CONSTRUCTION DELIVERY SYSTEMS: A COMPARATIVE ANALYSIS OF THE PERFORMANCE OF SYSTEMS WITHIN SCHOOL DISTRICTS

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The delivery of a construction project is characterized by the participation of several individuals. Owner, architect / engineer, and contractor are the most important players of this process. The owner's needs are expressed in plans and specifications created by the architect and physically performed by the contractor. Throughout the life of the project, there are contracts and several direct and indirect relationships among the players. The delivery system characterizes these aspects, from planning to controlling, of a construction project.

Multiple prime is one type of delivery system that is the subject of many discussions in the industry. General contractors, architects and owners believe that this system inherently has coordination problems. On the other side, specialty contractors believe that this system has several advantages because of the exclusion of the middleman and the direct relationship of these contractors to the owner. The goal of this study is to objectively analyze the performance of construction delivery systems within public school districts. The districts in the states of Pennsylvania, Ohio, New Jersey, Massachusetts, and Virginia form the population of this study.

Quantitative and qualitative measurements are used as the variables for comparison. ANOVA and two-sample t tests are used as statistical tools for the quantitative, and the Chi-Square test is used for the qualitative analysis. The data collected is divided into two different sets. The first set includes all the valid responses. The second set is limited to the analysis of projects greater than \$ 10,000,000. A section with the descriptive statistics of litigation cases is also included in this study.

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PREFACE

First I would like to thank Dr. Robert Ries for his guidance and support.

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INTRODUCTION

Humans use engineering principles to develop and change the environment. As our behavior and intelligence develops, Civil Engineering changes and evolves. New materials, processes and procedures arise, and construction has become more complex. As a result, the art of building today requires skilled and specialized individuals. Because of the complexities involved in this process, several norms, statutes, codes, and regulations have been created that dictate the way that buildings are built. Legislation has also influenced the relationship among players that are involved in the construction process.

Because of such complexity, standardized techniques guide the delivery of construction projects. These techniques and processes are the basis of what is known as Project Delivery Systems. Dorsey (1997, p. XI) states that "… project delivery system is a general term describing the comprehensive design / construction process, including all the procedures, actions, sequences of events, contractual relations, obligations, interrelations, and various forms of agreement – all aimed at successful completion of the design and construction of buildings and other structures."

There are several types of delivery systems and there is no best one for all cases. It depends on the circumstances and milieu that surrounds the project. However, controversial discussions in the industry have arisen about the performance of delivery systems, especially when comparing multiple prime with single prime delivery systems. As described in detail later in this document, multiple prime is characterized by the direct relationship between the owner and several specialized contractors. On the other hand, the single prime system is characterized by the exclusive relationship between the owner and a single prime contractor that is responsible for the entire project. This prime contractor may or may not subcontract portions of the project.

Different opinions can be heard from different groups within the construction industry. On one side, specialty contractors such as mechanical, electrical, and plumbing contractors defend the use of multiple prime as the best type of delivery system. One of the arguments is that they believe this system is beneficial for both specialty contractors and owners because there is no middleman, and a direct relationship between owner and contractor can be established. This situation would result in a cheaper job price because specialty contractors would present their best price directly to the owner. In addition, the owner has control over the prime contractors, and is able to easily communicate quality standards and performance.

On the other hand, some owners, architects and general contractors do not see the advantages in using the multiple prime delivery system. They believe that subcontractors are the principal beneficiaries of this system. They argue that the use of multiple prime contractors generates scheduling problems and inevitable delays, and there is no significant financial benefit from the system. Based on their arguments, the results range from schedule overruns to litigation to cost growth.

The intention of this study is to objectively analyze the performance of different delivery systems used in construction by school districts. Cost, schedule and quality measurements are the basis of the analysis. The first three chapters provide background information about the construction process and delivery systems. The fourth chapter presents the study scope, goals and limitations. The fifth chapter presents a brief discussion of past related studies. Finally, a detailed description of the methodology and the results obtained are discussed in the final sections of this dissertation.

1.0 OVERVIEW OF THE CONSTRUCTION PROCESS

1.1 THE CONSTRUCTION PROJECT

Cleland and Ireland (2002, p. 4) define a project as "… a combination of organizational resources pulled together to create something that did not previously exist and that will provide a performance capability in the design and execution of organizational strategies. Projects have a distinct life cycle, starting with an idea and progressing through design, engineering, and manufacturing or construction, through use by a project owner."

The construction industry is based on the execution of projects. In contrast to manufacturing products, the deliverables of these projects are, with very few exceptions, very unique. However, common questions are always involved in every type of project (Cleland and Ireland, 2002, p. 4):

- What will it cost?
- What time is required?
- What technical performance capability will it provide?
- How will the project results fit (long and short term) into the design and execution of organizational strategies?

These aspects form the "iron triangle" (Figure 1.1) that can be found in a project (Cleland and Ireland, 2002, p. 5):

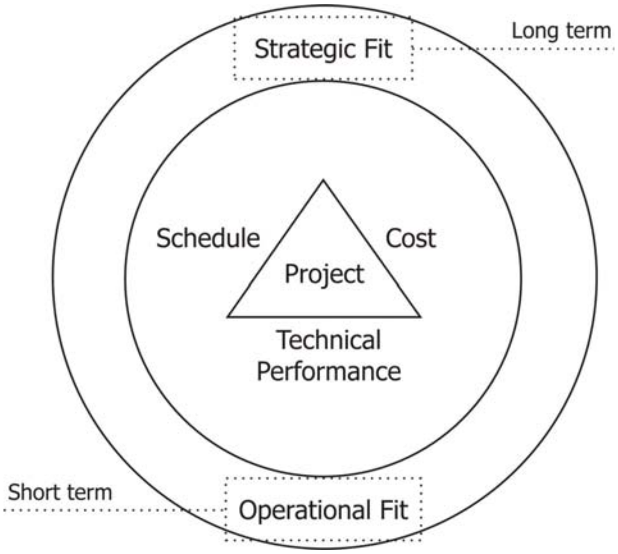


Figure 1.1 - Iron Triangle: Project Key Considerations

The triangle relates three variables that are common to every project: schedule, cost and technical performance (or quality). These variables are linked, and a change in one will affect the others. For example, for a project to be done faster, it would require more financial resources and the final quality might be compromised. From another perspective, a project with extremely high technical performance would require a greater amount of time and money to complete.

The challenge is to change one variable while not compromising the others. In the construction industry, for example, owners have asked for early completion within budget and quality parameters. Competition has forced contractors to find ways to achieve results that go beyond the increased use of labor and equipment to solve schedule problems, which may increase cost. Better management approaches, reduction of re-work, increased productivity and pre-construction services are some alternatives used by contemporary construction companies.

The project has to fit into the strategic and operational strategies of both parties. A successful project is characterized when owner and contractor, at the end of the project, are in a win-win situation, i.e., situations where the contractor is able to successfully develop the project within cost and time objectives while realizing a good profit margin, and when the owner is completely satisfied with the quality, and is able to profit from the deliverable.

If we assume that the project fits the owner's and contractor's strategies; schedule, cost, and quality are the three basic aspects used to analyze the performance of the project delivery systems in this study. Nevertheless, the construction industry has faced a great amount of litigation involving contractors, subcontractors, owners and companies that are directly related to the construction process. Litigation may be related to the way that the relationships are established and consequently to the type of delivery system involved. However, at this point, it is possible to affirm that there is no project immune to litigation, but there are various ways to prevent it. One question that will be considered is the correspondence of litigation frequency and extent within delivery systems.

1.2 CONSTRUCTION CLASSIFICATION

Correlation of strategic and operational strategies between parties in a construction project is directly related to the type of construction involved in the project. Some organizations have specialized according to construction classifications, which in some cases define their area of expertise.

There are different ways to classify the construction industry. According to Halpin & Woodhead (1998, p. 14-15), there are three major construction categories:

a) *Heavy and highway* → Construction of highways, bridges, airports, pipelines, dams, tunnels, etc.

b) *Nonresidential building:*

i) Building (Institutional and Commercial) → Construction of schools, universities, hospitals, warehouses, theaters, government buildings, recreation centers, commercial office centers, etc.

ii) Industrial (Light and Heavy) → Construction of petroleum refineries, petrochemical plants, nuclear power plants, steel mills, etc.

c) *Residential construction* → Construction of single-family homes, multi-unit townhouses, high-rise apartments and condominiums.

Figure 1.2 (Halpin & Woodhead, 1998, p. 15) shows how the industry is segregated in the United States by dollar value, according to the classification presented above:

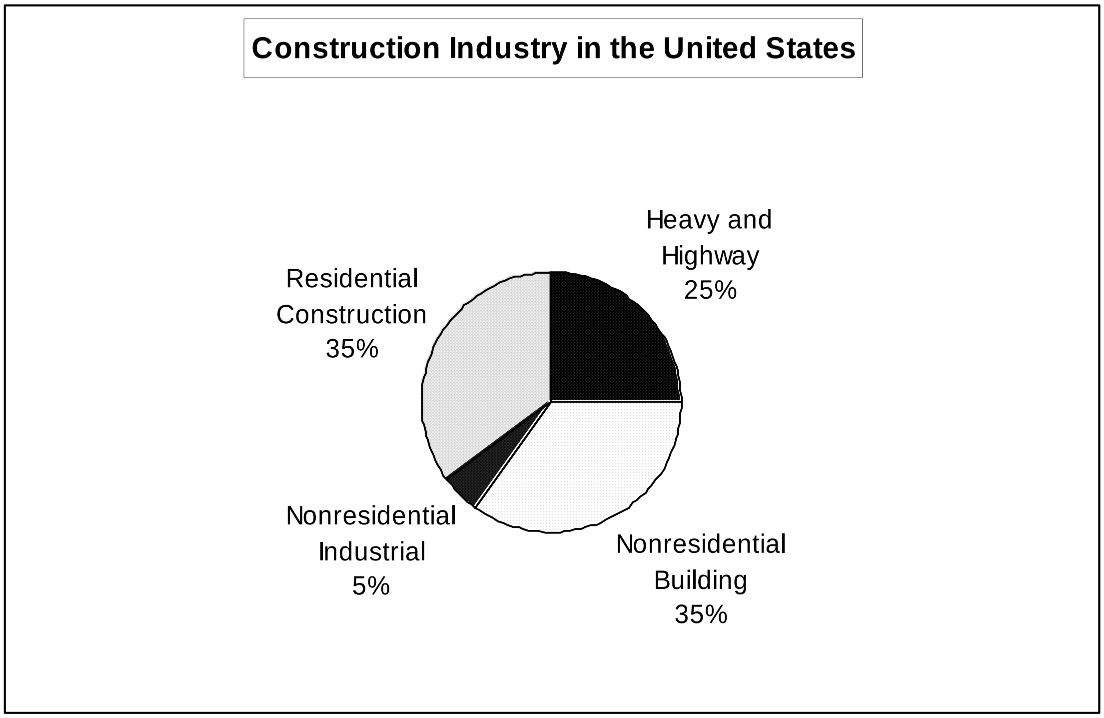


Figure 1.2 - Construction Industry in the United States

1.3 OWNERS CLASSIFICATION

Owners play the most important role within the construction process. Typically, there would not be a construction project without their need and without the financial resources that they provide to complete the project. They can be classified as public and private owners. Public owners correspond to entities that make use of public funds to provide constructed facilities for public use. Private owners are individuals or institutions that make use of private money to construct facilities that are solely for the benefit of the owner. Although the largest and most spectacular projects are usually related to the public sector, private owners are responsible for the largest volume of new construction in the U.S. According to Nunnally (2001, p. 3), this volume by dollar value of construction, is represented by Figure 1.3.

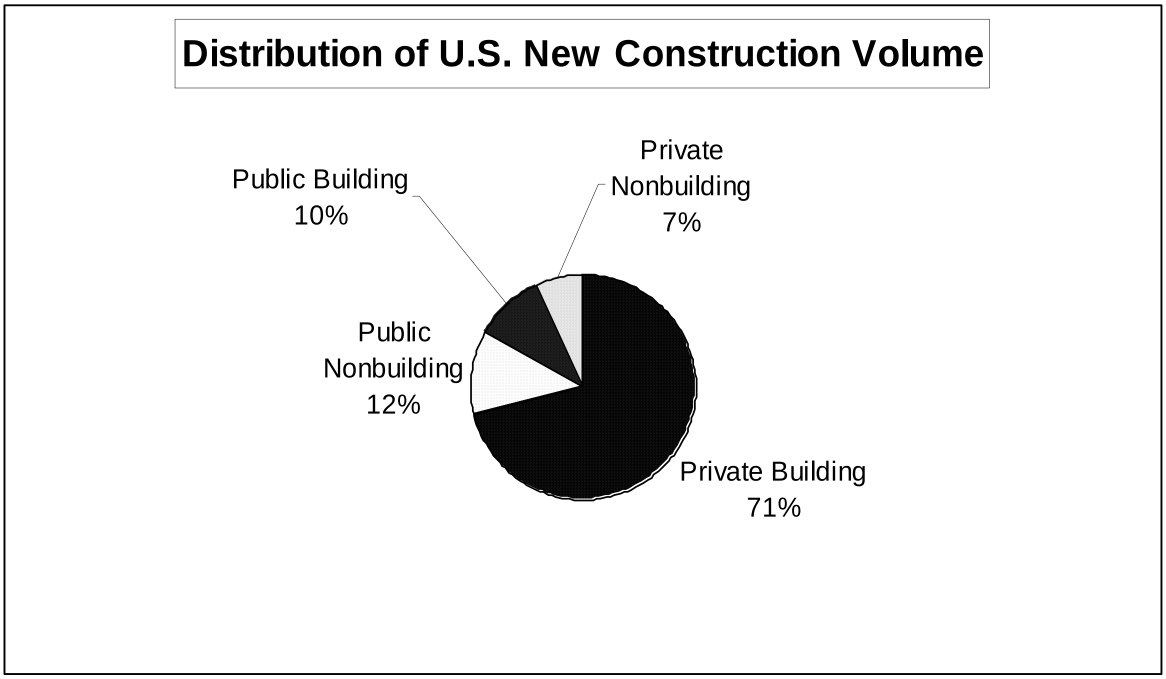


Figure 1.3 - Distribution of U.S. New Construction Volume

1.4 CONTRACTORS CLASSIFICATION

Agreements in the construction industry are usually established in contracts between the parties. For that reason, companies and individuals involved in this type of business are referred to as contractors. They can be classified from two different perspectives: according to their type of work and according to the contract agreement involved.

Based on the type of work, contractors can be classified as *general* and *specialty contractors*. General contractors execute most major construction projects and are able to perform a wide variety of activities. Specialty contractors execute specific activities in a project, such as electrical, mechanical, or plumbing work. The specialty contractors focus their work in just one activity because such activity requires a specialized and skilled labor force. The relationship among owner, general and specialty contractors determine the second classification that is based on the agreement involved.

The contractor, general or specialty, which has a direct relationship with the owner, is classified as a *prime contractor*. When the work agreement relates a contractor with the prime contractor, this contractor is classified as a *subcontractor*. General or specialty contractors can be classified as prime or subcontractors (see Figure 1.4) depending on the work agreements that exist between the parties. It is very common to see relationships between a prime contractor and various subcontractors (Figure 1.5). In a similar way, more than one prime contractor can relate to an owner, which characterizes the multiple prime contracting delivery system (Figure 1.6) that will be discussed further in this document.

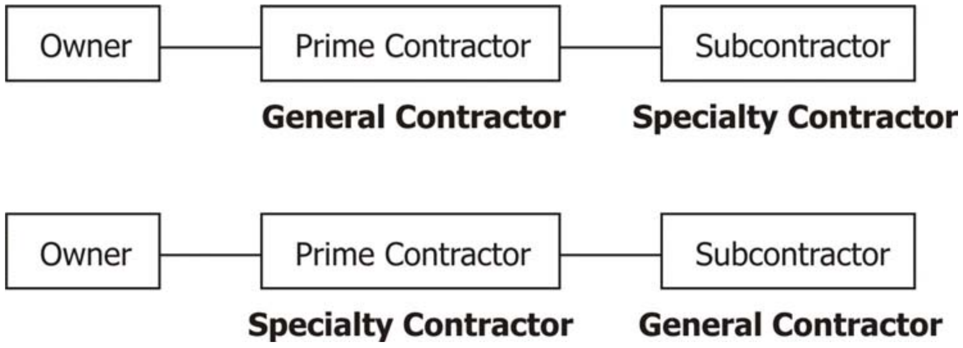


Figure 1.4 - Work Agreements between Parties

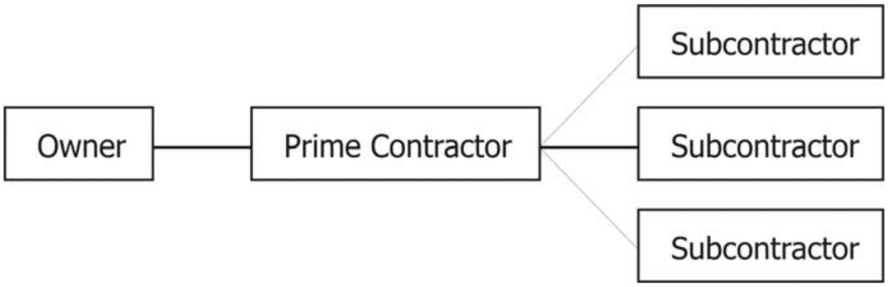


Figure 1.5 - Prime Contractor and Various Subcontractors

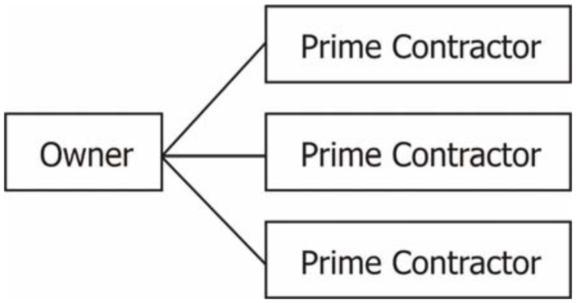


Figure 1.6 - Multiple Prime Contractors

1.5 THE CONSTRUCTION PROCESS AND ITS LIFE CYCLE

As a project-driven business, the construction process can be compared to a project's life cycle. Adams and Brandt in Cleland and Ireland (2002, p. 50) present Figure 1.7 as a way of looking at the life cycle of a project.

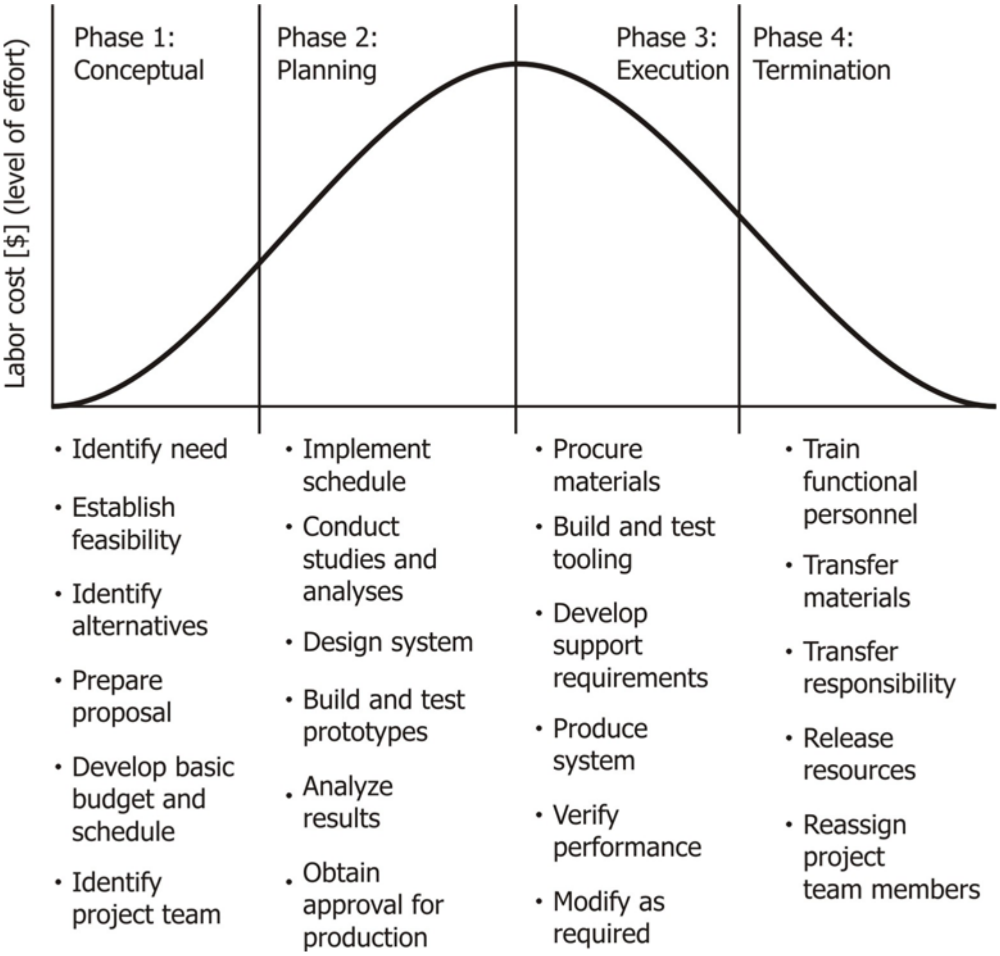
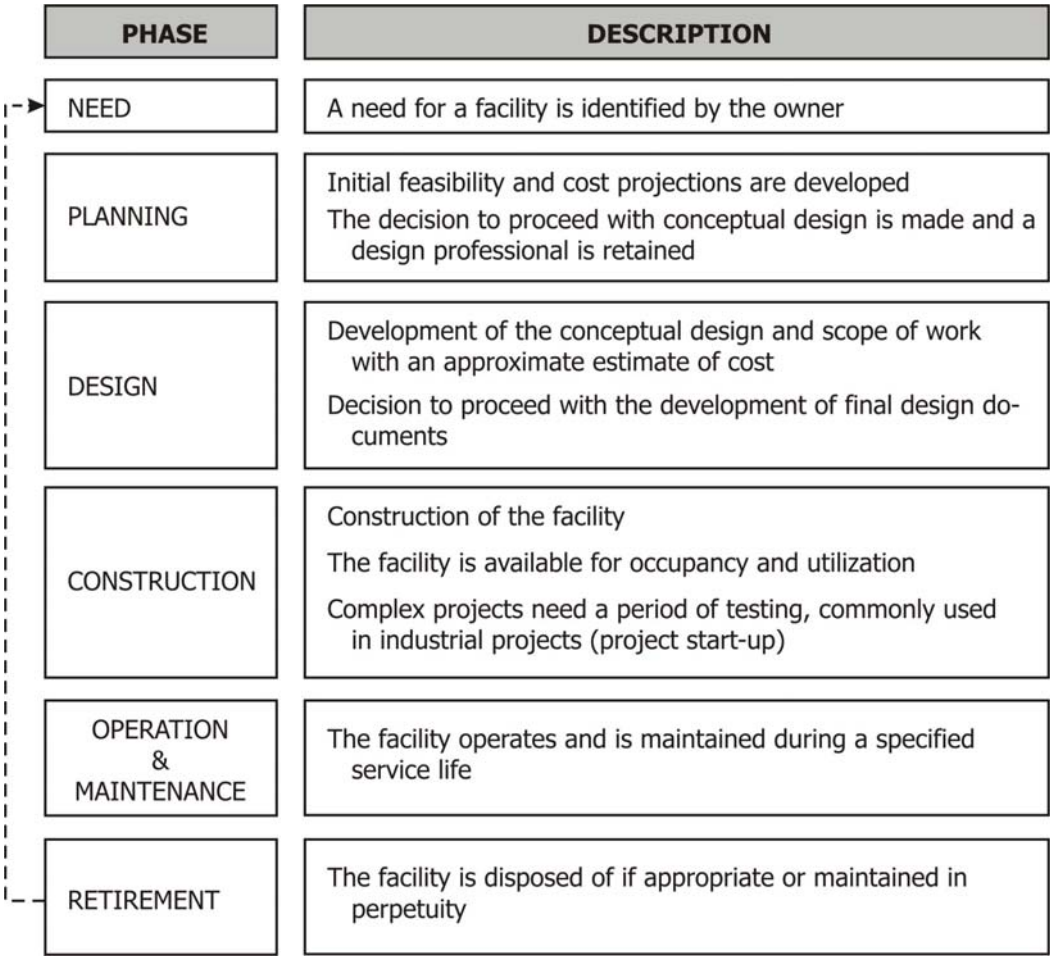


Figure 1.7 - Project's Life Cycle

A construction project presents an analogous life cycle (Figure 1.8) based on the above conception (adapted from Halpin & Woodhead, 1998, p. 11):



PHASE	DESCRIPTION
NEED	A need for a facility is identified by the owner
PLANNING	Initial feasibility and cost projections are developed The decision to proceed with conceptual design is made and a design professional is retained
DESIGN	Development of the conceptual design and scope of work with an approximate estimate of cost Decision to proceed with the development of final design documents
CONSTRUCTION	Construction of the facility The facility is available for occupancy and utilization Complex projects need a period of testing, commonly used in industrial projects (project start-up)
OPERATION & MAINTENANCE	The facility operates and is maintained during a specified service life
RETIREMENT	The facility is disposed of if appropriate or maintained in perpetuity

Figure 1.8 - The Construction Process

The construction project starts with the identification of the need to build a facility, followed by the planning and design phases, where the facility is conceptualized and parameters for monitoring and controlling the project are generated. The construction phase represents the time where the facility is built. Operation and maintenance is the utilization of the facility until its retirement that represents the end of the project's life cycle. Overlapping the construction process with the project's life cycle, it is possible to identify their similarities. As with any other project, construction progresses through its life cycle in different levels of cost, time, and performance. The conceptual phase requires less time, money and effort if compared to the execution phase. However, that will be the phase where generally, the scope is defined and the cost is committed. Figure 1.9 shows how the cumulative committed and spent costs progress through a project's life cycle.

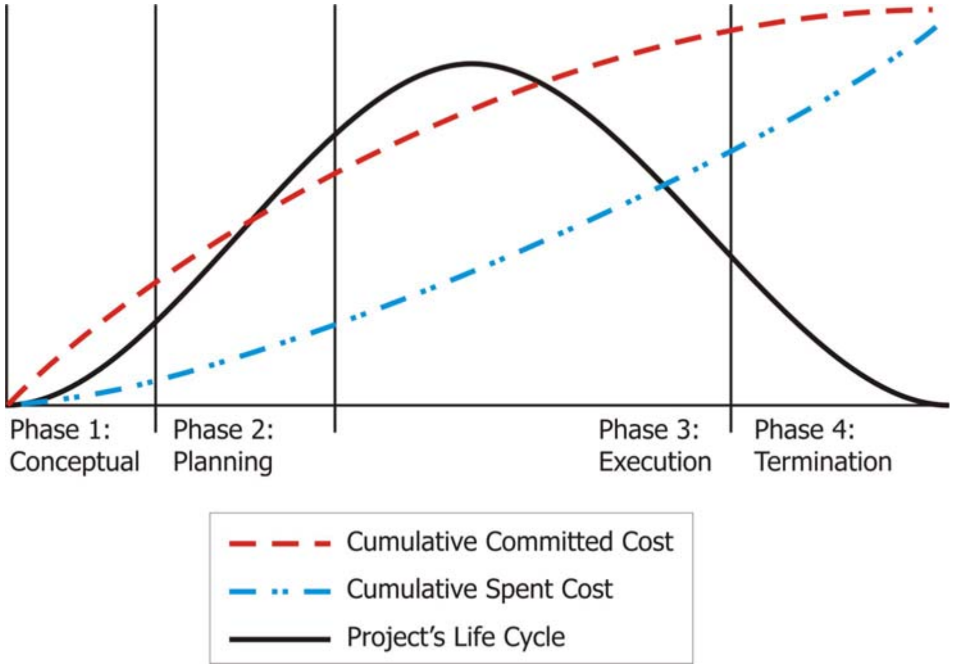


Figure 1.9 - The Cost in the Project's Life Cycle

Although all the project's phases are considered important and may be carefully developed, the analysis of the different project delivery systems will be focused on the design and construction phases. Before describing the different types of delivery systems, the following chapter presents the classification of stakeholders involved in the construction process.

2.0 CONSTRUCTION PROJECT STAKEHOLDERS

2.1 STAKEHOLDER DEFINITION AND CLASSIFICATION

Stakeholders are individuals, groups, organizations, institutions and other claimants who have or claim ownership, rights, or interests in a project and its activities. Based on this, every project is influenced and must be managed from a perspective that goes beyond the basic relationship between customers and the company that is performing the project. Because stakeholders may influence the development of the project, it is extremely important to identify, manage and predict their behavior. Cleland and Ireland (2002, p. 163) presents the following steps for managing stakeholders:

a) Identify appropriate stakeholders.
b) Specify the nature of the stakeholders' interest.
c) Measure the stakeholders' interest.
d) Predict what each stakeholder's future behavior will be to satisfy his or her stake.
e) Evaluate the impact of the stakeholders' behavior on the project team's latitude in managing the project.

Companies that can clearly identify stakeholders that are directly and indirectly involved with respective interests and how they can influence the final results of the project have a great advantage compared to the competition. During the identification process, companies can classify stakeholders in two major groups: *primary* and *secondary*.

“Primary stakeholders are those persons or groups on the project team who have a contractual or legal obligation to the project team and have the responsibility and authority to manage and commit resources according to schedule, cost, and technical performance objectives.” (Cleland and Ireland, 2002, p. 176-177) Because primary stakeholders are directly involved on the project and are, in most cases, committed to the successful accomplishment of it, they are usually easy to manage and direct.

“Secondary stakeholders are those who have no formal contractual relationship to the project but can have a strong interest in what is going on regarding the project.” (Cleland and Ireland, 2002, p.177) They represent the group that will not necessarily benefit from the project. As a result, project success may rely on the management of this group that, in some cases, may stop or delay the completion of the project.

2.2 IDENTIFICATION OF CONSTRUCTION PROJECT STAKEHOLDERS

There are several stakeholders involved in a construction project. Because the deliverables represent a significant change to the environment, a considerable number of people are involved, affected and influenced by these types of projects. The construction project’s final result is unique, and the identification and level of involvement of the stakeholders vary from project to project. Groups that in some instances are classified as secondary stakeholders may be classified as primary in other situations. Therefore, it is important to understand that every project must be specifically analyzed according to the nature of the project and the stakeholders’ level of involvement. Figure 2.1 is just a general identification of some stakeholders involved in a construction project.

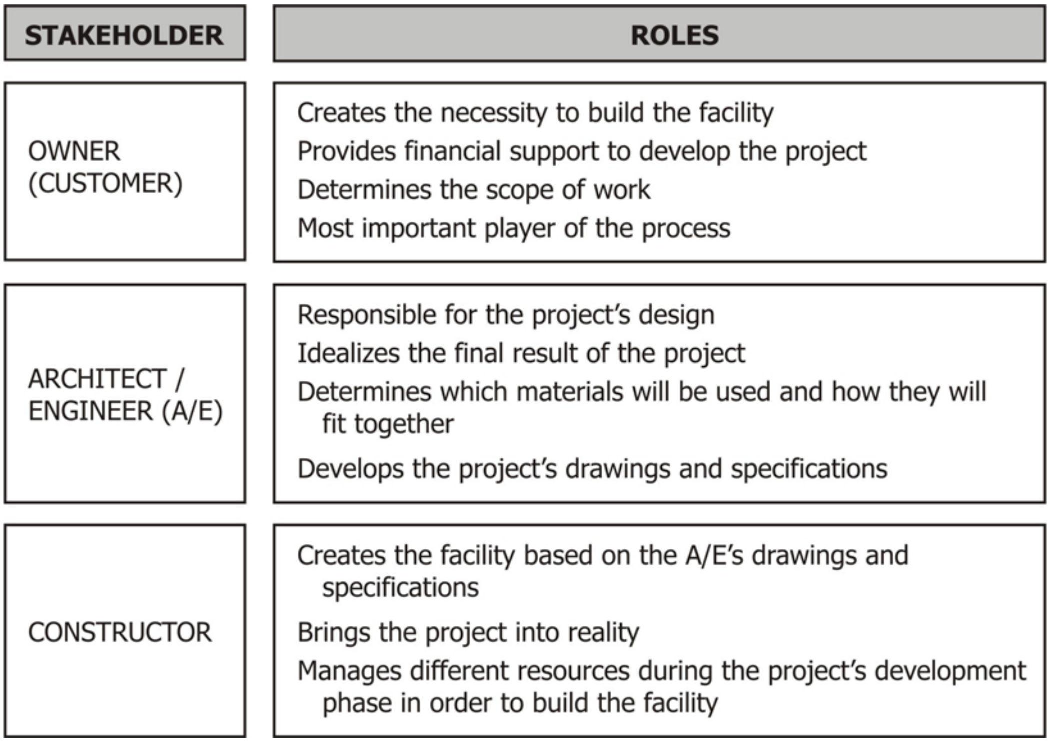
Figure 2.1 - General Construction Project Stakeholders

Every stakeholder perceives the project in a different manner. In some cases, a failure for one group represents a success for others. The challenge is to predict the behavior of key stakeholders and manage them in order to achieve the desirable objectives and goals previously established during the planning phase of the project. In the same fashion, project delivery systems are perceived differently. A specific delivery system, for example, may present advantages to the owner that may result in certain disadvantages for the contractor.

Independent of the perspective, there are three major stakeholders that play the most important roles within the construction process: the owner (or customer), the designer, usually known as architect / engineer (A/E), and the contractor. Although other stakeholders such as subcontractors, material and equipment suppliers, and so forth are important players in the construction process, the major development of the project involves these three entities.

2.3 ROLES OF MAJOR PRIMARY STAKEHOLDERS

Figure 2.2 presents some roles of the three major primary stakeholders involved in a construction project.



STAKEHOLDER	ROLES
OWNER (CUSTOMER)	Creates the necessity to build the facility Provides financial support to develop the project Determines the scope of work Most important player of the process
ARCHITECT / ENGINEER (A/E)	Responsible for the project's design Idealizes the final result of the project Determines which materials will be used and how they will fit together Develops the project's drawings and specifications
CONSTRUCTOR	Creates the facility based on the A/E's drawings and specifications Brings the project into reality Manages different resources during the project's development phase in order to build the facility

Figure 2.2 - Roles of Major Primary Stakeholders

As important stakeholders, these three players interact with each other as seen in Figure 2.3 (Halpin & Woodhead, 1998, p. 12). However, the relationships may vary depending on the type of delivery system.

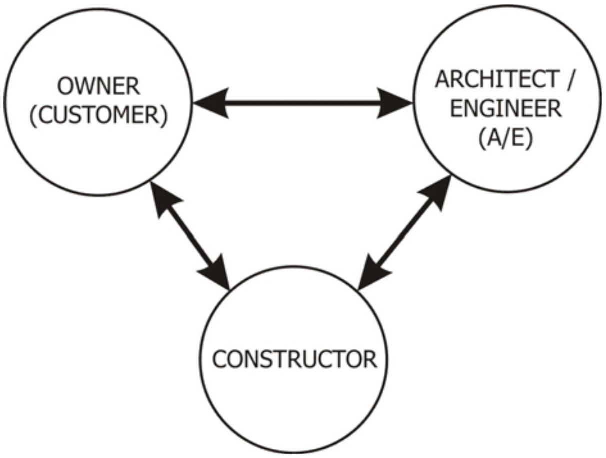


Figure 2.3 - Relationship between Major Stakeholders

3.0 PROJECT DELIVERY SYSTEMS

3.1 TYPES OF DELIVERY SYSTEMS

A successful project can be characterized as one that can achieve the final objective according to the quality specified during the design phase and can be delivered on time and within budget. Choosing the correct type of delivery system is one of the first steps that places a project on the right track. Although there are several types of delivery systems, the three most common types are *traditional*, *design/build*, and *construction management*. This document will describe these three types, giving emphasis to the *multiple prime contracting system* that is required by law for public projects in five U.S. states: Illinois, New York, North Carolina, North Dakota and Pennsylvania. Private owners must decide early in the project life cycle which delivery system best suits the project; whereas, in most cases, public owners do not have the flexibility to make such choice. As mentioned before, there is no best option for all cases, and the type of delivery system must fit the circumstances of the project.

Dorsey (1997, p. 5) presents the following points that can be used as criteria for determining the best project delivery system. It is important to keep the following list in mind when analyzing and choosing the delivery method.

a) Time available for the entire project, including design and construction;
b) Overall scope and complexity of the project;
c) Possibility of phased (or fast-track) construction;
d) Strength of the owner's staff with regard to the administration of a project;

e) Availability of qualified contractors, subcontractors, suppliers, and tradespersons;

f) Legal requirements, particularly in construction of public buildings;

g) Financial strength of the owner;

h) Budget and cash flow capabilities of the owner;

i) Design expectations of the owner;

j) Owner's desire for integration of the design and construction processes, including pre-construction services by contractors;

k) Special needs of users;

l) Special employment preference program requirements by owner;

m) Desired risk distribution.

Gould & Joyce (2003, p. 98) states that "…the dilemma for the owner in choosing delivery methods is one of price versus performance. Each project has distinctive requirements for problem solving, and some methods work better than others in solving problems." A good choice of the delivery system may diminish future project shortcomings.

It is common to see confusion between pricing systems and delivery systems. These are two different concepts that have been mistakenly and interchangeably used. In order to avoid such confusion, the following section describes the three major types of pricing systems (*lump sum*, *unit price*, and *cost plus a fee*) and some variations. A more detailed description of each delivery system is presented from Section 3.3 to Section 3.6.

3.2 PRICING SYSTEMS

The confusion mentioned in the last section rests on the fact that some delivery systems typically use a specific type of pricing system. As a result, people tend to correlate both. However, delivery systems may use any pricing system that is agreed to between the parties. Although they are two different concepts, the correct choice of a pricing system is as important as choosing the correct delivery system for a project.

The *lump sum* contract, also called *stipulated sum*, is the most common type of contract that exists in the construction industry, especially in the public sector. In this type of agreement, the contractor stipulates a total cost to perform a specific amount of work. The great advantage of this pricing system is that the owner has advance knowledge of the total cost of the facility, which minimizes his risk on the project. For this reason, the design, which includes a set of drawings and specifications, has to be complete in order to provide enough information for the contractor to correctly estimate the project. As a result, the time that is required for estimating the project is considerably high. Although negotiated contracts can make use of this type of pricing system, it is common to correlate lump sum contracts with the competitive bid process.

In the *unit price* contract, owner and contractor may not be able to precisely stipulate the amount of work that will be performed. Therefore, a price per unit is established based on a quantity that is given by the owner in order to provide a parameter to compare costs between contractors. However, the payment is based on the actual number of units performed during the job. This type of contract is often used for projects with large amounts of underground work where there is a great degree of uncertainty in terms of quantity.

Because the payment of this type of contract is based on actual units, the owner has to closely monitor the job. Another disadvantage relies on the fact that the exact cost of the project is not known until the last item is measured. Therefore, the risk involved in the project is lower for the contractor compared to the lump sum contract. On the other hand, an advantage of this pricing system is that the contractor may start the job before the design is finished, fast-tracking the delivery time.

The *cost plus a fee* agreement is characterized by the payment that the owner makes to the contractor based on the work cost plus an additional fee. There are several ways to determine the additional fee: a fixed percentage added to the cost, a sliding-scale percentage, and a fixed fee. This type of contract is widely used in situations when the owner needs to complete the project quickly and when the scope of the work is difficult to define, since all costs will be covered and a profit is guaranteed.

A variation of this type of pricing system is when the agreement stipulates a *guaranteed maximum price* (GMP). In this situation the construction firm guarantees the maximum cost of the project and the owner will not cover costs that go beyond this price. Sometimes incentives are added in form of money compensation if the contractor brings the project under the GMP. Gould & Joyce (2003, p. 113) interestingly describe the risk involved in this type of pricing system. "The risk to the owner is that, even with a GMP, the project begins with considerable unknowns. Project costs may be capped, but quality and scope may be sacrificed at the expense of the GMP. Without a GMP, scope and quality may be solid, but cost and schedule may increase. This type of contract requires a reputable contractor or construction manager whom the owner can trust implicitly."

A construction project is full of risks and unknowns. The only way that owners and contractors can be free of uncertainties is by not constructing. This is clearly not the choice of the parties that intend to perform a project. However, it is possible to correlate pricing systems and level of risk. Such correlation indicates which party retains higher risk based on the type of pricing system used during construction. Schuette & Liska (1994, p. 4) presents Figure 3.1 (adapted) that indicates this correlation:

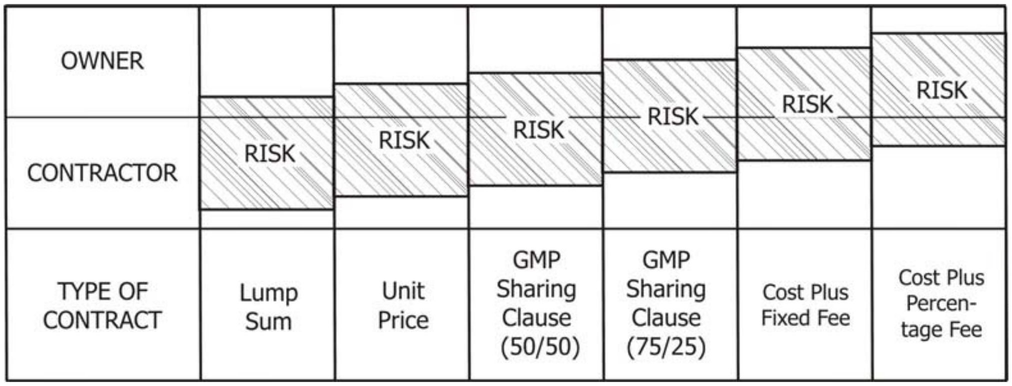


Figure 3.1 - Degree of Risk for Owner and Contractor

3.3 TRADITIONAL DESIGN-BID-BUILD

The traditional delivery system has three sequential and distinct phases: design, bid and build. In the first step, the owner contracts a design professional that will develop the project drawings and specifications necessary to build the facility. The payment for this service is usually a fee that may be a percentage of the estimated costs or a lump-sum amount.

The second step, the bid process, occurs when the design is fully completed. The owner conducts a competitive bid to obtain the lowest cost of the work or negotiates directly with contractors. Usually, the public sector, as required by law, uses a competitive bid process during this phase. However, there are some cases that “the Competition in Contracting Act (CICA), as implemented in the Federal Acquisition Regulation (FAR), allows for negotiation in the traditional system.” (Molenaar et al., 1998, p. 6)

Although the tradition in a bid process is to award the contract to the contractor that presents the lowest price, private and public owners have used companies’ technical capability as another parameter to make contractor selection decisions. Prequalification and evaluations that consider not just the final cost of the work are practices that have gained in popularity. Contractors have to be aware that the lowest price is not the only consideration that owners are using to award construction contracts.

The third phase is the process of constructing the facility. After knowing who has won the job and establishing the basis of the contract, the owner does not have to be fully involved in the construction process. He may hire someone to keep track of the job, monitor the quality, carry out the change order process, make payments, and check that the facility is being constructed according to the drawings and specifications. In some cases this individual is a representative of the design firm that acts in favor of the owner.

As seen on Figure 3.2, there is no contractual relationship between the design firm and the contractor. The owner has two distinct contract relationships, one with the architect / engineer and one with the prime contractor. As stated before, the owner looks for an A/E that develops the whole design used by the contractor to estimate the cost of the facility. Consequently, the contractor does not participate in the project design phase. Observe that Figure 3.2 also indicates the presence of only one single prime contractor that relates directly to the owner. This contractor may perform the job and / or subcontract it.

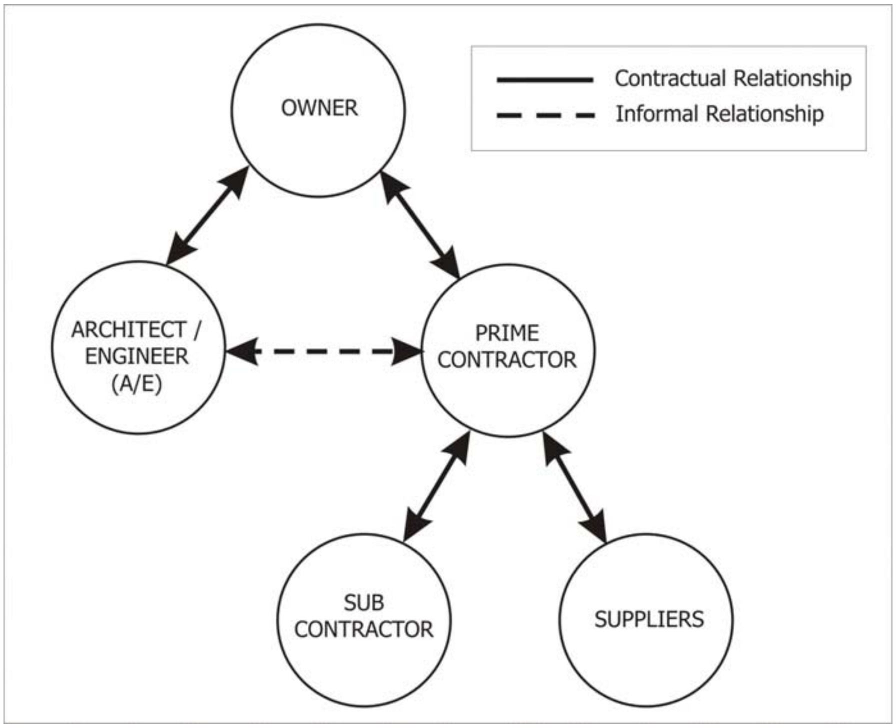


Figure 3.2 - Relationships in the Traditional Delivery System w/ Single Prime

3.4 MULTIPLE PRIME CONTRACTING

A derivation of the traditional design-bid-build method described earlier is the multiple prime contracting system. There are five U.S. states (Illinois, New York, North Carolina, North Dakota and Pennsylvania) that require public entities to contract separate prime contractors for major divisions of the work. In this case, the owner will have to directly interact with more than one contractor during the construction phase. According to Dorsey (1997, p. 49) the common divisions of work correspond to:

a) General construction;
b) Electrical construction;
c) Heating, ventilation, and air conditioning construction;

d) Plumbing construction;
e) Fire suppression;
f) Elevators;
g) Specialties, such as: kitchen equipment, computer networks, landscaping.

"In some cases, fire suppression is combined with plumbing, and sometimes HVAC and plumbing are under one contract. The public advertising and bid documents must clarify the number and types of contracts." (Dorsey, 1997, p. 49-50)

Because of the high number of owner-contractor channels in this delivery system, it is possible to conclude that this system is more vulnerable to coordination problems. In some cases, the owner hires a construction manager or uses the architect as the coordinator of the prime contractors in order to minimize this problem. This coordinator usually receives a fee for such service. Even in the presence of a coordinator, Dorsey (1997, p. 50) affirms that "…most general contractors prefer having all work under one contract, citing the following advantages:

a) Tighter overall project control;
b) Better adherence to schedule;
c) Simplifies administration by the owner;
d) Lower overall costs;
e) Direct problem-solving on the job;
f) Less difficulty in determining causes of delay."

The following figure shows the multiple channels that exist between the owner and prime contractors, as well as the lack of strong direct relationships among the prime contractors.

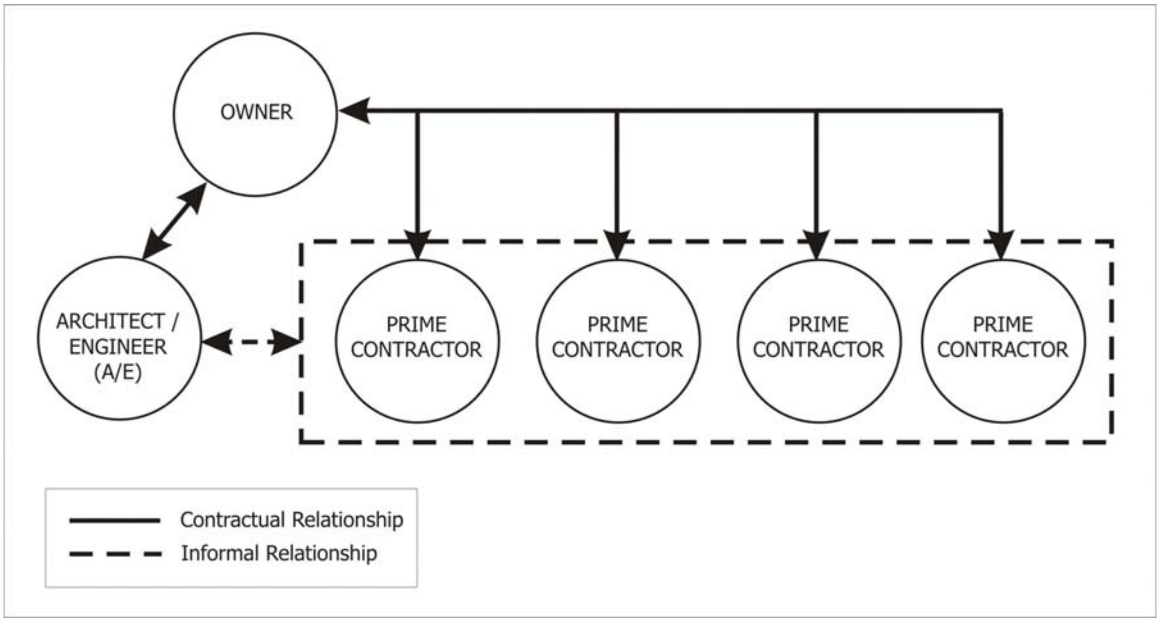


Figure 3.3 - Relationships in the Multiple Prime Contracting Delivery System

3.5 DESIGN-BUILD

In the traditional design-bid-build method, there is a clear separation between design and contractor entities. In the design-build delivery system, these two stakeholders are combined in one organization that performs both design and construction. This is the simplest contract format from the owner's perspective because there is just one channel linked to the owner. Figure 3.4 presents the relationships that exist in a design-build system.

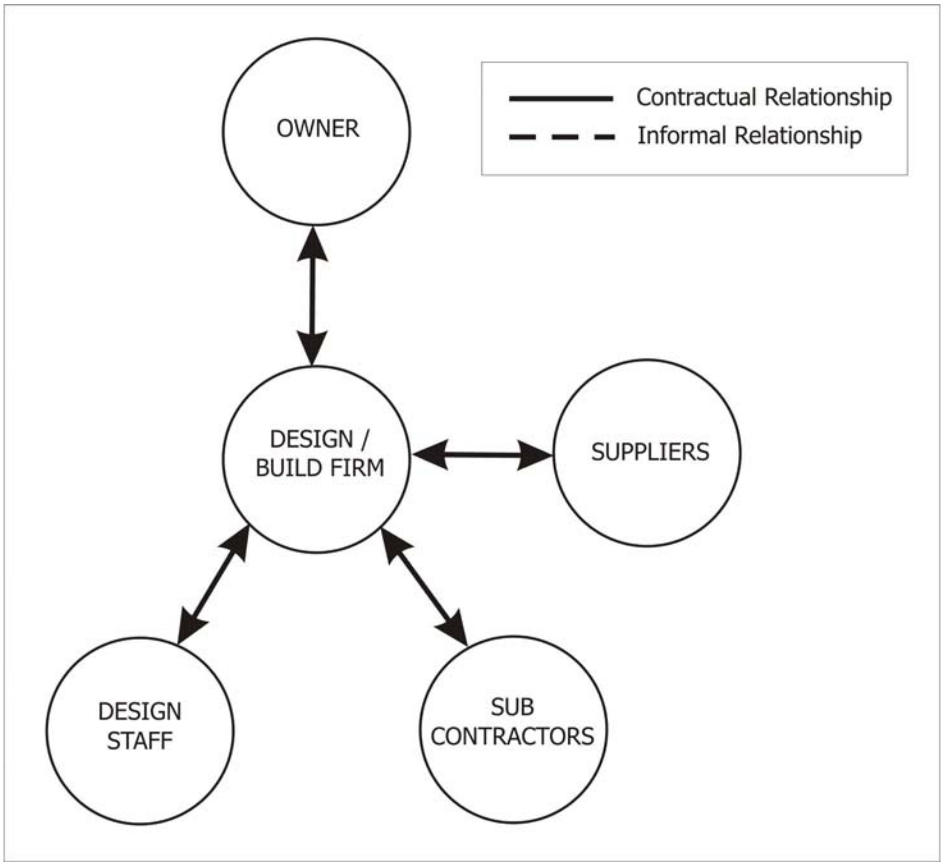


Figure 3.4 - Relationships in the Design-Build Delivery System

The design-build (DB) firm may employ both design and construction staff (in-house employees) or may become a partner with another company to perform a single project (Joint Venture DB). This entity usually hires subcontractors to perform specific jobs in the field. Because the design and construction processes become the responsibility of a single company, the owner will not be able to make a decision based on the lowest bid for a completed design, which may not guarantee the best price of the facility. As a result, the criteria for contracting with a design-build firm are strongly related to its reputation and capability. In order to overcome the dependence on a specific entity, Molenaar et al. (1998, p. 9) describes DB “bridging” as an alternative system that many owners have used. “Bridging refers to having an independent architect providing the initial design (typically 30-50%) and then assigning that design to the DB entity which becomes the final architect of record.”

The good communication between design and construction staff may be the strongest advantage of this system. Constructability analysis, value engineering, and rapid reaction to changes of the scope of the project are some of the advantages of this interaction. Eventually, all these advantages may result in better benefits for the owner compared to choosing the lowest bid price. More than this, in the design-build approach there is the potential to reduce the construction time because of the ability to fast-track the process. Industries have become very attracted to this type of delivery system because they are very dependent on time when developing products that have to be introduced to the market quickly.

On the other hand, the DB delivery system is not a perfect system. As in every method, a number of disadvantages can be highlighted. When pre-design is complete and construction has already started (fast-track situation), the opportunity for further inputs into the design is reduced. It is difficult to determine a fixed firm price of the facility. Basing the estimate just on the conceptual budget does not guarantee its total cost. Finally, putting the design and construction staff in the same entity diminishes the designer’s criticism of the project.

3.6 CONSTRUCTION MANAGEMENT

The construction manager (CM) is the new player in this delivery system that consists of a single individual or a team of professionals. Program Management, Professional Management, and Professional Construction Management are some variants of this type of delivery system, differentiated by the expertise of the management team and on the point of engagement in the project. Independent of the variance, the major roles of this new player are: advise the architect on constructability issues during the design phase; establish contract packages, even if not holding the contracts' responsibility; develop construction schedules; and manage the various entities that interact in the construction process. Summarizing, a CM is responsible to coordinate, organize, advise and manage the project. However, there are different levels of involvement between the construction manager and the project. Molenaar et al. (1998, p. 7) classifies the construction manager as follows.

One type is known as Pure CM. "The construction manager provides additional constructability advice to the owner and is responsible for monitoring many of the day-to-day construction activities." (Molenaar et al., 1998, p. 7) From the CM perspective, this classification is the most beneficial, because he does not assume a great deal of responsibility on the job. Therefore, all the risk associated to the project is transmitted to the owner. As seen in Figure 3.5, the construction manager has only informal relationships with every other entity. On one hand, the owner has an experienced construction professional working for him even in the early phases of the process; on the other, because this professional works just as a consultant, and does not have responsibility for any further failure, there is a possibility that he will not be as involved and committed to the project. This is, however, the variation most utilized by government agencies.

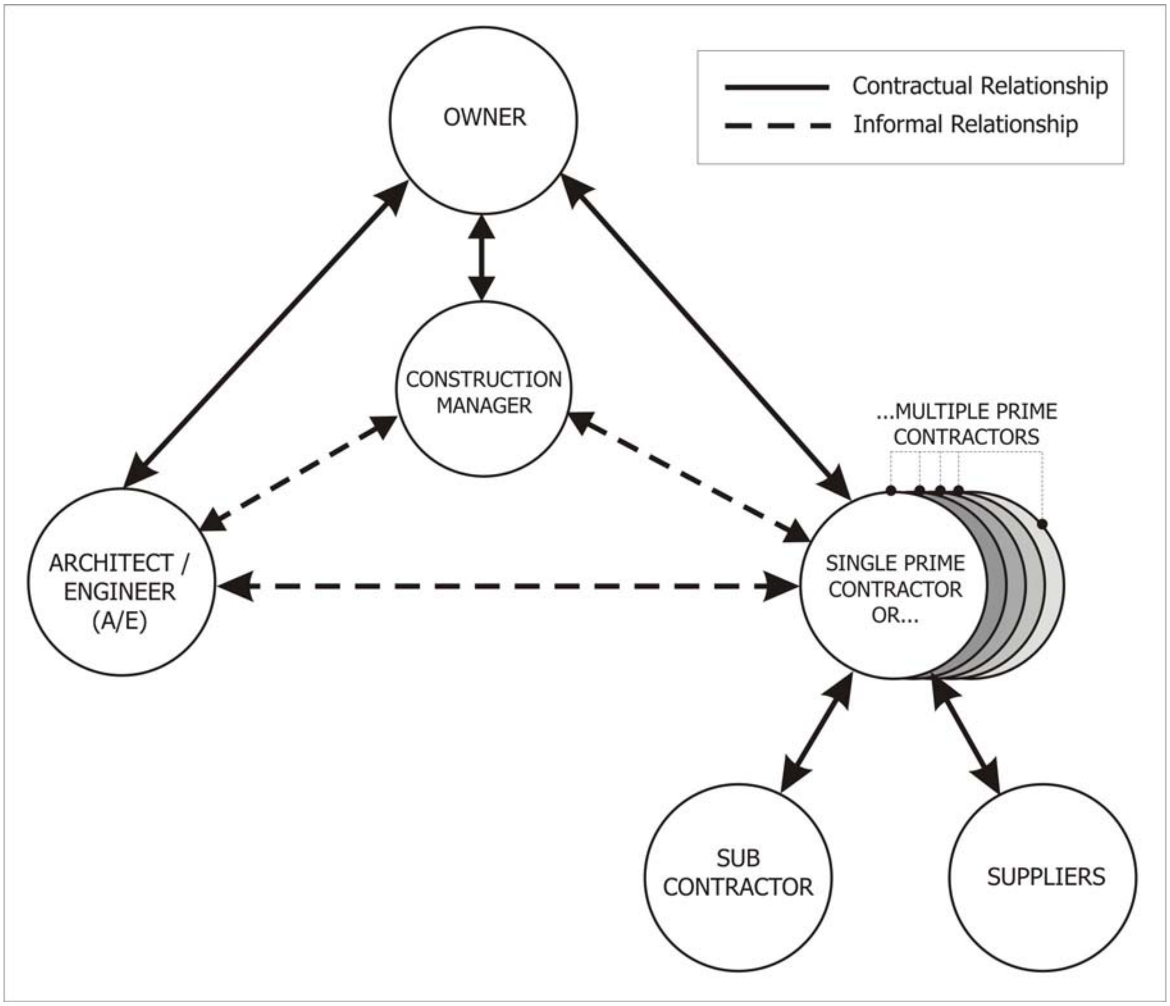


Figure 3.5 - Relationships in the Pure CM Delivery System

With the intention of taking advantage of the CM delivery system, but making the CM more responsible for the job and sharing the risk associated with the project, owners may require the construction manager to hold the contracts with schedule and price warranties. This is a second variation of the system, known as Construction Management at Risk (CM@Risk). The owner holds just one contract with the CM that, consequently, holds the other contracts involved in the project. In addition to all of the roles associated with the other variations presented before, the construction manager assumes a good deal of risk. From the CM point of view, this is not as comfortable as Pure CM described before, but does force him to successfully complete the project. Figure 3.6 presents the relationships involved in this type of delivery system. Observe that all the informal relationships that existed on Figure 3.5 relating to the construction manager have changed to contractual ones.

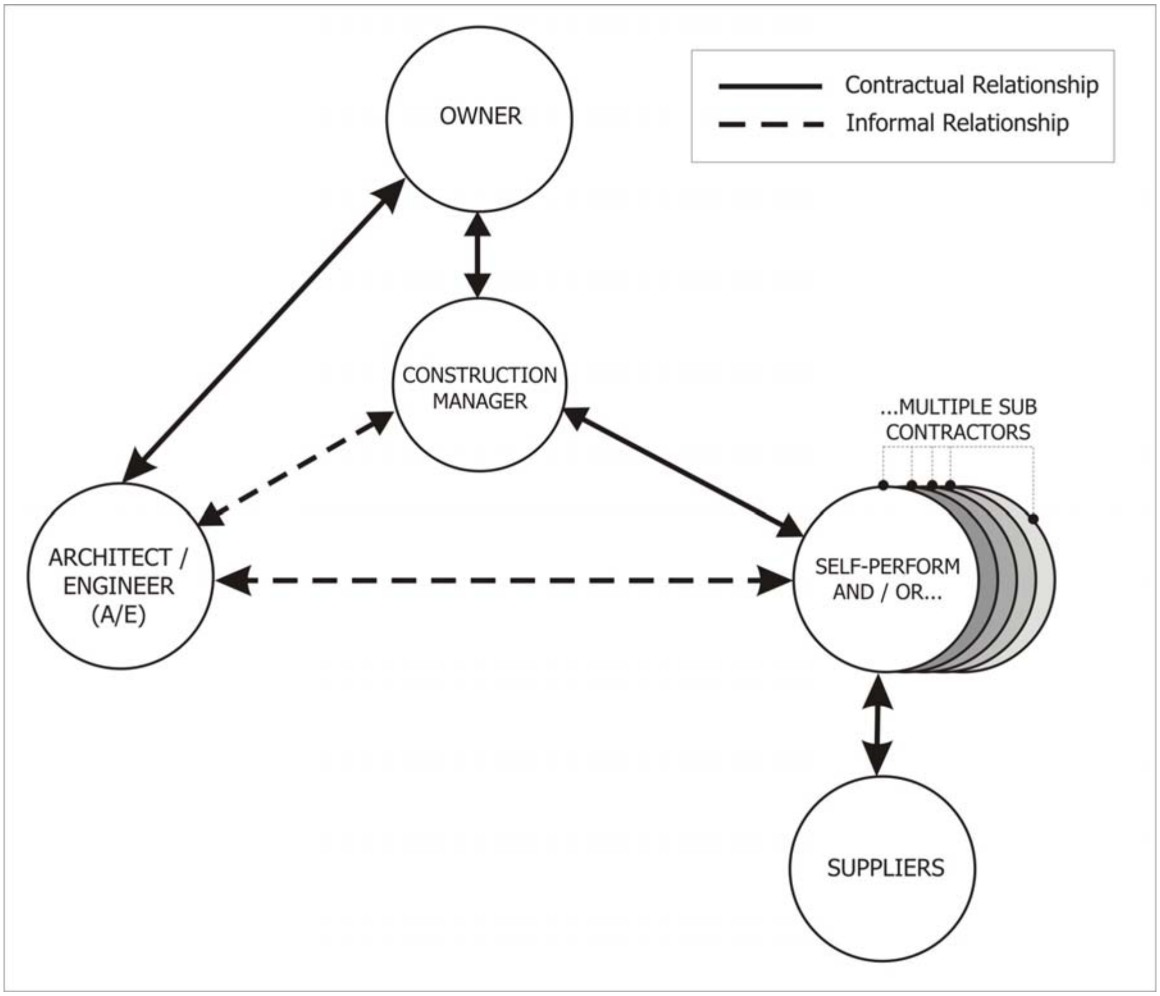


Figure 3.6 - Relationships in the CM@Risk Delivery System

Dorsey (1997, p. 115) affirms that "… construction management was born in the 1960s, when many factors converged to cause owners to seek alternatives to traditional general contracts." The following list is some of those factors that stimulated the creation of this type of delivery system:

a) Rapid inflation of construction costs;
b) Increasing complexity in buildings;
c) Prolonged construction schedules for complex buildings;
d) Difficulty in compressing the traditional design-bid-build time requirements;
e) A rise in litigation;
f) Difficult labor relations;
g) A growing number of disputes among parties to contracts.

4.0 STUDY OVERVIEW

4.1 PROBLEM DEFINITION AND GOAL

As mentioned earlier, there are five states (Illinois, New York, North Carolina, North Dakota and Pennsylvania) in the U.S. that require public construction projects to be performed with the multiple prime contracting delivery system. This type of delivery system has generated great discussion in the industry basically because of the diversity of opinions between specialty and general contractors. Specialty contractors defend the system because there is no middle entity between them and the owner. This relationship would lower costs, allow their bids to be reviewed by the owner, and simplify their payment process. On the other hand, general contractors attack the system. They argue that multiple prime is not beneficial to the owner and results in coordination problems, schedule overruns and vulnerability to litigation.

Such discussions were the incentive for this study. Based on them, several questions arose during the definition of the problem: Which delivery system has the best performance? Is multiple prime better or worse than single prime? What happens if we include an agent in the system? Would the system present different results? Is multiple prime a good or a poor delivery system? Is single prime more resistant to cost and schedule overruns compared to multiple prime?

With such questions in mind, this study intends to objectively analyze the performance of delivery systems within school districts, targeting multiple prime cases in comparison with others. Objectivity is based on statistical analysis of quantitative parameters such as cost and schedule, and on qualitative measurements based on the owner's perception. The following section presents the study's scope and limitations.

4.2 SCOPE AND LIMITATIONS

School districts in five states, located in the northeast portion of the U.S., were targeted in this study: Pennsylvania, Ohio, New Jersey, Massachusetts, and Virginia. Pennsylvania is one of the five U.S. states that require the use of the multiple prime delivery system in public construction projects. Ohio and New Jersey represent two states that recently removed the requirement for the use of multiple prime and granted public entities the possibility to choose the type of delivery system. Finally, Massachusetts and Virginia represent states without this requirement.

The ideal comparison between delivery systems would be based on identical projects located in identical locations. Such an ideal scenario is almost impossible to create. In order to overcome this problem, the choice of states located in the same region and projects within school districts were used to increase project similarities and reduce differences. However, the model is not perfect. There were several limitations of the study. The first limitation is that school districts are public entities with legal requirements that limit the types of delivery systems used in construction projects. The analysis is limited to the delivery systems where the number of cases is large enough to perform statistical analysis. Consequently, design-build and CM@Risk were not included.

Secondly, as explained in more detail later in this document, the information about construction projects was acquired by a survey that was sent to school districts' superintendents. They were targeted because of their access to detailed information about construction projects performed in their districts. Consequently, some limitations were created. The qualitative measures exclusively represent the perception of the owner. There are no insights from contractors and architects. In addition, there is great uncertainty about the knowledge of the respondents regarding the construction process. Another limitation related to the respondents is the fact that they are appointed officials and may not be familiar with projects performed in past administrations.

The number of cases available was also compromised because of the time between construction projects in any particular district. Based on the responses, it is estimated that districts perform a major renovation or new building construction project every 15 to 20 years. Therefore, some districts did not have recent projects, which reduced the number of cases available for analysis. The size of the school district also played an important role. For example, there are small districts that rent facilities and have never had any construction projects.

The study is based on the comparison of the performance of school districts' construction projects and their respective delivery systems. Because of the responses received, this study is limited to three delivery systems: Single Prime (SP), Multiple Prime (MP) and Multiple Prime with an Agent CM (MPwA). The comparison is based on quantitative and qualitative measurements. The quantitative variables are related to cost, schedule and litigation. The qualitative variables are related to the punch list, startup, call backs, administrative burden, team communication, team chemistry and project complexity. (See Section 6.3 for additional details)

Before going into detail about the methodology, the following section presents a brief description of past related work.

5.0 PREVIOUS STUDIES

5.1 KONCHAR AND SANVIDO

"A Comparison of United States Project Delivery Systems" was the first national study in the U.S. to compare design-bid-build (DBB), design-build (DB) and construction management at risk (CM@Risk) delivery systems for building projects. A total of 7600 organizations were surveyed and 351 responses were analyzed. Different types of facilities were represented in the sample: light industrial, multi-storey dwelling, simple office, complex office, heavy manufacturing, and high technology. A paper was published in the Journal of Construction Engineering and Management (Konchar and Sanvido, 1998). Mark Konchar and Victor Sanvido were inspired by a similar study performed by Bennett et al. (1996) on the comparison of 332 design-build and design-bid-build projects in the United Kingdom.

Cost differences were analyzed based on unit cost and cost growth. Schedule growth, construction speed, delivery speed and intensity were the basis for the time comparison. Finally quality parameters were based in three major areas: turnover, system and equipment quality. Konchar's study consisted of analyzing the mentioned variables using two-sample t-tests, Mood's median test and multivariate linear regression modeling. Both univariate and multivariate statistical models were used in the analyses. They presented elevated levels of significance for inference. As described by Konchar (1997, p. 81) "… quality is the least objective of all the performance metrics that were calculated." Therefore, the findings of quality parameters are not discussed in this document.

The significant results obtained from the two-sample t tests concluded that design-build had a mean unit cost less than design-bid-build projects; DB and CM@Risk presented better performance than DBB in terms of cost growth and schedule growth; DB was faster than DBB considering construction speed; DB also performed better than DBB and CM@Risk considering delivery speed; and there was no significant differences among the systems considering the intensity of the delivery systems.

According to the linear regression models, the primary results indicated that DB projects have 6.1% less unit cost than DBB and 4.5% less than CM@Risk; DB was 7% faster than CM@Risk and 12% faster than DBB; CM@Risk was 5.8% faster than DBB. In terms of delivery speed, DB is considered 33.5% faster than DBB and 23.5% faster than CM@Risk. Construction management at risk was 13.3% faster if compared to DBB in terms of delivery speed. In all these cases, the regression models had an R^2 of at least 88%.

According to Konchar and Sanvido (1998) the study concluded that "… projects administered using design-build project delivery can achieve significantly improved cost and schedule advantages. In addition, design-build projects produce equal and sometimes more desirable quality performance than construction management at risk and design-bid-build projects."

There are some weaknesses of the study that should be highlighted. First, there are a large number of independent variables in each regression equation and the variables with high P-values were not excluded. Second, the characteristics of the projects from the survey responses are used in the regression equations to generate expected values of the dependent variables. Mean values are reported and no confidence interval is provided, so consequently, the comparison does not present a good idea about the significance of the differences found among the systems. Data normality is not considered for the two-sample t tests. However, the sample size is large, which means that sample data normality is less important. All in all, the strengths of the study are greater than the weak points.

5.2 THE ILLINOIS STUDY

The State of Illinois Office of the Auditor General performed a study of construction contracting methods. The study addresses the discussion around single and multiple prime contracting systems. They "… obtained input from State agencies, contractors, architecture / engineering firms, professional trade associations, other states, and other governmental organizations. These entities had varying perspectives which may have been influenced by their economic interests." (Office of the Auditor General – State of Illinois, 2002, p. iii)

There was no inference in the study about the performance of single and multiple prime contracting. The questionnaires contained open ended questions that characterize the subjectivity of the study. Consequently, each group of individuals answered the questions based on their personal view point. No statistical tool was used during analysis. Page 96 (Office of the Auditor General – State of Illinois, 2002) of the study presents a survey that was sent to contractors. The only quantitative question includes the respondent's perception of cost growth in the event the projects had used single prime method instead of the current multiple prime method. This type of question would not allow cost growth to be calculated and, again, the response would reflect the interest of the individual surveyed.

The importance of the study lies in the discussion of the topic, but no effective conclusion can be inferred from the results. An interesting point in such a broad study is the fact that "… even when the overall percentage for a group favored a certain method, the responses were not homogeneous and there was variance in the group." (Office of the Auditor General – State of Illinois, 2002, p. xiii) Based on the results and on the widely differing perspectives it gathered, it was suggested to the General Assembly to consider a pilot program to evaluate the effectiveness of various construction contracting methods. This program would permit the Capital Development Board (CDB) to use different types of construction methods on a limited basis and report accurate records of the projects. Such records would be the basis of future analyses. At this point in time, the State of Illinois still requires the use of multiple prime contracting in public construction projects.

5.3 ELECTRI 21

Professor Brian Becker from the School of Management at the State University of New York at Buffalo prepared a report in 1993 with data from 73 New York state projects. The study used regression for the analysis. In one approach, the natural log of total cost is used as the dependent variable. The independent variables of the model were type of delivery system (single or multiple prime), natural log of estimated cost, natural log of trend variable, and rehabilitation.

The study concluded that "… single bid projects had a 2.9 percent higher final cost than projects with separate primes. More than 90 percent of this difference was due to the lower bid costs of separate-prime contracts." (Becker, 1993, p. 21) The results of the bid cost analysis also presented a disadvantage to the single prime delivery system. Such projects had 2.6% higher bid costs than multiple prime projects with an equivalent estimated cost. This study defends the use of separate bidding methods to decrease the cost involved in public construction projects.

The report does not indicate the P-values of the regression model coefficients. Consequently, it is impossible to predict the relationship strength between independent and dependent variables of the model. However, the study does not use the regression equation to make any type of prediction. The difference between the systems is solely based on the coefficient of the type of delivery system. Even though the study presents the standard error for each coefficient, the confidence of the difference is not specified. Another weakness of the study is the fact that the dependent variable indicates the project's total cost and, consequently, does not consider its size and scope. These differences could be minimized with the use of the unit cost as the dependable variable. However, the conclusions are based on a simple model that is valid and significant based on an R^2 of 0.944.

5.4 IMPACT OF THE WICKS LAW

The Wicks Law is the legislation that specifies the use of multiple prime contracting in New York. A 1999 report on the Impact of the Wicks Law on public construction in New York City presents "… an update of a previously performed study, which analyzed data collected prior to 1994. The present study includes data collected in 1998 for construction beginning in the years 1988 – 1997, and subsequently analyzes the cumulative data." (PriceWaterHouseCoopers, 1999, p. 6)

Results from a multiple regression analysis were used in this study. It concluded that "… projects built under the requirements of the Wicks Law cost more to construct and take longer to build than otherwise similar projects that are not subject to these requirements. The Wicks Law has a slightly larger impact on internal agency costs, than on external payments to contractors." (PriceWaterHouseCoopers, 1999, p. 26)

A previous study performed in 1991 and addressed by the Coalition to Save Taxpayer Dollars (1991) indicated that an estimated cost increase of 20-30 percent would result from the use of the Wicks Law. The document does not present details that would indicate the origin of the numbers. The questionnaire used is biased against the Wicks Law. The quantitative basis for the conclusions is not clear from the report.

5.5 SUMMARY

Even though Konchar does not address the problem of multiple prime and single prime contracting, its structure served as the basis of this study. Similarities can be found in some of the variables and tests used in this study. However, the results are not comparable because of differences in scope.

The Illinois study is limited to collecting opinions regarding multiple prime and single prime delivery systems. Therefore, no statistical conclusions are drawn and no comparison with the results of this study can be made.

The Electri 21 study addresses the same problem. It uses a single regression model that found a relationship between the type of delivery system and the total cost of the facility. Univariate tests were not used to predict the differences between the two delivery systems. Total cost was not used as a measure in this study. There was no consideration of schedule growth, unit cost, or construction speed in Electri 21. This study considers these variables as important measurements for comparison. Therefore, although the purposes of the studies are similar, the outcomes of Electri 21 and this study cannot be compared.

Finally, comparison with results of the impact of the Wicks Law study performed by PriceWaterHouseCoopers was limited by the availability of the full document for a detailed analysis and comparison to the results obtained in this study.

6.0 STUDY METHODOLOGY

6.1 TARGET POPULATION

As stated previously, the target population consists of school districts located in five different northeastern states of the United States: Pennsylvania, Ohio, New Jersey, Massachusetts, and Virginia. All school districts in each state were sent surveys for a total of 1862 districts. The questionnaires were sent to the districts' superintendents who, in some cases, forwarded it to staff.

The list of addresses was downloaded from each state's Department of Education web site. The strategy for the mailing process was based on Salant and Dillman's recommendations (1994, p. 138). Four mailings (see Appendix A) were sent every 3 weeks:

a) *First* → Advance-notice letter. The purpose of this letter is to let the sampling population know that they will be receiving a survey in the near future.

b) *Second* → Package with cover letter, questionnaire and a prepaid return envelope.

c) *Third* → A reminder letter about the survey and the importance of their participation in the study. It was sent to every district that had not answered the survey at that time.

d) *Fourth* → Final mailing with cover letter, questionnaire and prepaid return envelope to all non-respondent districts. This letter stipulates a deadline for the study.

This strategy was extremely effective in reaching the response rate that was achieved. Section 7.1 presents the number and a discussion of the response.

6.2 DATA COLLECTION INSTRUMENT

A pilot was conducted in the early stage of the study in order to verify the quality and effectiveness of the questionnaire. The first step in survey preparation consisted of determining the information necessary for future data analysis. Konchar (1997) was an important source in this process. The instrument used in that study was the basis for the creation of the first draft because of the similarity of measurements used in this study. Even though the instrument appeared to be adequate, a pilot was conducted in six school districts located in the Pittsburgh vicinity.

Although there was no useful data collection from the pilot, the insights were extremely important to tailor the instrument to the requirements of the study. There were eight more versions of the document. The final version can be seen in Appendix B.

The first section is general information about the respondent, in case it was necessary to contact them for clarification. The second section relates to general information about the project. An open question for the project description was included later in the document. This was an excellent way to have an idea about the project characteristics. The third section was used to indicate the type of delivery system used. It was decided to include single prime, multiple prime, single prime with an agent, multiple prime with an agent, design-build, and CM@Risk. Those delivery systems with an adequate number of cases for statistical analysis will be included.

Sections IV and V are the most important sections of the questionnaire. Section IV collects the cost of the project. It is divided into three subsections. The first subsection identifies the base building cost in three different stages: estimated, contract award and actual cost. The second subsection is the coordination cost of the project and finally the third indicates the number and total cost of change orders. Section V collects information about the project's schedule. The respondent was asked for the dates when they planned to build and the actual dates of construction. The first two items would be used if there were enough cases of design-build and CM@Risk systems. Since that was not the case, only the construction start and end dates were used.

The next section asks for the number and dollar amount of litigation cases involved in the project. Section VII is related to the quality parameters of the project. Even though there were three other building system quality questions, the punch list, difficulty of startup, number of call backs, overall expectations and level of administrative burden were the only information used in this study. Finally, the last section evaluates some team characteristics. This section was essential to have an idea of the members' experience and levels of communication, chemistry and complexity involved in the project. A glossary of terms was included at the end of the questionnaire in order to give the respondents definitions of the terms used.

6.3 DEFINITION OF VARIABLES

There are quantitative and qualitative types of variables used to compare the performance of the delivery systems in this study. Although, quantitative (or continuous) measurements are extremely important to the analysis because of their objectivity, qualitative (or categorical) measures indicate the perception of the owner about the construction project and the delivery system. The following tables present the types of variables that are used in this study.

Table 6.1 - Quantitative Variables Used in the Study

Quantitative Variables
a. $Construction\ Speed\ (ft^2/day) = \frac{Area}{Total\ asBuilt\ Const\ Time}$
b. $Unit\ Cost\ (\$/ft^2) = \frac{Actual\ Total\ Cost}{Area}$
c. $Cost\ Growth\ (\%) = \left(\frac{Actual\ Total\ Cost - Contract\ Award\ Total\ Cost}{Contract\ Award\ Total\ Cost} \right) x100$
d. $Const\ Schedule\ Growth\ (\%) = \left(\frac{Total\ asBuilt\ Const\ Time - Total\ asPlanned\ Const\ Time}{Total\ asPlanned\ Const\ Time} \right) x100$
e. $Change\ Order\ (\%) = \left(\frac{Total\ Change\ Order}{Actual\ Total\ Cost} \right) x100$
f. *Number of Litigation Cases*

Table 6.2 - Qualitative Variables Used in the Study

Qualitative Variables
a. *Length of Punch List*
b. *Difficulty of Facility Startup*
c. *Level of Call Backs after Owner Occupancy*
d. *Level of Administrative Burden*
e. *Project Team Communication*
f. *Project Team Chemistry*
g. *Litigation*

6.4 STATISTICAL TOOLS

Different types of statistical tools are used in this study in order to compare the performance of the three delivery systems. One-way ANOVA and two-sample t tests are used to analyze continuous variables, while the Chi-Square test is used for categorical analyses. This section presents and briefly discusses the tools used in this study. However, it is not the intention of this document to present a detailed description of the tests.

6.4.1 One-way ANOVA

The statistical methodology for comparing the means of several populations is called analysis of variance, or simply ANOVA. One-way ANOVA consists of the analysis of only one way of data classification. For example, the comparison of the means of cost growth of the three types of delivery systems.

According to Moore and McCabe (2003, p. 750), "ANOVA tests the null hypothesis that the population means are all equal. The alternative is that they are not all equal. This alternative could be true because all of the means are different or simply because one of them differs from the rest." Summarizing, ANOVA tests the two following hypotheses based on an F statistic:

Ho: $\mu_1 = \mu_2 = \mu_3 = \ldots = \mu_i$

Ha: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \ldots \neq \mu_i$

Side-by-side boxplots are a good preliminary way of visualizing the results of ANOVA tests. In case the plots overlap each other, it is more likely that there will be failure to reject Ho. However, if there is small within-group variation and there is no overlap of the quartiles as shown on the boxplots, the difference among centers is more likely to be significant, and there would be enough evidence to reject the null hypothesis and conclude the alternative one.

One of the requirements of the test is to assume that the standard deviations of the populations are equal. In ANOVA, a "pooled" standard deviation is used. As a rule of thumb, it is possible to assume that the standard deviations of the populations are equal every time that the following sampling standard deviation relationship is satisfied:

$$\frac{Largest\ S}{Smallest\ S} < 2.0$$

This rule is used in this study. Another requirement of the test is related to the normality of the population. According to Moore and McCabe (2003, p. 398), "… the central limit theorem allow us to use normal probability calculations to answer question about sample means from many observations even when the population distribution is not normal." As a sample size guideline, the following points can be considered:

a. Small Sample Size ($N < 15$) → Need population to be normally distributed
b. Medium Sample Size ($15 \leq N < 40$) → Some skewness in the distribution of the population is OK
c. Large Sample Size ($N \geq 40$) → Strong skewness in the distribution of the population is OK

The sampling distributions of this study will be tested for normality whenever necessary to validate the results obtained. Section 6.4.4 presents a brief discussion of this test.

6.4.2 Two-sample t

The two-sample t statistic is a statistical methodology for comparing two population means. It is basically the same methodology used in the ANOVA test. However, this test uses the t statistic and its P-value to analyze the significance of the difference in the sample means.

Two-sample t can be performed as one or two-sided. The following table indicates the null and alternative hypothesis for both, one and two-sided tests.

Table 6.3 - Hypothesis Tests for Two-sample t

One-sided	Two-sided
Ho: $\mu_1 = \mu_2$ Ha: $\mu_1 > \mu_2$ or $\mu_1 < \mu_2$	Ho: $\mu_1 = \mu_2$ Ha: $\mu_1 \neq \mu_2$

The advantage of this test compared to the ANOVA test is that there is no requirement for equality on populations' standard deviations. Both "pooled" and "non-pooled" situations can be used. However, the requirements for normality are the same. Two-sample t will be used as a secondary methodology in this study.

6.4.3 Chi-Square

The chi-square test is used to verify the possible relationship between two categorical variables. In this test a two-way table is created and the observed counts are compared to the expected counts of the cells. According to Moore and McCabe (2003, p. 624) "The chi-square statistic is a measure of how much the observed cell counts in a two-way table diverge from the expected cell counts." Therefore, the chi-square tests the following hypothesis:

Ho: Row and column variables are independent – there is no relationship

Ha: Row and column variables are not independent – there is a relationship

If the difference between expected and observed counts is large, there will be enough evidence against the null hypothesis (small P-value) and in favor of the alternative one. The chi-square distribution is an approximation to the normal approximation for a binomial distribution. The approximation is more accurate as the cell counts increase.

In order to validate the test, it is necessary that at least 80% of the expected cell counts must be greater than 5, with the exception of 2 X 2 tables where all four expected cell counts have to be 5 or more. Because it is not always possible to achieve the required cell counts, cells are combined or excluded for some tests.

6.4.4 Test for Normality

The sampling frequency will be tested for normality. This test will be performed to validate the methodology used. MINITAB® presents three different types of normality tests: Anderson-Darling, Ryan-Joiner and Kolmogorov-Smirnov. It is beyond the scope of this document to describe or detail such tests.

According to the MINITAB® help menu (2000), the normality test "… generates a normal probability plot and performs a hypothesis test to examine whether or not the observations follow a normal distribution. For the normality test, the hypotheses are:

Ho: data follow a normal distribution

Ha: data do not follow a normal distribution."

In this case a P-value will be generated and the null hypothesis will be tested for validity. In case of small P-values, there is enough evidence to reject Ho and data will be considered not normal. Otherwise, it will be considered normal. In this study, if the P-value is greater than 0.10, the sampling distribution will be considered normal for the tests. Also, for a more conservative approach, the Anderson-Darling test is used. The results will be solely based on the analysis of MINITAB® outputs. It is beyond the scope of this study to manually verify the tests.

Mathematical modifications can be applied to the values of a variable in order to decrease its variability. Transformation is commonly used in statistics as an alternative to bring data to a normal distribution. Therefore, whenever the test for normality fails, a natural log transformation will be applied in the analysis. In order to overcome the problem of null and negative variables during transformation, a constant will be added to move the minimum value of the distribution to 1.00. (Osborne, 2002)

6.5 CALCULATION METHODOLOGY

The use of the statistical tools will follow a calculation methodology. Figure 6.1 presents a general example of the flow chart that will be presented in every quantitative analysis. The intention of this chart is to give the reader a guide to the calculation process and a summary of the results obtained. The flow indicates the tests performed, their sequence, and if any significance was found during the test. Solid lines represent analysis performed, while dotted lines indicate that the analysis was not performed based on the necessities and consequences of the results previously obtained. This chart was slightly modified and adopted for different analyses.

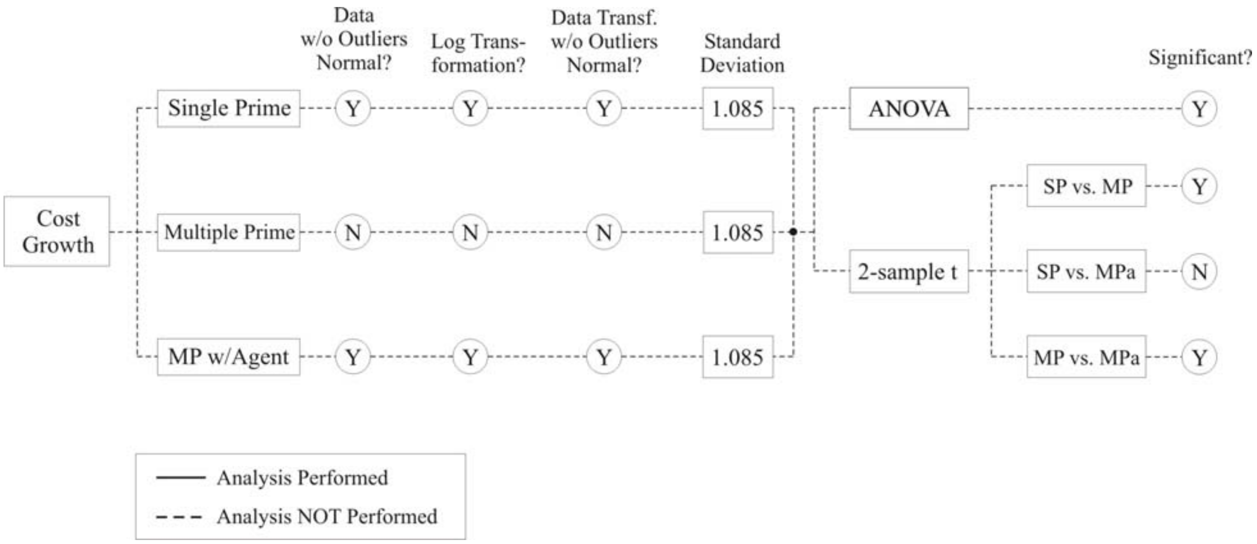


Figure 6.1 - General Example of the Calculation Process Flow Chart

Based on the chart above, the quantitative analyses will be based on the following calculation process:

1. Each delivery system data without outliers will be checked for normality. If normality is found, step 2 can be skipped.
2. The data set is transformed. The intention is to convert the conventional data into a normal distribution in case the test for normality in step 1 is invalid.
3. The non-normal distributions are excluded from the analysis. Consequently, in cases where just two systems are normal, the 2-sample t test is used independent of the values of the standard deviations.
4. If all three systems are normal, an analysis of their respective standard deviations is required to validate the ANOVA test. If the ratio of the largest and lowest values is

less than 2, ANOVA is performed. If there is a significant difference between standard deviations, the 2-sample t test replaces ANOVA.

5. Significance on the test is evaluated based on the P-value. Small P-values represent that the test is significant and conclusion can be drawn from the results. For this study, if the P-value is greater than 0.05, there is no significance on the test and no conclusions can be drawn.

On the other hand, analyses of qualitative variables are easier to perform. For this analysis, chi-square tests are used. The data section analysis (Sections 8 and 9) will present a discussion of each variable considered in the study. However, detailed information is presented only for the cases where statistical significance is found. The details of cases without statistical significance are presented in the Appendices C to F.

6.6 CODIFICATION

The use of statistical software packages requires the codification of categorical variables. This section presents a sequence of tables with the categorical codes used during data analysis.

Table 6.4 - Delivery System Codes

Code	Type of Delivery System
1	Single Prime
2	Multiple Prime
3	Agent CM w/ Single Prime
4	Agent CM w/ Multiple Prime
5	CM @ Risk
6	Design-Build

Table 6.5 - Team Chemistry Codes

Code	Description
1	Excellent
2	Adequate
3	Poor

Table 6.6 - Team Communication Codes

Code	Description
1	Excellent
2	Adequate
3	Poor

Table 6.7 - Complexity Codes

Code	Description
1	High
2	Average
3	Low

Table 6.8 - Punch List Length Codes

Code	Description
1	Less than a week
2	More than a week but less than 2 weeks
3	More than 2 weeks but less than 4 weeks
4	More than 4 weeks but less than 8 weeks
5	More than 8 weeks

Table 6.9 - Difficulty to Startup Codes

Code	Description
1	High
2	Medium
3	Low

Table 6.10 - Level of Call Backs Codes

Code	Description
1	High
2	Medium
3	Low

7.0 DATA SET OVERVIEW

7.1 RESPONSE RATE

A total of 1862 districts were contacted during this study. This list includes all school districts of the five states targeted. From the 334 (17.9%) districts that responded, 194 (10.4%) said that they would not participate. 103 cases of the 194 did not have a recent construction project (most recent being within the last 20 years ago). The remaining cases gave reasons that vary from no staff capability to no building ownership. From the 140 (7.5%) districts that returned the survey, 35 cases did not have enough data to be considered in the study and 105 (5.64%) presented good quality data.

Considering just the 105 cases of good quality data and a population of 1862 districts, the response rate of this study is 5.64%. This rate can be considered as the gross rate of the study because the real target population would be equivalent to the number of districts that have had a construction project completed in less than 20 years. This number is impossible to determine from the data collected. As a result, this study considers the nominal response rate of 5.64% based on the total number of districts contacted as the effective survey response.

The strategy of contacting the districts through the use of four sequential mailings was effective in raising the response rate of the study. Figure 7.1 indicates the number of districts that made contact after each mailing:

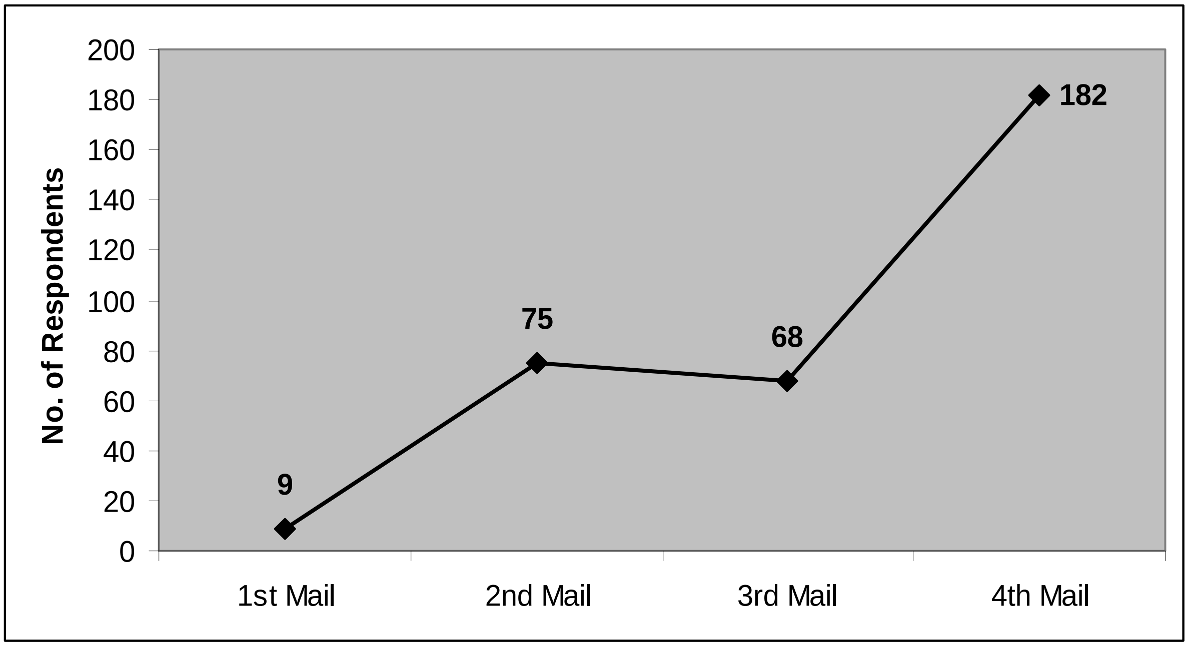


Figure 7.1 - Number of Respondents per Mailing

The 9 responses after the first mailing said that they did not have valid cases for the study and therefore would not be able to participate. Eleven cases from the 105 valid ones were excluded. They represent the three delivery systems that contained samples too small to be considered in the study: one case of CM@Risk, three design-build, and seven single prime with agent CM. Consequently, the remaining 94 are the cases used in the analysis. They represent single prime, multiple prime, and multiple prime with an agent CM systems. The following four figures (Figures 7.2 – 7.5) indicate the response classified by type of delivery system, state and state percentage.

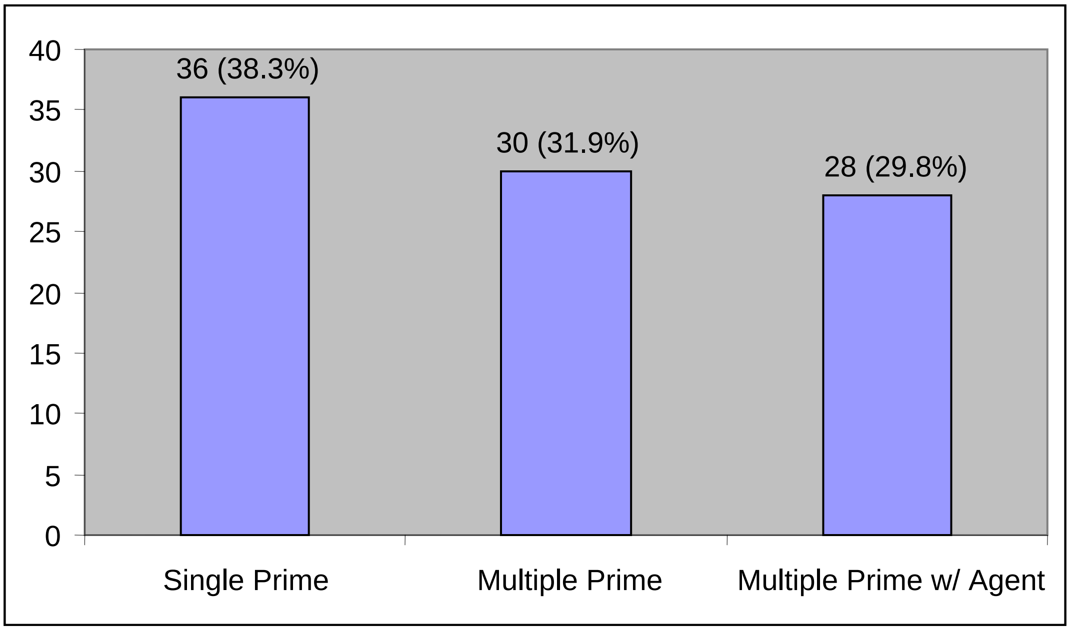


Figure 7.2 - Response by Delivery System

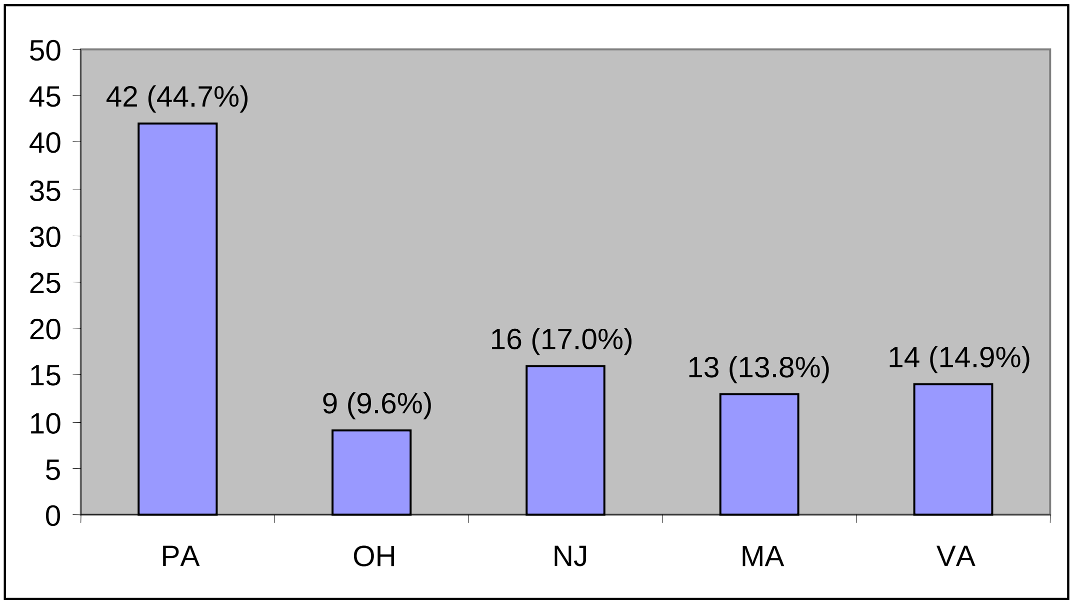


Figure 7.3 - Response by State

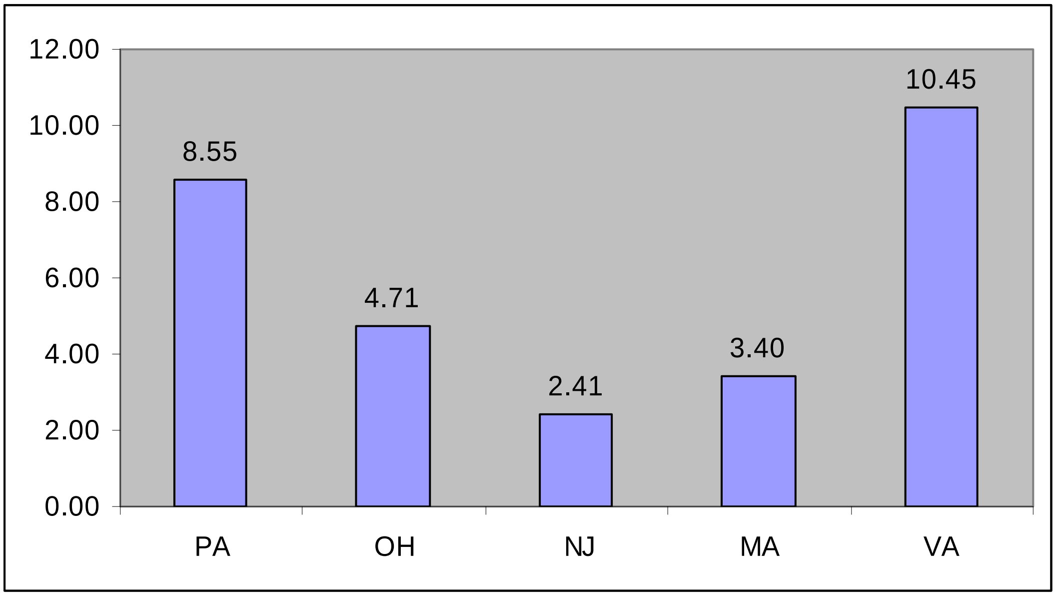


Figure 7.4 - Percentage Response of School Districts in Each State

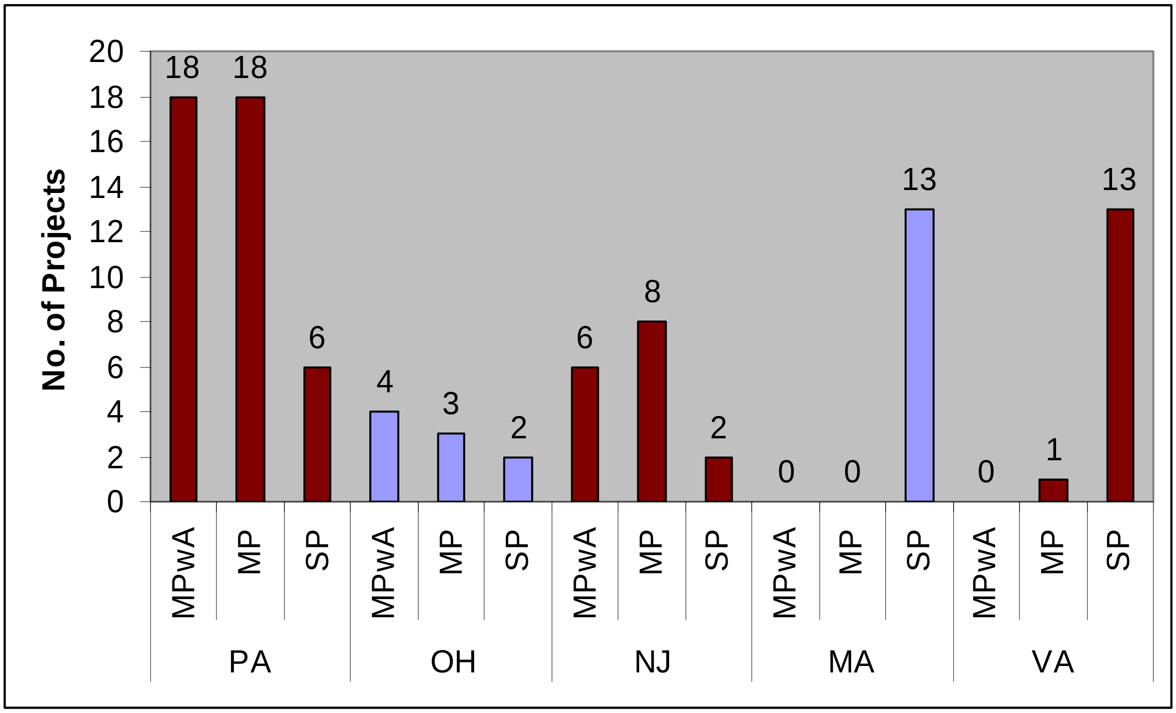


Figure 7.5 - Cases by State and by Delivery System

7.2 COST CORRECTION FOR TIME AND LOCATION

The total cost includes the design, construction, and coordination costs with the change orders and litigation costs of the project. All cases where the school district specified the dollar amount of litigation and the disputes that were settled, the amount was added to the total actual cost. Every analysis involving cost was corrected to time and location according to construction indexes. Following is a brief description of the corrections performed in this study.

7.2.1 Time Correction

Time correction is based on historical cost indexes from the 2003 R.S. Means® Building Construction Cost Data. These indexes, presented in Table 7.1, are used to convert building costs from one time to another time. All data costs are converted to year 2003. Because the actual 2004 index is not yet published, the nine 2004 cases are considered as completed in 2003 for time correction purposes. According to R.S. Means®, the formula used for time adjustment using the historical cost indexes is:

$$\frac{\mathit{Index\ for\ Year\ A}}{\mathit{Index\ for\ Year\ B}}\ x\ \mathit{Cost\ in\ Year\ B} = \mathit{Cost\ in\ Year\ A}$$

In the case of converting the cost to 2003, the formula is equal to:

$$\frac{\mathit{Index\ for\ Year\ 2003}}{\mathit{Index\ for\ Year\ B}}\ x\ \mathit{Cost\ in\ Year\ B} = \mathit{Cost\ in\ Year\ 2003}$$

Table 7.1 - Historical Cost Indexes (1986 - 2003)

Year	Index	Year	Index	Year	Index
2003	132.0	**1997**	112.8	**1991**	96.8
2002	128.7	**1996**	110.2	**1990**	94.3
2001	125.1	**1995**	107.6	**1989**	92.1
2000	120.9	**1994**	104.4	**1988**	89.9
1999	117.6	**1993**	101.7	**1987**	87.7
1998	115.1	**1992**	99.4	**1986**	84.2

7.2.2 Location Correction

Location correction is based on city cost indexes from the 2002 R.S. Means® Building Construction Cost Data. These indexes are used when it is useful to compare the costs from different cities and regions. In this study, the indexes are used to normalize the cost differences resulting from different locations.

In order to simplify this conversion, the state's average index is used. It is calculated based on the average of each state's cities listed in R.S. Means®. All data costs are converted to Pennsylvania costs. According to R.S. Means®, the formula used for location adjustment using the city cost indexes is:

$$\frac{City\ A\ Index}{City\ B\ Index}\ x\ City\ B\ Cost\ (known) = City\ A\ Cost\ (unknown)$$

In the case of converting the cost to Pennsylvania, the formula is equal to:

$$\frac{Pennsylvania\ Index}{State\ B\ Index}\ x\ State\ B\ Cost = Pennsylvania\ Cost$$

Table 7.2 presents the indexes considered in this study:

Table 7.2 - Location Cost Indexes Used in the Study

State	Index
Pennsylvania	98.2
Ohio	95.8
New Jersey	108.9
Massachusetts	105.7
Virginia	79.9

7.3 ANALYSES BASED ON THE SIZE OF THE PROJECT

Two sets of data analyses will be performed in this study. The first set presents the analysis of all projects and the second one of projects with total cost greater than \$ 10,000,000. The intention is to compare and verify if there is any performance difference between the two groups and to check if there is a possibility that smaller renovation and systems replacement projects would skew the results. For now on, the two data sets have the following codification:

DATA SET 1 → Includes ALL data collected;

DATA SET 2 → Includes data of projects with total cost greater than \$ 10,000,000.

The next section presents a summary table of descriptive statistics of continuous variables from the two data sets described above. There are two sets of tables (Tables 7.3 – 7.6) for each data set. The first table is related to all data including outliers. The second table does not include data outliers. Outliers are points below the lower limit and above the upper limit. These limits are characterized by (MINITAB, 2000):

Lower Limit: Q1 - 1.5 (Q3 - Q1)

Upper Limit: Q3 + 1.5 (Q3 - Q1)

Where Q1 represents the first quartile and Q3 the third quartile.

7.4 DATA SET 1 SUMMARY TABLES OF DESCRIPTIVE STATISTICS

Table 7.3 - Data Set 1 - Summary Table of Descriptive Statistics with Outliers

Variable	Dlv Sys	N	Mean	Median	St. Dev.	Q1	Q3
Const Speed (ft^2 / day)	MPwA	26	311.5	251.4	193.3	187.0	384.9
	MP	26	187.2	152.8	135.1	61.6	271.1
	SP	31	284.0	164.0	588.0	76.0	210.0
Unit cost (\$ / ft^2)	MPwA	27	119.7	126.7	53.5	83.0	161.3
	MP	26	120.2	112.3	58.7	78.7	166.3
	SP	31	126.6	139.6	68.1	78.3	160.9
Cost Growth (%)	MPwA	28	5.66	3.59	5.63	1.46	8.41
	MP	30	5.24	3.07	8.00	0.87	6.70
	SP	36	5.94	3.96	10.03	1.01	5.85
Schedule Growth (%)	MPwA	28	4.86	0.00	21.17	0.00	5.84
	MP	30	6.77	2.05	14.40	0.00	12.93
	SP	36	12.27	0.28	29.33	0.00	18.01
%C.O. (%)	MPwA	28	4.31	3.345	3.750	1.215	6.108
	MP	30	3.45	2.660	3.838	0.580	4.220
	SP	36	4.70	3.440	6.260	1.220	5.530

Table 7.4 - Data Set 1 - Summary Table of Descriptive Statistics without Outliers

Variable	Dlv Sys	N	Mean	Median	St. Dev.	Q1	Q3
Const Speed (ft^2 / day)	MPwA MP SP	25 25 25	265.1 174.6 153.3	250.6 151.5 146.0	107.2 121.2 105.8	186.1 58.1 69.8	358.6 256.7 198.8
Unit cost (\$ / ft^2)	MPwA MP SP	25 25 25	127.94 124.90 140.77	141.61 118.00 141.82	46.44 54.80 39.05	92.87 82.40 121.95	163.59 167.40 164.54
Cost Growth (%)	MPwA MP SP	26 28 34	4.471 3.293 4.021	3.315 2.900 3.410	3.652 2.989 3.725	1.360 0.595 0.780	6.985 4.888 5.585
Schedule Growth (%)	MPwA MP SP	21 27 27	1.321 4.730 3.130	0.00 0.00 0.00	2.312 9.220 6.990	0.00 0.00 0.00	3.345 10.860 8.100
%C.O. (%)	MPwA MP SP	27 27 33	3.796 2.409 3.264	3.300 2.530 2.210	2.626 2.117 2.815	1.160 0.460 1.060	5.680 3.470 5.070

7.5 DATA SET 2 SUMMARY TABLES OF DESCRIPTIVE STATISTICS

Table 7.5 - Data Set 2 - Summary Table of Descriptive Statistics with Outliers

Variable	Dlv Sys	N	Mean	Median	St. Dev.	Q1	Q3
Const Speed (ft^2 / day)	MPwA	18	296.0	277.0	102.1	208.8	384.9
	MP	12	242.7	238.0	99.3	152.1	348.2
	SP	14	240.4	198.8	96.7	185.9	339.2
Unit cost (\$ / ft^2)	MPwA	18	134.82	142.65	37.25	97.08	162.44
	MP	12	136.20	141.30	50.80	91.70	172.00
	SP	14	161.60	152.10	48.20	139.8	169.70
Cost Growth (%)	MPwA	19	4.749	3.21	4.129	1.140	8.570
	MP	14	4.351	3.50	2.849	2.742	7.005
	SP	15	5.050	4.47	4.380	2.510	5.720
Schedule Growth (%)	MPwA	19	1.60	0.00	15.69	0.00	5.21
	MP	14	8.19	7.37	17.95	-2.25	16.21
	SP	15	9.05	0.55	28.58	0.00	18.73
%C.O. (%)	MPwA	19	3.781	3.030	3.000	0.760	6.480
	MP	14	3.367	2.910	2.450	2.183	4.070
	SP	15	4.285	4.220	3.550	1.610	5.070

Table 7.6 - Data Set 2 - Summary Table of Descriptive Statistics without Outliers

Variable	Dlv Sys	N	Mean	Median	St. Dev.	Q1	Q3
Const Speed (ft^2 / day)	MPwA	18	296.0	277.0	102.1	208.8	384.9
	MP	12	242.7	238.0	99.3	152.1	348.2
	SP	14	240.4	198.8	96.7	185.9	339.2
Unit cost (\$ / ft^2)	MPwA	18	134.82	142.65	37.25	97.08	162.44
	MP	12	136.20	141.30	50.80	91.70	172.00
	SP	13	149.54	152.00	17.20	139.74	164.12
Cost Growth (%)	MPwA	19	4.749	3.210	4.129	1.140	8.570
	MP	14	4.351	3.500	2.849	2.742	7.005
	SP	14	4.088	4.455	2.367	2.380	5.435
Schedule Growth (%)	MPwA	17	2.201	0.00	3.11	0.00	4.49
	MP	13	4.670	6.79	12.68	-4.49	14.38
	SP	13	7.880	0.55	13.26	0.00	15.87
%C.O. (%)	MPwA	19	3.781	3.030	3.000	0.760	6.480
	MP	12	2.578	2.660	1.347	1.628	3.435
	SP	14	3.474	3.955	1.711	1.605	5.070

8.0 STATISTICAL ANALYSIS OF DATA SET 1

8.1 QUANTITATIVE ANALYSIS

This section presents the quantitative analyses of data set 1, which includes all projects surveyed. Construction speed, unit cost (cost / sf), cost growth, schedule growth, percentage of change order cost, and number of litigation cases are tested against the types of delivery systems. Litigation is addressed in this section with descriptive statistics only.

Outliers were removed for every analysis. Data is transformed before the exclusion of outliers in cases where the normality test fails. The data is tested again for normality. If the transformed data fails the normality test, the corresponding delivery system is removed from the analysis (see Section 6.5 for more details on the calculation methodology).

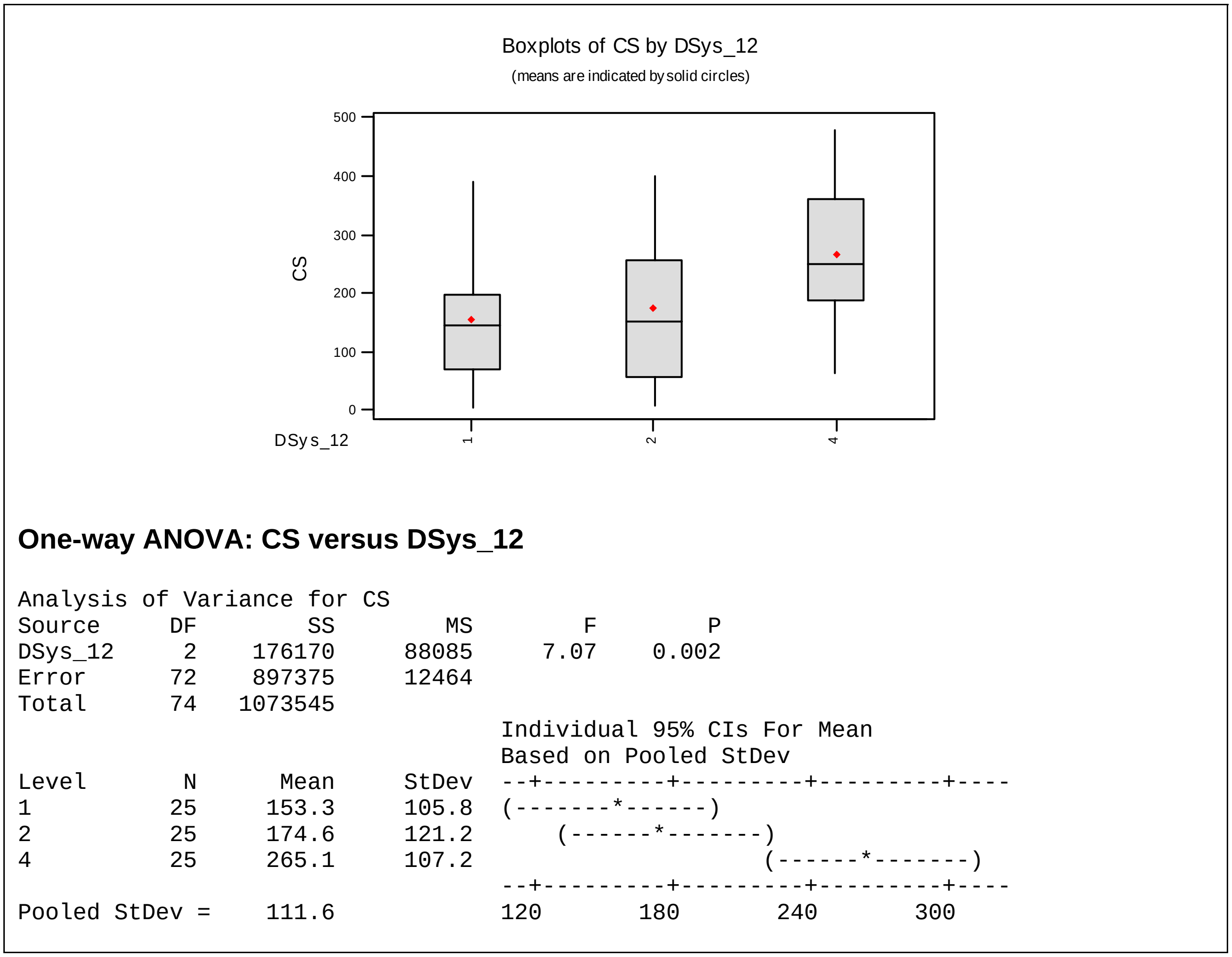
8.1.1 Construction Speed

This parameter specifies the speed of construction based on the amount of square feet constructed per day (see table 6.1(a) for equation). Data for all three delivery systems passed the Anderson-Darling normality test. The P-values for this test were 0.576, 0.107 and 0.242 for multiple prime with an agent (MPwA), multiple prime (MP) and single prime (SP) respectively. Consequently, there is no need for data transformation and the analysis is performed based on the actual data set.

The second step is to verify the relationship between the largest and smallest standard deviations in order to validate the ANOVA test:

$$\frac{Largest\ S}{Smallest\ S} < 2.0 \;---\; \frac{121.2}{105.8} = 1.15 < 2.0\ (OK)$$

The ANOVA test can be performed. Figure 8.1 presents the MINITAB® output obtained from the test:



One-way ANOVA: CS versus DSys_12

```
Analysis of Variance for CS
Source     DF        SS        MS        F        P
DSys_12     2    176170     88085     7.07    0.002
Error      72    897375     12464
Total      74   1073545
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
1          25     153.3     105.8  (-------*------)
2          25     174.6     121.2      (------*-------)
4          25     265.1     107.2                     (------*-------)
                                   --+---------+---------+---------+----
Pooled StDev =    111.6            120       180       240       300
```

Figure 8.1 - Construction Speed Results for Data Set 1

The P-value of 0.002 is statistically significant and the null hypothesis can be rejected. Therefore, it is possible to conclude that there is a relationship between construction speed and delivery systems. From the side-by-side boxplot in Figure 8.1, it is possible to see that the

MPwA is responsible for bringing the P-value down. The difference between the MP and SP means is not statistically significant.

In this sample, projects using multiple prime with an agent constructed more square footage per day than multiple prime and single prime systems. The inclusion of a CM in the process increases the speed of construction. The MPwA sampling mean of 265.1 sf/day is 51.83% higher than the MP and 72.93% higher than the SP system. These percentages represent the difference among systems based on the sample. They do not represent actual percentage differences in the population. The ANOVA test is able to identify the existence of population mean differences, but cannot indicate the level of such difference. Figure 8.2 shows the summary and flow of the calculation performed in this section.

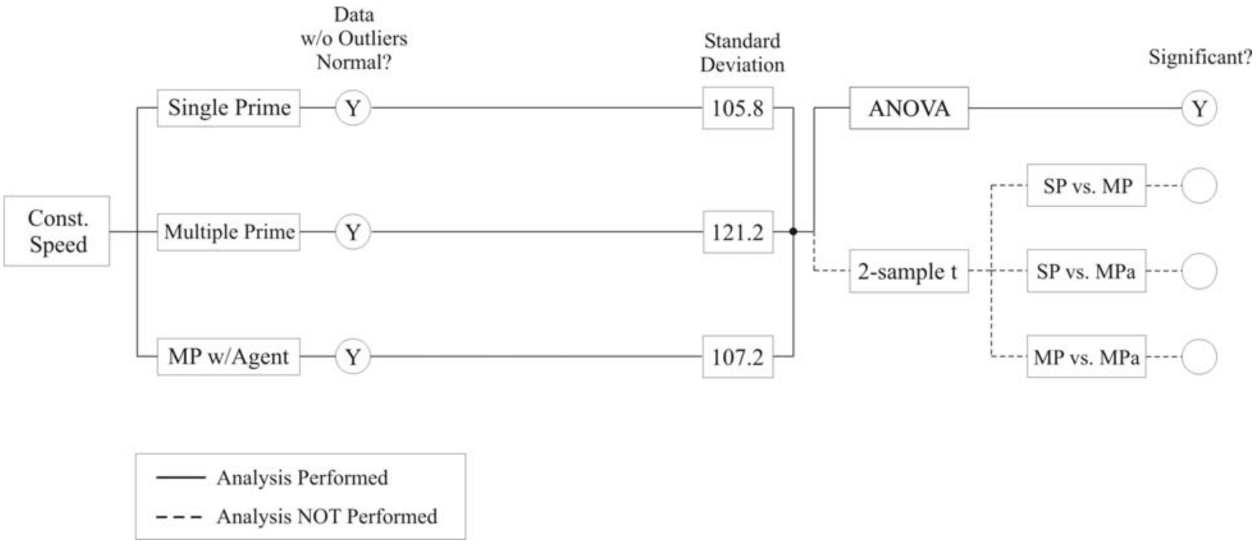


Figure 8.2 - Construction Speed Flow Chart - Data Set 1

8.1.2 Unit Cost

The unit cost is the total cost of the project divided by its area (see Table 6.1(b) for equation). All three delivery systems presented acceptable P-values for the Anderson-Darling normality test: 0.642, 0.254, and 0.565 (MPwA, MP, and SP respectively). Therefore, no data transformation is required.

The values of the standard deviations are close to each other, and the assumption of equal standard deviations can be used. Therefore, the ANOVA test can be used for analysis.

$$\frac{Largest\ S}{Smallest\ S} < 2.0 \;---\; \frac{54.8}{39.05} = 1.40 < 2.0\ (OK)$$

The result of the test indicated a P-value of 0.454. There is not enough evidence to conclude that there is any difference among the delivery systems regarding unit cost. Figure 8.3 indicates the tests performed and details of the results can be found in Appendix C.

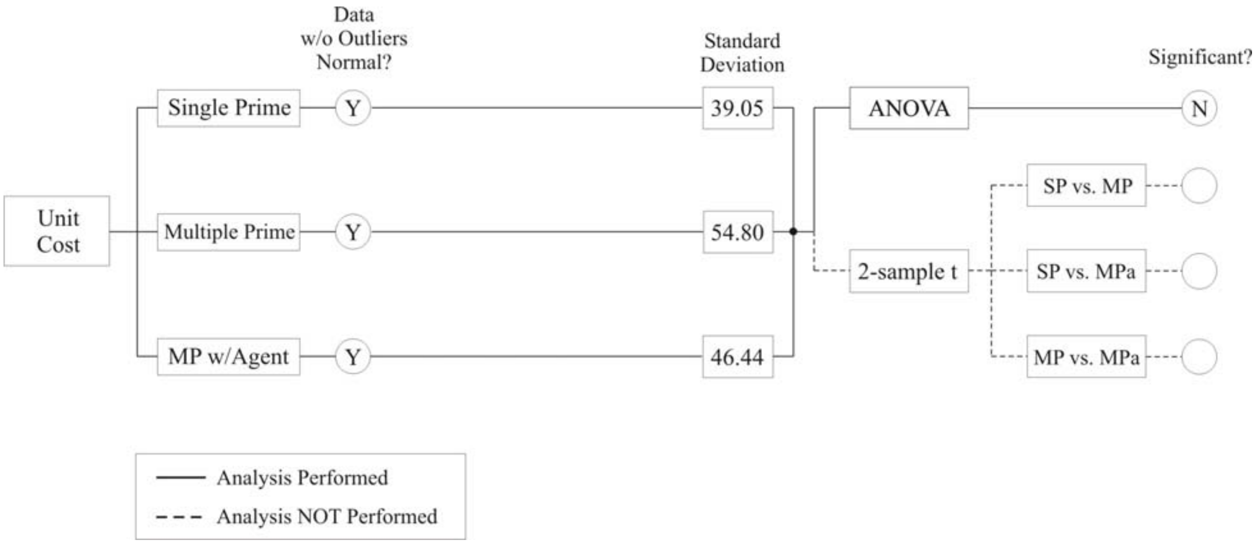


Figure 8.3 - Unit Cost Flow Chart - Data Set 1

8.1.3 Cost Growth

The P-values for the normality test are 0.008, 0.211, and 0.017 for SP, MP, and MPwA respectively. Just the multiple prime delivery system passed the test. Therefore, transformation of the original data was required in order to make any statistical test. After data transformation, the P-values were 0.261, 0.127, and 0.275 (SP, MP, and MPwA).

One of the problems with data transformation is related to the interpretation of the results obtained. However, this procedure is commonly used in statistics. The standard deviations of the systems after the mathematical modification are 0.5799, 0.716, and 0.578 (SP, MP, and MPwA). The relationship between the largest and smallest standard deviations is:

$$\frac{Largest\,S}{Smallest\,S} < 2.0 --- \frac{0.716}{0.578} = 1.24 < 2.0\ (OK)$$

Consequently, the ANOVA test could be used. The results obtained were not statistically significant (P-value = 0.557). There is not enough evidence to conclude the existence of a relationship between cost growth and delivery systems. Basically, all systems present similar cost growth means and the differences among them may result from sampling variation. The MINITAB® output and the side-be-side boxplot are presented in Appendix C. Figure 8.4 indicates the tests performed and the results obtained.

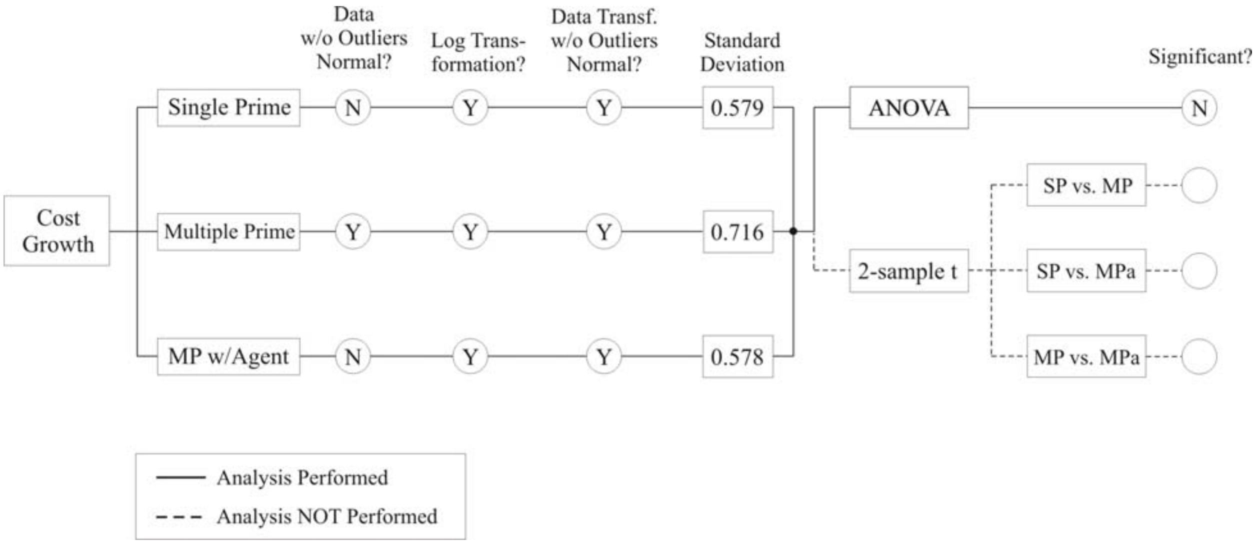


Figure 8.4 - Cost Growth Flow Chart - Data Set 1

8.1.4 Schedule Growth

The normality test for data set 1 schedule growth fails in all three delivery systems. The P-values of the Anderson-Darling test are 0.000, 0,010, and 0.000 for SP, MP, and MPwA respectively. The data was transformed with natural log. The normality test results obtained after the transformation were not satisfactory to perform the statistical tests used in this study (0.000, 0.006, and 0.000). Therefore, there are no conclusions for data set 1 related to this variable.

The difficulty of data normality of schedule growth can be explained by the characteristics of the projects involved in the study. School districts have a very tight schedule when dealing with construction jobs. Some of the jobs can only be performed outside of the academic year. Therefore, jobs that cannot be completed will experience a long delay. In this case, schedule growth does not represent the "real" delay or time advancement of the project.

The situation described above could be perceived from the data set collected. From the 94 cases, there were 19 outliers excluded from the original data. Also, after transformation, the number of cases was decreased to 74 cases (20 outliers removed). Figure 8.5 summarizes the tests performed in this section, which were limited to the normality tests of the data.

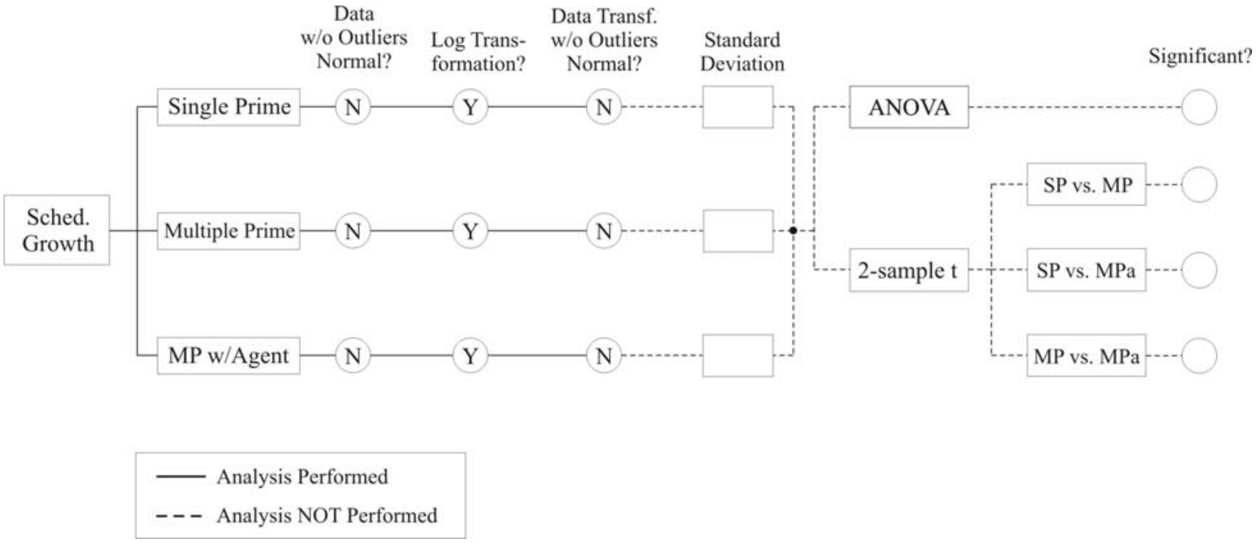


Figure 8.5 - Schedule Growth Flow Chart - Data Set 1

8.1.5 % Change Order

The percentage of change order relates the total cost of change orders with actual total cost (see Table 6.1(e) for equation). The number of change orders and the total dollar amount are dependent on the size of the project. The use of a percentage factor overcomes this dependency and better measures the increase in costs because of change orders.

The P-values obtained for the normality tests are 0.063, 0.452, and 0.151 (SP, MP, and MPwA respectively). SP fails the test and needs to be transformed. Two-sample t test can be performed to analyze MP and MPwA systems. The standard deviations of the last two systems are close to each other and a "pooled" analysis can be performed. Figure 8.6 summarizes the findings obtained before data transformation.

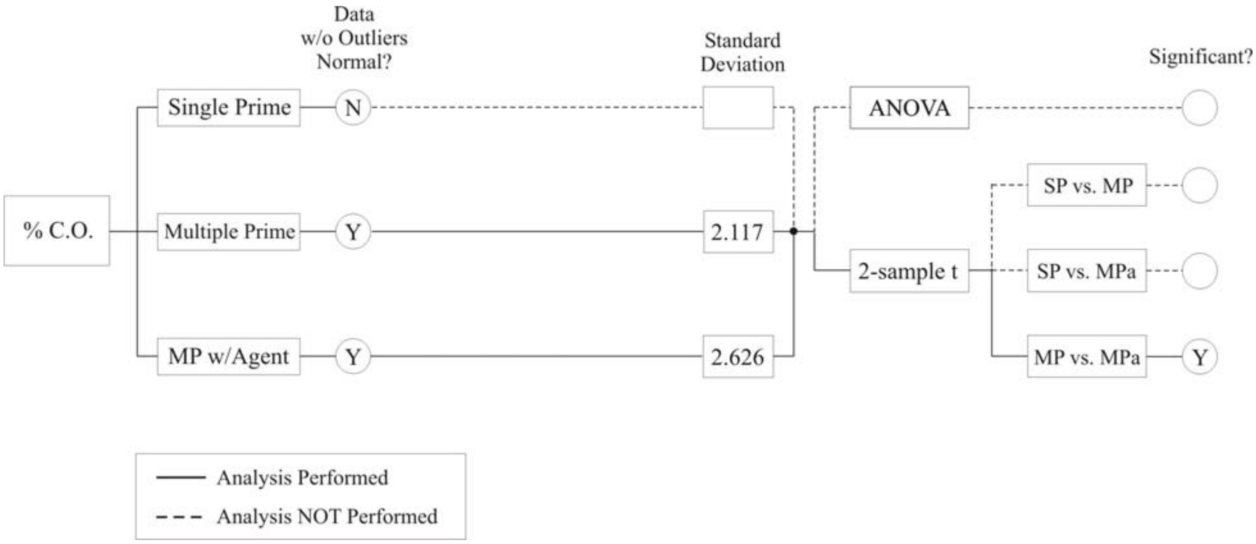


Figure 8.6 - %C.O. Flow Chart (MPwA vs. MP) - Data Set 1

A P-value of 0.037 indicated statistical significance on the results at the 5% level (α = 0.05). The hypotheses were created to verify if there are differences on the population means (Ha: $\mu_{MP} = \mu_{MPwA}$ and Ho: $\mu_{MP} \neq \mu_{MPwA}$). Figure 8.7 presents the results.

Two-Sample T-Test and CI: %CO4, %CO2

```
Two-sample T for %CO4 vs %CO2

       N      Mean     StDev   SE Mean
%CO4  27      3.80      2.63      0.51
%CO2  27      2.41      2.12      0.41

Difference = mu %CO4 - mu %CO2
Estimate for difference:  1.387
95% CI for difference: (0.084, 2.690)
T-Test of difference = 0 (vs not =): T-Value = 2.14  P-Value = 0.037  DF = 52
Both use Pooled StDev = 2.39
```

Figure 8.7 - Two-sample t Results for %C.O. Data Set 1 (MPwA vs. MP)

From the data analysis, it is found that MPwA has a higher %C.O. mean when compared to the MP system. In the sample, MPwA is approximately 58% higher than MP.

The transformation of the data set with natural log normalized the SP system. The P-values are 0.411, 0.523, and 0.344 (SP, MP, and MPwA respectively). Two tests are performed after transformation. One tests SP vs. MP and the other SP vs. MPwA. The hypotheses are:

Test 1 → Ho: $\mu_{SP} = \mu_{MP}$ and Ha: $\mu_{SP} \neq \mu_{MP}$

Test 2 → Ho: $\mu_{SP} = \mu_{MPwA}$ and Ha: $\mu_{SP} \neq \mu_{MPwA}$

No significance could be found in either test. A P-value of 0.552 was found in the first test and a P-value of 0.448 was found in the second test. For additional details, see Appendix C. Figure 8.8 indicates the tests performed.

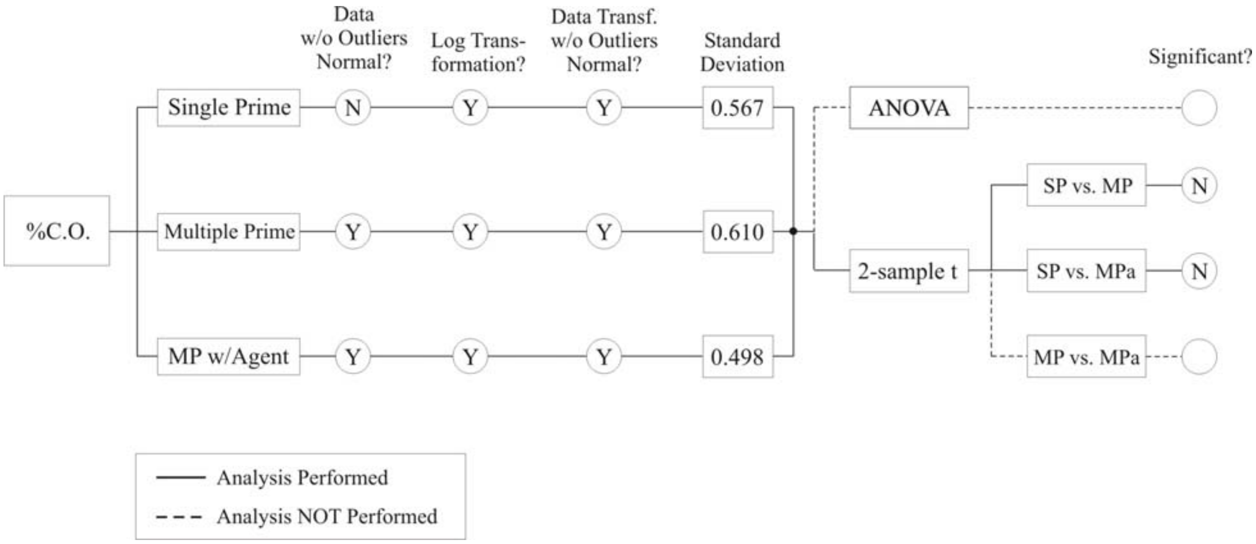


Figure 8.8 - %C.O. Flow Chart - Transformed Data Set 1

There is a consideration in this test that should be mentioned. The survey asked for the reasons for the change orders granted in the project. The list of responses included the following items (see Appendix B for a copy of the questionnaire):

a. Lack of detail during the design phase

b. Owner has changed the scope of work

c. Conditions unforeseen when the contract was agreed

d. Avoid litigation and settle disputes

e. Other reason to be indicated by the respondent

The results obtained in the previous tests include the dollar amount of all reasons described above. Item "b" represents a change imposed by the owner on the contractor and consequently an increase (or decrease) in the final cost of the project. A better measurement of the delivery system would be obtained with the exclusion of the dollar amount related to the change of scope by the owner. This new test was performed.

A new data set was created. In this new set, the dollar amount for item "b" was removed from the calculation of change order percentage. With the exception of SP after transformation (P-value = 0.110), all systems failed the normality test before and after data transformation (P-values = 0.008, 0.011, and 0.002; P-values = 0.110, 0.046, and 0.038 respectively). Therefore, it was impossible to make any analysis of the % C.O. considering the exclusion of the dollar amount related to change of scope by the owner. Table 8.1 indicates the descriptive statistics of this new data set without outliers before transformation.

Table 8.1 - Data Set 1 - C.O. w/o Change of Scope Descriptive Statistics (no Outliers)

Variable	Dlv Sys	N	Mean	Median	St. Dev.	Q1	Q3
% C.O. (w/o Change of Scope)	MPwA	28	2.897	2.040	2.507	0.620	5.215
	MP	28	1.550	1.355	1.561	0.010	2.512
	SP	34	2.167	1.680	2.140	0.208	3.412

The only significant test in this section indicates that MPwA has higher %C.O. than MP including the cases where the owner has changed the scope of the project. This conclusion may not be significant because a change order not controlled by the contractor may not represent a valid measurement of performance.

8.1.6 Litigation

The intention of both owner and contractor is to conclude the project without any type of disputes. However, litigation cases may result from construction contracts. For this sample, 9.57% of the projects had litigation cases. The majority of the sample did not have litigation, so the distribution of cases was not normal and it was impossible to perform quantitative analysis. Therefore, this section is limited to the descriptive statistics. Furthermore, litigation cases will be considered as a binary variable and analyzed with the Chi-Square test (see Sections 8.2 and 9.2).

There were 14 litigation cases in 9 different projects. Figure 8.9 indicates the number of cases with their respective delivery systems.

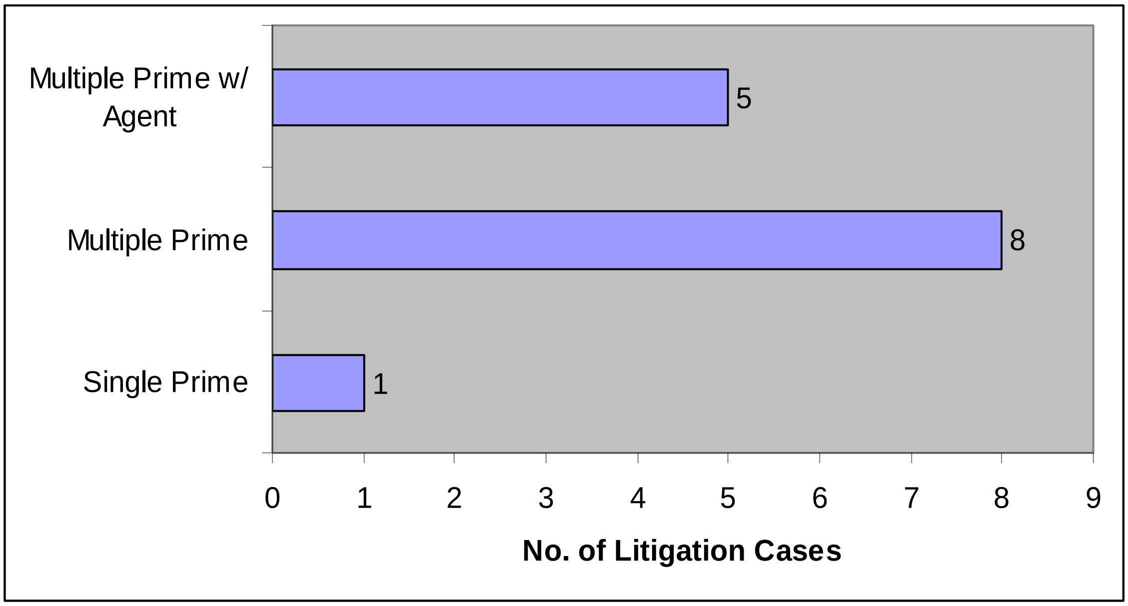


Figure 8.9 - Number of Litigation Cases per Delivery System for Data Set 1

There were 8 cases related to multiple prime, 5 to multiple prime with an agent and one case to the single prime delivery system. Even though it is not possible to make any inference about the population, the small sample collected indicates that single prime presents considerably fewer numbers of litigation cases when compared to the other two types of delivery systems. This can be explained by the direct and simple relationship that just one entity has with the owner. In the other two cases the owner has to deal with several prime contractors and the possibility of litigation is greater. Figure 8.10 indicates the litigation cases expressed as a percentage of projects per delivery system.

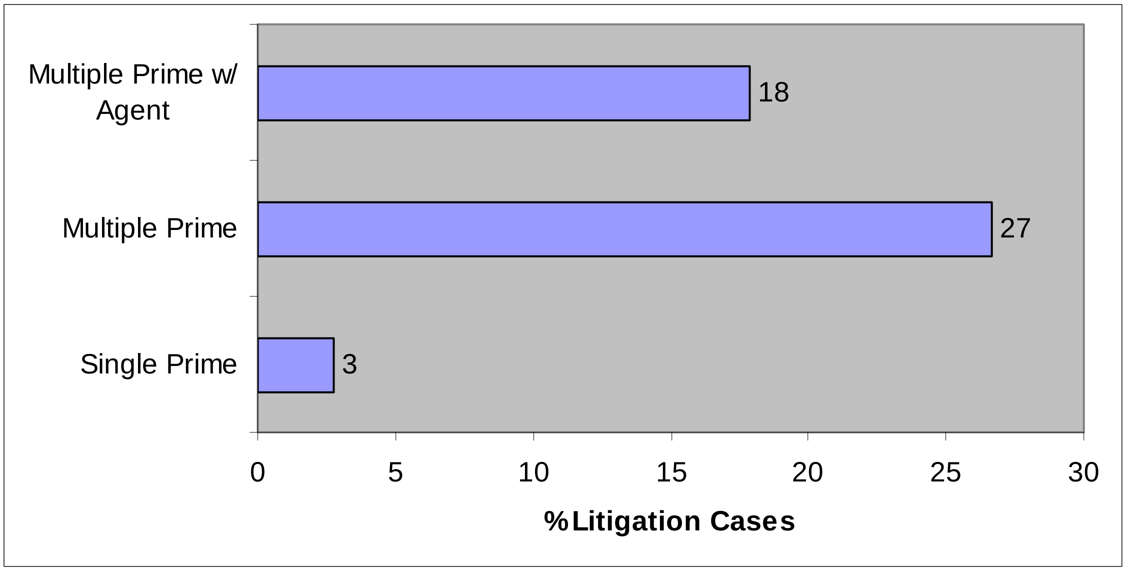


Figure 8.10 - Litigation Cases Expressed as a % of Projects per Delivery System (DS1)

A comparison with a national average would be extremely valuable to analyze the performance of the systems. However, determining the number of construction-related litigation cases in the United States is almost impossible because the courts do not maintain statistics of the cases. It would be necessary to verify each case individually. Also, a great number of cases are settled in alternative dispute resolution that do not necessarily result in public records.

8.2 QUALITATIVE ANALYSIS

The Chi-Square is used to test qualitative variables. As explained in Section 6.4.3, this test verifies the relationship between two categorical variables in a two-way table. Small P-values reject the null hypothesis and conclude that the variables are not independent. The condition for this test is based on the expected cell counts. At least 80% of the cells must have expected counts higher than 5.0. Tables 2 X 2 require all expected cell counts to be higher than 5.0. Combination and exclusion of cells are possible solutions to bring the table to this condition.

Seven variables are analyzed in this section against the three delivery systems: length of punch list, difficulty of facility startup, level of call backs after owner occupancy, level of administrative burden, project team communication, project team chemistry, and litigation cases. Appendix D presents the MINITAB® outputs for all the non-significant tests (high P-values). They are presented after any combination or cell exclusion.

The length of the punch list was divided into 5 levels (for more detail, see Section 6.6). The result including all 5 levels indicated 11 cells with expected counts less than 5.0. Because of the condition previously explained, levels 1 and 2 were combined with level 3. As a result, level 3 corresponds to the cases where the punch list length is more than one day and less than four weeks. This combination resulted into 3 levels of punch list length with 2 cells with expected count less than 5.0. These 2 cells represent 22.22% of the total, being close to the requirement of the test. The P-value is 0.294 and it is conclusive that the variables are independent.

The difficulty of facility startup was classified in high, medium, and low (levels 1, 2, and 3 respectively). Three cells with expected counts less than 5.0 resulted from the first test. This represents 33.33% of the cells and fails the test. Therefore, level 1 (high) was deleted from the analysis because of the small number of cases. The P-value of 0.627 indicates that there is no relationship between the delivery systems and the difficulty of facility to startup.

The number of call backs after owner occupancy was also classified in three levels: high, medium, and low (levels 1, 2, and 3 respectively). The high level of call backs had the least occurrence among all delivery systems. They represented the cells with expected counts less than 5.0 (3 cells out of 9 = 33.33%). Therefore, the cases with high level of call backs were excluded from the analysis. The P-value of 0.694 indicated that there is not enough evidence to reject Ho. No relationship exists between delivery systems and level of call backs.

The level of administrative burden is classified in a five level scale where 1 represents the highest level and 5 the lowest level. Because of the small number of cases with levels 4 and 5, the results of this test indicated the presence of 3 cells with expected counts with less than 1.0 and 6 cells with less than 5.0. The test is invalid. The exclusion or combination of the cells in this test is not convenient because the scale would be reduced to 3 levels and the low levels would not have representation. Therefore, no conclusions can be drawn about the level of administrative burden.

There were 3 options related to project team communication: excellent, adequate, and poor (levels 1, 2, and 3 respectively). Three cells, all in the poor level, presented expected counts less than 5.00. After the exclusion of the poor level, there were no cells with expected counts less than 5.00. The P-value of 0.466 indicated that no relationship exists between the two categorical variables.

On the similar scale, team chemistry was classified in excellent, adequate, and poor (levels 1, 2, and 3 respectively). Because of the small number of cases with poor level of chemistry in the three types of delivery system, they presented the 3 cases with expected counts less than 5.00. Excluding this level, the test could be performed and the P-value of 0.879 indicated that there is no relationship between team chemistry and the type of delivery system.

Finally, the Chi-Square test of litigation was performed based on the existence or not of litigation cases. In this case, the variable assumed two possible values: 0 and 1 where 0 represents the projects with no litigation case and 1 the projects with at least one case. Consequently, a 3 X 2 table is created. The existence of 3 cells with expected counts less than

5.0 fails the analysis. The exclusion of one column would also invalidate the test. More projects with litigation cases would be necessary to make it valid. Therefore, no conclusions can be drawn based on the existent data set.

As can be seen, the qualitative analysis of the study is limited by the number of samples collected. In most cases, the exclusion and combination of columns is necessary to make the test valid. The Chi-Square test becomes more accurate as the cell counts increase. This limitation of the study results in no conclusion between any categorical variable and the delivery systems.

9.0 STATISTICAL ANALYSIS OF DATA SET 2

9.1 QUANTITATIVE ANALYSIS

This section presents the quantitative analyses of data set 2 that includes projects with total cost of at least \$ 10,000,000. Construction speed, unit cost (cost / sf), cost growth, schedule growth, and percentage cost of change orders are tested against the types of delivery systems. This section also presents the statistics of litigation cases by delivery system. The methodology and considerations of the tests are the same as presented in Section 8.1.

9.1.1 Construction Speed

Multiple prime and multiple prime with an agent passed on the Anderson-Darling normality test (P-values of 0.307 and 0.609 respectively). With P-value of 0.017, the single prime system fails the normality test. Therefore, the first analysis of this section is based on the actual data of MP and MPwA on a two-sample t test. Another test will be considered afterwards based on data transformation.

MPwA and MP have standard deviations equal to 102.1 and 99.3 respectively. In this case the “pooled” two-sample t test can be performed. It is assumed that both populations have equal standard deviations. The hypotheses tested are:

Ho: $\mu_{MPwA} = \mu_{MP}$

Ha: $\mu_{MPwA} > \mu_{MP}$

Figure 9.1 presents the result of the two-sample t test:

Two-Sample T-Test and CI: CS4, CS2

```
Two-sample T for CS4 vs CS2

      N      Mean     StDev   SE Mean
CS4  18       296       102        24
CS2  12     242.7      99.3        29

Difference = mu CS4 - mu CS2
Estimate for difference:  53.3
95% lower bound for difference: -10.8
T-Test of difference = 0 (vs >): T-Value = 1.42  P-Value = 0.084  DF = 28
Both use Pooled StDev =  101
```

Figure 9.1 - Two-sample t Results for Construction Speed Data Set 2 (MPwA vs. MP)

The P-value of 0.084 is close to significant at 95% level of confidence ($\alpha = 0.05$). According to the literature, α dictates the acceptable risk of incorrectly rejecting Ho. In this case if considering $\alpha = 0.10$, the result obtained would give enough evidence to reject Ho and conclude Ha. The difference between the two systems presented higher significance (smaller P-value) when including all projects in the analysis.

The sampling means indicate that MPwA constructs 22% more square footage per day than MP. This is just a parameter of comparison between the two systems. Even though there is not enough evidence against Ho at 95% level of confidence, the results obtained can be considered significant based on the results that were obtained when considering all samples in the data set. Figure 9.2 indicates the steps for this analysis.

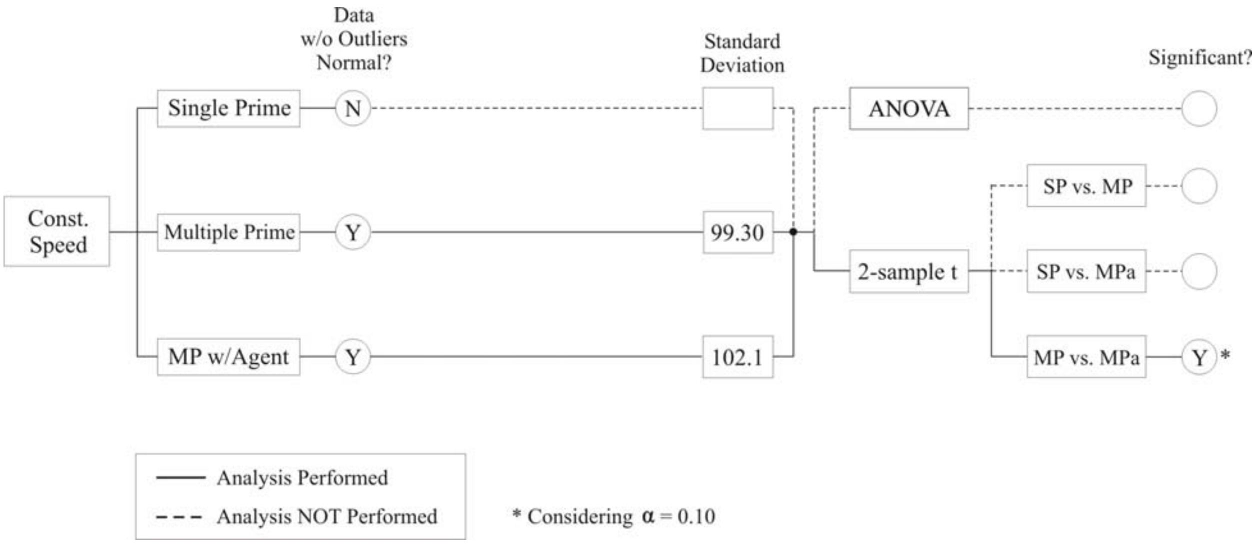


Figure 9.2 - Construction Speed Flow Chart (MPwA vs. MP) - Data Set 2

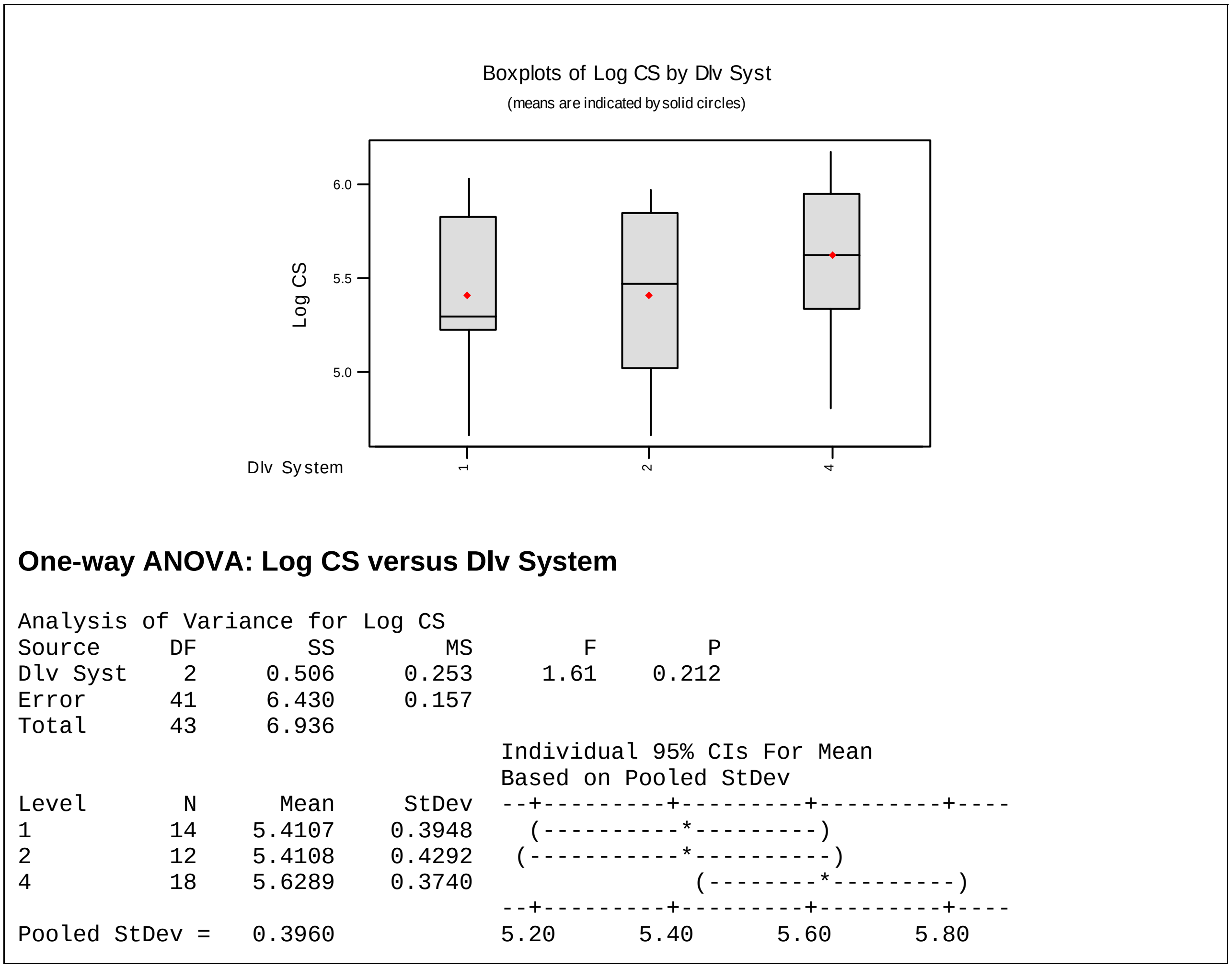
A second type of analysis is performed based on the natural log transformation of all three delivery systems' data. The intention of this transformation is to bring the extreme values of the single prime system closer and consequently reducing the effect of skewness. Even though MP and MPwA do not need to be transformed, the comparison can only be performed if all systems have the transformed variable. The exclusion of outliers is performed after the log transformation.

After transformation, all three cases pass the normality test. The standard deviations of the systems are close to each other (0.395 – SP; 0.429 – MP; 0.3740 – MPwA) and the ANOVA test can be performed. The result of the ANOVA test (P-value = 0.212) is not statistically significant. However, the boxplot graphic indicates a difference between MPwA and the other two types of delivery systems. Therefore, a two-sample t test is performed to analyze the following hypotheses:

Ho: $\mu_{MPwA} = \mu_{SP}$

Ha: $\mu_{MPwA} > \mu_{SP}$

The two figures below (Figures 9.3 and 9.4) indicate the results obtained for the two tests described above. A brief conclusion will be drawn at the end of this section.



One-way ANOVA: Log CS versus Dlv System

```
Analysis of Variance for Log CS
Source     DF        SS        MS        F        P
Dlv Syst    2     0.506     0.253     1.61    0.212
Error      41     6.430     0.157
Total      43     6.936
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
1          14    5.4107    0.3948    (----------*---------)
2          12    5.4108    0.4292   (-----------*----------)
4          18    5.6289    0.3740                (--------*---------)
                                   --+---------+---------+---------+----
Pooled StDev =   0.3960            5.20      5.40      5.60      5.80
```

Figure 9.3 - ANOVA Construction Speed Results for Transformed Data Set 2

```
Two-Sample T-Test and CI: Log CS4, Log CS1


Two-sample T for Log CS4 vs Log CS1

          N      Mean     StDev   SE Mean
Log CS4  18     5.629     0.374     0.088
Log CS1  14     5.411     0.395      0.11

Difference = mu Log CS4 - mu Log CS1
Estimate for difference:  0.218
95% lower bound for difference: -0.014
T-Test of difference = 0 (vs >): T-Value = 1.60  P-Value = 0.060  DF = 30
Both use Pooled StDev = 0.383
```

Figure 9.4 - Two-sample t Results for Construction Speed Transf. Data Set 2 (MPwA vs. SP)

A P-value of 0.060 is close to significant at α = 0.05. This result presents almost enough evidence to reject Ho and conclude Ha. Based on the results obtained from all the tests performed in this section, it is possible to conclude that MPwA constructs more square footage per day than SP and MP delivery systems. Figure 9.5 presents the summary chart of the tests performed.

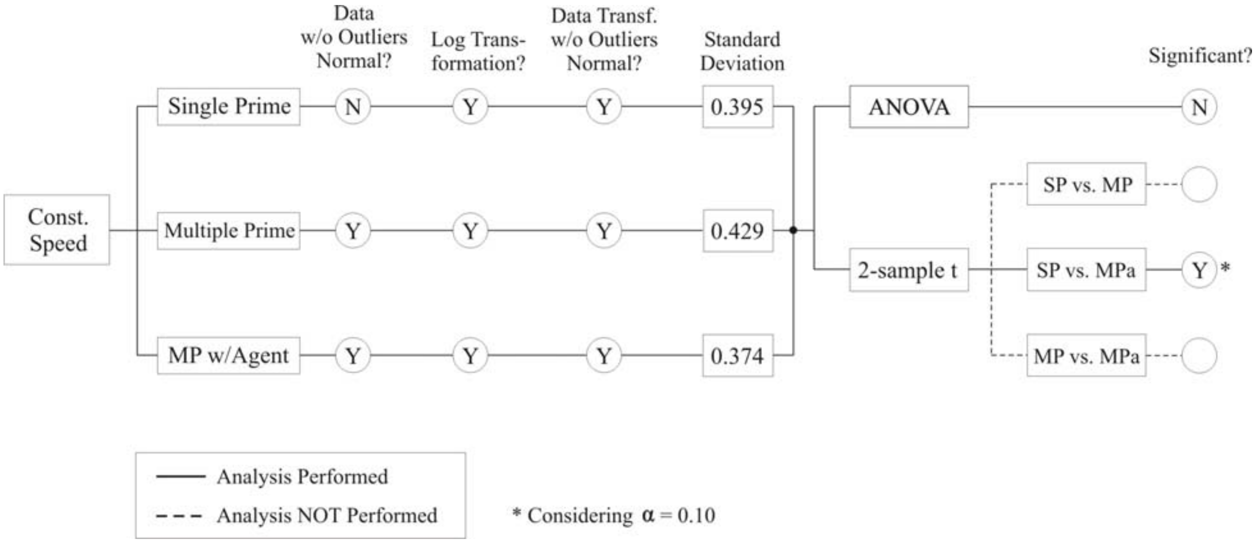


Figure 9.5 - Construction Speed Flow Chart - Transformed Data Set 2

9.1.2 Unit Cost

All three delivery systems passed the Anderson-Darling normality test (P-values = 0.691 for SP, 0.554 for MP, and 0.458 for MPwA). However, the condition for the ANOVA test is not satisfied. The relationship between the largest and smallest standard deviations is equal to:

$$\frac{Largest\ S}{Smallest\ S} < 2.0 --- \frac{50.80}{17.20} = 2.95\ (\ Not\ OK\ )$$

In this case, the two-sample t-test can be performed assuming that the populations have different standard deviations (“not pooled” approach). In this case the following hypotheses are created to test the three delivery systems:

Table 9.1 - Hypotheses for Unit Cost Test - Data Set 2

Hypothesis 1	Hypothesis 2	Hypothesis 3
Ho: $\mu_{MP} = \mu_{SP}$ Ha: $\mu_{MP} \neq \mu_{SP}$	Ho: $\mu_{MP} = \mu_{MPwA}$ Ha: $\mu_{MP} \neq \mu_{MPwA}$	Ho: $\mu_{SP} = \mu_{MPwA}$ Ha: $\mu_{SP} \neq \mu_{MPwA}$

All the tests performed did not present statistical significance to reject the null hypothesis. The P-values of the tests are equal to 0.403, 0.936, and 0.153 for hypothesis 1, 2, and 3 respectively. The results are shown in Appendix E. Therefore, it is possible to conclude that there is no relationship between unit cost and delivery systems. There is not enough evidence that would indicate a difference on the unit cost population means. Figure 9.6 presents the summary of the methodology performed in this section.

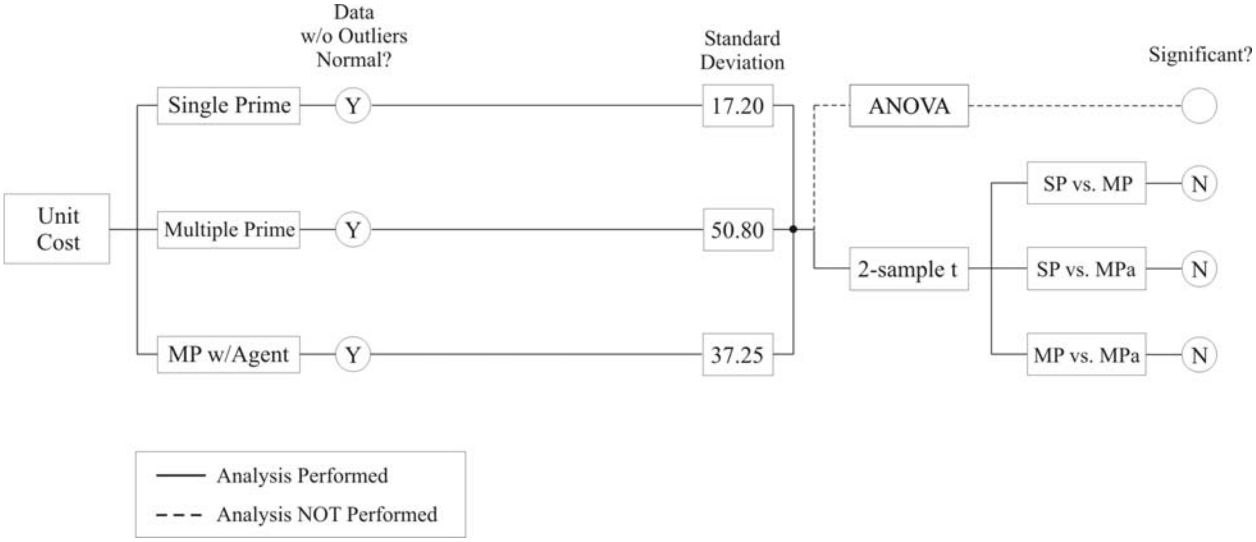


Figure 9.6 - Unit Cost Flow Chart - Data Set 2

9.1.3 Cost Growth

The MPwA system failed the normality test (P-value = 0.025). The other two cases presented valid P-values to be considered normal (SP – 0.596 and MP – 0.179). Therefore, a two-sample t test is performed considering the original data set for SP and MP. Two other tests will be performed to compare MPwA with SP and MP based on natural log transformed data.

The hypotheses for the first test performed are:

Ho: $\mu_{SP} = \mu_{MP}$

Ha: $\mu_{SP} \neq \mu_{MP}$

The P-value is equal to 0.792. Therefore, the test indicates that there is no difference between the cost growth means of SP and MP systems. The MINITAB® output is shown in Appendix E and Figure 9.7 indicates the summary of the tests performed.

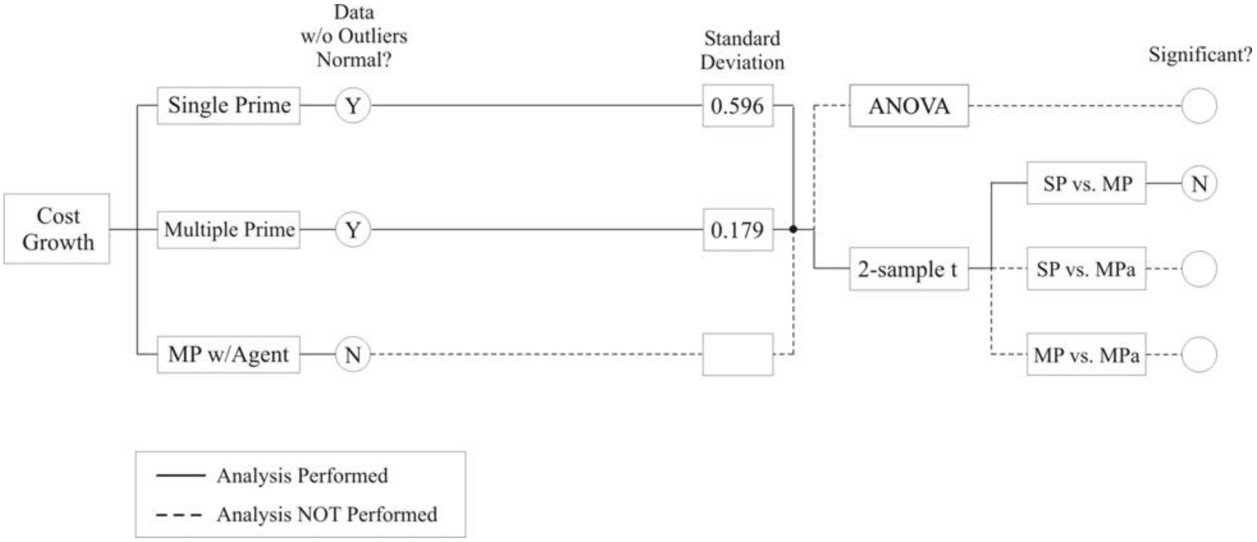


Figure 9.7 - Cost Growth Flow Chart (SP vs. MP) - Data Set 2

The P-values for the normality test of the natural log transformed data are 0.442, 0.384, and 0.160 (SP, MP, and MPwA respectively). Two other two-sample t tests will be performed in this section. The first test compares the means of SP and MPwA. The second test is based on the comparison of MP and MPwA. Following are the hypotheses to be analyzed in both tests:

Test 1 → Ho: $\mu_{SP} = \mu_{MPwA}$ and Ha: $\mu_{SP} \neq \mu_{MPwA}$

Test 2 → Ho: $\mu_{MP} = \mu_{MPwA}$ and Ha: $\mu_{MP} \neq \mu_{MPwA}$

There was no statistical significance to reject the null hypothesis (Ho). P-value of test 1 is 0.580 and test 2 is 0.510. No inference can be drawn from the results obtained. Appendix E presents the MINITAB® outputs of the tests performed in this section. Figure 9.8 shows a summary of the two tests described above.

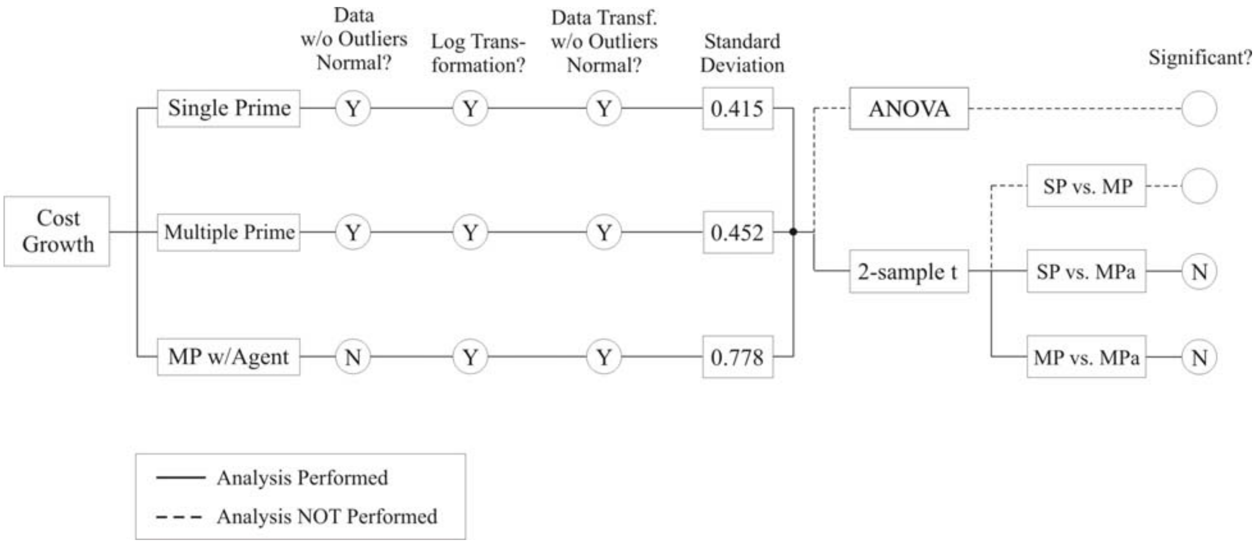


Figure 9.8 - Cost Growth Flow Chart - Transformed Data Set 2

9.1.4 Schedule Growth

Generally, changing the sampling to projects over $ 10,000,000 reduced the variability of the projects' variables. However, the schedule growth variable still had great variability. The normality test P-values are equal to 0.017, 0.616, and 0.000 (SP, MP and MPwA respectively). After natural log transformation, the MP system was still the only one considered normal (P-value = 0.675). The other two systems did not pass the normality test (SP – 0.058 and MPwA – 0.000). Most of the projects do not experience schedule growth, whereas a few of the projects have a great deal of schedule growth. As can be seen in Table 7.6, the median values of MPwA and SP are close to zero, whereas their mean values are greater than zero, which characterizes the skewness of these distributions. Therefore, no tests can be performed to analyze the differences between the systems based on schedule growth. As discussed earlier, a larger sample size would eliminate the requirement for a normality test (see Section 6.4.1). Figure 9.9 summarizes the tests performed in this section, which were limited to the normality tests of the data.

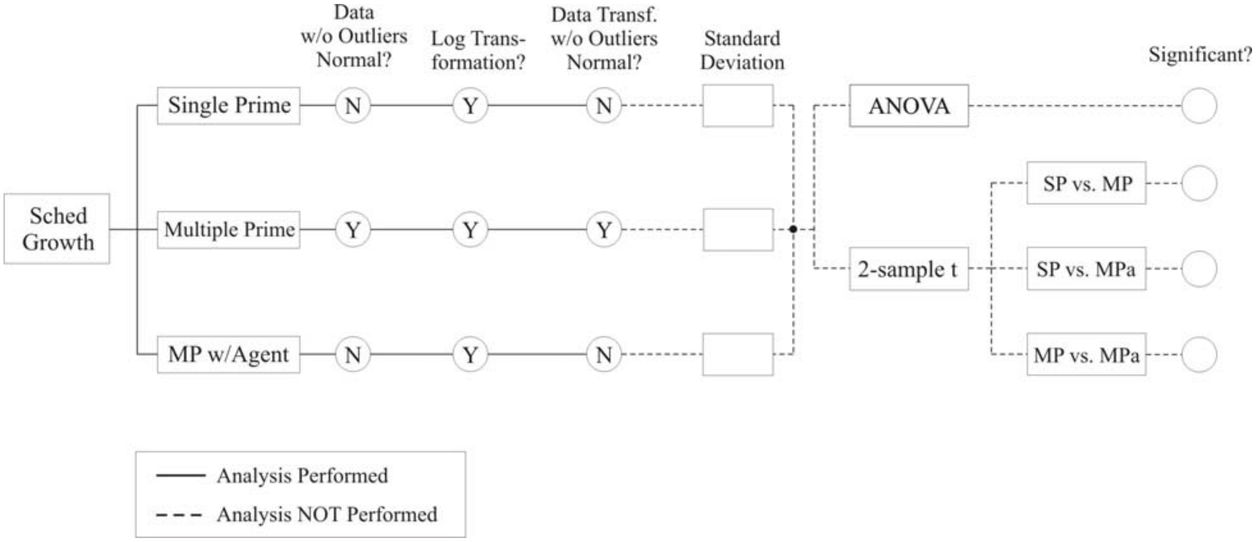


Figure 9.9 - Schedule Growth Flow Chart - Data Set 2

9.1.5 % Change Orders

Multiple prime is the only delivery system that passes the normality test before and after transformation. The P-values for the Anderson-Darling normality test are 0.021, 0.450, and 0.079 (SP, MP, and MPwA respectively) before transformation. These values are slightly increased after the transformation to 0.084, 0.509, and 0.080, but not sufficient to pass the normality test. Therefore, no statistical test could be performed when considering all the reasons for change orders.

As explained in Section 8.1.5, the analysis of % of change orders can also be analyzed if the dollar amount related to change of the scope by the owner is removed. A new data set was created with this consideration. MPwA is not considered in the analysis because of normality failure in both before and after data transformation (P-values = 0.001 and 0.012 respectively). The P-values of the normality test for SP and MP before transformation are 0.511 and 0.383 respectively. Consequently, SP and MP are tested against each other based on the original data set. Two-sample t test is used and the hypotheses to be tested are:

Ho: $\mu_{SP} = \mu_{MP}$

Ha: $\mu_{SP} \neq \mu_{MP}$

The P-value obtained in the analysis is equal to 0.968. There is not enough evidence to reject Ho. Therefore, there is no statistical significance that indicates a relationship between the percentage of change orders and the type of delivery system used in a construction project. The output of this test can be found in Appendix E. Figure 9.10 presents a summary of the test performed in this section.

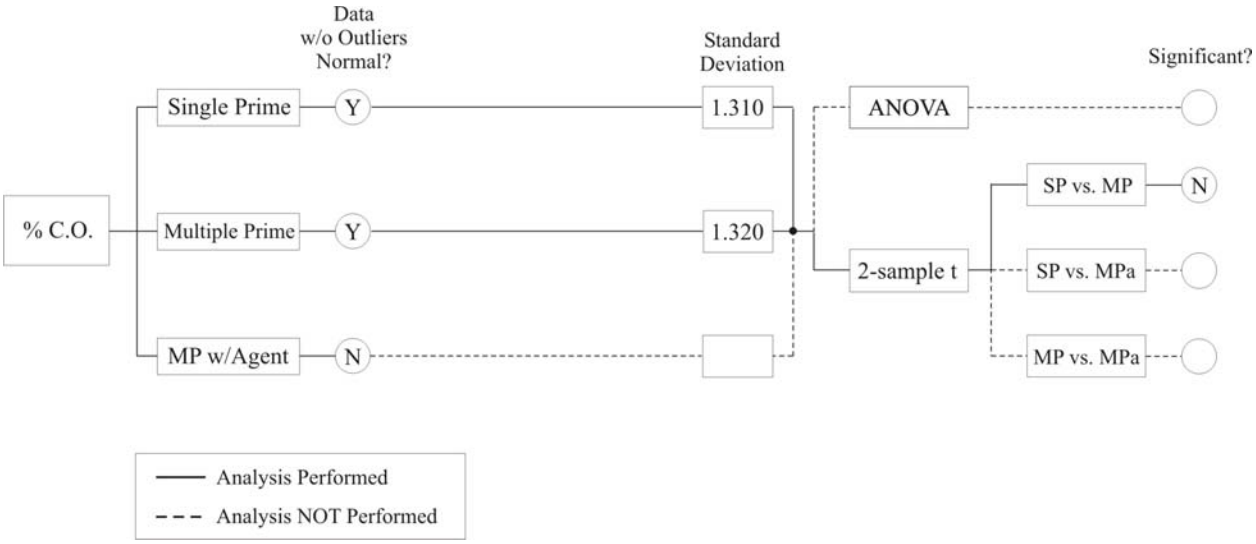


Figure 9.10 - %CO w/o Change of Scope by Owner Flow Chart - Data Set 2

Table 9.2 indicates the descriptive statistics of the percentage of change order variable not considering the change of scope by the owner in data set 2.

Table 9.2 - Data Set 2 - C.O. w/o Change of Scope Descriptive Statistics (no Outliers)

Variable	Dlv Sys	N	Mean	Median	St. Dev.	Q1	Q3
% C.O. (w/o Change of Scope)	MPwA MP SP	19 13 15	2.816 2.262 2.283	1.720 2.460 2.050	2.752 1.318 1.309	0.580 1.065 1.220	5.500 2.890 3.250

9.1.6 Litigation

Figure 9.11 presents the number of litigation cases for data set 2. Twelve of the 14 litigation cases in data set 1 occurred in projects with total costs greater than $ 10,000,000. Of the cases removed, one case was single prime and the other multiple prime with an agent. Therefore, single prime resulted in no litigation case and MPwA was reduced to 4.

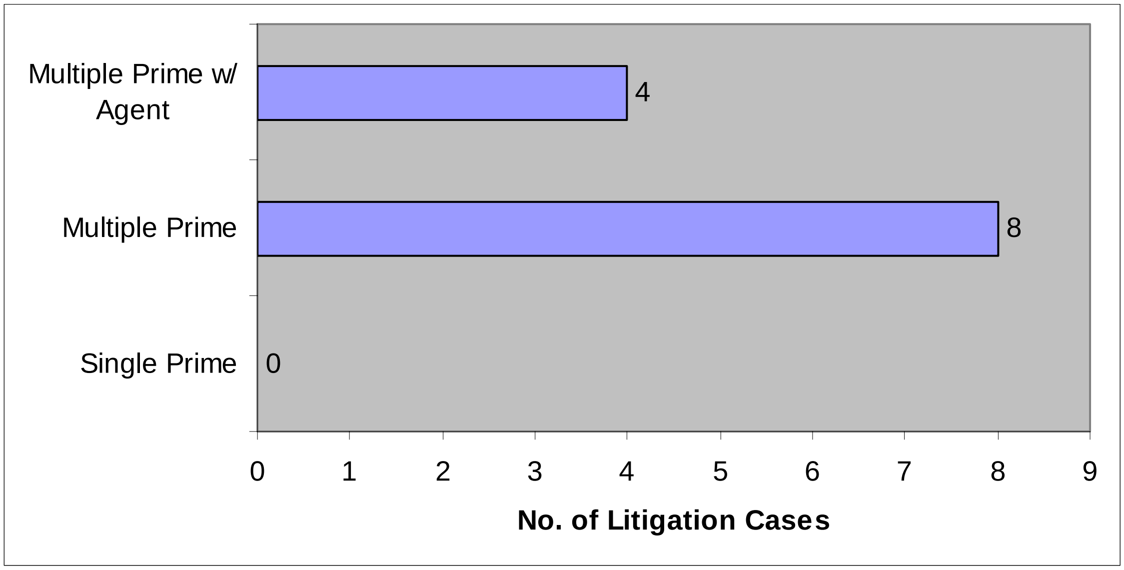


Figure 9.11 - Number of Litigation Cases per Delivery System for Data Set 2

Figure 9.12 indicates the litigation cases expressed as a percentage of projects per delivery system for data set 2. The percentage differs from the results obtained in data set 1 (see Section 8.1.6) because of the reduction of the number of projects in each delivery system. Consequently, the percentage is increased. The results obtained in data set 2 present a stronger difference between the systems when compared to the results obtained in data set 1.

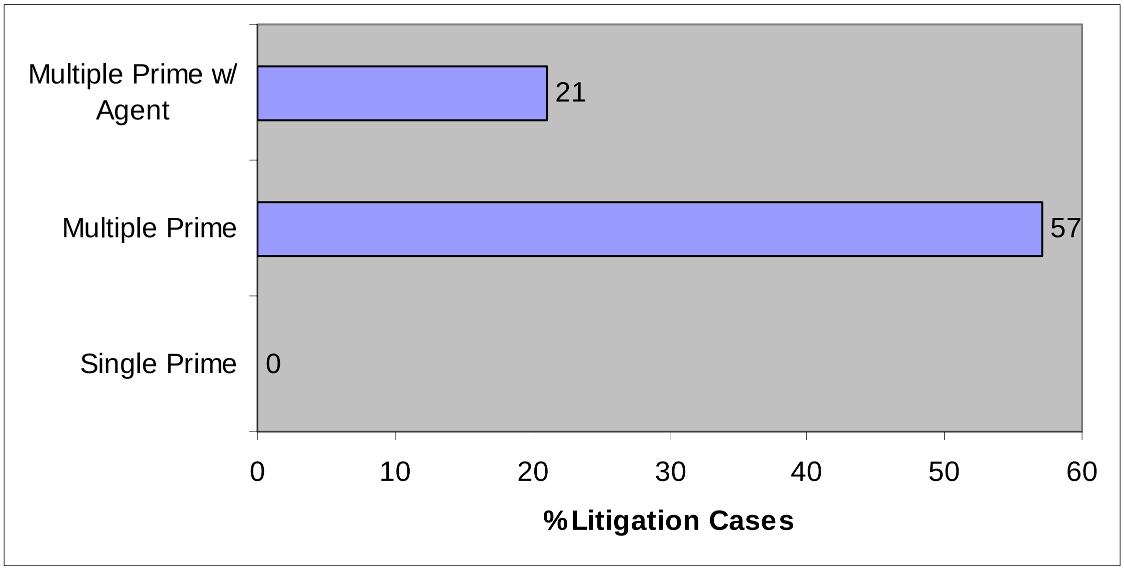


Figure 9.12 - Litigation Cases Expressed as a % of Projects per Delivery System (DS2)

9.2 QUALITATIVE ANALYSIS

The qualitative analysis of data set 2 is based on the Chi-Square test. The methodology and variables used are the same as in Section 8.2. However, the results may be compromised because the number of cases in each test is reduced. 48 of the 94 total cases previously analyzed are tested in this section. This is a 49% reduction of the cases. As mentioned previously, they represent the group of projects with at least $ 10,000,000 total cost. The MINITAB® output is presented in Appendix F for the cases with high P-values or invalid tests.

The punch list length test could not be performed. The results showed that 6 cells have expected counts less than 1.0 and 9 cells have less than 5.0. A close look to the output indicates that there is no case within level two (punch list duration more than a week but less than 2 weeks). Therefore, no exclusion or combination can be used to validate the test.

As seen in Section 8.2, the high level of difficulty of facility startup presented cells with expected counts less than 5.0. With the exclusion of the 4 cases that lied in this group, the P-value resulted in 0.210. Conclusively, there is not enough evidence to reject the null hypothesis that state that the variables are independent.

The level of call backs after owner occupancy presented an initial result of 4 cells with expected cell counts less than 5.0. 3 of them were on the high level of call backs. After the exclusion of this level, only one cell contained expected count less than 5.0. Because this cell represents 16.67% of a 3 X 2 table, the test is valid. The P-value of 0.484 does indicate that delivery systems and the level of call backs are independent.

The level of administrative burden test presents the same problem as in data set 1. Added to this is the fact that there is no case with level 5 (low) administrative burden, the exclusion of level 4 would indicate a scale from high to medium burden (1 to 3) and the results would be misrepresented. Another problem is that just 2 out of the 12 cells have expected counts higher than 5.0. Consequently, the test is not valid and it is impossible to conclude anything about the level of administrative burden.

Team communication initially presented 2 cells with expected counts less than 1.0 and 4 cells with less than 5.0. Excluding the poor level of team communication, all the expected count cells are higher than 5.0. Therefore, the test is valid and the P-value is 0.413. No relationship can be established between communication and the types of delivery systems.

The team chemistry test had initially 3 cells with expected counts less than 5.0. After their exclusion (all at level 3 – poor level), the test turns to be valid. The P-value of 0.972 indicates that the variables are independent.

Finally, the litigation test does not fulfill the requirement of 80% of the cells with expected counts higher than 5.0. In this test, 50% of the cells lie in this situation. The exclusion of any cell would invalidate the test. However, if valid, the result of 0.092 (P-value) would be significant at the 10% level ($\alpha = 0.10$). Even though the conclusions cannot be drawn for the population, the test indicates that the single prime delivery system tends to have less litigation cases than multiple prime and MPwA systems. As previously discussed in Section 8.1.6, the direct and simple relationship that one entity has with the owner may explain why the number litigation cases involved in this type of delivery system is smaller when compared to multiple prime systems.

In order to allow a more definitive analysis of the qualitative variables discussed in this section, the number of samples should be increased. This limitation of the study results in no conclusion between any categorical variable and the delivery systems. It is expected that a larger sample would probably indicate some relationship between the variables.

10.0 CONCLUSIONS

Projects are building blocks that help organizations achieve objectives and goals that support their mission and vision. Three key criteria are always involved in a project: schedule, cost and technical performance. It is easy to understand the inter-related nature of the criteria. Tolerance of failure is less in a highly competitive market. Construction companies that do not satisfy the customer's expectations may soon be out of the market. The choice of the project delivery system has a significant impact on the three criteria of schedule, cost and technical performance.

Because of legal requirements, public entities do not have the same flexibility as private entities in choosing the type of delivery system in a construction project. There are five U.S. states that require the use of the multiple prime contracting system on public projects. This study objectively analyzed the performance of this system in comparison to single prime and multiple prime with a CM agent. The motivation was based on the controversies that multiple prime have raised in the construction industry.

Two sets of data were created in the study. The first one included all the valid sample cases collected from school districts. The second considered the cases where the total cost of the school district construction project was at least $ 10,000,000. The three delivery systems (SP, MP, and MPwA) did not present significant differences on several statistical analyses. However, significance was found in some tests.

Considering the full data set, projects using multiple prime with a CM agent constructed more square feet per day than multiple prime and single prime (see Section 8.1.1). No significance was found between the construction speed of multiple prime and single prime. A two-sample t test indicated that MPwA has a higher percentage of change orders than MP (see Section 8.1.5). In this test, change orders caused by a change of scope by the owner were included in the calculation of the variable.

When considering projects costing more than \$ 10,000,000, significance could be found on the construction speed parameter. Two-sample t tests were performed (see Section 9.1.1) and projects using MPwA constructed more square feet per day when compared to both MP and SP. This was significant at the 10% level ($\alpha = 0.10$). The inclusion of a manager in the coordination process resulted in a faster construction rate. Every other parameter, qualitative or quantitative, in both data sets, did not present any significant differences among the systems.

Based on the findings of this study, several arguments surrounding these delivery systems can be addressed:

Unit Cost

No difference in unit cost could be found between multiple prime and single prime. Therefore, the argument by specialty contractors that the use of the multiple prime system results in lower construction cost than single prime is not supported.

Cost growth and % Change Orders

No differences in cost growth or % change orders could be found between multiple prime and single prime, both when owner changes of scope were considered and when they were not. Therefore, the position that single prime systems have less cost growth and fewer change orders is not supported.

Schedule growth and Coordination

The non-normality of the sample distributions did not allow for the comparison of delivery systems based on schedule growth. Therefore, the position that multiple prime systems incur project delays could not be tested. In addition, no relationship was found between several qualitative variables relating to coordination and delivery systems.

Litigation

Finally, based on the statistics related to litigation cases (Section 8.1.6), single prime presented a considerably smaller number of cases when compared to multiple prime and multiple prime with an agent systems. As discussed previously, this conclusion cannot be inferred to the population, but gives a good idea regarding the volume of litigation involved in the different types of delivery systems.

There is no perfect system. There are advantages and disadvantages to every system. However, there is a better choice depending upon the circumstances of the project and on the benefits that the primary stakeholders may realize from specific project delivery systems. In every project, but especially in the construction industry, uniqueness is a basic characteristic. The owner, consequently, has to analyze the peculiarities of every project, making the choice where the advantages overcome the disadvantages. The ideal situation would be if public owners had the same flexibility as private owners in choosing the delivery system that best fits their situation. The Minnesota alternative is an example on how to make use of the good aspects of both the single and multiple prime systems.

This study found fewer significant differences than similarities when comparing the delivery systems. However, the sample size limited the analysis and should be taken into consideration. The conclusive differences found in this study indicate that multiple prime systems with the addition of a construction manager have faster construction speed. It has been perceived that specific groups tend to prefer specific systems based on their individual interests. The choice of the most appropriate delivery system for the project must be based on the needs of the owner and, for public projects, the protection of the public interest. The development of alternatives that would satisfy every stakeholder involved in the construction process will not progress without continuous analyses and debate of the topic. Hopefully this study contributes to this debate, and stimulates additional studies and discussions of the subject.

11.0 FUTURE WORK

The results obtained in this study concluded that there are fewer differences than similarities when comparing single prime, multiple prime, and multiple prime with a CM agent. These results were, at some level, limited by the sample size. Therefore, a future study with the same scope of work and a higher sample size would result in a better comparison of the systems. According to the Central Limit Theorem, increasing the sample size of any population results in a sample with a normal distribution. Therefore, the normality requirement is achieved whenever the number of cases in the sample is increased. Consequently, less data transformation is required and a comparison is better represented.

In order to obtain more cases, future research should consider targeting other states in the country. Therefore, other types of delivery systems such as design-build and CM@Risk could be included in the analysis. In addition, with the inclusion of these two systems, a comparison of the whole construction process, including the design phase, can be performed.

From the same perspective, a larger scope can be considered for future work. In this case, other types of projects should be included in the scope of the study. The analysis could include the comparison of the systems based on different types of facilities such as office buildings, school districts, and unique projects such as stadiums. Finally, the inclusion of different stakeholders' perspectives should be considered for qualitative parameters. The next section presents an alternative found by the state of Minnesota used to overcome problems related to both single and multiple prime delivery systems.

12.0 CONCLUDING REMARK

12.1 THE MINNESOTA ALTERNATIVE

Minnesota is one of the U.S. states where public entities are free to choose the delivery system that best fits their situations. However, general contractors, specialty contractors and public authorities developed a bidding procedure that overcomes most of the problems related to both single and multiple prime delivery systems. The intention is to avoid the bid shopping and bid peddling seen with the use of single prime, and the lack of coordination in the multiple prime system. Becker (1993, p. 19) discusses and presents the procedure of this alternative as follows:

a. "The Building Construction Division (BCD) will use only single prime contracts on state projects under its jurisdiction;
b. The two AIA sections for mechanical and electrical contracts are bid two days prior to the single prime due date and submitted to the State Materials Management Division;
c. General contractors have two days to review the scope of work with participating sub-contractors and are free to choose among any of the sub-contractors who have submitted a bid proposal;
d. The posted price of the selected sub-contractor cannot be changed by either the prime contractor or the sub-contractor;

e. Sub-contractors must submit a joint bid bond payment to the state and the selected prime contractor; but the sub-contractor can identify in writing individual general contractors with whom they will not work;
f. The state will select the lowest responsible bidder among the prime contractors; and
g. The bid-posting policy will apply to all projects valued in excess of $ 100,000."

This alternative has the advantage of increased competition among specialty contractors, while eliminating problems of bid shopping and bid peddling. In addition, the owner has the advantage of dealing with only one entity, in this case the single prime, which will be responsible for the job coordination. Also, general contractors can select among sub-contractors and sub-contractors can indicate those general contractors with whom they refuse to work.

Another point extensively discussed is timely payment. As discussed previously, most sub-contractors prefer to deal directly with the owner because of the exclusion of a middleman that would be responsible for controlling their payment. To overcome this problem, the state of Minnesota included clauses that specify the payment procedure to sub-contractors based on prompt payment, level of retainage and enforcement. In case of payment delays, the single prime contractor would be required to pay penalties to the sub-contractor. The intention of this alternative is to make the system a good option for both general and specialty contractors.

APPENDIX A

SURVEY LETTERS

1st LETTER

Dear Superintendent,

The Department of Civil and Environmental Engineering of the University of Pittsburgh is conducting a study of the performance of construction delivery systems in school projects in Pennsylvania, Massachusetts, Ohio, New Jersey and Virginia. The study includes a confidential survey of recent school construction project characteristics. We believe that the outcome of the survey will benchmark the performance of alternative project delivery systems and may help improve the performance of future school construction projects.

You will receive a questionnaire in mid-January. Thank you in advance for your time and consideration.

Sincerely,

David Col Debella
Graduate Research Assistant
Construction Management Program
Department of Civil and Environmental Engineering
University of Pittsburgh

2nd LETTER

Dear Superintendent,

As we mentioned in our previous letter, the Department of Civil and Environmental Engineering of the University of Pittsburgh is conducting a study of the performance of construction delivery systems in school construction projects. Attached to this package you will find the confidential survey that we are using as the instrument to collect data on the construction. We believe that the results of this study will provide guidance that will help all school districts improve the performance of their construction projects.

Please complete the questionnaire based on any **complete** construction project. If, however, the project is divided in phases and all phases are **not complete**, you may provide information regarding phases **completed to date**. If the school district has completed multiple separate projects, please feel free to copy the questionnaire for each project, or contact us for additional survey packages.

We estimate that the survey will take from 30 to 45 minutes to complete, including the time to collect data. It is important that you complete the entire questionnaire. Sections IV and V (Cost and Schedule) will require you to enter specific information, which we estimate will require the majority of your time. These sections, however, are essential for the study.

You may be assured of complete confidentiality. Your name will never be associated with any of the responses received. You may receive a summary of the study results by writing "copy of results requested" on the back of the survey, and printing your name and address below it.

I would be happy to answer any questions you may have, either about the intent of this study or specific questions regarding the survey. You may contact me by phone or e-mail.

Your participation is extremely valuable and it is essential for the success of this study. Thank you very much for your time and assistance.

Sincerely,

David Col Debella
Graduate Research Assistant
Construction Management Program
Department of Civil and Environmental Engineering
University of Pittsburgh

3rd LETTER

Dear Superintendent,

Last month, a questionnaire seeking information about construction projects in school districts was mailed to you. This study includes all districts in Pennsylvania, Virginia, Ohio, Massachusetts and New Jersey.

If you have already completed and returned the questionnaire to us, please accept our sincere thanks. If not, please do so as soon as possible. We are especially grateful for your help. We believe that your participation in this study will lead to improving the performance of future school construction projects.

We'd like to remind you that this study is based only on completed projects, but if a project is divided in phases, you may provide information regarding the phase or phases completed to date. You may also provide information about construction projects that were completed in **any** previous administration. Although this may require additional time on your part, your representation in the study sample is valuable to us.

If you did not receive a questionnaire, or if it was misplaced, please contact us by phone or by e-mail and we will send one in the mail to you today.

You may also contact us if you have any questions, either about the intent of this study or specific questions regarding the survey. Your participation is extremely valuable and it is essential for the success of this study. Thank you very much for your time and assistance.

Sincerely,

David Col Debella
Graduate Research Assistant
Construction Management Program
Department of Civil and Environmental Engineering
University of Pittsburgh

4th LETTER

Dear Superintendent,

About two months ago, we wrote to you seeking information about construction projects in your school district. As of today, we have not received your completed questionnaire. We realize that you may not have had time to complete it. However, we would genuinely appreciate hearing from you.

The study is being conducted so that school districts can have a comparative analysis of construction delivery systems, which could positively affect the school construction process. We are writing to you again because the study depends upon your participation in this survey. We would like to remind you that **any** complete construction project in your district, even from past administrations, can be used for the questionnaire.

If you have already completed and returned the questionnaire to us, please accept our sincere thanks. We are especially grateful for your help. In the event that your questionnaire has been misplaced, a replacement is enclosed. We would be happy to answer any questions that you may have about the study. Please contact us by phone or by e-mail.

Again, your participation is extremely important and essential for the success of the study. Due to time constraints, we will only be considering questionnaires that are postmarked on or before **May 20th, 2004**. Thank you very much for your assistance.

Sincerely,

David Col Debella
Graduate Research Assistant
Construction Management Program
Department of Civil and Environmental Engineering
University of Pittsburgh

APPENDIX B

INSTRUMENT OF DATA COLLECTION

SECTION I: General Information

School district: ____

Respondent who provided data: ____________________________________

Address: ____

Phone number: ____________________________ E-mail: ________________

SECTION II: Project Characteristics

Year of completion: ________

Type of project: ☐ Renovation ☐ New construction

☐ Both (please specify respective percentages): ______ % Renovation ______ % New construction

Project gross square footage: ___________ sf No. of floors: _________

Please briefly describe the type of service performed in the construction project:

____

____

____

SECTION III: Project Delivery System

Check the project delivery system that was used on the project: (Please check only one option)

☐ Single prime ☐ Agency CM w/ Single Prime ☐ CM @ Risk*

☐ Multiple prime** ☐ Agency CM w/ Multiple Prime** ☐ Design-Build

(*) **CM @ Risk:** Did the CM Company self- perform the job?

☐ Yes, the company performed 100% of the job.

☐ Yes, the company performed the job, but subcontracted part of it.

Please indicate the respective job percentages: _____ % Self-performance _____ % Subcontract

☐ No, the company subcontracted 100% of the job.

(**) If **Multiple Prime** or **Agency CM w/ Multiple Prime**, indicate in the following table the types of primes and number of each prime involved in the project.

Type of Prime	Number
General Contractor	
Electrical Contractor	
Mechanical Contractor	

Type of Prime	Number
HVAC	
Other: ________________________	
Other: ________________________	

SECTION IV: Cost

Base Building

Indicate project costs, in dollars, on the following table. Please specify design and construction costs separately if possible (use columns A and B). If not, indicate the total design and construction costs using only column C. Please deduct all land costs, owner costs, and any other items not related to the base building.

Stage	**Types of Cost**		
	Column A	Column B	Column C
	Design Costs	Construction Costs	Design and Construction Costs
Estimated			
Contract Award			
Actual Cost			

Coordination Cost

Check the option used and indicate the cost to coordinate the project (You may check more than one option)

☐ Coordination was included in the contract costs
Which contractor was responsible for the coordination? ______________________________

☐ The district hired an agent Total cost ($): ____________ or % of Project total cost: ________
What type of agent? ☐ Construction Management ☐ Project Management ☐ Other: ____________

☐ Internal staff (clerk of the works) Total cost ($): ____________ or % of Project total cost: ________
☐ Other: ________________ Total cost ($): ____________ or % of Project total cost: ________
☐ None

Change Orders

No. of change orders involved in the project: _________

Total of all change orders ($): ____________________

Indicate the corresponding dollar amount for each reason (column A) or estimate the percentage based on the total of all change orders (C.O.) for each reason (column B) in the following table:

Reason	Column A	Column B
	Amount ($)	**% Sum of all C.O.**
Lack of detail during the design phase (Omissions in the documents)		
Owner has changed the scope of work		
Conditions unforeseen when the contract was agreed (Changed Conditions)		
Avoid litigation and settle disputes		
Other: ______________________________		

SECTION V: Schedule

Please provide the following schedule information

Item	As Planned (mm/dd/yyyy)	As Built (mm/dd/yyyy)
Date project was advertised		
Design start date (Notice to Proceed)		
Construction *start* date (Notice to Proceed)		
Construction *end* date (Substantial Completion)		

What percentage of design was complete when the construction entity joined the project team? _____________ %

(If the construction company was not involved in the design phase, enter 100%)

SECTION VI: Litigation

Please provide the following litigation information, when applicable

No. of litigation cases related to the project: _______

Total dollar amount related to the cases: ___________________________________

(Please include all the process costs, including insured portion when applicable)

SECTION VII: Quality

Punch List: What was the length of the punch list? ______ # of items

How long did it take to complete the punch list phase?

- ☐ Less then a week
- ☐ More than a week, but less than 2 weeks
- ☐ More than 2 weeks, but less than 4 weeks
- ☐ More than 4 weeks, but less than 8 weeks
- ☐ More than 8 weeks

Difficulty of facility startup:

☐ High ☐ Medium ☐ Low

Number of call backs after owner occupancy:

☐ High ☐ Medium ☐ Low

Did the overall quality of the building meet your expectations?

☐ Yes ☐ No

Check your level of administrative burden involved on the project:	1 (High)	2	3	4	5 (Low)

Check your level of satisfaction on the entire project:	1	2	3	4	5
Check your level of satisfaction with the project's heating system:	1	2	3	4	5
Check your level of satisfaction with the project's cooling system:	1	2	3	4	5
Check your level of satisfaction with the project's lighting system:	1	2	3	4	5
	(Not Satisfied)				(Better than Expected)

SECTION VIII: Team Characteristics

Check the appropriate items related to the team members involved on the project

Team selection:

(Indicate the selection process with a letter next to each team member.

____ Architect
____ Single prime contractor
____ General contractor
____ Electrical specialty contractor
____ Mechanical specialty contractor
____ HVAC specialty contractor
____ Construction manager
____ Project manager
____ Other: ____________________

(a) Open bidding
(b) Open bidding w/ prequalification process
(c) Negotiated contract
(d) Internal staff

What was your perception of team member experience with similar facilities?

Architect	☐ Excellent	☐ Average	☐ None
Single prime contractor	☐ Excellent	☐ Average	☐ None
General contractor	☐ Excellent	☐ Average	☐ None
Electrical specialty contractor	☐ Excellent	☐ Average	☐ None
Mechanical specialty contractor	☐ Excellent	☐ Average	☐ None
HVAC specialty contractor	☐ Excellent	☐ Average	☐ None
Construction manager	☐ Excellent	☐ Average	☐ None
Project manager	☐ Excellent	☐ Average	☐ None
Other: ____________________	☐ Excellent	☐ Average	☐ None

Check the option that best describes the following topics:

Project team communication:	☐ Excellent	☐ Adequate	☐ Poor
Project team chemistry:	☐ Excellent	☐ Adequate	☐ Poor
Project complexity:	☐ High	☐ Average	☐ Low
Regulatory/Legal constraints:	☐ Many	☐ Few	☐ None

Glossary of Terms

Section II

Project Gross Square Footage:	Total square footage of the construction or renovation. If construction and / or renovation were performed in more than one floor, the total square footage is the sum of every floor area. This number is not related to the school district area.

Section III

Single Prime:	Agreement between owner and a single entity to perform construction under a single contract. The single prime contractor may have performed or subcontracted portions or all of the project.
Multiple Prime:	Agreement between owner and more than one entity to perform construction on one project. The owner holds separate contracts with every party involved in the construction process. It is most likely that the multiple primes involved do not subcontract a substantial portion of their work.
Agency CM w/ Single Prime:	In addition to the single prime contractor, the owner hires a Construction Management (CM) entity to coordinate, organize, advise, and manage the project. The agency CM does not hold any contract for construction, which results in an informal relationship with the other entities.
Agency CM w/ Multiple Prime:	The CM entity has the same responsibilities as described above. In this case, however, multiple prime contractors are directly related to the owner.
CM@Risk:	The owner holds just one contract with the CM entity that in turn holds the other contracts involved in the construction phase of the project. The CM entity usually guarantees schedule and price.
Design-Build:	Agreement between owner and a single entity to perform both design and construction under a single contract. Portions or all of the design and construction may be performed by the entity or subcontracted to other companies.

Section IV

Estimated Cost:	Costs that were estimated by the owner or the engineer / architect. These costs represent the amount that were expected by the owner for the project.
Contract Award Cost:	Costs indicated by the parties involved in the construction at the time of their award. In case of multiple prime delivery system, indicate the sum of all contracts awarded. These costs are the prices agreed to between owner and contractor(s) before the beginning of the project.
Actual Cost:	These costs represent the actual final costs spent by the owner in the project.

Section V

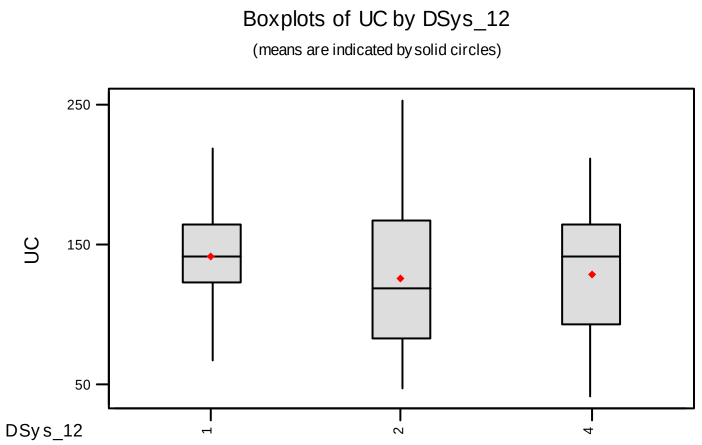
Schedule As Planned:	Indicate the dates that were planned for start and end of each phase listed.
Schedule As Built:	Indicate the actual dates of start and end of each phase listed.

Section VII

Punch List:	List of building's deficiencies and items to be corrected pending further inspections and before final completion can occur.

APPENDIX C

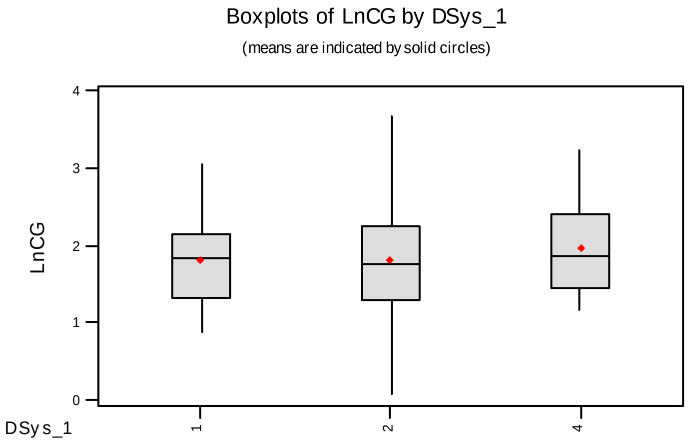
DATA SET 1 QUANTITATIVE ANALYSIS OUTPUTS



One-way ANOVA: UC versus DSys_12

```
Analysis of Variance for UC
Source     DF        SS        MS        F        P
DSys_12     2      3559      1779     0.80    0.454
Error      72    160327      2227
Total      74    163886
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----------+---------+---------+------
1          25    140.77     39.05            (------------*-----------)
2          25    124.86     54.77   (-----------*------------)
4          25    127.94     46.44     (-----------*------------)
                                   ----------+---------+---------+------
Pooled StDev =    47.19                    120       135       150
```

Figure C. 1 - Unit Cost Results for Data Set 1



One-way ANOVA: LnCG versus DSys_1

```
Analysis of Variance for LnCG
Source     DF        SS        MS        F        P
DSys_1      2     0.463     0.231     0.59    0.557
Error      90    35.328     0.393
Total      92    35.791
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
1          35    1.8146    0.5799    (----------*---------)
2          30    1.8020    0.7159   (----------*----------)
4          28    1.9621    0.5784          (-----------*-----------)
                                   --+---------+---------+---------+----
Pooled StDev =    0.6265           1.60      1.80      2.00      2.20
```

Figure C. 2 - Cost Growth Results for Data Set 1

Two-Sample T-Test and CI: Ln%CO1, Ln%CO2

```
Two-sample T for Ln%CO1 vs Ln%CO2

         N      Mean     StDev   SE Mean
Ln%CO1  35     1.676     0.567     0.096
Ln%CO2  30     1.589     0.610      0.11

Difference = mu Ln%CO1 - mu Ln%CO2
Estimate for difference:  0.087
95% CI for difference: (-0.205, 0.379)
T-Test of difference = 0 (vs not =): T-Value = 0.60  P-Value = 0.552  DF = 63
Both use Pooled StDev = 0.587
```

Figure C. 3 - Two-sample t Results for %C.O. Transformed Data Set 1 (SP vs. MP)

Two-Sample T-Test and CI: Ln%CO1, Ln%CO4

```
Two-sample T for Ln%CO1 vs Ln%CO4

         N      Mean     StDev   SE Mean
Ln%CO1  35     1.676     0.567     0.096
Ln%CO4  28     1.780     0.498     0.094

Difference = mu Ln%CO1 - mu Ln%CO4
Estimate for difference:  -0.104
95% CI for difference: (-0.377, 0.169)
T-Test of difference = 0 (vs not =): T-Value = -0.76  P-Value = 0.448  DF = 61
Both use Pooled StDev = 0.538
```

Figure C. 4 - Two-sample t Results for %C.O. Transformed Data Set 1 (SP vs. MPwA)

APPENDIX D

DATA SET 1 QUALITATIVE ANALYSIS OUTPUTS

```
Tabulated Statistics: Dlv Sys_1, PL3

 Rows: Dlv Sys_     Columns: PL3

          3        4        5      All

 1       14        5       16       35
      10.11     5.44    19.44    35.00

 2        7        3       18       28
       8.09     4.36    15.56    28.00

 4        5        6       16       27
       7.80     4.20    15.00    27.00

 All     26       14       50       90
      26.00    14.00    50.00    90.00

Chi-Square = 4.938, DF = 4, P-Value = 0.294
2 cells with expected counts less than 5.0

  Cell Contents --
                Count
                Exp Freq
```

Figure D. 1 - Data Set 1 Chi-Square Test Result - Length of Punch List

```
Tabulated Statistics: Dlv Sys_2, Startup

 Rows: Dlv Sys_     Columns: Startup

          2        3      All

 1       10       23       33
      11.93    21.07    33.00

 2       11       15       26
       9.40    16.60    26.00

 4        9       15       24
       8.67    15.33    24.00

 All     30       53       83
      30.00    53.00    83.00

Chi-Square = 0.935, DF = 2, P-Value = 0.627

  Cell Contents --
                Count
                Exp Freq
```

Figure D. 2 - Data Set 1 Chi-Square Test Result - Difficulty of Facility Startup

Tabulated Statistics: Dlv Sys_3, Call Backs

```
 Rows: Dlv Sys_     Columns: Call Bac

           2        3      All

 1        14       20       34
       15.11    18.89    34.00

 2        11       15       26
       11.56    14.44    26.00

 4        11       10       21
        9.33    11.67    21.00

 All      36       45       81
       36.00    45.00    81.00

Chi-Square = 0.731, DF = 2, P-Value = 0.694

  Cell Contents --
                  Count
                  Exp Freq
```

Figure D. 3 - Data Set 1 Chi-Square Test Result - Level of Call Backs

Tabulated Statistics: Dlv Sys_4, Burden

```
 Rows: Dlv Sys_     Columns: Burden

           1        2        3        4        5      All

 1        10        7        9        5        2       33
       10.24    10.24     8.72     3.03     0.76    33.00

 2         5       14        9        1        0       29
        9.00     9.00     7.67     2.67     0.67    29.00

 4        12        6        5        2        0       25
        7.76     7.76     6.61     2.30     0.57    25.00

 All      27       27       23        8        2       87
       27.00    27.00    23.00     8.00     2.00    87.00

Chi-Square = 14.563, DF = 8
* WARNING * 3 cells with expected counts less than 1.0
          * Chi-Square approximation probably invalid
6 cells with expected counts less than 5.0

  Cell Contents --
                  Count
                  Exp Freq
```

Figure D. 4 - Data Set 1 Chi-Square Test Result - Level of Administrative Burden

Tabulated Statistics: Dlv Sys_5, Commun

```
 Rows: Dlv Sys_     Columns: Commun

          1        2      All

 1       18       17       35
      20.68    14.32    35.00

 2       18       11       29
      17.14    11.86    29.00

 4       16        8       24
      14.18     9.82    24.00

 All     52       36       88
      52.00    36.00    88.00

Chi-Square = 1.526, DF = 2, P-Value = 0.466

  Cell Contents --
                  Count
                  Exp Freq
```

Figure D. 5 - Data Set 1 Chi-Square Test Result - Team Communication

Tabulated Statistics: Dlv Sys_6, Chem

```
 Rows: Dlv Sys_     Columns: Chem

          1        2      All

 1       15       21       36
      16.14    19.86    36.00

 2       13       15       28
      12.55    15.45    28.00

 4       11       12       23
      10.31    12.69    23.00

 All     39       48       87
      39.00    48.00    87.00

Chi-Square = 0.258, DF = 2, P-Value = 0.879

  Cell Contents --
                  Count
                  Exp Freq
```

Figure D. 6 - Data Set 1 Chi-Square Test Result - Team Chemistry

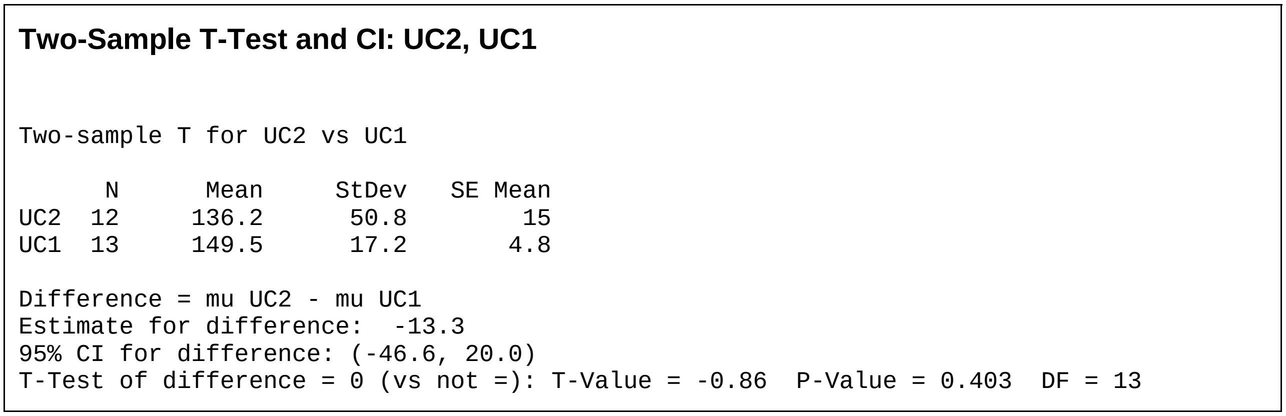
Tabulated Statistics: Dlv Sys_8, Litig

```
 Rows: Dlv Sys_     Columns: Litig

           0        1      All

 1        35        1       36
       32.55     3.45    36.00

 2        26        4       30
       27.13     2.87    30.00

 4        24        4       28
       25.32     2.68    28.00

 All      85        9       94
       85.00     9.00    94.00

Chi-Square = 3.128, DF = 2, P-Value = 0.209
3 cells with expected counts less than 5.0

  Cell Contents --
                  Count
                  Exp Freq
```

Figure D. 7 - Data Set 1 Chi-Square Test Result - Litigation

APPENDIX E

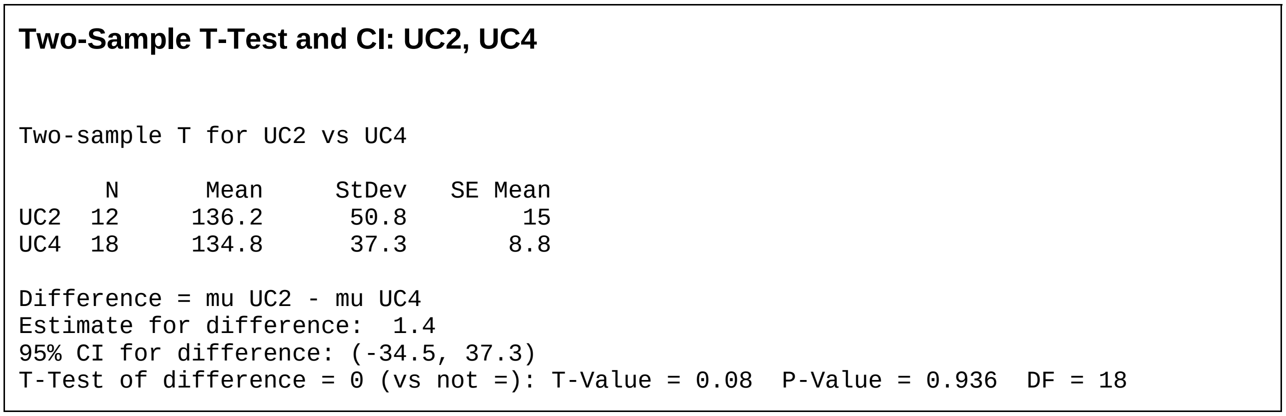
DATA SET 2 QUANTITATIVE ANALYSIS OUTPUTS



Two-Sample T-Test and CI: UC2, UC1

```
Two-sample T for UC2 vs UC1

      N      Mean     StDev   SE Mean
UC2  12     136.2      50.8        15
UC1  13     149.5      17.2       4.8

Difference = mu UC2 - mu UC1
Estimate for difference:  -13.3
95% CI for difference: (-46.6, 20.0)
T-Test of difference = 0 (vs not =): T-Value = -0.86  P-Value = 0.403  DF = 13
```

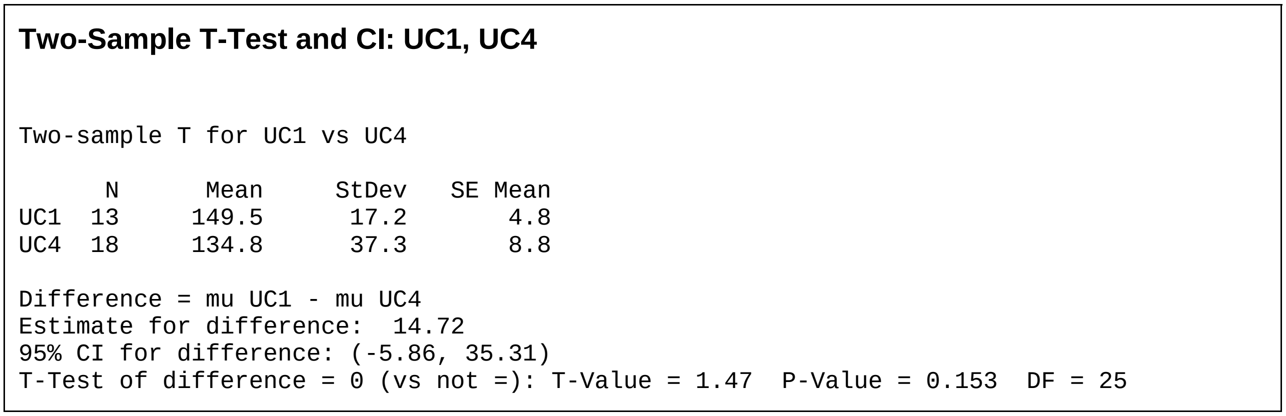
Figure E. 1 - Unit Cost Results for Data Set 2 - Two-sample t (MP vs. SP)



Two-Sample T-Test and CI: UC2, UC4

```
Two-sample T for UC2 vs UC4

      N      Mean     StDev   SE Mean
UC2  12     136.2      50.8        15
UC4  18     134.8      37.3       8.8

Difference = mu UC2 - mu UC4
Estimate for difference:  1.4
95% CI for difference: (-34.5, 37.3)
T-Test of difference = 0 (vs not =): T-Value = 0.08  P-Value = 0.936  DF = 18
```

Figure E. 2 - Unit Cost Results for Data Set 2 - Two-sample t (MP vs. MPwA)



Two-Sample T-Test and CI: UC1, UC4

```
Two-sample T for UC1 vs UC4

      N      Mean     StDev   SE Mean
UC1  13     149.5      17.2       4.8
UC4  18     134.8      37.3       8.8

Difference = mu UC1 - mu UC4
Estimate for difference:  14.72
95% CI for difference: (-5.86, 35.31)
T-Test of difference = 0 (vs not =): T-Value = 1.47  P-Value = 0.153  DF = 25
```

Figure E. 3 - Unit Cost Results for Data Set 2 - Two-sample t (SP vs. MPwA)

Two-Sample T-Test and CI: CG1, CG2

```
Two-sample T for CG1 vs CG2

      N      Mean     StDev   SE Mean
CG1  14      4.09      2.37      0.63
CG2  14      4.35      2.85      0.76

Difference = mu CG1 - mu CG2
Estimate for difference:  -0.264
95% CI for difference: (-2.298, 1.771)
T-Test of difference = 0 (vs not =): T-Value = -0.27  P-Value = 0.792  DF = 26
Both use Pooled StDev = 2.62
```

Figure E. 4 - Cost Growth Results for Data Set 2 - Two-sample t (SP vs. MP)

Two-Sample T-Test and CI: LnCG1, LnCG4

```
Two-sample T for LnCG1 vs LnCG4

        N      Mean     StDev   SE Mean
LnCG1  13     1.612     0.415      0.12
LnCG4  19     1.480     0.778      0.18

Difference = mu LnCG1 - mu LnCG4
Estimate for difference:  0.132
95% CI for difference: (-0.351, 0.615)
T-Test of difference = 0 (vs not =): T-Value = 0.56  P-Value = 0.580  DF = 30
Both use Pooled StDev = 0.657
```

Figure E. 5 - Cost Growth Results for Transf. Data Set 2 - Two-sample t (SP vs. MPwA)

Two-Sample T-Test and CI: LnCG2, LnCG4

```
Two-sample T for LnCG2 vs LnCG4

        N      Mean     StDev   SE Mean
LnCG2  13     1.640     0.452      0.13
LnCG4  19     1.480     0.778      0.18

Difference = mu LnCG2 - mu LnCG4
Estimate for difference:  0.160
95% CI for difference: (-0.330, 0.650)
T-Test of difference = 0 (vs not =): T-Value = 0.67  P-Value = 0.510  DF = 30
Both use Pooled StDev = 0.667
```

Figure E. 6 - Cost Growth Results for Transf. Data Set 2 - Two-sample t (MP vs. MPwA)

Two-Sample T-Test and CI: %CO-S2, %CO-S1

```
Two-sample T for %CO-S2 vs %CO-S1

         N      Mean     StDev   SE Mean
%CO-S2  13      2.26      1.32      0.37
%CO-S1  15      2.28      1.31      0.34

Difference = mu %CO-S2 - mu %CO-S1
Estimate for difference:  -0.020
95% CI for difference: (-1.043, 1.003)
T-Test of difference = 0 (vs not =): T-Value = -0.04  P-Value = 0.968  DF = 26
Both use Pooled StDev = 1.31
```

Figure E. 7 - %CO w/o Change Scope by Owner Result - Data Set 2

APPENDIX F

DATA SET 2 QUALITATIVE ANALYSIS OUTPUTS

```
Tabulated Statistics: Dlv Sys, PL

 Rows: Dlv Sys     Columns: PL

           1        3        4        5      All

 1         0        1        2       11       14
        0.30     0.61     3.04    10.04    14.00

 2         0        0        2       12       14
        0.30     0.61     3.04    10.04    14.00

 4         1        1        6       10       18
        0.39     0.78     3.91    12.91    18.00

 All       1        2       10       33       46
        1.00     2.00    10.00    33.00    46.00

Chi-Square = 5.434, DF = 6
* WARNING * 6 cells with expected counts less than 1.0
          * Chi-Square approximation probably invalid
9 cells with expected counts less than 5.0

  Cell Contents --
                  Count
                  Exp Freq
```

Figure F. 1 - Data Set 2 Chi-Square Test Result - Length of Punch List

```
Tabulated Statistics: Dlv Sys_1, Startup

 Rows: Dlv Sys_     Columns: Startup

           2        3      All

 1         5        9       14
        6.33     7.67    14.00

 2         8        4       12
        5.43     6.57    12.00

 4         6       10       16
        7.24     8.76    16.00

 All      19       23       42
       19.00    23.00    42.00

Chi-Square = 3.124, DF = 2, P-Value = 0.210

  Cell Contents --
                  Count
                  Exp Freq
```

Figure F. 2 - Data Set 2 Chi-Square Test Result - Difficulty of Facility Startup

Tabulated Statistics: Dlv Sys_2, Call Backs

```
 Rows: Dlv Sys_     Columns: Call Bac

          2        3      All

 1       10        4       14
       8.26     5.74    14.00

 2        6        5       11
       6.49     4.51    11.00

 4        7        7       14
       8.26     5.74    14.00

 All     23       16       39
      23.00    16.00    39.00

Chi-Square = 1.453, DF = 2, P-Value = 0.484
1 cells with expected counts less than 5.0

  Cell Contents --
                  Count
                  Exp Freq
```

Figure F. 3 - Data Set 2 Chi-Square Test Result - Level of Call Backs

Tabulated Statistics: Dlv Sys_3, Burden

```
 Rows: Dlv Sys_     Columns: Burden

          1        2        3        4      All

 1        7        2        5        0       14
       4.98     3.73     4.36     0.93    14.00

 2        2        7        4        1       14
       4.98     3.73     4.36     0.93    14.00

 4        7        3        5        2       17
       6.04     4.53     5.29     1.13    17.00

 All     16       12       14        3       45
      16.00    12.00    14.00     3.00    45.00

Chi-Square = 8.677, DF = 6
* WARNING * 2 cells with expected counts less than 1.0
          * Chi-Square approximation probably invalid
10 cells with expected counts less than 5.0

  Cell Contents --
                  Count
                  Exp Freq
```

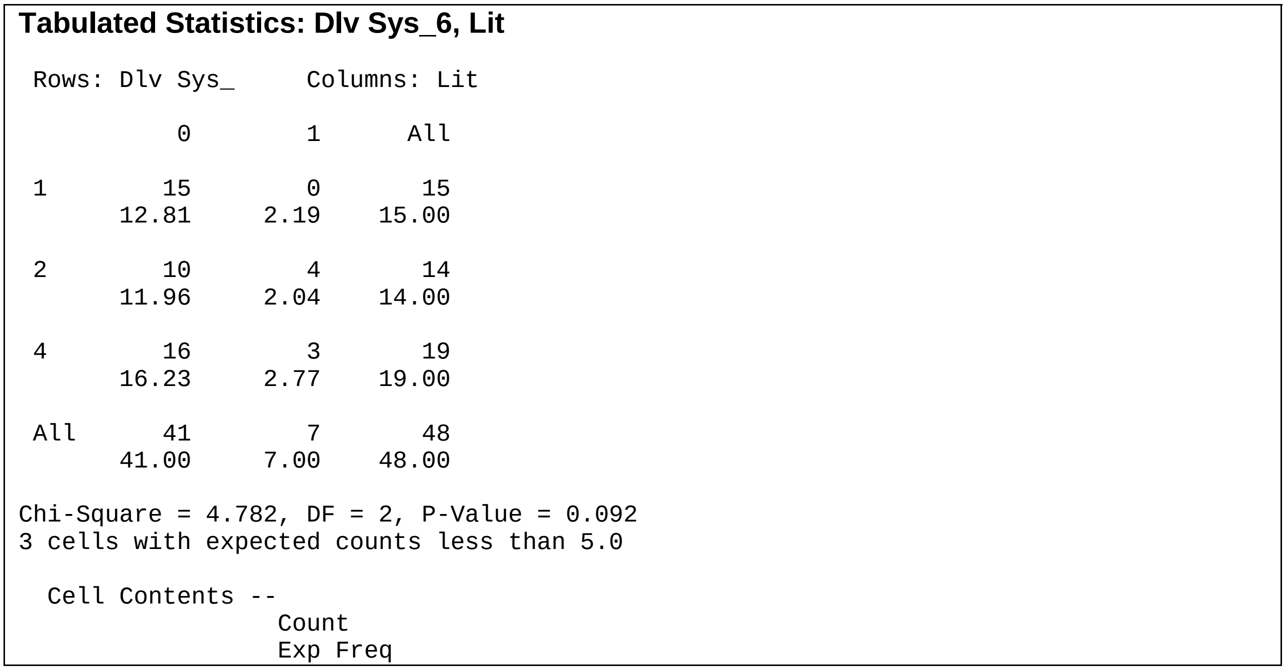
Figure F. 4 - Data Set 2 Chi-Square Test Result - Level of Administrative Burden

```
Tabulated Statistics: Dlv Sys_4, Comm

 Rows: Dlv Sys_     Columns: Comm

           1        2      All

 1         8        7       15
        9.33     5.67    15.00

 2         8        6       14
        8.71     5.29    14.00

 4        12        4       16
        9.96     6.04    16.00

 All      28       17       45
       28.00    17.00    45.00

Chi-Square = 1.769, DF = 2, P-Value = 0.413

  Cell Contents --
                  Count
                  Exp Freq
```

Figure F. 5 - Data Set 2 Chi-Square Test Result - Team Communication

```
Tabulated Statistics: Dlv Sys_5, Chem

 Rows: Dlv Sys_     Columns: Chem

           1        2      All

 1         7        8       15
        6.82     8.18    15.00

 2         6        8       14
        6.36     7.64    14.00

 4         7        8       15
        6.82     8.18    15.00

 All      20       24       44
       20.00    24.00    44.00

Chi-Square = 0.056, DF = 2, P-Value = 0.972

  Cell Contents --
                  Count
                  Exp Freq
```

Figure F. 6 - Data Set 2 Chi-Square Test Result - Team Chemistry



Tabulated Statistics: Dlv Sys_6, Lit

```
 Rows: Dlv Sys_     Columns: Lit

           0        1      All

 1        15        0       15
       12.81     2.19    15.00

 2        10        4       14
       11.96     2.04    14.00

 4        16        3       19
       16.23     2.77    19.00

 All      41        7       48
       41.00     7.00    48.00

Chi-Square = 4.782, DF = 2, P-Value = 0.092
3 cells with expected counts less than 5.0

  Cell Contents --
                  Count
                  Exp Freq
```

Figure F. 7 - Data Set 2 Chi-Square Test Result - Litigation

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