will be built) is 86.1. To adjust the cost for location:

$$C_l = C_e \left({}^{I_l}/_{I_e} \right)$$

$$C_{Newport\ News} = C_{San\ Diego} \left({}^{86.1_{Newport\ News}}/_{104.5_{San\ Diego}} \right)$$

$C_{Newport\ News}$ = \$4,933,627 (0.824) =\$4,064,931 (See Appendix B)

Table 3 summarizes the comparable project data normalized for both time and location.

Table 3 Comparable Project Data - Normalized

Project Name	Floor Area (SF)	Adjustment Factor for Price Level	Adjustment Factor for Location	Normalized Building Cost
CSU at San Marcos	20,000	1.067	0.824	$4,064,931
Duke University	71,770	1.016	1.049	$21,563,370
PSU	63,300	1.292	0.922	$19,831,534
SJSU	53,000	1.067	0.733	$13,771,964
U of Kentucky	72,714	1.287	0.957	$20,298,903

Table 3 Comparable Project Data - Normalized

Figure 5 is a Scatter Plot of the normalized cost data for the comparable projects. Inspection of this data suggests that it is linear and, as a consequence of that, that linear regression would be an appropriate tool to use to construct a cost model to be used to forecast the cost of the William and Mary Student Health Center.

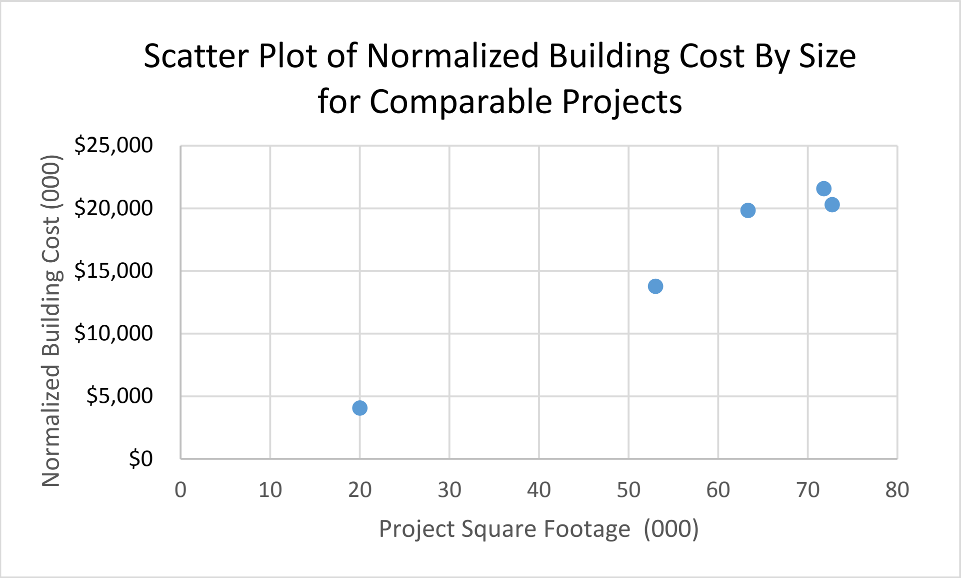


Figure 5 Normalized Building Cost by Size for Comparable Projects

3.4 Point Estimation Using Linear Regression

The bulk of the effort of preparing the estimate occurs in step 8, Develop Point Estimate. For this project that means the linear regression analysis.

Regression analysis has been selected as the model or analysis methodology for this data. There are four (4) steps that should be followed to perform a regression analysis. As described in Regression Analysis by Example (Chatterjee 2012) those steps include:

1. Formulating the problem. This includes selecting a set of variables, choosing a form of the model and selecting a method of fitting and specifying assumptions.
2. Fitting the model
3. Validating assumptions. This would include plotting residuals and detecting any outliers.

4. Evaluating the Fitted Model

3.5 Formulating the Problem

The objective of this work is to develop a model to estimate the cost of the Building element of the (to be built) Student Health Center at the College of William and Mary. While there is generally a lack of information about projects in the pre-design phase/or stage, based on the data that has been developed, a linear regression analysis is felt to be the best approach to modeling this problem. The known information includes the location, date of completion and gross floor area of the comparable projects and similar information about the project to be estimated (except for date of completion).

This model would take the general form of:

$$Y = mx + b + \epsilon \quad \text{(Chaterjee 2012) where:}$$

Y is the dependent variable, in this case the cost of project being estimated

M is the slope of the line of the equation

x is the independent variable, in this case the gross floor area of the building (square feet (SF))

b = Y axis intercept or constant

ϵ = error

Adjusting the equation for the project of interest results in the following equation:

$$Cst = m(GFA) + b + \epsilon \quad \text{where:}$$

$Cst = cost\ in\ US\ dollars$ (the dependent variable)

m = the slope of the line from the regression analysis

GFA = the Gross Floor Area of the building to be constructed (the independent variable)

B = the Y intercept or constant

ϵ = error

The assumptions for this problem include the “standard” assumptions for any regression analysis including:

a. The population regression function is linear.

b. The error terms are independent

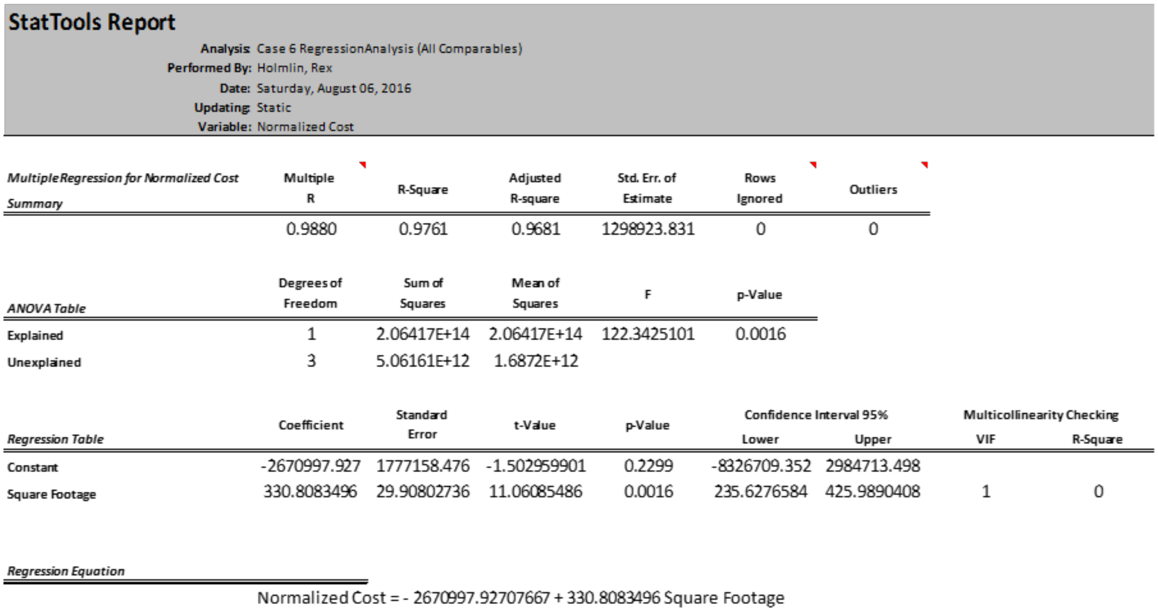
c. The error terms are distributed normally

d. The errors terms have equal variance (Chatterjee 2012, PSU 2016)

3.6 Fitting the Model

Data from five comparable projects were selected to be included in the proposed regression model. The comparable projects ranged in size from 20,000SF to 72,714 SF in gross floor area. Figure 6 depicts the regression analysis and results for this base case.

The R^2 is 0.9761 and the P Value is 0.0016. Both of which suggest this regression model explains a significant proportion of the data and that the slope is a very significant variable. However, the value of the constant in the Regression Table in Figure 6 is 0.2299. This term is not significant and, potentially, may be dropped.



StatTools Report

Analysis: Case 6 RegressionAnalysis (All Comparables)
Performed By: Holmlin, Rex
Date: Saturday, August 06, 2016
Updating: Static
Variable: Normalized Cost

Multiple Regression for Normalized Cost *Summary*	Multiple R	R-Square	Adjusted R-square	Std. Err. of Estimate	Rows Ignored	Outliers
	0.9880	0.9761	0.9681	1298923.831	0	0

ANOVA Table	Degrees of Freedom	Sum of Squares	Mean of Squares	F	p-Value
Explained	1	2.06417E+14	2.06417E+14	122.3425101	0.0016
Unexplained	3	5.06161E+12	1.6872E+12		

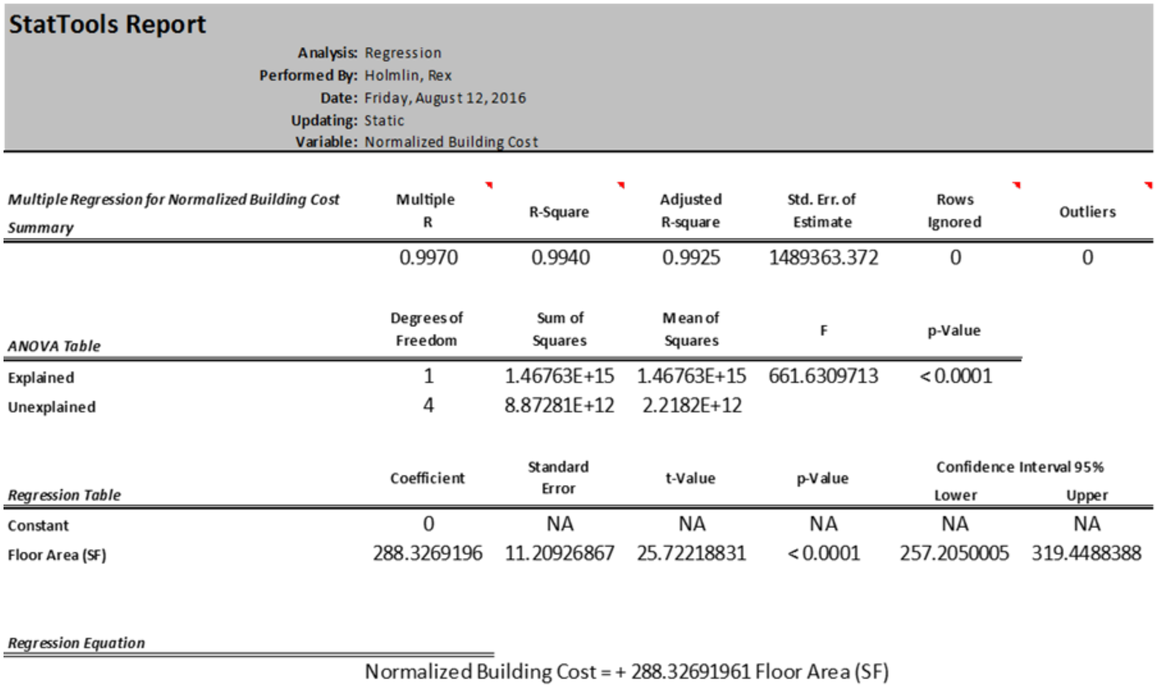
	Coefficient	Standard Error	t-Value	p-Value	Confidence Interval 95%		Multicollinearity Checking	
Regression Table					Lower	Upper	VIF	R-Square
Constant	-2670997.927	1777158.476	-1.502959901	0.2299	-8326709.352	2984713.498		
Square Footage	330.8083496	29.90802736	11.06085486	0.0016	235.6276584	425.9890408	1	0

Regression Equation

Normalized Cost = - 2670997.92707667 + 330.8083496 Square Footage

Figure 6 Regression Analysis of all Comparable Projects

To validate this a regression analysis holding the intercept to zero was performed. Figure 7 depicts the results of this regression analysis. The R^2 is 0.9940 which is superior to the R^2 of the model with the constant (Figure 6). The P Value is less than 0.0001 which is superior to the model with the constant. The F value is 661.63 which is also superior to the regression analysis shown in Figure 6. The conclusion is that a regression model including all five data points but holding the constant as zero is a better model for predictability and explanation of the data than the same model with a regression constant.



StatTools Report

Analysis: Regression
Performed By: Holmlin, Rex
Date: Friday, August 12, 2016
Updating: Static
Variable: Normalized Building Cost

Multiple Regression for Normalized Building Cost *Summary*	Multiple R	R-Square	Adjusted R-square	Std. Err. of Estimate	Rows Ignored	Outliers
	0.9970	0.9940	0.9925	1489363.372	0	0

ANOVA Table	Degrees of Freedom	Sum of Squares	Mean of Squares	F	p-Value
Explained	1	1.46763E+15	1.46763E+15	661.6309713	< 0.0001
Unexplained	4	8.87281E+12	2.2182E+12		

Regression Table	Coefficient	Standard Error	t-Value	p-Value	Confidence Interval 95% Lower	Confidence Interval 95% Upper
Constant	0	NA	NA	NA	NA	NA
Floor Area (SF)	288.3269196	11.20926867	25.72218831	< 0.0001	257.2050005	319.4488388

Regression Equation

Normalized Building Cost = + 288.32691961 Floor Area (SF)

Figure 7 Regression Analysis with Zero Constant

3.7 Constant Held to Zero

To validate this model a series of supplemental regression analysis will be conducted. One comparable project will be removed from each analysis and the regression equation from Figure 7 (Normalized Building Cost = 288.3269 * Floor Area) will be used to forecast the cost of the comparable project that was not included. Table 4 describes the grouping of comparable projects for the supplemental regression analyses.

Table 4 Supplemental Regression Analysis and Comparable Groupings

Case No.	Comparable Projects incorporated into Regression Analysis
1	CSU at San Marcos, Pennsylvania State University, San Jose State University, University of Kentucky
2	Duke University, Pennsylvania State University, San Jose State University, University of Kentucky
3	California State University at San Marcos, Duke University, San Jose State University, University of Kentucky
4	California State University at San Marcos, Duke University, Pennsylvania State University, University of Kentucky
5	California State University at San Marcos, Duke University, Pennsylvania State University and San Jose State University

Table 4 Supplemental Regression Analysis and Comparable Groupings

Table 5 summarizes key information from the Supplemental Regression Analyses. The R^2 values range from 0.9923 to 0.9960 and the P Values are all (well) less than 0.05 The 5 Comparable Zero Intercept case falls within the range of the supplemental analyses which strongly supports its' use for forecasting the subject project's building cost.

Table 5 Summary of Supplemental Regression Analysis

Case	Regression Slope	Regression Constant	R^2	F	P Value
1	283.3322	0	0.9923	385.8623	0.0003
2	290.2993	0	0.9960	738.0796	0.0001
3	280.9964	0	0.9948	573.0086	0.0002
4	293.7156	0	0.9952	623.3447	0.0001
5	292.2458	0	0.9923	384.6086	0.0003

Table 5 Summary of Supplemental Regression Analysis

As part of the Zero Intercept model analysis the cost of the comparable project not included in the analysis was estimated based on the Zero Intercept regression model. The results of that model are shown in Table 6. The percentage error ranges from approximately -10.3% to 39.4%. This error range is smaller than the range that is expected in the typical industry class five estimate which ranges from -50% to +100%.

Table 6 Forecast of Supplemental Regression Analysis Comparable Costs

Case	"Missing" Comparable	Forecast Cost of "Missing" Comparable	Actual Cost of Missing Comparable (Normalized to Williamsburg, VA.)	Percentage Error
1	CSU San Marcos	$5,666,642	$4,064,931	39.4%
2	Duke University	$20,834,781	$21,563,370	-3.4%
3	PSU	$17,786,958	$19,831,534	-10.3%
4	SJSU	$15,566,927	$13,771,964	13.0%
5	U of Kentucky	$21,250,361	$20,298,903	4.7%

Table 6 Forecast of Supplemental Regression Analysis Comparable Costs

The project with the largest error in forecasted cost was at the low end of the size range (20,000 SF). This is likely caused by (1) the small number of total data points and (2) the fact that the other projects are concentrated at the higher end of the project size range (20,000SF to 72,000SF) which impacted the slope calculation (when the intercept was set to zero). We may anticipate that the forecast cost for the subject project may be higher than what it may actually turn out to be.

3.8 Confidence Interval Data

The range of the 95% confidence interval data is 257.205 (lower) to 319.448 (upper). This slope data is the cost per square foot of each project. Table 7 summarizes the 95% confidence interval data for square footage. If the population is sampled many times and interval estimates made each time, the resulting intervals will bracket the population 95% of the time (NIST 2010). Four of the five data points fall within the

95% confidence interval, but with such a small sample size having 80% of the data points in conformance suggests that the confidence interval range is correct and that we may expect forecast data to fall within the range.

Table 7 Confidence Interval Summary (Square Footage)

Case	Lower 95% Confidence Interval	Normalized Cost/Square foot	Upper 95% Confidence Interval
CSU at San Marcos	237.4292	203.25	329.2351
Duke University	256.2933	300.45	324.3053
PSU	243.6386	313.29	318.3542
SJSU	256.6386	259.85	318.3542
U of Kentucky	244.8216	279.16	339.67

Table 7 Confidence Interval Summary (Square Footage)

Based on this analysis, the cost of student health centers may be estimated by using the following equation:

$$C_{SHC}=288.327\ (\text{GFA})$$

Where:

C_{SHC} = Estimated cost of to-be-built student health center, in 2016 US dollars

GFA = gross floor area of to-be-built health center

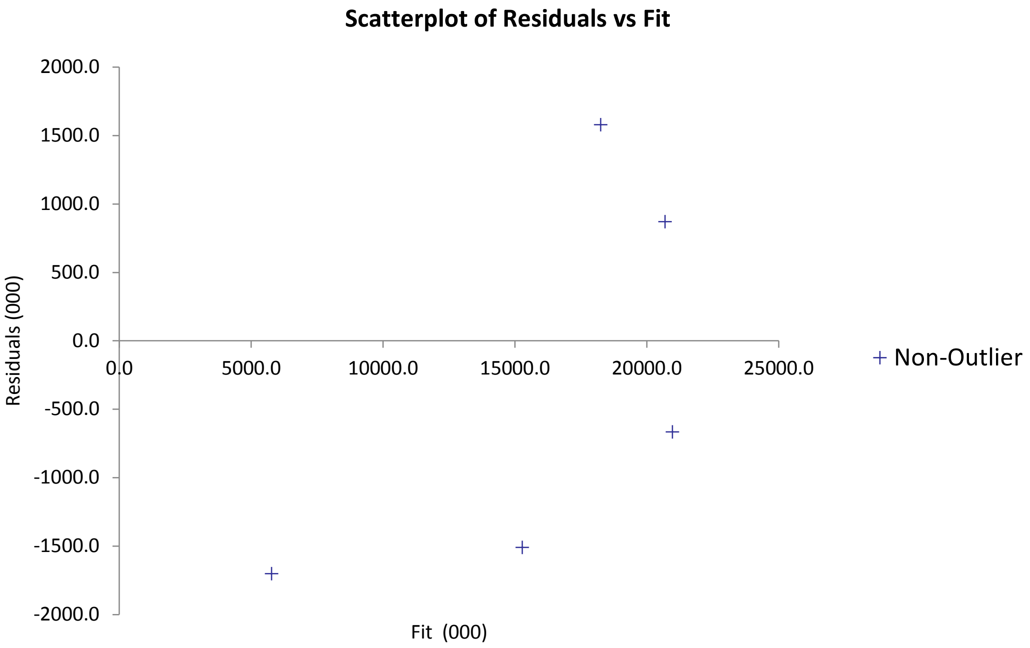
3.9 Validating Regression Assumptions

Prior to forecasting the cost of the to-be-built health center at the College of William and Mary, it is appropriate to analyze the regression residuals and verify that the assumptions inherent in linear regression analysis have not been violated.

As described earlier, there are four (4) assumptions implicit in simple linear regression analysis (Chatterjee 2012, PSU 2016). The first of these is that the population regression function is linear. The scatterplots shown in Figures 5 as well as the R^2 in Figure 7 support the validity of this first assumption.

Although the dataset for this project is quite small, Figure 8 (Scatterplot of Residuals versus Fit) can be used to detect non-linearity and unequal variances (PSU 2016).

Figure 8 Scatterplot of Residuals versus Fit



The residuals are on either side of ‘0’, form an (approximately” horizontal band around ‘0’ and there are no apparent outliers (PSU 2016). Both Figure 8 and Figure 9 (Scatterplot of Residuals versus Square Footage) support the validity of the independence assumption because there is no discernable pattern in the residual plots.

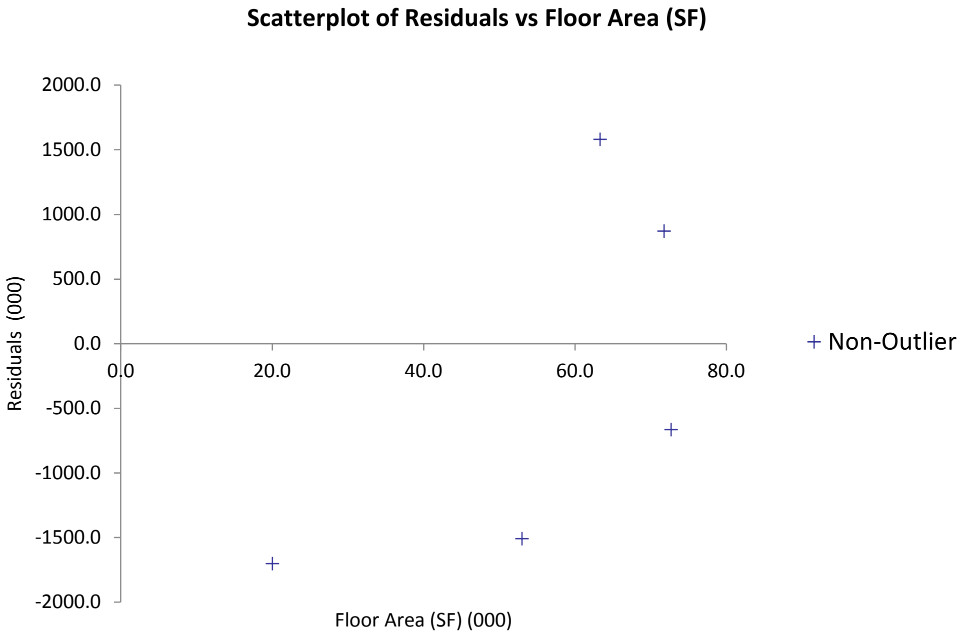


Figure 9 Scatterplot of Residuals vs Floor Area

The normality of the residuals may be determined by a normal probability plot. Developed by Chambers in 1983, this technique can help determine whether a dataset is approximately normally distributed (NIST 2010). If the plotted points form a straight line (approximately) then the distribution is normal. Figure 15 suggests that the residuals for the Base case dataset are approximately normal. This supports the last of the regression analysis assumptions.

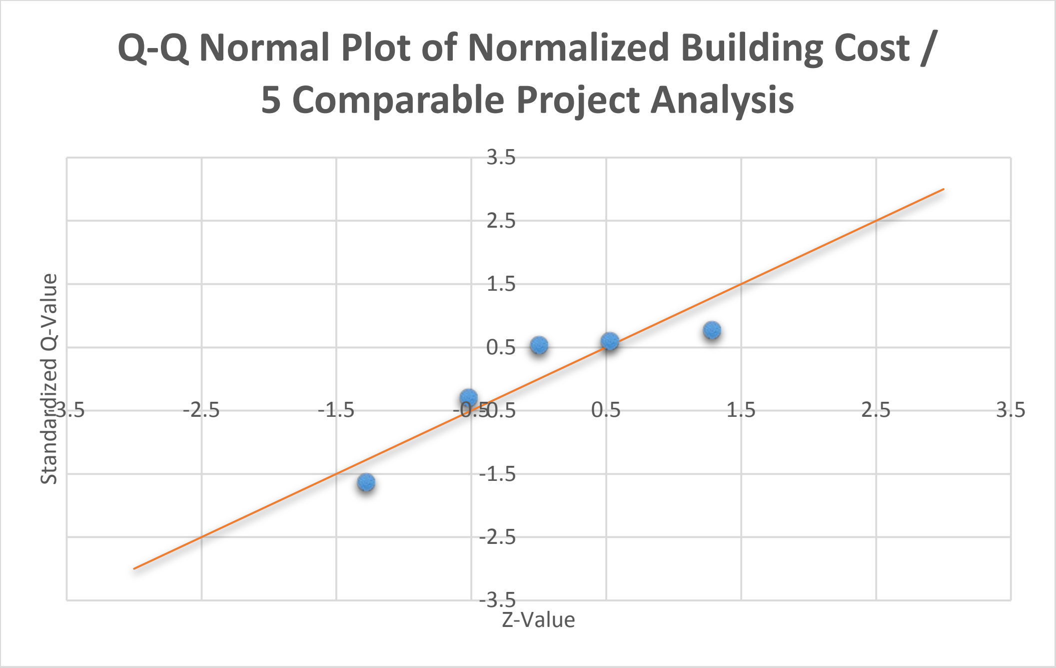


Figure 10 Q-Q Plot of Normalized Cost/Student Wellness Center Dataset

3.10 Estimation of Project Duration

Historically, three aspects of a project have been judged to be important. The project's scope, cost and schedule (PMI 2013). Efforts to estimate duration early in the project are constrained by the same factors that impact scope and cost, namely the lack of information and overall definition of the project.

Three methods of estimating project definition early in a project have been identified. These include Bromilow equations, Love-Tse-Edwards formula and the Square Root rule. The Bromilow equation (Bromilow 1977) is:

$$T = 313C^{0.3}$$

T= construction time in working days

C= Final Cost in millions, 1972 dollars (projects must be normalized to 1972 costs)

For purposes of the Praxis a month was assumed to have twenty (20) working days.

Comparable project data duration was available in months based on data provided by project staff and available on the internet

Appendix G is an EXCEL spreadsheet depicting the use of the Bromilow equation in the Praxis project.

A second approach to estimating project duration is the use of a Time-Cost formula developed by Love, Tse and Edwards (Love 2005)[4]. The methodology takes into account both floor area and the number of floors.

This formula is expressed:

$$Log(T) = 3.178 + 0.274Log(GFA) + 0.142Log(Floor)$$

T= time in weeks

GFA = Gross Floor Area $(000\ m^2)$

Floor = number of floors in the building

Log = natural log (base of e (2.178281))

This methodology assumes knowledge of both the floor area and the number of floors. This may not always be the case in pre-design phases. Appendix G is an EXCEL Spreadsheet depicting the use of this equation on the Praxis project.

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[4] The article in the *Journal of Construction Engineering and Management* is silent as to units for this equation. The units were identified by trial and error and by communication with the primary author.

The final methodology used on this project is the Square Root Rule for project duration described in the Practice Standard for Estimating (PMI 2005). This equation is expressed as:

$$T_p = T_e \left({}^{C_p}\!/_{C_e} \right)^{0.5}$$

T_p = Time proposed the estimated duration of the project being estimated

T_e = Time existing the actual construction time of a completed project that is being used as a comparable to the proposed project

C_p = Cost of proposed project

C_e = Cost of existing project; the cost of the existing project being used as a comparable

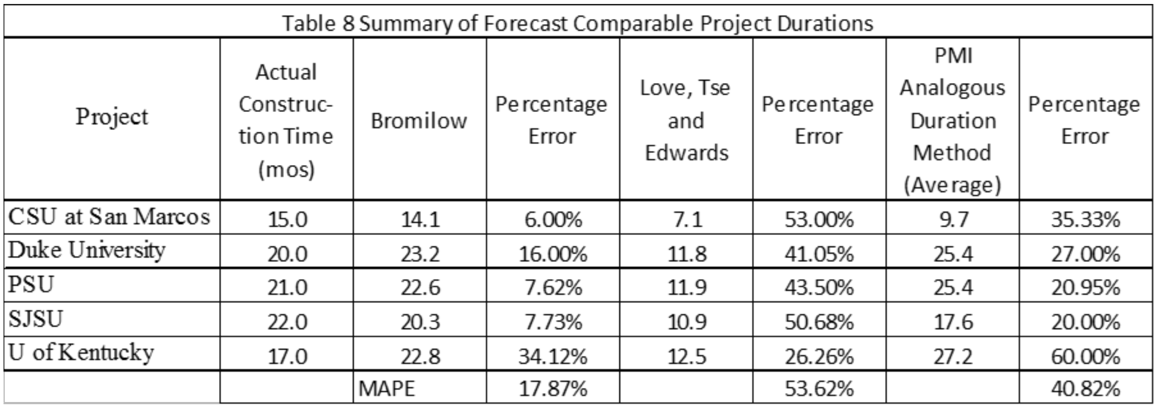
Table 8 Summary of Forecast Comparable Project Durations

Project	Actual Construction Time (mos)	Bromilow	Percentage Error	Love, Tse and Edwards	Percentage Error	PMI Analogous Duration Method (Average)	Percentage Error
CSU at San Marcos	15.0	14.1	6.00%	7.1	53.00%	9.7	35.33%
Duke University	20.0	23.2	16.00%	11.8	41.05%	25.4	27.00%
PSU	21.0	22.6	7.62%	11.9	43.50%	25.4	20.95%
SJSU	22.0	20.3	7.73%	10.9	50.68%	17.6	20.00%
U of Kentucky	17.0	22.8	34.12%	12.5	26.26%	27.2	60.00%
		MAPE	17.87%		53.62%		40.82%

Table 8 Summary of Forecast Comparable Project Durations

The Bromilow Model has the lowest Mean Absolute Percentage Error and will be used to forecast the William and Mary Student Health center project duration.

Chapter IV Results

4.1 Scope-Cost Match

As noted in Chapter 3, Methods, it was determined that a regression analysis model would be used to take the information about comparable projects and develop a model to forecast the cost of the proposed Student Health Center.

Data on five (5) projects was gathered and normalized. These include completed student health centers at (1) California State University San Marcos, (2) Duke University, (3) Pennsylvania State University, (4) San Jose State University and (5) University of Kentucky.

A regression equation was developed based on a model developed from all five data points, but with a zero intercept. This equation had the highestR^2, and best P Value and F scores. Based on this work the equation C_{SHC}=288.327 (GFA) will be used to forecast the cost of the William and Mary Student Health Center. Using this equation, the forecast cost of the 23,000 SF William and Mary Student Health Center is $6,631,521 or $6.63 million.

4.2 Scope –Duration Match

After the cost question, the next question project teams are asked is how long the project will take to be complete. In the pre-design, or feasibility, phases this is most often answered based on expert judgement of the project team members. As noted on Chapter III, Methods, three different approaches were taken to forecast the duration of the to-be-built project. These methodologies included use of Bromilow equations, a Time-Cost equation developed by Love-Tse and Edwards and the Square Root rule.

As noted earlier, the Bromilow Equation had the lowest mean absolute percentage error and will be used for estimating the Student Health Center project's duration. Using the Bromilow Model the estimated duration of the William and Mary Student Health Center project is 16.3 months. Appendix G details the computation of the durations of the comparable projects.

Chapter V Discussion

5.1 Student Health Center at William and Mary

The objective of this project was to forecast the cost of the building and construction duration of a new 23,000 SF student health center at the college of William and Mary (A-E RFP 2015). Based on the regression cost model, the cost for the building (bricks and mortar, excluding site costs and general conditions) is forecast to be $6.63 million. The 95% confidence interval of the forecast ranges from $5.91MM to $7.35 MM. The range of the 95% confidence interval forecast (estimate) is 21.6%. Current industry expectations for a Class V estimate have a range of 150% (-50% to +100%). This suggests that this methodology holds potential for better early phase cost estimating.

The forecast for construction duration, based on the Bromilow equation is approximately 16.3 months. Discussion with William and Mary project staff suggest that an “expert opinion” duration estimate would be approximately 12 months. The Bromilow equation is based on construction practices of the 1970’s so it is more than possible that improvements in materials and technology would result in faster construction times today. Certainly the Bromilow duration estimate would form a conservative upper bound for construction duration.

As part of this work, a Work Breakdown Structure for the project was developed (Figure 4). It was hypothesized that removing the site costs and general conditions costs from the work being estimated would lower the variability of the results and improve the accuracy of the model. Figure 11 is a scatter diagram of the Site Costs versus building size and Figure 12 is a scatter diagram of the General Conditions cost versus building size. The scatter diagrams seem to support the notion that site costs and general conditions are a source of variation in cost models and estimating these costs separately may be appropriate as it results in improved accuracy in building cost modeling.

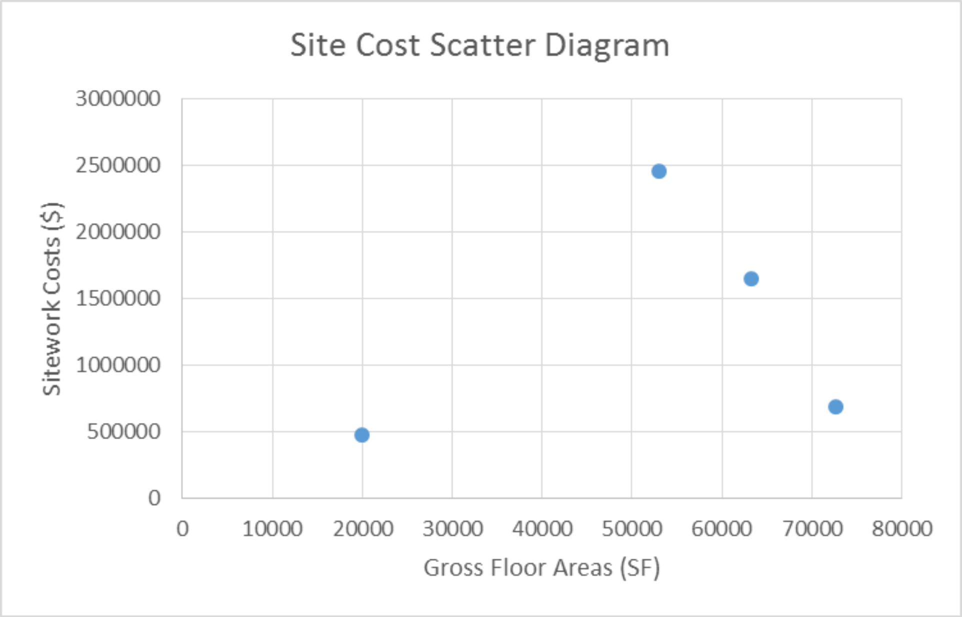

Figure 11 Scatter Plot of Site Costs

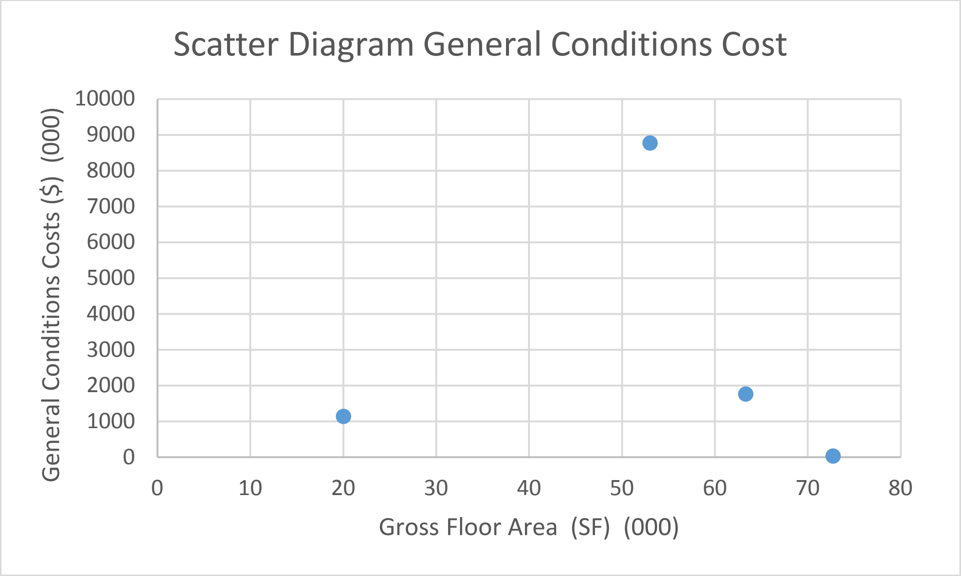

Figure 12 Scatter Plot of General Conditions Costs

As noted in the introduction, project teams face several challenges in developing pre-design cost and duration estimates. These include lack of definition in the project scope and variable skill levels of the project team. It is not uncommon for pre-design estimates to have a range of -50% to +100% of the actual cost. The approach used on this project appears to have provided a much smaller range for cost (- 10.3% range to +39.4%) and +/- 18% for duration. Cost estimate uncertainty in this range is often not seen until much later in the project life cycle, so this methodology may hold some potential promise for assisting project teams with cost estimation at the pre-design stage of a project.

While the statistics associated with the selected model is quite good (R^2 =0.994, P Value < 0.0001 and F Value =661. 63), there are also some limitations that should be well understood. These include:

a. The model **should not** be used to estimate costs for other building types. The comparable projects s were for a specific building type. Estimates of other types of buildings will require their own modeling effort.

b. This model estimates the cost for the building (bricks and mortar) only. Site costs and general conditions, as well as other project costs (design, inspection, etc.) must be estimated by the project team and added to the cost estimated by the model to determine total project costs.

c. The model **should not** be used to estimate costs outside the range of the data used to construct it. In this case student health centers smaller than 20,000SF and larger than 72,000 SF will require their own modeling effort.

d. The model estimates costs to February 2016 for projects in Williamsburg, Virginia. This result would need to be normalized to account for price level changes after that data and for construction at other locations.

Reduction of cost estimate uncertainty is an important step in setting a project team up for success. The approach used here is also in the skill set of many, if not most, project teams. The amount of information required is relatively low and specialize software packages are not needed.

The approach used here should not, under any circumstances, be considered a “silver bullet” and the end of project cost management. By achieving scope-budget match prior to the start of design, the project team has the confidence that, properly managed going forward, the cost targets can be met. However, there should be no feeling in the design team that cost management is over and that careful attention to all aspects of cost management will not be required going forward.

This approach also allows the team to provide design-to-cost targets for the various members of the design team. Many times there are not cost targets and the architects, engineers and other sub-consultants don’t have any idea as to what their portion of the project their design should cost. These design-to-cost targets are particularly important for overall project success. As noted earlier, approximately 2/3 of costs are locked in by the completion of project concept phase/conceptual design. Without cost targets, the project team essentially gets to hope for the best and will likely enter a period of chasing costs and a series of cost reduction exercises.

This approach also provides an easy (ier) transition into using more sophisticated tools regarding scope definition during preliminary design such as the Project Definition Rating Index (PDRI) (Department of Energy 2011, National Research Council 1990).

5.2 Knowledge Management

While this work was focused on cost estimating, it may also provide some recommendations that may be useful at the enterprise level of the firm. Knowledge management takes a comprehensive, as well as systematic approach, to the “information” assets of an organization. It does this by identifying, capturing, collecting, organizing, indexing and retrieving this knowledge (Chopp 2013). The methodology developed and applied in this Praxis is one application of knowledge management. It takes knowledge an organization may have and “captures” comparable project cost and other data (from outside sources). Optimally, this information is stored in a manner in which it is retrievable along with the results of any modeling that is done. More broadly, data mining and “Big Data” applications in project management should be as applicable as they are in other industries.

If an organization is doing similar projects, this knowledge will be an important asset in the future and help inform the thinking and decision-making of both project teams and senior leaders. As the database grows, and the firm develops greater expertise in cost estimating, techniques such as case based reasoning and neural networks which require larger amounts of information than were used in this project may be judged to be useful for the organization.

5.3 Opportunities for Further Work

The work done here is based on a limited number of projects and a specific building type. There are opportunities to generalize this work with more extensive project samples as well as link it to design phase tools such as the Project Definition Rating Index and Design-to-Cost targets. Additional opportunities exist within knowledge management and/or “big data”/data analytics.

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Appendix A Basis of Estimate

Project. Student Health Center

Owner. College of William and Mary

Location. Williamsburg, VA.

Location Cost Index.

Date of Estimate. February, 2016

1. **Scope of Estimate**. The scope of this estimate includes a 27,400SF student health center. The project is new construction. The estimate is for the “bricks and mortar” portion of the project only. Civil/sitework, General Conditions and other “soft costs” are excluded.

   Assumptions: the project will be designed and constructed to the standards of the W&M Design manual.
2. **Organization Process Assets**. The project will use the standard procedures established by the W&M Facilities Planning, Design and Construction department.
3. **Project Work Information**. This is a pre-design estimate. The estimate is meant to be a level 5 estimate as defined by the Association for the Advancement of Cost Engineers International.
4. **Estimating Assumptions**.
5. **Constraints**.

6. **Estimation Techniques**. The estimate will use parametric estimation based on similar projects. The estimate will be checked by (1) using the cost estimating relationship developed from the comparable projects again the guaranteed maximum price (GMP) for the Duke University Student Health Center and (2) analogous estimating techniques.
7. **Resources needed to (prepare the) Estimate**. The resources needed to prepare the estimate include (1) a project breakdown structure, (2) cost data from comparable projects (3) cost and location index information to normalize cost data and (4) one estimator.
8. **Estimate confidence**. As a class 5 estimate the estimate will fall with -50% to +100% of the actual bid price. Much higher accuracy is hoped for, but this is the target.
9. **Contingency Planning Reserve**. Estimation of contingency is outside the scope of this estimate.
10. **Risk Assessment**. Assessing a conceptual phase risk register is outside the scope of this estimate.
11. **Management and Monitoring Processes**.
12. **Improvement Processes**.

Appendix B Project Comparable - California State University at San Marcos

Located in southern California north and east of San Diego, California State University at San Marcos was founded in 1989 and is the twentieth campus in the California state university system. The first 600 students enrolled in the fall of 1990. Enrollment in 2015 was just over 14,000 students.

The student health center was located off-campus for fifteen years; in August of 2013 construction on a new 20,000 SF student health center began. Construction was complete in October of 2014. Total construction cost for this project were $4.625 million. The new facility is a LEED Gold certified two story structure with exam and counseling rooms, health education and waiting areas. Total project costs was $9.5 MM.

Appendix B Project Comparable California State University at San Marcos – Project Cost Breakdown

Cost Item Description	Amount	Categorization	G/C	Site	Bldg	Other
100% Preliminary Design	$87,595					$87,595
Construction Documents	$653,205					$653,205
General Conditions	$1,004,735		$1,004,735			
Bond	$74,623		$74,623			
Liabuility Insuracne	$64,647		$64,647			
Survey	$6,750					$6,750
Final Cleanup	$4,777				$4,777	
Earthwork	$145,363			$145,363		
Erosion copntrol	$34,976			$34,976		
AC Paving	$1,500			$1,050		
Site Concrete	$52,930			$52,930		
Wet Utilities	$122,980			$122,980		
Gas Service	$7,500			$7,500		
Landscape	$110,392			$110,392		
Concrete Reinforcing	$93,497				$93,497	
Structural Concretew	$305,235				$305,235	
Polished concrete	$8,610				$8,610	
Masonry	$378,181				$378,181	
Structural steel	$149,091				$149,091	
Metal decking	$45,130				$45,130	
Misc. Metals	$103,900				$103,900	
Finish carpentry	$174,181				$174,181	
Waterproofing	$26,628				$26,628	
Insultation	$34,487				$34,487	
Roofing	$50,292				$50,292	
Sheet metal	$48,771				$48,771	
Doors, Frames and Hardware	$113,500				$113,500	
Overhead doors	$10,000				$10,000	
Pass-through weindow	$2,000				$2,000	
Glass & Glazing	$157,810				$157,810	
Lath & Plaster	$26,448				$26,448	
Metal Studs & Drywall	$292,313				$292,313	
Tile	$126,239				$126,239	
Flooring	$72,997				$72,997	
Acoustic Ceiling	$59,240				$59,240	
Painting	$36,829				$36,829	
Visual Display surfaces	$4,050				$4,050	
Specialities	$10,730				$10,730	
Signage	$3,500				$3,500	
Fire extinguishers	$1,500				$1,500	
Window coverings	$17,704				$17,704	
Furniture	$8,000				$8,000	
Elevators	$150,000				$150,000	
Fire Sprinklers	$66,879				$66,879	
Plumbing	$287,938				$287,938	
HVAC	$789,527				$789,527	
Electrical	$965,025				$965,025	
TOTAL	**$6,992,205**		**$1,144,005**	**$475,191**	**$4,625,009**	**$747,550**

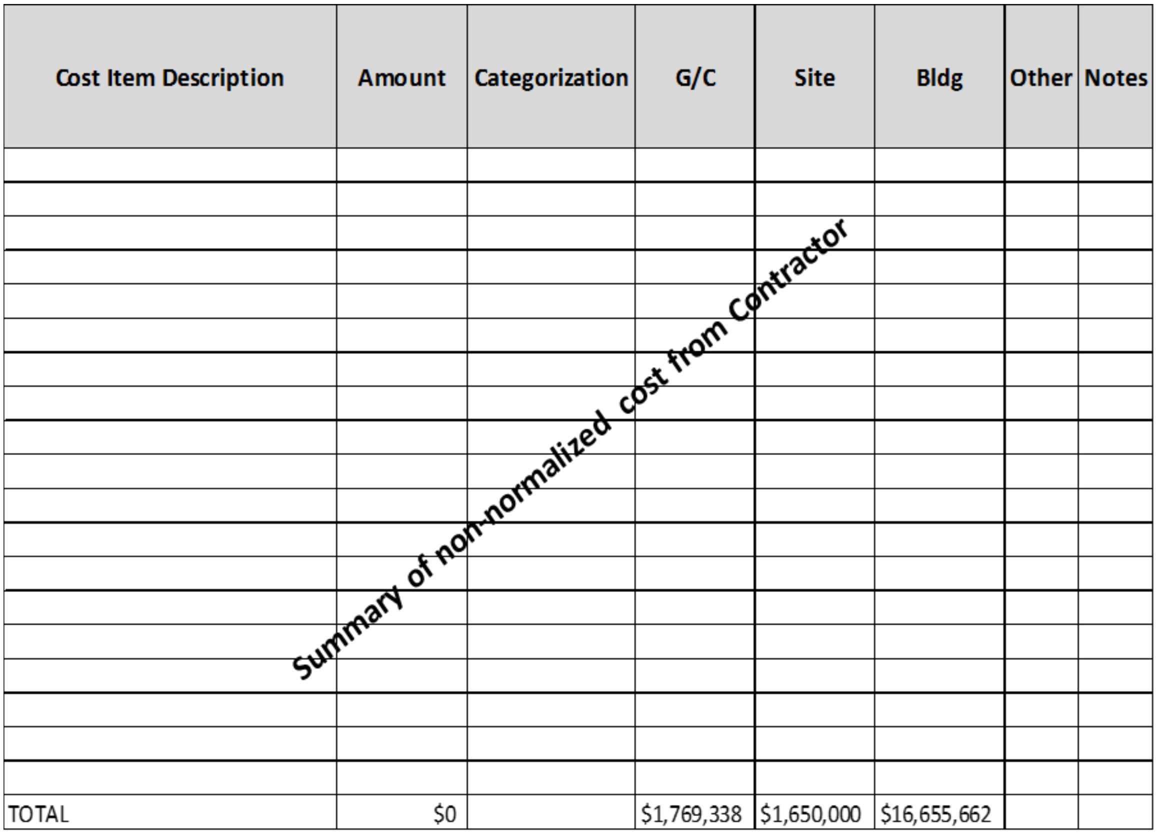
Appendix B Project Comparable Cost Data for California State University at San Marcos – Cost Normalization

University/College	California State University, San Marcos
Location	San Marcos, CA.
Project Name	Student Health Center
Size in Square feet	20,000
Construction Start Date	Aug-13
General Conditions (Information only)	$1,144,005
Site Work (Information only)	$475,191
Building Cost	$4,625,009
Completion Date	Oct-14
Start Date for Historical Index	Aug-13
ENR Construction Cost Index	9545
ENR Construction Cost Index (1 February, 2016)	10181.92
Calculated Time Adjustment Factor	1.06672813
Postal Zip Code	92096
Nearest Means City Index Used	San Diego, CA.
Above City's Means 'Total' Location Factor	104.5
Project Site Location Factor (Newport News, VA.)	86.1
Calculated Location Adjustment Factor	0.824
Building Cost	$4,625,009
Building Cost Adjusted to Feb. 2016	$4,933,627.201
Building Cost adjusted to Williamsburg, VA.	$4,064,931.120
Size	20,000
Normalized Cost/SF (Building Only)	$203.25

Appendix C – Project Comparable Pennsylvania State University

Located in central Pennsylvania, the Pennsylvania State University Park campus is part of a twenty campus state university system with more than 100,000 students. The student health center was a 63,300 SF project. The project is multi-story and features floor to ceiling windows as well as 60 examination rooms and spaces for group therapy, health education and an art gallery. While not LEED certified, the building has a green roof to reduce stormwater runoff and reduce heating and cooling costs. Construction began in the fall of 2006 and was complete in the fall of 2008. Construction cost for the project were $26 MM.

Appendix C- Project Comparable - Pennsylvania State University – Project Cost Data



Cost Item Description	Amount	Categorization	G/C	Site	Bldg	Other	Notes
TOTAL	$0		$1,769,338	$1,650,000	$16,655,662		

Summary of non-normalized cost from Contractor

Appendix C- Pennsylvania State University – Data Normalization

University/College	Pennsylvania State University
Location	University Park , PA.
Project Name	Student Health Center
Size in Square feet	63,300
Construction Start Date	October 2006
General Conditions (Information only)	$1,769,338
Site Work (Information only)	$1,650,000
Building Cost	$16,655,662
Completion Date	June, 2008
Start Date for Historical Index	Oct-06
ENR Construction Cost Index	7883
ENR Construction Cost Index (1 February, 2016)	10181.92
Calculated Time Adjustment Factor	1.292
Postal Zip Code	16802
Nearest Means City Index Used	Altoona, PA.
Above City's Means 'Total' Location Factor	93.4
Project Site Location Factor (Newport News, VA.)	86.1
Calculated Location Adjustment Factor	0.922
Building Cost	$16,655,662
Building Cost Adjusted to Feb. 2016	$21,512,954.209
Building Cost adjusted to Williamsburg, VA.	$19,831,534.876
Size	63,300
Normalized Cost/SF (Building Only)	$313.29

Appendix D Project Comparable San Jose State University

The 52,000 SF Student Wellness Center houses the student health center, counseling center and wellness center. Construction began in June of 2013 and was complete 22 months later in March of 2015. The normalized building cost for this project was $13.77 MM. The building is three stories in height and was designed and built to meet LEED Gold standards. It will house staff of 70. In addition to exam and treatment rooms, the building design provides for nursing stations, physical therapy center, a pharmacy and juice bar. The building has a structural steel frame and concrete decks with ceiling height are 15 feet. The project used a design-build form of project delivery.

Appendix D Project Comparable - San Jose State University

Cost Item Description	Amount	Categorization	G/C	Site	Bldg	Other	Notes
General Conditions	$8,482,601.80	G/C	$8,482,601.80				
Foundations & SOG	$648,106.40	Bldg			$648,106.40		
U/G Utilities	$1,327,702.74	Site		$1,327,702.74			
Building Concrete	$151,248.15	Bldg			$151,248.15		
Auger Cast Piles	$448,648.00	Bldg			$448,648.00		
Site Concrete & Finishings	$379,783.49	Site		$379,783.49			
Rain Screen	$335,757.00	Bldg			$335,757.00		
Structural Steel	$1,499,491.40	Bldg			$1,499,491.40		
Metal Decking & Jr. Steel	$161,805.00	Bldg			$161,805.00		
Misc. Metals & Stairs	$208,158.12	Bldg			$208,158.12		
Rough Carpentry	$48,075.00	Bldg			$48,075.00		
Roofing & Waterproofing	$234,640.00	Bldg			$234,640.00		
Aluminum Panel	$491,387.00	Bldg			$491,387.00		
Finish Carpentry/Millwork	$612,199.18	Bldg			$612,199.18		
Doors, Frames & Hardware	$427,618.70	Bldg			$427,618.70		
Curtain Wall & Int. Glazing	$1,338,206.25	Bldg			$1,338,206.25		
Interior Drywall and Insulatio	$1,002,037.07	Bldg			$1,002,037.07		
Ext. Framing, Lath & Plaster	$956,750.00	Bldg			$956,750.00		
Ceramic Tile	$57,431.00	Bldg			$57,431.00		
T-Bar celing	$425,056.00	Bldg			$425,056.00		
Carpet & VCT	$372,389.25	Bldg			$372,389.25		
Terrazzo Flooring	$128,418.30	Bldg			$128,418.30		
Painting	$168,657.55	Bldg			$168,657.55		
Signage	$75,200.00	Bldg			$75,200.00		
Toilet Partitions & Specialties	$97,229.46	Bldg			$97,229.46		
Misc. Specialties	$97,489.00	Bldg			$97,489.00		
Audio Visual	$551,732.39	Bldg			$551,732.39		
Landscaping & Irrigation	$751,539.96	Site		$751,539.96			
X-Ray	$173,130.42	Bldg			$173,130.42		
Elevator	$169,589.60	Bldg			$169,589.60		
Fire Sprinkler- Design Build	$264,235.00	Bldg			$264,235.00		
Plumbing Design Build	$951,152.46	Bldg			$951,152.46		
HVAC Design Build 2506889.0	$2,506,889.02	Bldg			$2,506,889.02		
Electrical Design Build	$2,995,567.53	Bldg			$2,995,567.53		
Grading and Paving	$286,544.80	Site	$286,544.80				
Architectural Fee	$2,090,797.80	AE Fee				$2,090,797.80	
TOTAL	$30,917,264.84		**$8,769,146.60**	**$2,459,026.19**	**$17,598,294.25**	**$2,090,797.80**	**$30,917,264.84**
			28.36%	**7.95%**	**56.92%**	**6.76%**	

Appendix D- Project Comparable -San Jose State University

University/College	San Jose State University
Location	San Jose CA.
Project Name	Student Health Center
Size in Square feet	53,000
Construction Start Date	June 2013
General Conditions (Information only)	$8,769,147
Site Work (Information only)	$2,459,026
Building Cost	$17,598,294
Completion Date	March 2015
Start Date for Historical Index	Jun-13
ENR Construction Cost Index	9542
ENR Construction Cost Index (1 February, 2016)	10181.92
Calculated Time Adjustment Factor	1.067063509
Postal Zip Code	95192
Nearest Means City Index Used	San Jose, CA.
Above City's Means 'Total' Location Factor	117.4
Project Site Location Factor (Newport News, VA.)	86.1
Calculated Location Adjustment Factor	0.733
Building Cost	$17,598,294
Building Cost Adjusted to Feb. 2016	$18,778,497.343
Building Cost adjusted to Williamsburg, VA.	$13,771,964.406
Size	53,000
Normalized Cost/SF (Building Only)	$259.85

Appendix E Project Comparable - University of Kentucky

Located in Lexington, Kentucky and established in 1865, the University of Kentucky has an enrollment of almost 31,000 students. Construction of a 72,714 SF student health center began in November of 2006 and was completed in March of 2008. Construction cost for the new building was $16.48MM. Located adjacent to the Kentucky Clinic, the student health center includes administrative offices, examination rooms, a pharmacy and medical staff offices. The building is a multi-story glass and brick building.

Appendix 1–E University of Kentucky – Project Cost Data

Cost Item Description	Amount	Categorization	G/C	Site	Bldg	Other
Rose Street Clsoure	$39,974	Site		$39,974		
Testing & Special Inspections	$43,200	G/C	$43,200			
Sitework	$610,043	Site		$610,043		
Drilled Concrete Piers & Shafts	$45,800	Bldg			$45,800	
Concrete	$1,495,000	Bldg			$1,495,000	
Structural & Miscellaneous Stee	$2,098,000	Bldg			$2,098,000	
Masonry	$906,600	Bldg			$906,600	
Roofing	$284,621	Bldg			$284,621	
General Trades	$1,235,300	Bldg			$1,235,300	
Glass & Glazing	$1,262,560	Bldg			$1,262,560	
Metal Studs & Drywall	$1,576,975	Bldg			$1,576,975	
Elevators	$420,584	Bldg			$420,584	
Plumbing & HVAC	$4,113,900	Bldg			$4,113,900	
Fire Protection	$178,390	Bldg			$178,390	
Electric & Communications	$2,144,700	Bldg			$2,144,700	
Millwork	$436,525	Bldg			$436,525	
Flooring	$260,790	Bldg			$260,790	
Landscape & Site Treatment	$35,109	Site		$35,109		
Window Treatments	$26,192	Bldg			$26,192	
TOTAL	$17,214,263		$43,200	$685,126	$16,485,937	

Appendix E Project Comparable – University of Kentucky – Cost Normalization

University/College	University of Kentucky
Location	Lexington, KY.
Project Name	Student Health Center
Size in Square feet	72,714
Construction Start Date	November 2006
General Conditions (Information only)	$43,200
Site Work (Information only)	$685,126
Building Cost	$16,485,937
Completion Date	March 2008
Start Date for Historical Index	Nov-06
ENR Construction Cost Index	7911
ENR Construction Cost Index (1 February, 2016)	10181.92
Calculated Time Adjustment Factor	1.287
Postal Zip Code	40506
Nearest Means City Index Used	Lexington, KY
Above City's Means 'Total' Location Factor	90
Project Site Location Factor (Newport News, VA.)	86.1
Calculated Location Adjustment Factor	0.957
Building Cost	$16,485,937
Building Cost Adjusted to Feb. 2016	$21,218,365.777
Building Cost adjusted to Williamsburg, VA.	$20,298,903.260
Size	72,714
Normalized Cost/SF (Building Only)	$279.16

Appendix F Project Comparable – Duke University

Located in Durham, North Carolina and established in 182465, Duke University has an enrollment of approximately 15,000 students. Construction of a 72,770 SF student health center began in April 2015 and is forecast for completion 20 months later. . Construction cost (non-normalized) for the new building was $27.11 MMMM.

Appendix F

Duke University Comparable

University/College	Duke University
Location	Durham, NC
Project Name	Student Health Center
Size in Square feet	71,770
Construction Start Date	April, 2015
General Conditions (Information only)	$3,690,215
Site Work (Information only)	$3,179,473
Building Cost	$20,241,390
Total Cost (not normalized)	$27,111,078
Completion Date	N/A
Start Date for Historical Index	Apr-15
ENR Building Cost Index	5501
ENR Building Cost Index (1 February, 2016)	5588.02
Calculated Time Adjustment Factor	1.016
Postal Zip Code	27710
Nearest means City Index Used	Durham, NC
Above City's Means 'Total' Location Factor	82.1
Project Site Location Factor (Newport News, VA.)	86.1
Calculated Location Adjustment Factor	1.049
Building Cost	$20,241,390
Building Cost Adjusted to Feb. 2016	$20,561,587
Building Cost adjusted to Williamsburg, VA.	$21,563,370
Size	71770
Normalized Cost/SF (Building Only)	$300.45

22.82 Months

ENR Feb 2016 Cost Indice	10181.92
ENR June 1972 Cost Indice	1753
Price Level Normalization	0.172167921

Appendix G Duration Forecast

Appendix G

Duration Forecasts Love, Tse & Edwards Time Cost Model

Project	Actual Construction Cost (Normalized)	GFA (in 000 SF)	GFA (in Square Meters)	Number of Floors	Actual Construction Time (mos)	Forecast Time (Log T)	Forecast Time in Weeks	Forecast Time in Months
California State University San Marcos	$4,064,931	20,000	1.86	1	15	3.347752142	28.2	7.05
Duke University	$21,563,370	71,770	6.67	3	20	3.853950787	47.17	11.79
Pennsylvania State University	$19,831,535	63,300	5.88	4	21	3.860295878	47.46	11.865
San Jose State University	$13,771,964	53,000	4.92	3	22	3.770784428	43.4	10.85
University of Kentucky	$20,298,903	72,714	7	4.5	17	3.915010788	50.14	12.535

Love, Tse & Edwards Formula Computations

$$Log(T) = 3.178 + 0.274Log(GFA) + 0.142Log(Floor)$$

T= time in weeks

GFA = Gross Floor Area (000 m^2)

Duration Forecast Using Bromilow Equations

Project	Actual Construction Cost (Normalized)	Actual Construction Cost (1972 Dollars)	Actual Construction Duration	Bromilow Model Working Days	Bromilow Model Forecast Working Time in Months
California State University San Marcos	$4,064,931	$700,794	15	281.3	14.1
Duke University	$21,563,370	$3,717,525	20 (3)	464.1	23.2
Pennsylvania State University	$19,831,535	$3,418,957	21	452.6	22.6
San Jose State University	$13,771,964	$2,374,287	22	405.7	20.3
University of Kentucky	$20,298,903	$3,499,531	17	455.8	22.8
W&M Student Health Center	$6,631,521	$1,143,274	N/A	325.8	16.3
ENR Feb 2016 Cost Indice	10181.92				
ENR June 1972 Cost Indice	1753				
Price Level Normalization	0.172167921				
(1) Model validation using cost model forecast cost					
(2) Forecast duration using GMP normalized cost					
(3) GMP Contract duration					

The Bromilow equation (Bromilow 1977) is:

$$T = 313C^{0.3}$$

T= construction time in working days

C= Final Cost in millions, 1972 dollars (projects must be normalized to 1972 costs)

Square Root Rule Duration Forecast

PROPOSED Project	California State University San Marcos	Duke University	Pennsylvania State Universit	San Jose State University	University of Kentucky	Average of Forecast Duration	Actual Duration	Percent Error
California State University San Marcos		8.7	9.5	12.0	7.6	9.4	15	-37.08%
Duke University	34.5		21.9	27.5	17.5	25.4	20	26.87%
Pennsylvania State University	33.1	19.2		26.4	16.8	23.9	21	13.71%
San Jose State University	18.2	16.0	20.8		14.0	17.2	22	-21.69%
University of Kentucky	33.5	19.4	21.2	26.7		25.2	17	48.35%

Project	Actual Construction Cost (Normalized)		GFA (in 000 SF)	Number of Floors	Actual Construction Time (mos)
California State University San Marcos	$4,064,931		20,000	1	15
Duke University	$21,563,370		71,770	3	20
Pennsylvania State University	$19,831,535		63,300	4	21
San Jose State University	$13,771,964		53,000	3	22
University of Kentucky	$20,298,903		72,714	4.5	17

$$T_p = T_e \left({C_p}/{C_e} \right)^{0.5}$$

T_p = Time proposed the estimated duration of the project being estimated

T_e = Time existing the actual construction time of a completed project that is being used as a comparable to the proposed project

C_p = Cost of proposed project

C_e = Cost of existing project; the cost of the existing project being used as a comparable