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ABSTRACT

Title of Dissertation: A RISK-BASED COST CONTROL METHODOLOGY FOR CONSTRUCTING COMPLEX STRUCTURES WITH THE MOBILE OFFSHORE BASE AS A CASE STUDY

William J. Bender, Doctor of Philosophy, 2000

Dissertation Directed by: Professor Bilal M. Ayyub
Department of Civil and Environmental Engineering

The civil engineering profession has long recognized the need for cost control on projects. Cost control and prevention of cost escalation may be considered the most important function of project managers. Several techniques have been established to control construction costs, unfortunately all of these techniques rely on controlling line items which have already experienced cost escalation. This research presents an alternative to these established methods by presenting a risk-based cost control system that employs a simulation technique for cost forecasting and combines risk analysis with earned value. Utilizing the presented approach project managers will be able to anticipate potential cost concerns, forecast costs at completion, and proactively prevent cost variances.

Existing cost control methodologies are described in some detail. Most notable is the earned value technique which is currently used by the construction industry. Its disadvantage is that it does not aggressively forecast potential cost issues.

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There is a recognized benefit to performing a risk analysis when developing a project's strategy, cost estimate, and schedule. The maximum benefit from a risk analysis is achieved when project managers actively manage the risk identified and quantified in a risk analysis. Risk analysis techniques as applied to construction are presented, expanded upon, and combined with cost control to present a proposed methodology.

A risk-based methodology is presented that provides an early warning and accounts for potential negative and positive cost impacts. The proposed methodology is applied to the planning and execution phases of a project. In the planning phase risk assessment matrix tables are used to quantify risks and simulation is used to develop target costs and schedule that accounts for uncertainty. The execution phase applies similar techniques and earned value is used to help control cost. Decision analysis techniques are used in both phases to assist project managers to make timely and appropriate decisions.

A case study that applies the proposed methodology is demonstrated as it applies to building the proposed Mobile Offshore Base (MOB). The MOB is estimated, scheduled and all of the steps in the proposed methodology are demonstrated.

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A RISK-BASED COST CONTROL METHODOLOGY FOR CONSTRUCTING COMPLEX STRUCTURES WITH THE MOBILE OFFSHORE BASE AS A CASE STUDY

By

William J. Bender

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, Collage Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2000

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LIST OF ABBREVIATIONS

AACE	Association for the Advancement of Cost Engineering
AC	Annual Cost
AHP	Analytic Hierarchy Process
AIAA	American Institute of Aeronautics and Astronautics
AR	Annual Revenue
ASCE	American Society of Civil Engineers
α	Shape parameter used in probability distributions
C_n	Cost risk event
C_f	Forecasted Total Cost
Co	Complexity risk event
C_t	Cost incurred to time t
$C(t)$	Consequence as a function of time
CI	Capitol Investment
CII	Construction Industry Institute
CS_x	Casual Scenario of event x
COMPASS	Cost Management Planning Support System
CPI	Cost Performance Index
CPM	Critical Path Method
Cum	Cumulative
C/SCSC	Cost/Schedule Control System Criteria
DOD	Department Of Defense

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DARPA	Defense Advanced Research Projects Agency
E_n	Environmental risk event
EAC	Estimate At Completion
EAC_C	Estimate At Completion based on Cost
EAC_{CS}	Estimate At Completion based on Cost and Schedule
EMV	Expected Monetary Value
Eq_n	Equipment or facilities risk event
ETA	Event Tree Analysis
EV	Earned Value
FMEA	Fault Modes and Effects Analysis
ft	Feet
FTA	Fault Tree Analysis
GB	Grand Block
GOM	Gulf of Mexico
HAZOP	Hazard and Operability study
I	Inflation risk event
i	Interest rate
L_x	Likelihood for event x
L_n	Labor risk event
M	10^6
M_n	Construction Management risk event
m	Meters
MOB	Mobile Offshore Base

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MCS	Monte Carlo Simulation
N	Periods of time
NA	Not Applicable
NPV	Net Present Value
O_x	Outcome of event *x*
ONR	Office of Naval Research
P L Hull	Port Lower Hull
PrHA	Preliminary Hazard Analysis
P_x	Occurrence Probability of event *x*
P_t	Proportion of project complete to time *t*
PO_x	Number of People effected by risk event *x*
$P(t)$	Probability as a function of time
PMI	Project Management Institute
Q	Quality risk event
Sa_n	Safety risk event
S_n	Schedule risk event
S_N	Salvage after N periods of time
S L Hull	Starboard Lower Hull
SPI	Schedule Performance Index
Su_n	Supply risk event
σ^2	Variance
U_x	Utility for event *x*
μ	Mean

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W_n	Weather risk event
WBS	Work Breakdown Structure
X	Random variables

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1. INTRODUCTION

1.1. Background

The construction of a complex structure is a major undertaking. In the public sector project feasibility and public support for future projects are partially based on the success of past projects. For example, when a major public works project such as Boston's "Big Dig" costs escalate by billions (Reuters 2000), similar major tunneling projects may have difficulty gaining public support, such as, Seattle's proposed light rail tunnel (Seattle Post Intelligencer 2000a). In the private sector large complex structures can be financially rewarding or devastating for both the builder and owner. Most complex projects share the common theme that they are fraught with risks and uncertainty that can cause cost escalations. For example, Laufer and Howell (1993) found that about 80% of all projects begin the construction process with a high level of uncertainty. The construction project manager has a challenging task to build a complex project that is on budget. The primary focus of this research is to present a methodology to assist engineering project managers to control cost when constructing a complex structure.

Project management is the application of knowledge, skills, tools, and techniques to project activities in order to meet or exceed stakeholder needs and

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expectations from a project (PMI 1997). These needs and expectations revolve around the project's scope, schedule, cost and quality. Project management functions consist of: scope, cost, time, human resources, communications, quality, contract/procurement, risk, and project integration (PMI 1997). This dissertation focuses on the cost control aspect of project management.

Project managers in the civil engineering and shipbuilding professions have long recognized the need for improvements in the area of cost control (Humphreys 1991) and (Storch et al 1995). Managing costs includes estimating, scheduling, accumulating and analyzing cost data, and finally implementing measures to correct a cost problem. Current cost control techniques tend to focus on variances in line items once the cost overrun has been discovered (Fleming and Hoppelman 1996). What is needed is a cost control methodology that proactively seeks out potential cost issues and provides project managers with as much warning as possible before their occurrence.

Risk analysis is identified as a major subset to project management (PMI 1997). However, its application appears limited within the field of construction project management. It is limited in its widespread use (Al-Bahar and Crandall 1990), sometimes it is only applied to developing schedules (Mulholland and Christian 1999), or cost estimates (Hulett 1995). The reasons for this limited use are difficult to quantify. McKim (1992) proposed that risk analysis is viewed by construction cost engineers as an intimidating subject and Blair (1999) states that the data required to apply risk analysis is often expressed in linguistic terms and is difficult to apply in a classic quantitative risk analysis. An application of fuzzy logic and set theory can be

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used as a solution to the later reason (Blair 1999), and (Ock 1995). Al-Bahar and Crandall (1990) also point out that construction professionals tend to use rules of thumb, rely on intuition and experience when dealing with risk. What is needed is an application of risk analysis to help project managers control cost that is relatively simple to apply, can be used throughout the life cycle of a construction project, accounts for the tendency of construction professionals to apply risk in linguistic terms and apply their experience.

A better cost control technique that would anticipate potential cost issues by using risk analysis and simulation techniques to highlight potential areas prone to cost escalation is needed. Additionally, this risk analysis should be used to highlight areas where cost savings or a competitive advantage may be gained. A risk analysis methodology that helps to reduce cost issues in the execution phase of a project should be a dynamic process, constantly updated, as new information becomes available. The new risk analysis information along with cost forecasting tools should be combined to better anticipate a project's cost problems and completion costs.

This study presents a proposed methodology for cost control that intertwines both risk analysis and cost control techniques. The proposed methodology is applicable to the planning and execution phases for building a complex structure.

1.2. Objectives

The primary objective of this research is to develop a novel methodology to control costs when constructing complex structures. This proposed methodology employs a synchronous combination of risk analysis, state of the art simulation, and

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cost control techniques. The primary objective can be broken down into sub-objectives that include:

- Presenting the current state of the art cost control and risk analysis techniques as applied to complex construction projects.
- Defining suitable cost control and risk methods for developing a risk-based cost control methodology.
- Presents a proposed methodology to control costs when constructing complex structures.
- Demonstrates the proposed methodology through the use of a case study.
- Performs a verification and validation on the proposed methodology.
- Documents conclusions and recommendations.

Cost and risk techniques are presented in some detail. The establishment of existing methods is important to understand the underlining principles of these disciplines. Suitable methods of cost control and risk techniques are then presented to form the basis of the proposed methodology. The criteria for suitable methods are a combination of simplicity, applicability, and practical application. The suitable cost and risk techniques are combined into a proposed methodology that provides project managers a method to control cost when constructing complex projects. To demonstrate the proposed methodology it is exercised in a case study that develops the construction of a complex project from the planning through the execution phase. The proposed methodology along with its integral software is verified and validated for its accuracy and realistic application.

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1.3. Brief Overview of Proposed Methodology

The proposed methodology combines project management tools to create a novel method for forecasting and controlling the costs of constructing a complex structure. A project's costs are a function of the project schedule (Carr 1993) and the integration of cost and schedule control is an important part of the proposed methodology. Figure 1-1 shows an overview of the two phases of a construction project and that a risk analysis method is applied to both phases to achieve the objective of delivering a project on budget and on time.

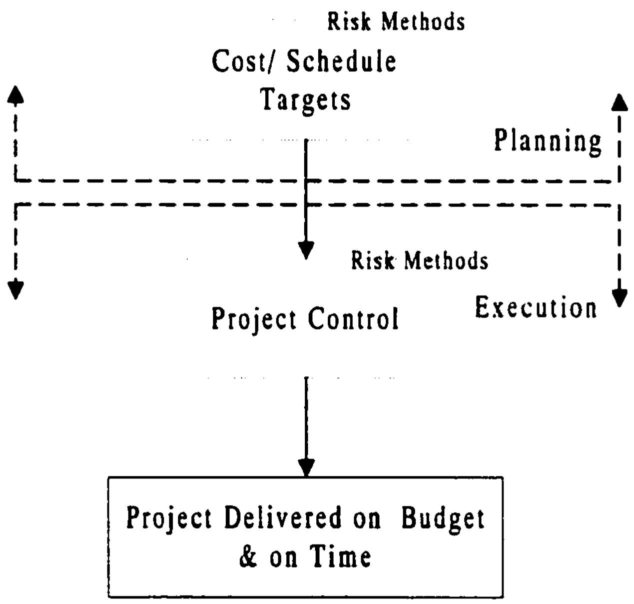

Figure 1-1. Top Level Risk-Based Cost Control

The primary benefit of using a risk-based approach to cost control is in the assessment of project cost and schedule targets, understanding the uncertainty affecting them, and ensuring they are achieved as a project progresses. Risk methods that account for uncertainty are used to develop realistic budgets and schedules or

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targets in the planning phase. Risk methods combined with cost control methods are used during project execution to monitor and control the project's direction.

The overall proposed methodology that applies risk analysis for cost control is shown in greater detail in Figure 1-2. As shown in Figure 1-2 the top portion relates to planning and the bottom section relates to execution. The main difference between these two is that planning uses a risk-based approach to develop costs and schedule targets, while execution uses a risk-based approach to control project costs.

The proposed methodology has several central themes that enables it to provide the tools necessary to control costs. These are:

- Through early risk identification and assessment project managers will have a warning of the potential negative or opportunistic risks on a project. This early identification of risk events is paramount in controlling costs because it affords decision-makers an opportunity and the time necessary to take corrective action or seize opportunities.
- Combines a novel blend of risk and cost control methodologies that synergistically assist project managers in controlling costs.
- Provides a continuous process that monitors initial assessments throughout the life of a project. Risk assessment and cost control data are updated during the life of a project.

As shown in Figure 1-2 the proposed methodology has a similar and hierarchical structure. The objectives of the first phase are to use the project information to; 1) identify risks for mitigation and opportunities to take advantage of, 2) develop target cost and schedule, 3) assist in determining a project's viability. In the planning phase

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the risks are identified, risk events, associated probabilities, and consequences are defined. The probabilities and consequences of risks are combined to form a risk assessment and representative risk profiles. The proposed methodology uses a risk assessment matrix technique to assess the risk. Once risk profiles are defined, a risk management methodology formulates a risk management plan that includes the procedures for risk acceptability and a decision analysis method. Risk acceptance is based on the cost effectiveness of risk reduction and the decision analysis methodology uses goal or decision trees.

The second phase of this process is repeated again but with some changes. New information is used to update a risk assessment and is shown in Figure 1-2 as lightly dotted lines from the first assessment of probabilities and consequences blocks to the second set of assessment of probabilities and assessment of consequences block. The lightly dotted lines represent items that are monitored or updated throughout the life of a project. The cost and schedule targets form the baseline of the earned value analysis that is combined with the risk assessment to better assess overall project risk and control costs. Continuous earned value analysis and risk assessments are performed during the project's execution phase by collecting data as the project progresses. The objective and output from the second phase are decisions used to control project costs. These decisions are monitored for their effectiveness through earned value and risk assessment data until the project is completed.

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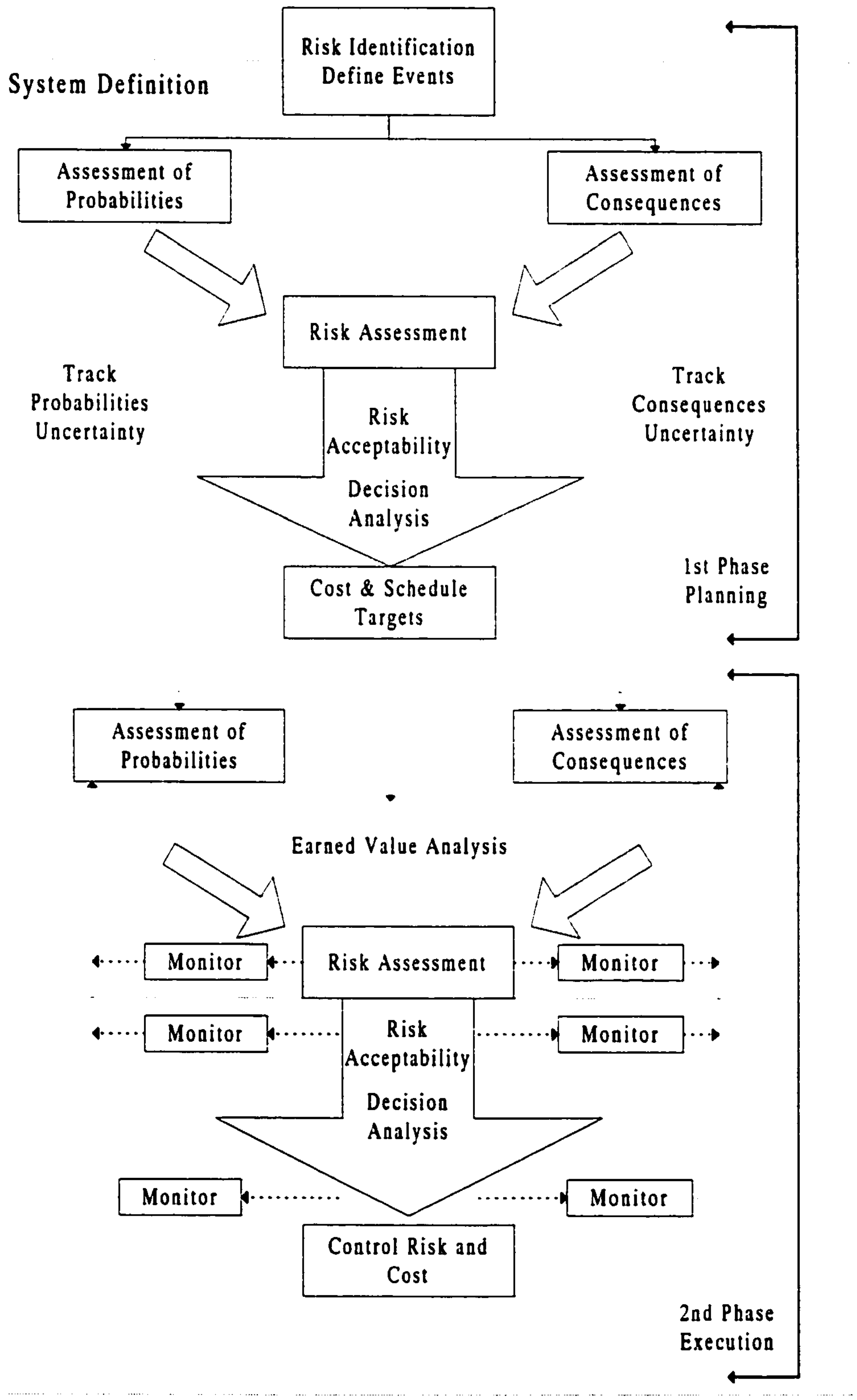

Figure 1-2. Risk-based Cost Control

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1.4. Scope

This dissertation topic includes the entire concept of risk analysis and cost control as used within the framework of the construction industry. The primary focus is on cost control and using a risk-based approach to deliver projects under budget.

The proposed methodology is applicable to the entire project's life cycle except the operation phase. Cost control and risk management may be most valuable in the planning and requirements definition stage, therefore, a significant amount of effort is applied to this phase. Cost control during the execution phase is also crucial to the economic success of a project and an equal amount of effort is applied to this phase.

The mechanics of cost planning or estimating and scheduling are the subject of several undergraduate texts. These topics are only presented as an overview.

An overview of cost control and risk analysis techniques is presented and a more in-depth coverage of these two subjects is supplied as they apply to the construction industry. The details of several cost control methods will be described. As a subset to risk analysis, several risk assessment and decision analysis techniques are presented to develop a basis for the proposed methodology.

The proposed methodology of using risk-based cost control will be documented in detail. A case study to demonstrate risk analysis, simulation, and cost control applications of the proposed methodology is provided.

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1.5. Dissertation Organization

This dissertation is organized into five main parts; 1) background, 2) proposed methodology, 3) case study, 4) verification and validation, and 5) conclusions and recommendations. An organization chart of the dissertation is presented in Figure 1-3.

This chapter begins the background phase of the dissertation by providing the objectives, proposed methodology overview, scope, and organization. The background information necessary to develop the identified project management subjects of cost control and risk analysis is presented in Chapters two and three. These chapters essentially provide a literature review of the current state of the art in cost control and risk analysis. As shown in Figure 1-3 their findings provide a basis for the proposed methodology.

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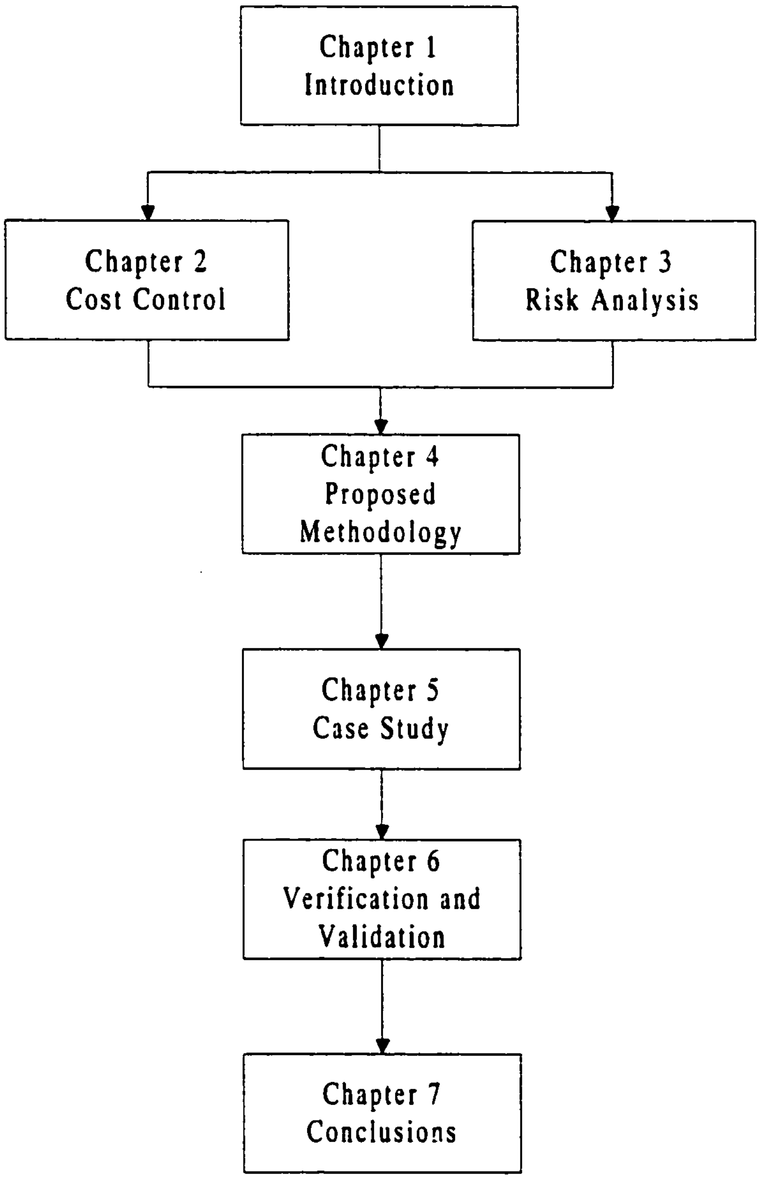

Figure 1-3. Dissertation Organization

The proposed methodology is developed and presented in both a macro and micro perspective in Chapter four. Initially a high level approach is used to describe the proposed methodology and then the details of the actual steps within the proposed methodology are discussed in-depth.

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The case study has been intermingled into the entire dissertation. Chapter one presents the Mobile Offshore Base (MOB), Chapter two uses conventional methods to establish a cost and schedule to build the MOB. In Chapter five the proposed methodology is applied to the planning and execution phases of constructing a MOB. The execution phase of the case study is based on a hypothetical scenario since a MOB has not been built.

Chapter six contains verification and validation of the methodology. The case study's application of the proposed methodology is also verified and validated in this chapter.

Finally the dissertation is summarized in Chapter seven. Conclusions and recommendations of this research are also presented in this chapter.

1.6. Mobile Offshore Base (MOB)

The proposed risk-based cost control methodology is applied to the construction of a MOB. To develop an appreciation for the complexity of a MOB platform this section describes the MOB. There are five different concepts for the proposed MOB. One of these concepts that best represents all concepts will be used as a case study.

1.6.1. MOB Background

The Office of Naval Research (ONR) has established a science and technology program to explore the concept of a prepositioned floating military base called the Mobile Offshore Base (MOB). A MOB is a large platform, up to 1500m (1 mile) in

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length by 120m (400 feet) in width, that could be moved for long-term deployments in support of national defense priorities. The platform would be unprecedented in size and operations compared to any floating structure built to date. Operational requirements for the MOB include the ability to support Air Force cargo aircraft, support container ships, provide massive storage of bulk and liquid stores, house 10,000 or more troops, and discharge various amphibious craft.

The origin of the Mobile Offshore Base (MOB) program dates back to October 1992 when the Defense Advanced Research Projects Agency (DARPA) initiated a program to study marine platforms. This MOB work was concept specific, and typically these studies were performed in conjunction with a preliminary design. In 1996 this work was transferred to the Office of Naval Research (ONR). ONR continued these MOB concept studies, developed various concepts, performed preliminary designs, and developed rough order-of-magnitude construction costs and schedules for a MOB. The following provides short summaries to these studies:

- *Steel rigidly connected semisubmersible.* Work by Brown & Root (Brown & Root 1994) for DARPA developed the concept of six steel rigidly connected semisubmersible modules connected to form a MOB. Each module is 152m (500ft) in length by 92m (300ft) in beam. The total length of this MOB concept is 912m (3000ft).
- *Steel hinged semisubmersible.* A preliminary design for a MOB was presented by McDermott (McDermott 1996) for DARPA. The drawings presented in this study, although conceptual are the most complete of all of the presented concepts. This concept used five separate modules connected by compliant connectors to make up

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a MOB. These modules are 300m (985ft) in length, for a total MOB of 1500m (4925ft) long and 152m (500ft) in beam.

- *Steel independent or dynamically positioned semisubmersible.* Bechtel (Bechtel 1997) developed an independent module semisubmersible MOB concept for ONR. The concept presented in this study was comprised of three very large modules held into position by a dynamic positioning system onboard each module. This concept has three modules that are 485m (1591ft) in length and 120m (394ft) in beam. The entire concept is 1455m (4773ft) in length.
- *Flexible Bridges Between Semisubmersible.* A proposal by Kvaerner (Kvaerner 1999) for ONR developed a MOB concept of three semisubmersibles linked together by two flexible bridge trusses. The semisubmersibles are steel and provide the storage volume for the entire MOB. The flexible bridges are minimal structures yet have enough buoyancy capacity to float into position prior to connection. The semisubmersibles and flexible bridges are 258m (846ft) and 430m (1410ft) in length respectively. The total MOB length and beam for this concept is 1634m (5358ft) and 120m (394ft) respectively.
- *Concrete and steel semisubmersible.* A study by Aker (Aker 1997) for DARPA developed a MOB concept of four linked semisubmersibles. The semisubmersibles consist of reinforced concrete for the lower hulls and columns with steel for the upper hull and bracing. Each module is 380m (1246ft) in length and 152m (500ft) in beam. The total MOB length is1520m (4984ft).

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1.6.2. MOB Concept for Case Study

Only one MOB concept will be fully developed as a case study. The steel hinged semisubmersible or simply "hinged MOB" is selected because it is the most representative of all the concepts and has the most complete preliminary drawings of all the proposed concepts. This concept is appropriate because it is not the largest, smallest, or most unique. The methodology presented in this dissertation could be applied to all concepts or other large and complex structures.

1.6.2.1. Hinged Semisubmersible

This concept consist of five rectangular semisubmersible steel modules, each 300m long by 152m wide (985ft by 500ft) connected by hinges as shown in Figure 1-4. The hinges allow relative pitch motion. A dynamic positioning system provides absolute positioning of the overall MOB and relative positioning of each module during connection. Principle characteristics of this concept are listed in Table 1-1.

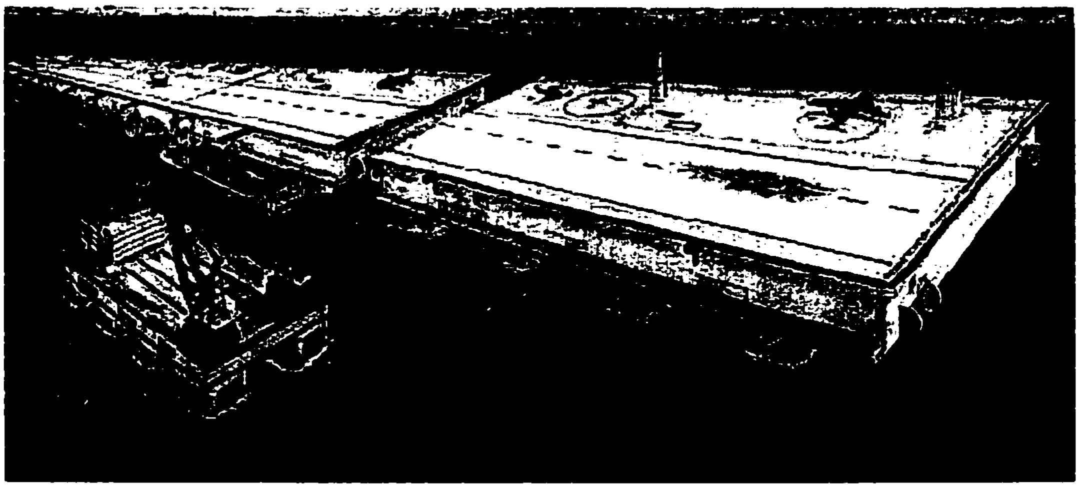

Figure 1-4. Hinged Semisubmersible Concept (McDermott Shipbuilding1996)

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McDermott Shipbuilding Inc. developed this concept under a contract with the US Navy (McDermott Shipbuilding 1996). Preliminary design drawings showed typical hull and body sections made from stiffened panels. These drawings were used to develop material and quantity estimates.

Table 1-1. Characteristics of a Hinged Semisubmersible Concept

Principal Characteristics	Meters	Feet
Length	1500	4922
Breadth	152	500
Depth	75.6	250
Draft, transit Draft, operational	13 39	43 128
Modules (5 total)		
Lower hull		
Length by breadth by depth	270 X 38 X 16	886 X 125 X 53
Columns 4 per side		
Distance On Center	66	217
Height by width by width	35 X 21 X 24	115 X 57 X 69
Gable Braces 1 per column		
Horizontal Length by Diameter	79 X 10	260 X 33
Diagonal Length by Diameter	50 X 5	165 X 16
Upper Hull/deck		
Length by breadth by depth	300 X 152 X 24.6	985 X 500 X 80

Later chapters discuss how and where a hinged MOB could be built. In Chapter two a construction cost and schedule are presented that is developed using conventional methods. Chapter five applies the proposed methodology for building the hinged MOB.

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2. COST CONTROL

A good definition of cost control is from Stewart et al. (1995) "The application of procedures that result in early illumination of potential changes in resource requirements and in the timely surveillance of the usage of funds to permit action that will keep cost within a predetermined range." This definition implies that active efforts to control cost are achievable. This chapter presents currently established methods to achieve cost control.

Construction and project management comprises a broad spectrum of skills and techniques. This overview provides the methods of cost control as applied to construction project management. Cost control methods as applied by practitioners and developed by academics will be reviewed as applied to large civil or shipbuilding projects.

2.1. Overview of the Construction Project Process

Construction of a project may be performed by several delivery methods. For the purpose of this research a traditional method was assumed because it is by far the most generic construction process (Gould 1997) and it is similar to the shipbuilding industry (Storch et al. 1995). The diagram in Figure 2-1 is presented as the traditional construction process that consists of the feasibility or preliminary design, design, construction and operation phases. Although cost control is applied in all project

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phases this research will focus on cost control that begins in the feasibility phase and intensifies in the construction phase.

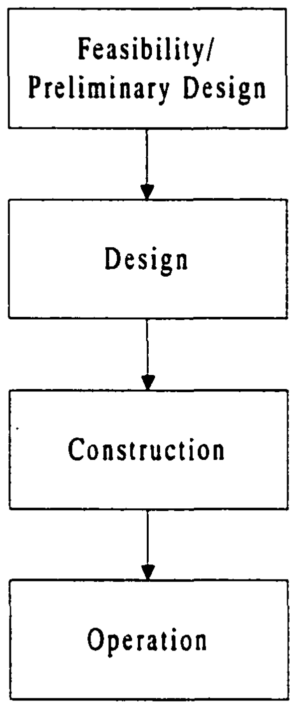

Figure 2-1. The Construction Project Process

2.1.1. Feasibility or Preliminary Design

Normally a project begins with a concept, where conceptual planning or a preliminary design will be performed and feasibility assessment will be made. During this feasibility phase conceptual drawings or a preliminary design is produced to help establish the feasibility of a project. The owner is also establishing requirements during this phase and therefore the concept's scope may fluctuate. The concept may only consist of a rough sketch to engineered drawings that lack specific detail.

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During this phase cost control is mostly practiced through project scope control, requirements analysis, and understanding the principle cost ramifications of various options.

2.1.2. Design

If the project is feasible a detailed design is performed. The design phase of a project will produce detailed drawings that are sufficient to develop contract drawings. During this phase specific items such as equipment, structural systems, and overall dimensions are finalized.

During the design phase cost control is performed through scope control and value engineering. Value engineering is a team effort between designers, owners and builders to optimize the cost of a project. It is best applied in the design phase of a project and can result in savings of between 5-10% of construction costs (Mitten 1997).

2.1.3. Construction

During the construction phase the actual physical building of the project is accomplished. This stage is comprised of two parts, planning and execution. During the planning phase a detailed cost estimate and schedule will be developed. During the execution phase the actual project gets built.

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2.1.4. Operation

The operation of a new facility begins once the construction is completed. This research will not involve the risks or costs associated with facility's operation.

2.1.5. Cost Control During the Entire Project Process

The ability to influence cost is greatest when the project is in the feasibility phase. An example of this concept is presented in Figure 2-2. Consider a Mobile Offshore Base (MOB) module (Ayyub and Bender 1999), the greatest ability to influence costs will be early in the feasibility phase where requirements and criteria are developed. As MOB the project develops through the design and construction phases there is less ability to influence costs. Finally in the sea trials phase or commissioning phase for building construction there is virtually no cost savings available.

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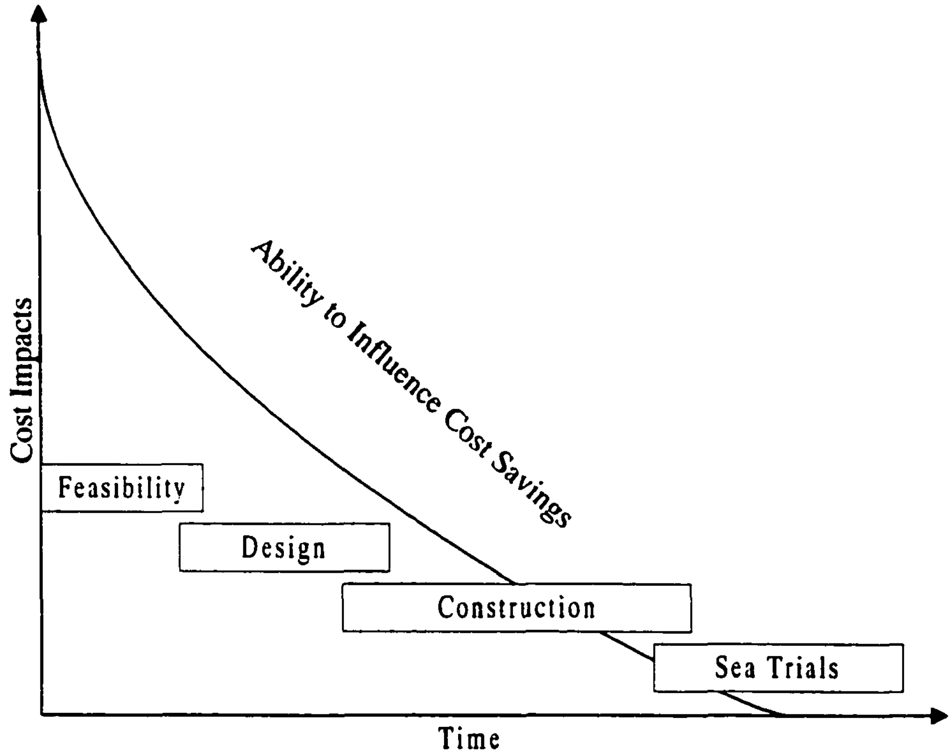

Figure 2-2. Ability to Influence Cost Savings

Although the greatest ability to influence costs is early in a projects cycle, one of the phases that potentially has the greatest ability to increase planned costs is during the construction phase (Halpin and Woodhead 1998). This is because planning estimates are based on certain assumptions and contain a high level of uncertainty. Any number of things can and do happen differently than planned during a complex project. An effective cost control program is required during the construction phase to ensure appropriate management attention is focused on preventing a cost overrun due to unforeseen or different conditions.

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2.2. Established Cost Control Methods

This section provides a literature review of the established methods for providing cost control. These methods relate to project planning and execution techniques that are applied from feasibility through construction.

2.2.1. Introduction to Cost Control

Cost control is needed to help ensure a project will have the correct quality, remain within budget, and finish on time. One of the most important functions of management once a project is identified is cost and schedule control. Cost control needs to be paramount during the feasibility and design phases. This is because a project's feasibility is normally tied to the cost of a project. Cost control during the design phase is important because decisions made in design can have a major impact on life cycle costs. Cost control during the construction phase can be paramount for large projects due to their potentially high construction cost and profiles. For example, lack of a stringent cost control program contributed to a new baseball stadium in Seattle costing $100 million more than the estimated cost of $417 million (Snel 1999), also the "Big Dig" in Boston, the Third Harbor Tunnel/ Central Artery project is projecting a $3.3 billion (Reuters 2000) construction overrun due to technical problems and cost control issues.

2.2.1.1. Cost Control versus Cost Accounting

Cost control should not be confused with cost accounting. Cost accounting involves recording cash receipts and disbursements, accounts payable, accounts

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receivable, inventory and initial investment, and keeping other general and subsidiary ledger accounts. Cost accounting identifies, defines, measures, and reports the various elements of direct and indirect cost associated with producing goods and services (Rayburn 1993). The objective of cost accounting is communicating the financial information to management for planning, controlling, and evaluating resources (Rayburn 1993). Thus, cost accounting is a means to an end. This research will not focus on the inter workings of a cost accounting system but instead focus on cost control using data provided by sound cost accounting techniques.

2.2.1.2. Specific Cost Control Methods

Cost control techniques are fairly well established and most construction or project management texts (Gould 1997) and (Kerzner 1992) will have a section on cost control. Most methods break a project into smaller work tasks or activities. Once the project begins the estimated costs of the activities are compared to the actual costs. Cost control methods use information so corrective action can be taken when a deviation from a planned performance occurs. This comparison may or may not be in conjunction with the schedule. Finally most cost control systems forecast an estimate of the final completion costs.

There are several methods that have been developed for project cost control. The most notable are; cost trend analysis, management exception reporting, range estimating, Cost Management Planning Support System (COMPASS), forecasting unit costs, and the earned value system. Each of these methods except the COMPASS method identify cost problems once they have manifested and are reactionary vice

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anticipatory to potential cost problems. This research focuses on a method to improve the earned value technique, therefore, it will be described in some detail. For completeness a brief overview of other cost control techniques is presented.

All of these techniques have at least two procedures or subsections that are common to all techniques. These two procedures are work breakdown and cost estimating. Additionally most cost control techniques have a scheduling component. Although these topics are integral to cost control systems they will only be briefly introduced at the end of this chapter as part of the MOB case study development. These topics are only presented as an overview since they are routinely covered in most undergraduate texts in construction management (Gould 1997) and (Mincks and Johnson 1998).

2.2.2. Cost Trend Analysis Method

Cost trend analysis or tracking curves is a system of cost control that compares budgeted costs with actual reported costs along with an estimate of the percent of project completion (Heinze and Westney 1997). This method integrates the cost and schedule together and allows management to identify cost issues in relation to the project's progress.

Cost trend analysis may be considered "classic or conventional cost control" since it is routinely applied in various degrees to small and large projects (Halpin 1985). The process for a classic cost control system is shown in Figure 2-3. The process begins by stating objectives and developing a plan to meet the objectives. Planning typically begins by breaking down the project into manageable parts and

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developing an estimate of the costs and a schedule for completion. As the project progresses, data is collected and any variances are analyzed. If the estimate at completion or future performance indicates a problem, management must take corrective action and the process begins again until the project is completed. The success of a project and its cost control program is determined once a project is completed and a determination is made as to how well the objectives were met.

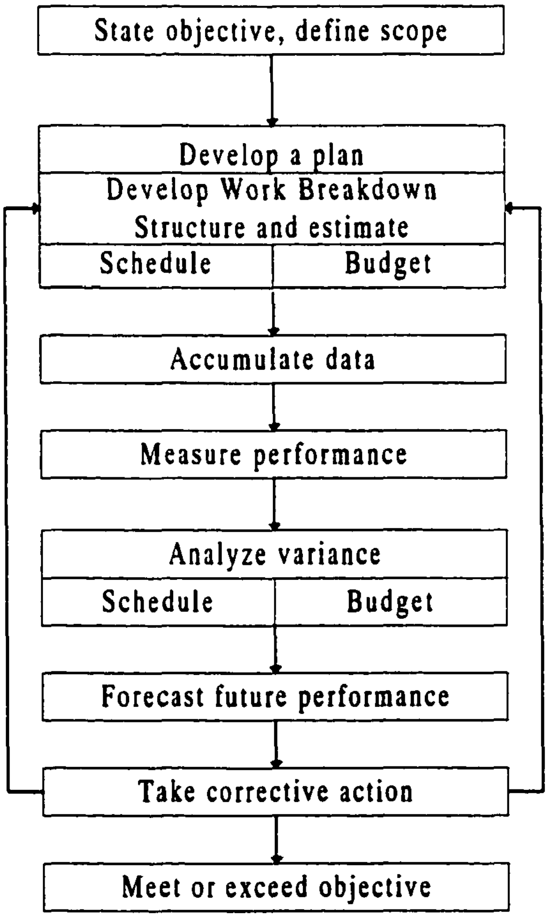

Figure 2-3. Classic Cost Control

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2.2.2.1. *Planning for Cost Trend Analysis*

An important step in any control process is establishing the objectives of the project. The objectives for most projects are defined in terms of quality, schedule, and cost (Kazi and Charoenngam 1999). Depending on the nature of the project, one aspect may need more control than another may, but all are interrelated.

Once the objectives are established the project's detailed estimate and schedule are developed. This is done by breaking down the project into manageable parts and developing a strategy for accomplishing the work.

2.2.2.2. *Performance Measurement*

To measure performance, cost data is accumulated and compared to the budgeted amounts. The data accumulated is the actual cost of items such as labor, materials, and equipment. This data needs to be timely and properly recorded in appropriate cost codes to ensure accurate comparisons are made.

2.2.2.3. *Analysis and Forecast*

The analysis portion of a classical cost control program compares actual dollars spent to the budgeted values. With this knowledge a forecast of the final completion cost can be made. The difference between the budget and the new forecast is the variance. When costs run below the budget the variance is favorable, if costs are expected to be above the budgeted amount the variance is unfavorable. An important aspect of cost control is cost and schedule integration. These two items must be considered together in order to develop an accurate understanding of a project's costs characteristics.

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The trend analysis method of cost control recognizes that most projects develop an S or "lazy S" curve when cumulative costs or labor hours are charted with time or progress. An example of this trend curve is shown in Figure 2-4. This curve depicts that projects typically experience a first period of accelerating progress or cost, a steady state of progress or expenditures and finally a decelerated rate of progress or spending.

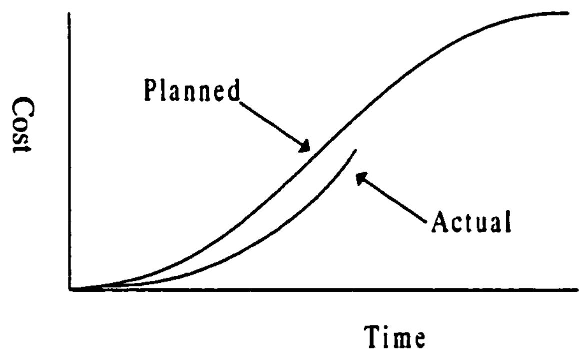

Figure 2-4. S Curve for a Project

The collected actual cost data is plotted along with the planned or budget cost data to form two S curves. A forecast of the final cost is projected using the original budget trend curve as a guide. This forecasting method takes a significant amount of judgement and the data must be extrapolated to the completion of the project. Management must be careful to ensure projections are not overly optimistic, because subordinates have a natural tendency to skew results to avoid criticism.

The trend analysis shown in Figure 2-4 shows a measure of the performance against a baseline. The key to an effective cost control program is analyzing the data, determining what corrective action might be appropriate and then taking action. Once corrective action is taken the effects should be monitored to gage their effects.

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2.2.2.4. *Benefits of Cost Trend Analysis*

By representing budget costs versus actual costs on charts, management is exposed to a clear picture of the trends on a project. This chart provides a quick representation of how a project is doing. Provided management's philosophy allows open communications the forecasting method should provide an insight to the final completion costs.

2.2.2.5. *Limitations of Cost Trend Analysis*

One limitation of cost trend analysis is that it does not consider which activities are cumulatively accounted for in determining actual values of cost expended. For example, actual cost expenditures may appear to be in line with budget values to date but if these items do not reflect items that should have been completed along the critical path the project may be behind schedule. If a project is behind schedule it will normally finish over budget.

2.2.3. Management Exception Reporting Method

Management exception reporting is a method of cost control that focuses attention on cost variances by comparing actual to budgeted costs (Hendrickson and Au 1989) and (ASCE 1985). Those items that show a variance between expected and actual costs are highlighted for management review.

2.2.3.1. *Project Budget*

For control and monitoring purposes the original detailed cost estimate is typically converted to a project budget. The budget follows the same format as the

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detailed estimate for example, it uses the cost-coding format of a Work Breakdown Structure (WBS). The budget is typically "rolled up" or detailed line items from the estimate are combined to establish a baseline for a particular activity.

2.2.3.2. Project Control and Forecasting

Expenses incurred during the course of a project are recorded to specific categories of cost codes and compared to the budget. For project control, managers would focus particular attention on items indicating substantial deviation from budgeted amounts. A report of cost items that have deviations between budgeted and actual costs is presented to management for review and action.

A linear extrapolation method is used to forecast the expected final costs. For example the forecasted total cost, C_f, is

$$C_f = \frac{C_t}{p_t} \qquad (2\text{-}1)$$

where C_t is the cost incurred to time t and p_t is the proportion of the project completed at time t. This forecasting method may be used to forecast an individual activity or group of activities. The proportion of work competed is typically estimated by field personnel and may be based on milestone accomplishment, actual measurement of work units completed or through subjective judgement. For project control management would forecast specific work items to develop an understanding of an approximate completion cost compared to the budgeted amount.

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2.2.3.3. Benefits of Management Exception Reporting

The management exception reporting method of cost control is routinely used by the construction industry (ASCE 1985). The reason for this is its simplicity. This method can be used for the smallest to largest projects by simply using the preexisting estimate to develop a budget, tracking all cost against the budget, and focusing attention of the variances in cost.

2.2.3.4. Limitations of Management Exception Reporting

Although a simple and easy to use method, the analysis of cost variances once they have occurred may provide information to decision-makers too late to be of significant value. For example, if the cost of the foundation work appears more expensive than the budget and this work is nearly completed, it may be too late to rectify an over run situation. Additionally on large projects with thousands of line items the volume of cost accounts makes this method too cumbersome by sorting through so much data to be effective.

The major flaw of this system is that cost variances are not linked to the schedule. Generally items that take longer than expected on projects will result in higher than expected cost. Therefore, a project activity that appears on budget but is several weeks behind will most likely complete with a cost over run. This method is not suited for complex and large construction projects because of this limitation.

Efforts have been made to automate an exception reporting system (Abu-Hijeh and Ibbs 1993). This automated system allows users to identify critical control points and specify selective exception reports to focus control efforts.

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2.2.4. Range Estimating

Range estimating is a cost control technique that combines Pareto's law and a modified Monte Carlo simulation (Curran and Curran 1995). Pareto's law is essentially that only a few of the critical elements will account for the largest percentage of the cost variances or stated another way, "20% of the elements effect 80% of the outcome" (Gould 1997). Critical elements are identified, quantified, and ranked according to their ability to effect the overall project cost. The range estimating method uses ranges of cost and probability factors instead of the traditional probability density functions that are used in a typical Monte Carlo simulation. The probability factors are expressed as a percentage between 0% and 100% that a value of a critical element will materialize between its target and lowest value.

During construction the identified critical elements are closely monitored for any cost variances. This allows management to focus actions on areas that will have the largest cost impacts. Construction professionals practice this cost control method by monitoring the critical path and expensive work items.

2.2.4.1. Establishing Range Estimating Critical Elements

The critical elements are those elements that can cause substantial changes in the cost of a project. For example, when constructing a building with a steel frame, the steel erection is nearly always critical. Any delays or problems in steel erection will invariably cause the building to become behind schedule and over budget.

Critical elements typically number between 10 and 20. They are found by asking a series of questions to find the elements of a project that could cause a

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significant variance to the final price. Specific elements are found by a downward search through the hierarchy of cost elements. For example, if labor cost could cause a variance to the final price, each major labor cost category would be looked at to determine if it alone could cause a significant variance.

2.2.4.2. *Establishing Range Estimating Inputs*

Once the critical elements have been identified, the variability (uncertainty) of each must be quantified. Each critical element that is typically expressed as an estimate, budget or forecast is called the target. A probability factor is applied to the target to represent the actual expected value of the target. This probability factor is expressed as a percentage between 0% and 100%. For a critical cost element it represents the probability that its actual value will result in the favorable portion of its range. A range of possible values is specified for each critical element. This range represents the lowest and highest values the critical element can assume. The probability factor is applied to this range to establish the expected value of a specific critical element. For example, if the steel erection labor target is $50,000, the probability factor is 25% and the range is between $40,000 to $60,000. There is a three-chances-in-four that the expected value can exceed the target and can result in a value between $50,000 and $60,000.

2.2.4.3. *Range Estimating Simulation*

All the elements of a project, fixed non-critical elements and variable critical elements are simulated using a simple program for personal computers. The actual result of the variable critical elements is determined during the simulation based on

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using a random number generator. The simulations highlight areas with the potential to cause large variances. Management can then focus their attention on these areas.

2.2.4.4. Benefits of Range Estimating

When using this method users are afforded the opportunity to apply a simple probability technique, yet do not need to be skilled in the probabilistic techniques required of a Monte Carlo simulation. This is because the method uses ranges and probability factors instead of probability density functions and their parameters. Additionally this method highlights only the items that may have the potential to cause the greatest cost increases.

2.2.4.5. Limitations to Range Estimating

The advantage of range estimating is its simplicity but this ignores the appropriate application of classical probability theory to the process. Range estimating is similar to a Monte Carlo simulation without the rigor of applying appropriate probability density functions and their parameters.

This method supplies highlighted areas for management to focus attention on but it does not provide any real metrics or parameters to gage a projects cost effectiveness during the construction process. Its main value is in planning not controlling cost.

2.2.5. Cost Management Planning Support System

A recently proposed methodology that assists management in evaluating the potential for cost escalation is the Cost Management Planning Support System

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(COMPASS) (Hastak et al. 1997). The COMPASS system identifies attributes of potential cost drivers, uses influence patterns, and a computerized decision support strategy to assist managers in developing a cost control strategy.

2.2.5.1. Identifying Attributes

Attributes are defined as factors that may lead to a cost escalation. Sample attributes are management errors, regulatory approval, and errors or rework that might be the cause for project cost growth. The collective effect of the identified attributes is modeled using influence diagrams.

2.2.5.2. Computerized Decision Support Strategy

To assist the decision-maker a computer based decision model made up from three modules was developed. Module 1: identifies and calibrates attributes from historical data of previous projects to be used in the current project. Module 2: determines the probable cost influence of attributes in a new project. Module 3: uses decision trees to develop a cost control strategy.

2.2.5.2.1. Module 1 Data Processing and Group Decision Models

Data from past projects that are similar in scope and have experienced cost escalation are used to identify attributes that caused a cost problem. These attributes are subjectively modeled to show which attributes contributed the most to a cost escalation. The new project team then subjectively calibrates the project attributes to better reflect the expected attribute effects based on these new project characteristics.

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2.2.5.2.2. Module 2 Probable Weighted Percentage Cost Escalation

The objective of this module is to determine the cost influence of all attributes and the probable total project cost growth. The percentage of cost escalation due to each attribute is estimated by establishing a range of potential cost escalation due to each attribute. The probable total project cost growth is calculated by summing all attributes with an expected cost escalation. This total cost escalation is also expressed in terms of a range.

2.2.5.2.3. Module 3 Decision Analysis Model

Various cost control options are analyzed to determine a cost control strategy that could be used to minimize an expected project cost escalation. This analysis uses decision trees made up of the attributes that could contribute the most to a potential cost overrun. The decision analysis highlights the attributes that management should focus attention on to minimize any cost escalation.

2.2.5.3. Benefits of Cost Management Planning Support System

This cost control method provides a systematic method to focus attention on the likely sources of a cost overrun. The method also identifies the probability of a cost escalation and the magnitude of an expected cost escalation.

2.2.5.4. Limitations of Cost Management Planning Support System

This method shows promise but has not been adopted by the project or construction management professions. The level of effort needed by a project team to establish and calibrate project attributes may make this method cumbersome.

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Although this systems is a very good project planning tool its application during construction appears limited because it does not provide any periodic updates.

2.2.6. Forecast Unit Costs

Forecast units cost is a method of cost control that compares the actual inputs and outputs to the project budget (Orczyk 1997). Typically the units for inputs are labor hours. The units for the outputs vary based on the type of work. For example, concrete placement is measured by the yd^3, and pipe installed by the lineal foot.

This method makes use of the fact that labor hours are the most difficult construction quantities to estimate and have a pronounced effect on total cost (Aaron 1997). The reason labor hours are difficult to estimate are because of the various factors that effect labor productivity, for example, weather, rework, changes, overtime, morale, and other labor associated issues. Labor has a pronounced effect on the cost of a project because it has been estimated that on a typical construction project labor comprises about 40% of the total cost (Adrian 2000).

2.2.6.1. Comparisons Between Budgeted and Actual Units

This method makes comparisons at the cost code level as defined by the Work Breakdown Structure (WBS). For example a cost code of 03140, continuous concrete footings is estimated in terms of cost, labor hours, and quantity of cubic yards of concrete. These values are used to develop a unit cost of $\$/yd^3$ and labor hours/ yd^3 of concrete. A budget of these metrics are established for the entire project. As

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construction progresses, comparisons are made between budget unit costs and actual unit costs to understand the performance of a project.

2.2.6.2. Forecasting Final Costs

This method forecasts the final cost of a project by using either the budget unit cost or the actual unit cost along with the estimated remaining quantities to establish a final cost. Both of these unit cost measures may be used to develop a range for the final cost.

2.2.6.3. Benefits of Forecasting Unit Costs

This method provides a technique that breaks down the work into identifiable and controllable work units. For example, if the actual labor hours/ yd^3 of concrete are different than budgeted, management can focus attention on the productivity of concrete operations. An advantage of this method is that most contractors are familiar with some of the more common unit costs, any actual unit costs that differ from the norm can be easily identified.

2.2.6.4. Limitations of Forecasting Unit Costs

The method of comparing budgeted unit cost with actual values does not include the effects of schedule. A unit costs that appears to be about right may be misleading if the project is behind schedule and additional resources are needed to get back on schedule.

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2.2.7. Cost/Schedule Control Systems Criteria

The Cost/Schedule Control System Criteria (C/SCSC) is a cost and schedule integration tool used by project mangers. It has been used since 1967 when DOD implemented a set of criteria to be universally applied to all their procurements (Fleming 1988). These criteria were needed because government procuring agencies wanted a way to better estimate the total cost and duration of planned or existing programs. The main thrust of the criteria was planning, budgeting, accounting, and analysis. C/SCSC specifically requires planned budgets, established baselines, methods to compare earned value, and an analysis of any variances. The C/SCSC techniques are still in effect today for all major DOD procurements and have been adopted by the construction industry in various forms (Sing 1991).

2.2.8. Earned Value Method

Earned value is the core of C/SCSC. It is still the tool of choice by DOD in the 1990's and has been affirmed as a valuable management tool for project managers outside of DOD (Abba 1997). In its purest form it is a simple and effective cost monitoring and forecasting technique applicable to a host of industries (Fleming and Koppelman 1996). It has been successfully applied to the shipbuilding (Fuente and Manzanares 1996) and construction industries (Riggs 1987) and (Carr 1993). It is a management technique that relates resource planning to schedules and technical performance requirements. All work is planned, budgeted, and scheduled in time-phased "planned value" increments, constituting a performance measurement baseline. All work is "earned" on the same basis as it was planned or in dollars. Planned values

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are compared with earned values and any differences are called a variance. Also compared are actual cost values to provide an objective measure of cost performance. Again actual costs are compared to earned values to obtain variances.

2.2.8.1. Earned Value Definitions

This section contains definitions that describe the earned value concept. For simplicity, care has been taken to avoid unnecessary use of acronyms and jargon in defining earned value terms. These terms do have correlation to the principles as defined by C/SCSC (Fleming 1988).

Planned Value is the baseline or budget. It represents the cost estimate spread out monthly over the construction period.

Earned Value is the value of the work that has been performed. It represents a dollar value for the physical work accomplished.

Actual Cost is the cost incurred to accomplish the earned value. Actual cost represents the real cost that has been paid to accomplish the work.

Schedule Variance is derived when a comparison is made between planned and earned value. The schedule variance is in terms of dollars. A negative variance indicates the project is behind schedule and a positive variance indicates the project is ahead of schedule.

Cost Variance is the derived value when comparing earned value to actual cost. A negative variance indicates the project is over budget and a positive variance indicates the project is under budget.

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Estimate At Completion (EAC) is the estimated cost of the project once it has been completed.

Schedule Performance Index (SPI) is a metric to forecast the expected completion date and is found by:

$$\text{SPI} = \frac{\text{Earned Value}}{\text{Planned Value}} \tag{2-2}$$

The estimated completion period using this metric is found by:

$$\text{Estimated completion period} = \frac{\text{Planned completion period}}{\text{SPI}} \tag{2-3}$$

Cost Performance Index (CPI) is a metric used to forecast EAC as follows:

$$\text{CPI} = \frac{\text{Earned Value}}{\text{Actual Cost}} \tag{2-4}$$

The EAC can be determined using CPI as follows:

$$\text{EAC}_{\text{C}} = \frac{\text{Total Planned Value}}{\text{CPI}} \tag{2-5}$$

where EAC_{C} is the Estimate At Completion found using CPI. This estimate is generally considered to be a reliable indicator of the "minimum" total project cost (Fleming and Koppelman 1996).

The CPI and SPI can be used in conjunction to statistically forecast a range for the EAC. A second EAC using these indices is EAC_{CS} and is found by:

$$\text{EAC}_{\text{CS}} = \frac{\text{Total Planned Value}}{(\text{CPI})(\text{SPI})} \tag{2-6}$$

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This estimate is considered to represent a high end forecast (Fleming and Kopplemen 1996) but when used in conjunction with EAC_C a range of estimates is obtained.

2.2.8.2. Illustrative Example of Earned Value

An example is used in this section to demonstrate the earned value technique. The following example is simplified and its only purpose is to numerically and graphically show earned value concepts. An example of producing a single lower hull for the hinged MOB concept that is expected to cost $200K and take 8 months to build is presented.

Table 2-1 shows the budget or planned value of building one lower hull for the hinged concept spread out over the time expected to build a lower hull. The dollar values per month would be derived from the original estimate and schedule.

Table 2-1. Planned Value for One Lower Hull Hinged Concept

Month	1	2	3	4	5	6	7	8	Total
Planned Value ($k)	10	15	25	30	30	30	40	20	200

Table 2-2 shows the progress of this project at the five-month point. The value in the month column of earned value is the work accomplished to date. The schedule variance for each month is also shown in Table 2-2. The total column represents the cumulative planned, earned value and schedule variance to date. After the fifth month the project is $10K behind schedule. The SPI found by using Eq. 2-2 as

$$SPI = \frac{\$100k}{\$110k} = 0.909$$

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The estimated completion period using Eq. 2-3 at the five month point is as follows:

$$\text{Estimated completion period} = \frac{8\ \text{months}}{0.0909} = 8.8\ \text{months}$$

Table 2-3 compares the earned value to the actual costs at the five-month point. The values in the month columns of earned value is the work accomplished to date and the values in the actual costs rows are the costs reported each month. The CPI at the five-month point is found by using Eq. 2-4 as follows:

$$\text{CPI} = \frac{\$100\text{k}}{\$115} = 0.870$$

The EAC_C using this CPI is found using Eq. 2-5 as follows:

$$EAC_C = \frac{\$200\text{K}}{0.870} = \$230\text{k}$$

Using the combined metrics of SPI and CPI the EAC_{CS}, a range of estimates can be found as

$$EAC_{CS} = \frac{\$200\text{k}}{(0.870)(0.909)} = \$253\text{k}$$

The range of the Estimate at Completion is from \$230k to \$253k. This value appears to be reasonable given that at the five month point the project is both over budget and behind schedule.

Graphical representation can be used to communicate the results of Tables 2-2 and 2-3 as shown in Figure 2-5. The cumulative planned, earned and actual cost values are plotted by month for one lower hull of the hinged concept at the five-month point. Figure 2-5 shows that the earned value or work accomplished is behind the

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planned value. Therefore, the project would require expediting the construction processes or the schedule needs to be extended to take longer than 8 months. The project has been running mostly under budget until the fifth month where it is now running over budget. The graphical display allows managers to view trends in cost and schedule variances.

Table 2-2. Earned Value for One Lower Hull Hinged Concept

Month	1	2	3	4	5	6	7	8	Total
Planned Value ($k)	10	15	25	30	30	30	40	20	110
Earned Value ($k)	5	10	20	30	35	-	-	-	100
Schedule Variance ($k)	-5	-5	-5	0	+5	-	-	-	-10

Table 2-3. Earned Value and Actual Cost for One Lower Hull Hinged Concept

Month	1	2	3	4	5	6	7	8	Total
Earned Value ($k)	5	10	20	30	35	-	-	-	100
Actual Cost ($k)	5	10	20	35	45	-	-	-	115
Cost Variance ($k)	0	0	0	-5	-10	-	-	-	-15

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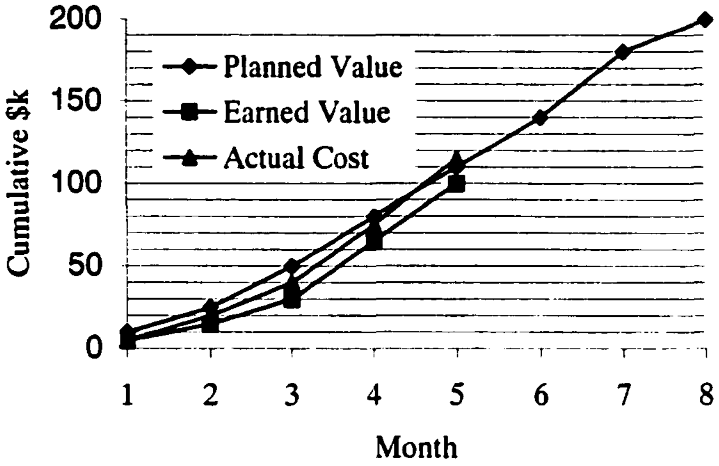

Figure 2-5. Earned Value Example for One Lower Hull Hinged Concept

2.2.8.3. Benefits of Earned Value

The earned value system of cost control provides a technique that integrates cost and schedule in similar terms. For example, cost and schedule adherence are both represented and quantified in terms of dollars. Earned value can be displayed as curves for a graphical representation of quantifiable data, such as cumulative cost versus time. These curves clearly highlight any problems and provide an early warning if a project will be behind in schedule or cost.

2.2.8.4. Shortfalls with Earned Value

The earned value system is an excellent tool to identify and manage a project's costs and schedule. Yet there are some shortfalls to this system. For example, except for the planned values any risk analyses performed in earlier phases of a project are not considered in an earned value analysis. Also the risk analysis information is not included when forecasting cost and schedule at completion. Figure 2-6 pictorially shows a representative example of the Estimate At Completion (EAC). As shown in

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Figure 2-6 the two EACs are calculated using a straight line method. This method is a good approximation for EAC, but the actual costs are better represented by an "S" curve. Earned value collects data for the value of work completed and actual costs expended without discriminating if the work is on the critical path or not. Project managers should ensure this data includes work along the critical path. Otherwise, the project may appear to be on schedule from the results of an earned value analysis but the project could be behind schedule if activities along the critical path are delayed and the earned value of the work credited is non-critical.

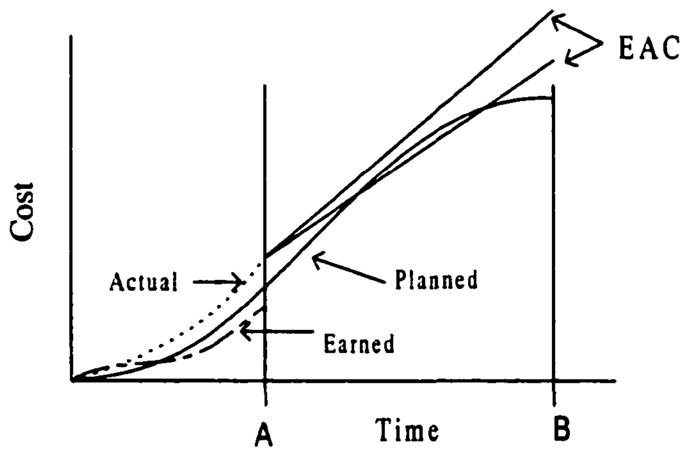

Figure 2-6. Earned Value Estimate at Completion

A better method of estimating the EAC based on an earned value system and risk analysis is desirable. Any previously performed risk analysis work can be updated with new information and compared to actual conditions to assist in forecasting an EAC.

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2.3. Cost Control Uncertainties and Problems

The basics of any cost control program are to manage the cost uncertainties associated with projects. The existing methods of cost control do this with varying degrees of success. All cost control techniques can be improved to provide managers with better information. This section will describe the uncertainties and problems associated with the cost control methods mentioned above.

2.3.1. Uncertainties

A large or complex project is fraught with the uncertainties. These uncertainties may be considered as a range of events that may happen and produce risks affecting the project. The cost of a project is arguably the most important metric of a project's success and remains uncertain until all invoices have been paid. Other uncertainties can directly or indirectly lead to increased costs. This section will describe major uncertainties associated with projects and those that a cost control program should address.

2.3.1.1. Estimating Costs

All estimates which directly or indirectly make up a project's costs will be uncertain. For example, the complexity and productivity of assembling large structural components will never exactly be known in advance. Subcontractor cooperation, equipment performance, quality workmanship, and discounts on materials, are some examples of the type of items that are uncertain. All of these

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uncertainties can contribute to making an estimate uncertain. The important issue in a cost control program is to know that these costs exist and their values may fluctuate.

The WBS method of breaking the total costs into parts is used to assess the uncertainty of costs. The uncertainty of each part of a project is described and then the parts are put back together to give a whole picture of the uncertainty associated with total project costs.

2.3.1.2. Planned Schedule

A planned schedule is really an educated guess of the activities a project will require, how these activities interrelate, and how long each activity will take. The uncertainties associated with these activities are the effects of interactions between activities and the duration of the activities. For example, one delayed activity may delay several activities or cause their duration's to take longer than expected. Impacts to the schedule are important to cost control because of the strong linkage between cost and schedule.

Using the Critical Path Method (CPM) of scheduling all activities are identified and their duration's are estimated based on crew sizing, labor productivity, and other assumptions. The total uncertainty in a schedule is accounted for by understanding the uncertainty of each activity and then putting them all together.

2.3.1.3. Forecasting Cost at Completion

Once a project begins, estimated costs become known once an invoice has been paid or an activity is completed. Management's attention needs to focus on the future, how the project will finish with respect to completing on or below budget.

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This forecasted final completion cost is known as Estimate At Completion (EAC). There are basic uncertainties regarding the methods of computing an EAC. In Christensen (1993) fifteen different methods to calculate EAC are identified. All of these methods contain some degree of uncertainty.

The EAC contains the similar uncertainties associated with estimating. New uncertainties of determining how much of the project is currently completed and extrapolating this to completion are the new uncertainties introduced. Other uncertainties introduced into estimating completion cost are selecting the appropriate calculation method, the accuracy of input information, and subjective judgement.

2.3.1.4. Management Actions

A cost control program will include establishing budgets and a system to monitor performance. A better-cost control program goes one step further and takes actions based on the project's performance compared to a budget. The actions taken and the results of these actions are uncertain events. The actions are designed to lower costs in a specific area and may have unexpected ramifications in other areas. Therefore the actions taken must be monitored for their effectiveness.

2.3.2. Problems With Cost Control Methods

Several cost control methods have been presented and discussed. All have particular advantages and disadvantages. Table 2-4 presents these cost control methods with their advantages and disadvantages.

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Table 2-4. Cost Control Methods Summary

Method	Advantage	Disadvantage
Cost Trend Analysis	Graphical view of trends.	Ignores critical path activities.
Management Exception Reporting	Simplest form of cost control. Used at least in some form by most of the industry.	Cost variances discovered too late, no schedule link, can become cumbersome on large projects.
Range Estimating	Applies simple probability to the most critical items.	Data acquisition may be difficult, useful planning tool but not suited for controlling cost
COMPASS	Provides diagnosis of cost problem.	Requires extensive effort to develop and apply.
Forecast Unit Costs	Simple unit costs are developed that are easily compared to actual.	Does not include effects of the schedule.
Earned Value	Compares cost and schedule in similar terms, results show both cost and schedule variances, graphical.	EAC approximated by straight line, analysis ignores critical path.

Several cost control methods and their limitations have been introduced and discussed in the preceding sections. Collectively the limitations and associated problems associated with some or all of the established cost control methods can be categorized as data acquisition, absence of risk based decision analysis, schedule integration, unknown causes of variances, and forecasting final completion cost. These problems are discussed fully in the next section on cost control needs.

2.4. Cost Control Needs

The most important objective of any cost control method is the ability to detect and control cost escalation early in a project. The techniques or basic inputs to achieve this are establishing estimates or budgets, developing a schedule, obtaining cost control data, performing a risk analysis, applying cost and schedule integration,

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identifying causes of variances, and estimating final completion cost. The requirement that cost and schedule are integrated is paramount since they are closely linked and interrelated. Also any proposed remedies to problems should be based on the identified causes of variances not just the symptoms. A robust cost control method needs to be able to forecast the final competition cost.

2.4.1.1. Cost Control Data

The ability to have an effective cost control program relies on a process to provide timely, reliable, and appropriate data (Zahn 1998). Management depends on a reliable and quick exchange of information in order to successfully implement cost control strategies. How data is recorded, refined and organized effects its usefulness as a snapshot of the project. The data must be screened and corrected before management uses it.

2.4.1.2. Implementation of Risk Analysis Techniques

The nature of large and complex projects makes them inherently risky. Risk analysis and management techniques are needed to account for and manage this risk with respect to cost. Risk analysis methodologies are fully presented in Chapter three.

2.4.1.3. Cost and Schedule Integration

Cost and schedule integration has been identified for quite sometime as a required element in an effective cost control system (Ibbs and Ashley 1987). This integration is required because of the tight linkage and interdependency between cost

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and schedule. Simply stated, any impacts to the schedule will result in impacts to the cost (or vice versa) of a project.

2.4.1.4. Identifying the Causes of a Variance

An important aspect of cost control is recognizing the causes of variances not just the symptoms. The symptoms of cost problems are easy to detect, they are variances on charts or management exception reports. These symptoms highlight cost items that have already experienced cost escalation. What is needed is a method that also recognizes the root causes for any cost escalation (Hastak et al. 1996).

Distinguishing between causes and symptoms is important because appropriate management actions are required to solve the causes of any the cost escalation. Without a clear understanding of the causes management's actions may actually make the problem worse or at the very least waste time, energy, and result in missed opportunities.

2.4.1.5. Predicting the Estimate At Completion

Estimating how a project will finish is important to all parties of the project team. Typically the bottom line for any project is, how much will it cost to complete the job? This is because owners are financing costs, designers have their reputation and liability at stake, and builders are anticipating a profit.

To be effective a cost control method must be able to reliably forecast the completion costs from as early as possible in the construction cycle (Halpin and Woodhead 1998). This early warning system is required to allow management time to implement changes to correct a cost escalation situation.

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2.5. Project Estimating and Scheduling Using a Case Study

Common to all cost control methods is establishing an estimate of the project's cost. A schedule is also used as an integral management tool and in most cost control methods it is integrated with the estimated costs. This section provides an overview of cost estimating and scheduling to provide the reader with a basic understanding of these project management tools. Then using the presented concepts an overview of how the case study was estimated and scheduled is presented. For an in-depth discussion of the case study methods and results the reader is referred to Ayyub et al. (1999a) and Ayyub et al. (1999b).

2.5.1. Work Breakdown Structure (WBS)

A system to properly describe construction work processes is a Work Breakdown Structure (WBS). The WBS provides a framework that defines the specific task within a project. At the start of the construction execution phase the allocation of a projects resources in terms of cost and schedule are applied to the WBS to establish a project's budget and planned schedule. Therefore the WBS also serves as a framework for cost control because it allows managers to compare plans, schedules, and budgets as the projects progress. Rasdorf and Abudayyeh (1992) confirm the idea of a WBS as the foundation of a cost and schedule control tool. They recommend that a WBS or "work packaging model" be used for cost and schedule integration on construction projects.

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Of course for a tool to function properly it must be applied correctly. For a WBS to function properly, three rules are given by Mansay (1991):

- WBS hierarchical levels must be compatible.
- Activities must have a definable output.
- Activities must have a definable duration.

An example of a compatible hierarchical level are the WBS items of "build lower hulls" is on the same WBS level as "build upper hull" but not "stiffeners for plate sections that make up the decks and bulkheads of the upper hull". The WBS of "build lower hulls" is valid because it has a definable output and duration.

2.5.1.1. WBS for Case Study, Hinged Concept

The hinged concept is broken down into components that can be built and transported from various facilities. Table 2-5 shows the work breakdown structure for lower hull, columns and braces for this concept. Table 2-6 shows the work breakdown structure for the upper hull.

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Table 2-5. Work Breakdown Structure for Components of the Hinged Concept

WBS	Component	Comments
11010.H	Lower hull	Each lower hull is modularly constructed at a single shipyard. Each hull weighs **21,150 metric tons.**
11011.H	Lower port hull	
11012.H	Lower starboard hull	
11500.H	Columns 4 per side	Each column is 35m tall by 21m x 24m, erected from 8 blocks 4-21m x 17.5m x 3m @ 247 metric tons and 4-18m x 17.5m x 3m @ 213 metric tons. Total weight of all columns is **14,720 metric tons.**
11511.H	Port column 1	
11511.H.1 21x17.5x3	Port Column 1 block 1 21x17.5x3	
11511.H.2 21x17.5x3	Port Column 1 block 2 21x17.5x3	
11511.H.3 21x17.5x3	Port Column 1 block 3 21x17.5x3	
11511.H.4 21x17.5x3	Port Column 1 block 4 21x17.5x3	
11511.H.1 18x17.5x3	Port Column 1 block 1 18x17.5x3	
11511.H.2 18x17.5x3	Port Column 1 block 2 18x17.5x3	
11511.H.3 18x17.5x3	Port Column 1 block 3 18x17.5x3	
11511.H.4 18x17.5x3	Port Column 1 block 4 18x17.5x3	
11512.H	Port column 2	
11513.H	Port column 3	
11514.H	Port column 4	
11521.H	Starboard column 1	
11522.H	Starboard column 2	
11523.H	Starboard column 3	
11524.H	Starboard column 4	
11400.H	Diagonal braces 1 per column,	Each column has one diagonal or gable brace that is 50m by 5 m in diameter that weighs 140 metric tons. Between each set of columns is a 79m by 10 m diameter brace that weighs 440 metric tons. Total weight of braces is **2,880 metric tons.**
11411.H	Port diagonal brace column 1	
11412.H	Port diagonal brace column 2	
11413.H	Port diagonal brace column 3	
11414.H	Port diagonal brace column 4	
11421.H	Starboard diagonal brace column 1	
11422.H	Starboard diagonal brace column 2	
11423.H	Starboard diagonal brace column 3	
11424.H	Starboard diagonal brace column 4	
11440.H	Horizontal Brace 1 per column pair	
11441.H	Horizontal brace columns 1	
11442.H	Horizontal brace columns 2	
11443.H	Horizontal brace columns 3	
11444.H	Horizontal brace columns 4	

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2.5.1.1.1. Lower Hull Hinged Submersible

Lower hulls are similar in size to the hull of a large ship. Each lower hull is 270m long by 38m wide by 16m tall or about the size of a large hull ship. Recently built large hull Navy ships are used herein to estimate the time and resources required to construct a vessel of this magnitude.

2.5.1.1.2. Columns Hinged Submersible

Modules for this concept have four columns per side. They are 35m tall and box shaped 21m by 24m with rounded corners. Smaller shipyards could modularly fabricate these structures and then add them to the lower hulls at a major shipyard or afloat. The columns are essentially large tubular structures constructed from stiffened panels. The walls of the columns are made from panels, with stiffened panels as inner shells. The thickness of the column walls is 3m, transverse web frame spacing is 3m and typical frame spacing is 1m.

2.5.1.1.3. Braces for Hinged Semisubmersible

The braces for each MOB module are the smallest of the main structural components. The braces are "gable" shaped with 50m long by 5m in diameter diagonals and 79m long by 10 m in diameter horizontal members. The braces could be fabricated at smaller shipyards or major industrial sites located near water for barge transportation to a MOB assembly site. The WBS for these components are shown in Table 2-4.

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2.5.1.1.4. Upper Hull for Hinged Semisubmersible

At 300m long by 152m wide and 24.6m deep, the upper hull will comprise the largest components of a MOB module. This concept has several decks. 05 deck (weather deck), 04, 03&1/2, 03, 02&1/2, and 01 (bottom of hull). It will need to be constructed from smaller blocks to allow modular construction because the largest drydock or graving dock in the US is only 75m wide (Maritime Administration 1997). Smaller modularization, combined with afloat assembly will allow construction from the majority of shipyards in the US. To ensure maximum possible participation by the nation's shipyards the blocks for the upper hull are sized from 15m by 21m by 3m thick weighing 139 metric tons to 21m by 30m by 5.5m thick weighing 284 metric tons. The work breakdown for the upper hull is shown in Table 2-5. Each block or panel is numbered and is represented by block # in the WBS column of Table 2-5.

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Table 2-6. Work Breakdown Structure for the Upper Hull of the Hinged Concept

WBS	Component	Comments Sizes in m and weights in metric tons
13000.H	Upper Hull, any deck	
13610.H	01 deck	
13610.H.(block #)15x21x3	01-02 deck blocks	Blocks size in m and weights in metric tons, all are 3m deep: 4-15x21@161, 16-15x24@170, 4-15x30@237, 8-20x21@212, 32-20x24@231, 8-20x30@292, 4-21x21@205, 16-21x24@219, 4-21X30@299. Total weight of **21,256 metric tons.**
13610.H.(block #)15x24x3	01-02 deck blocks	
13610.H.(block #)15x30x3	01-02 deck blocks	
13610.H.(block #)20x21x3	01-02 deck blocks	
13610.H.(block #)20x24x3	01-02 deck blocks	
13610.H.(block #)20x30x3	01-02 deck blocks	
13610.H.(block #)21x24x3	01-02 deck blocks	
13610.H.(block #)21x24x3	01-02 deck blocks	
13610.H.(block #)21x30x3	01-02 deck blocks	
13620.H	02-021/2 panels	Egg crate panels between 02-021/2 decks, 20-20x4@13, 10-21x4@14, 21-24x4@15, 7-30x4@19. Total weight of **840 metric tons.**
13620.H (panel #)20x4	02-021/2 panels	
13620.H (panel #)21x4	02-021/2 panels	
13620.H (panel #)24x4	02-021/2 panels	
13620.H (panel #)30x4	02-021/2 panels	
13625.H	02&1/2 –03 deck blocks	Blocks size in m and weights in metric tons, all are 5m deep: 4-15x21@176, 16-15x24@195, 4-15x30@236, 8-20x21@219, 32-20x24@246, 8-20x30@308, 4-21x21@227, 16-21x24@259, 4-21X30@323. Total weight of **23,400 metric tons.**
13625.H.(block #)15x21x5	02&1/2 –03 deck blocks	
13625.H.(block #)15x24x5	02&1/2 –03 deck blocks	
13625.H.(block #)15x30x5	02&1/2 –03 deck blocks	
13625.H.(block #)20x21x5	02&1/2 –03 deck blocks	
13625.H.(block #)20x24x5	02&1/2 –03 deck blocks	
13625.H.(block #)20x30x5	02&1/2 –03 deck blocks	
13625.H.(block #)21x21x5	02&1/2 –03 deck blocks	
13625.H.(block #)21x24x5	02&1/2 –03 deck blocks	
13625.H.(block #)21x30x5	02&1/2 –03 deck blocks	

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Table 2-6. (continued). Work Breakdown Structure for the Upper Hull of the Hinged Concept

13630.H	03-031/2 deck panels	Egg crate panels between 03-031/2 decks, 20-20x3.6@11, 10-21x3.6@13, 21-24x3.6@14, 7-30x3.6@18. Total weight of **770 metric tons.**
13630.H.(panel #)20x3.6	03-031/2 deck panels	
13630.H.(panel #)21x3.6	03-031/2 deck panels	
13630.H.(panel #)24x3.6	03-031/2 deck panels	
13630.H.(panel #)30x3.6	03-031/2 deck panels	
13631.H	03&1/2 deck plating	Deck plating for 03&1/2 deck 12-20x24@78, 6-21x24@82, 4-21x30@102, 4-20x30@97. Total weight of **2224 metric tons.**
13631.H.(plate #)20x24	03&1/2 deck plating	
13631.H.(plate #)21x24	03&1/2 deck plating	
13631.H.(plate #)21x30	03&1/2 deck plating	
13631.H.(plate #)20x30	03&1/2 deck plating	
13635.H	03&1/2-04 deck panels	Egg crate panels between 031/2-04 decks, 18-20x7.6@22, 32-21x7.6@24, 53-24x7.6@27, 7-30x7.6@33. Total weight of **2,826 metric tons.**
13635.H.(panel #)20x7.6	03&1/2-04 deck panels	
13635.H.(panel #)21x7.6	03&1/2-04 deck panels	
13635.H.(panel #)24x7.6	03&1/2-04 deck panels	
13635.H.(panel #)30x7.6	03&1/2-04 deck panels	
13640.H	04-05 deck blocks	Blocks size in m and weights in metric tons, all are 3m deep: 4-15x21@176, 16-15x24@195, 4-15x30@248, 8-20x21@231, 32-20x24@260, 8-20x30@325, 4-21x21@240, 16-21x24@273, 4-21X30@340. Total weight of **24,266 metric tons.**
13640.H .(block #)15x24	04-05 deck blocks	
13640.H .(block #)15x30	04-05 deck blocks	
13640.H .(block #)15x21	04-05 deck blocks	
13640.H .(block #)20x21	04-05 deck blocks	
13640.H .(block #)20x24	04-05 deck blocks	
13640.H .(block #)20x24	04-05 deck blocks	
13640.H .(block #)21x21	04-05 deck blocks	
13640.H .(block #)21x24	04-05 deck blocks	
13640.H .(block #)21x30	04-05 deck blocks	
Total weight of one module of the hinged concept is **135,482 metric tons.**		

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2.5.2. Cost Estimation

To understand the cost of a project an estimate is developed. This estimate is really only an "educated guess". An estimate must be an accurate reflection of reality but at various stages of a project the estimate only needs to show the level of detail necessary to make relevant decisions. Carr (1990) suggests general estimating principles that help to ensure good estimating practices:

- Appropriate level of detail and completeness.
- Documentation.
- Contingency.

Based on the project phases shown in Figure 2-1 the types of estimates are; conceptual, design development, and construction. Estimates are expensive, therefore, each type of estimate should only require an appropriate amount of resources to produce an estimate with the level of detail required to make a decision at a specific phase. Additionally management must balance the additional cost to produce an extremely accurate estimate with the value of the expected returns.

An estimate is a permanent document that serves as a basis for decisions. Therefore, it must be clearly understood, checked, and verified. Proper documentation is required to assist others that may work on or update an earlier estimate.

An estimate has several areas of uncertainty, such as quantities, productivity, unforeseen conditions and market forces. As more information is known about a project a more accurate estimate may be made but it will still contain some level of uncertainty. In a risk-based approach to cost control these uncertainties must be

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accounted for. Additionally, identified risks may require a contingency is put into the estimate to plan for any potential cost growth.

2.5.2.1. Conceptual Estimate

The conceptual estimate is based on a preliminary design and is used to develop a rough order of magnitude of the costs associated with a project. A project's feasibility is based on this estimate. This estimate may be based on parameters such as square foot cost for a retail outlet, dollars per ton of steel for a marine platform, or number of students for a school project. The conceptual estimate includes the highest level of uncertainty because of the many assumptions that are based on the level of detail provided in the preliminary design.

2.5.2.2. Design Development Estimate

This estimate is normally based on the nearly finished or completed design for a project. It is based on much more information than available in the conceptual phase. This estimate may include specific pricing of special equipment, systems, and quantities. The design estimate can be used as a tool to perform cost and performance or aesthetic trades. This estimate includes a level of uncertainty that is improved from the conceptual estimate.

2.5.2.3. Construction Estimate

The construction managers that will execute the construction process perform the construction estimate. This estimate will include; estimates from various subcontractors, detailed quantity take offs, productivity based on past projects and a

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strategy to successfully accomplish the project. The construction estimate contains the least amount of uncertainty, yet may still only be accurate to about –10% to +15% (Wendling and Lorance 2000).

2.5.2.4. Estimate for Case Study, Hinged Concept

Estimates for the hinged concept were based on the preliminary drawings developed under another study by McDermott (1997). From these drawings weights of specific components were established and production indices were applied to obtain a construction duration. A summary of where specific components might be built is shown in Table 2-7.

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Table 2-7. Proposed Production for Hinged Concept Using Afloat Assembly Model

Facility	Components
Lower Hulls	
Newport News	Port Lower Hull, 16-20m x 30m x 3m, 8-20m x 30m 5.5m, 8-21m x 30m x 3m, 4-21m x 30m x5.5m UH blocks
Avondale Industries New Orleans	Starboard Lower Hull
Braces	
TDI-Halter Point Escatawpa MS	Hz Braces and 20m x 24m deck plate
Gulf Coast Fabricators, lakeside MS	Diagonal Braces
Columns	
Kvaerner Philadelphia PA	Columns 1-4
Detyens Charleston	Columns 5-8
Upper Hull Blocks & Plate	
Baltimore Marine Industries	8-15m x 21m x 3m, 32-15m x 24m x 3m, 8-15m x 30m x 3m UH blocks
Alabama Shipyard, Mobile AL	50-20m x 24m x 3m UH blocks
Ingalls, Pascagoula, MS	8-20m x 21m 5.5m, 24-20m x 24m x 5.5m, 4-21m x 21m 5.5m, 12-21m x 24m x 5.5m UH blocks
Tampa Bay Shipbuilding	14-20m x 24m x 3m, 8-21m x 21m x 3mUH blocks
Bath Iron Works, Bath ME	16-20m x 21m x 3m UH blocks
NASSCO San Diego	32-21m x 24m x 3m UH blocks
AMFELS, Brownsville TX	6-21m x 24m, 4-20m x 30m, 4-21m x 30m deck plate & 7.6m plate
Todd Shipyards Seattle	58-20m, 21m, 24m & 30m x 3.6m plates for UH
Portland Shipyard	58-20m, 21m, 24m & 30m x 4m plates for UH
Atlantic Marine, Mobile AL	41- 20m & 21m x 5.5m panels for UH
Bender Shipbuilding, Mobile Al	56-24m & 30m x 5.5m panels for UH
N Florida Shipyard JAX FL	4- 21m x 21m x 3m blocks for UH
Atlantic Drydock JAX FL	4- 21m x 21m x 3m blocks for UH
Erector & Offshore Assembler	
J. Ray McDermott, Morgan City, LA/ Aransas Pass, TX	Onshore assembler

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2.5.2.4.1. Estimate Assumptions

Several basic assumptions are required to estimate the cost of a very unique marine platform.

2.5.2.4.1.1. Afloat model

The method for construction a MOB module is similar to how the largest offshore oil platforms are constructed with the use of at sea assembly. Large components such as the lower hulls and columns are towed out to deep water in the Gulf of Mexico. A lower hull is ballasted down and columns are floated over, then the lower hull is ballasted up and the components are connected. This process continues until the upper hull sections are connected to the columns. An illustration of joining the upper hull sections to the lower hulls and columns is shown in Figure 2-7.

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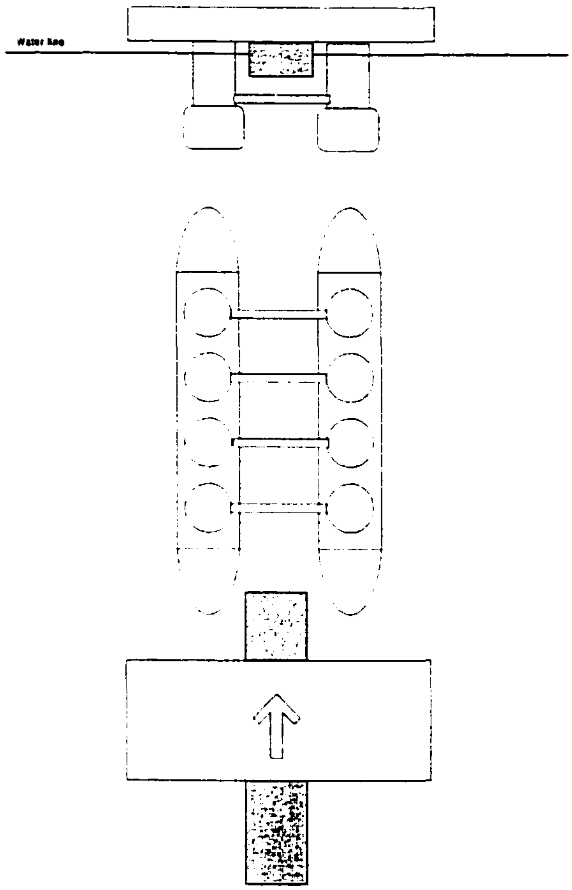

Figure 2-7. Afloat Assembly of Upper Hull to Lower Hull

The MOB concept is assumed to be constructed at shipyards on the East, West and Gulf coast of the US. Component construction at a particular location was based on: number of building positions, crane capacity, channel restrictions, location, labor strength, and experience in shipbuilding or repair. The major offshore industrial site at Aransas Pass, Texas was selected as the large upper hull grand block erection site. This facility was chosen because of capabilities and experience of the facilities. Offshore from this site is where finished components would be assembled at sea. Other than contacting various facilities about crane or building position capacities, no consideration was made in regards to facilities construction backlog, it was assumed

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that if a facility was capable of performing the assigned work it will be scheduled into existing backlog.

2.5.2.4.2. Estimate for Lower Hull, Hinged Concept

These structures were parametrically estimated by comparison to the hull construction duration of other large vessels at a particular facility. For example, the estimate for the lower hull built at Avondale is based on construction times of the recently launched Strategic Sealift ships built at this facility (NAVSEA 1999). A parametric adjustment is made for the size differential between the lower hull and ships constructed at Avondale. This example is shown in Table 2-8.

Table 2-8. Avondale Shipyard Parametric Estimate, Afloat Assembly

Parameter	Strategic Sealift ship	Lower Hull
Months to launch	22 months	14 (estimated)
Size	290m by 32m beam by 28m depth	270m by 38m beam by 16m depth

2.5.2.4.3. Estimate for Columns, Hinged Concept, Afloat Assembly Model

The columns for this concept are large and require a shipyard with large drydocks and heavy lift capacity. The shipyards that utilize the former Naval Shipyards at Philadelphia and Charleston were selected for this construction. Column construction is envisioned to be assembled from four large blocks, e.g. each side of the column. Table 2-9 shows the construction and transportation duration for the columns built at these shipyards and shipped to Aransas Pass.

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Table 2-9. Estimate for Hinged Concept Columns, Afloat Assembly

Columns	Take off quantity Metric tons/column	Construction Duration/column	Transportation Duration
1-4, Philadelphia	1560	71 work days	23 calendar days
5-8, Charleston	1560	71 work days	13 calendar days

2.5.2.4.4. Estimate for Braces, Hinged Concept Afloat Assembly Model

The braces for this concept are relatively small components compared to other structural members. The braces are constructed at smaller shipyards along the gulf coast for ease of transportation to Aransas Pass. As shown in Table 2-10 the construction and transportation times for these components are presented.

Table 2-10. Estimate for Hinged Concept Braces, Afloat Assembly Model

Braces	Take off quantity Metric tons/brace	Construction Duration/brace	Transportation Duration
Diagonal, Lakeshore MS	235	16 work days	5 calendar days
Horizontal, Point Escatawpa MS	716	50 work days	5 calendar days

2.5.2.4.5. Estimate for Upper Hull, Hinged Concept Afloat Assembly Model

The upper hull is the largest component, it is so large that is must be broken down into smaller blocks to allow for construction and erection. These smaller blocks will be joined to form grand blocks. The grand blocks will be floated out to deep water for assembly with other grand blocks and components to form the entire upper hull and MOB module. Table 2-11 shows selected examples of the estimate for the upper hull construction.

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Table 2-11. Estimate for Selected Portions of Upper Hull, Afloat Assembly

Upper Hull Component Size in meters	Take off quantity Metric tons/each	Construction Duration/ Block	Transportation Duration
15 x 21 x 3 block, 04-05 deck Baltimore Marine Industries	139	8 work days	22 calendar days
21 x 30 x 5 block, 021/2-03 deck Newport News	284	15 work days	20 calendar days
20 x 4 panels between 031/2 & 04 deck Portland	10	0.5 workday	5 calendar days
20 x 24 panels for 031/2 deck Brownsville TX	18	1 work day	3 calendar days

2.5.2.5. Estimated Cost for MOB Case Study

Once the build strategy, activity duration's and weights of specific components was established costs were estimated by applying metrics developed from several published sources. (McDermott Shipbuilding Inc and McDermott Technology Inc, 1997), (NAVSEA 1999), and (Aker 1997). These metrics along with specific components were inputted into an off the shelf cost estimating software program called Timberline (Timberline 2000). A cost estimate based on using discrete estimates for the components was developed. This established a preliminary cost estimate of $3,834 million dollars for the hinged concept.

2.5.3. Scheduling

Scheduling activities are a crucial step in planning for a project. The schedule allows planners to forecast resource requirements and most importantly allows a project to be built "on paper" before actual construction begins.

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2.5.3.1. Critical Path Method Scheduling

Identified WBS activities are best scheduled using the Critical Path Method (CPM) (Mincks and Johnson 1997). The WBS activities are sequenced to show the flow of work to complete the project. Activities that are critical are combined to form the longest length of time for a project. Any delay in a critical activity will result in a delay of the entire project and therefore require careful monitoring. The CPM network along with the estimated cost of activities on a schedule is the primary driver of a cost control system.

CPM is an established tool used in the construction industry (Riggs 1986). Its main advantages are in its ability to communicate graphically the sequence, logic and duration of a construction project. As a control tool the CPM schedule is used to highlight the activities that potentially cause the most impact to the duration of the entire project. Yet like any tool it must be correctly applied to be useful in project management. The CPM schedule will be most useful when planners make realistic estimates of an activity's duration and buffers are provided between activities (Jaafari 1984).

There are some limitations to using a CPM schedule. It can become unwieldy when planners put too much detail into the model, it can be time consuming to maintain, and it does not explicitly model interdependence of resources for activities. Additionally, as the proponents of the lean construction philosophy point out, CPM only models part of the activities involved in the construction process (Koskela 1992). CPM models the "conversion" activities or activities that change resources into a product. It ignores "flow" activities, or non-value adding activities such as waiting,

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moving, or inspecting. This study models flow activities along with traditional building or conversion activities.

2.5.3.2. Schedule for MOB Case Study

A MOB construction schedule was developed using the Critical Path Method (CPM). The critical path for this concept and scenario is building the lower hulls and then assembling the grand blocks on to the module. This process is shown in Figure 2-8 and is the basis for the CPM model. The heavy lines signify the critical path and the light lines indicate simple precedence. Activity duration and the values that were used to build the CPM schedule in Figure 2-8 is shown in Table 2-12. In the CPM model the activity duration is discretely represented and does not account for uncertainty. This schedule estimate is referred to as a point estimate.

2.5.3.2.1. Lower Hulls

The lower hulls are planned to be concurrently built at the Avondale and Newport News shipyards. Once completed they are towed out to sea for column connection prior to the float over of the first grand block. The CPM model accounts for lower hull building and transportation time.

2.5.3.2.2. Block and Panel Construction

Blocks and panels that combine to form the upper hull are built, erected and assembled in groups according to the grand blocks they form. A total of thirteen shipyards were proposed to build blocks or panels and are accounted for in the lower levels of the CPM.

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2.5.3.2.3. Column and Brace Construction

Columns for this concept are built at two separate shipyards, with four built at Charleston and four built at Philadelphia. They are transported to the main block assembly site for assembly into the columns prior to assembly at sea with the lower hulls and grand blocks. The braces for this scenario could be built at the TDI Halter shipyard in Point Escatawpa, MS.

2.5.3.2.4. Erection and Assembly

The blocks are transported to Ingleside, TX for erection and assembly of the grand blocks. The grand blocks are assembled to the columns in deeper water of the Gulf of Mexico.

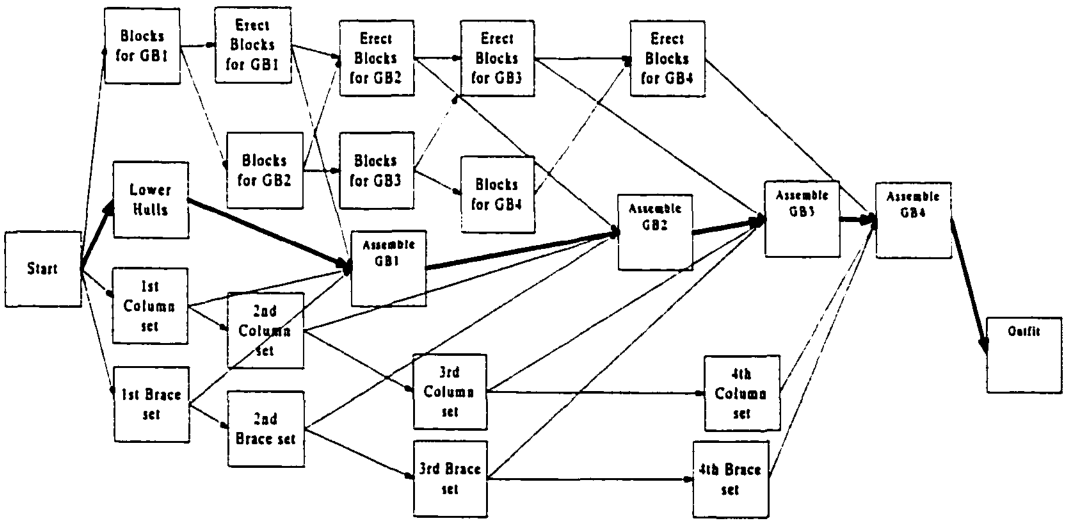

Figure 2-8. Top Level Layout of Hinged Concept with Afloat Assembly

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Table 2-12. Hinged Concept with Afloat Assembly CPM Analysis

Acti-vity ID	Activity Description	Average Duration (Months)	Predec -essor	Early Start	Early Finish	Late Start	Late Finish	Total Float
A	Lower Hulls	14	-	0	14	0	14	0
B	1st Column set	3.5	-	0	3.5	9	12.5	9
C	2nd Column set	3.5	B	3.5	7	12.5	16	9
D	3rd Column set	3.5	C	7	10.5	16	19.5	9
E	4th Column set	3.5	D	10.5	14	19.5	23	9
F	Build 1st set of 3 braces	1.5	-	0	1.5	12.5	14	12.5
G	Build 2nd set of 3 braces	1.5	F	1.5	3	15.5	17	14
H	Build 3rd set of 3 braces	1.5	G	3	4.5	18.5	20	15.5
I	Buiid 4th set of 3 braces	1.5	H	10.5	14	19.5	23	9
J	Build Blocks for GB1	3	-	0	3	5	8	5
K	Build Blocks for GB2	3	J	3	6	8	11	5
L	Build Blocks for GB3	3	K	6	9	11	14	5
M	Build Blocks for GB4	3	L	9	12	15.5	18.5	6.5
N	Erect Blocks for GB1	4.5	J	3	7.5	8	12.5	5
O	Erect Blocks for GB2	4.5	K, N	7.5	12	12.5	17	5
P	Erect Blocks for GB3	4.5	L, O	12	16.5	14	18.5	2
Q	Erect Blocks for GB4	4.5	M,P	16.5	21	18.5	23	2
R	Grand Block 1 Assembly	3	A,B,F, N	14	17	14	17	0
S	Grand Block 2Assembly	3	C,G,O, R	17	20	17	20	0
T	Grand Block 3 Assembly	3	D,H,P, S	20	23	20	23	0
U	Grand Block 4 Assembly	3	E,I,Q, T	23	26	23	26	0
V	Outfit	6	U	26	32	26	32	0

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2.5.3.3. Estimated Schedule for MOB Case Study

Using the Critical Path Method of scheduling the total construction duration for one module of the hinged concept is 32 months. The entire MOB can be built in about 8 years, assuming a schedule overlap of 50%.

2.5.3.4. Estimated Cost and Schedule for MOB Case Study

The point estimates for building the MOB case study is presented in Table 2-13. These estimates are considered point estimates because they use deterministic values to estimate the final cost or schedule estimate.

Table 2-13. Hinged MOB Construction Point Estimate

Hinged Concept	Schedule Results	Cost Results ($ million)
Module	32 (months)	767
Entire MOB	8 (years)	3,834

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3. RISK ASSESSMENT AND MANAGEMENT METHODS

Risk analysis techniques are presented in this chapter to provide background information on how existing risk techniques are used in engineering and project management.

3.1. Risk Analysis

Risk analysis is fairly well documented in the literature. Yet, in construction, project management, engineering, health and safety, environmental, business and other industries the terminology is not consistently applied. This chapter documents the risk analysis work as applied to all of these disciplines but specifically focuses on project management topics. Additionally risk engineering or the application of risk analysis to take advantage of potential cost and schedule benefits is presented.

3.1.1. Definition of Risk

The literature abounds with definitions of risk. Risk can be a somewhat ambiguous term unless its definition and convention are clearly stated. Kumamoto and Henley (1996) have identified five attributes of risk. These are likelihood, outcome, significance, causal scenario, and population. The following risk descriptions are adapted from Kumamoto and Henley (1996) and describe the

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elements of risk. Finally, a definition of risk and its convention used in this dissertation is presented.

3.1.1.1. Likelihood and Outcomes

The concept of risk is used to assess and evaluate uncertainties associated with an event. Risk can be measured as a pair of the likelihood (probability of occurrence) of an event and the outcomes (consequences) associated with the event's occurrence. This pairing is not a mathematical operation, a scalar or vector quantity, but a matching of an event's likelihood of occurrence with the expected outcome. This pairing can be represented by the following equation:

$$Risk = \lfloor (L_1, O_1)(L_2, O_2), \ldots, (L_x, O_x) \rfloor \quad (3\text{-}1)$$

In this equation L_x is the likelihood of event x, and O_x is the occurrence outcome of the event. Equation 3-1 is the generally accepted expression for risk. Risk is commonly evaluated as the product of likelihood of occurrence and the impact of an event:

$$RISK\left(\frac{Consequence}{Time}\right) = LIKELIHOOD\left(\frac{Event}{Time}\right) \times IMPACT\left(\frac{Consequence}{Event}\right) \quad (3\text{-}2)$$

In the above equation, the likelihood can also be expressed as a probability. In this evaluation of risk one may also think of risk as an uncertainty associated with a particular damage or loss.

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3.1.1.2. Consequence Significance

The significance of each risk consequence must be evaluated in terms of an amount of gain or loss. For example the significance of a consequence may be measured in dollars lost, days delayed, or fatalities. The significance varies directly with the amount of loss or inversely with the amount of gain. A utility is a measure of this significance. A risk profile for several alternatives that includes a utility is defined as:

$$\text{Risk} \equiv [(L_x, O_x, U_x), x = 1, \ldots, n] \qquad (3\text{-}3)$$

Where U_x is the utility for an event x. This representation of risk indicates a dependence of the significance of the consequence.

3.1.1.3. Causal Scenario

The probability as well as the outcome significance can be evaluated when a casual scenario for the outcome is defined. Risk in this case can be defined as:

$$\text{Risk} \equiv [(L_x, O_x, U_x, CS_x), x = 1, \ldots, n] \qquad (3\text{-}4)$$

Where *CSx* is the casual scenario that specifies 1) causes of outcome O_x and 2) event propagation for the outcome. This representation of risk shows a dependence on the causal scenario developed as part of a risk assessment.

3.1.1.4. Population

The population affected by a risk is also an important attribute when considering risk. Thus a risk may be written as:

$$\text{Risk} \equiv [(L_x, O_x, U_x, CS_x, PO_x), x = 1, \ldots, n] \qquad (3\text{-}5)$$

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Where PO_x is the number of people affected by the risk. This risk has also been referred to as societal risk.

3.1.1.5. Risk Definition Used

This dissertation will use the common definition of risk as a pair of the probability of occurrence (likelihood) of an event, and the consequence (outcome) associated with the event's occurrence. This pairing can be represented by the following equation:

$$Risk \equiv [(P_1, C_1),(P_2, C_2),\ldots,(P_x, C_x)] \quad (3\text{-}6)$$

In this equation P_x is the occurrence probability of event x, and C_x is the occurrence consequences or outcomes of the event.

This definition is used because of its application to the project management field. The term probability is used because it frequently is used to express the likelihood of an occurrence in project management literature (PMI 1996) and (AACE 2000). The consequences of a risk event in the project management field will most likely be in terms of dollars, the significance of which is self-evident. Casual scenarios are best suited for accident or fault scenarios and thus are not typically used in project management. Finally, populations are not normally affected by the risk presented in project management.

3.1.1.6. Risk Profiles

A plot of occurrence probabilities and consequences is called the Farmer curve (Farmer 1967). An illustrative example of a Farmer curve comparing the risk of

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construction with and without a constructability program is shown in Figure 3-1. Constructability is defined as the optimum use of construction knowledge in planning, design, procurement and field operations to achieve overall project success (CII 1986). Studies have shown that constructability programs reduce the costs and schedule of a construction project (Kartam 1996) and (Russell and Gugel 1993). As shown in Figure 3-1 a construction project without a constructability program is riskier than one with a constructability program. For a given occurrence probability the consequences in terms of dollars are greater for a project without a constructability program.

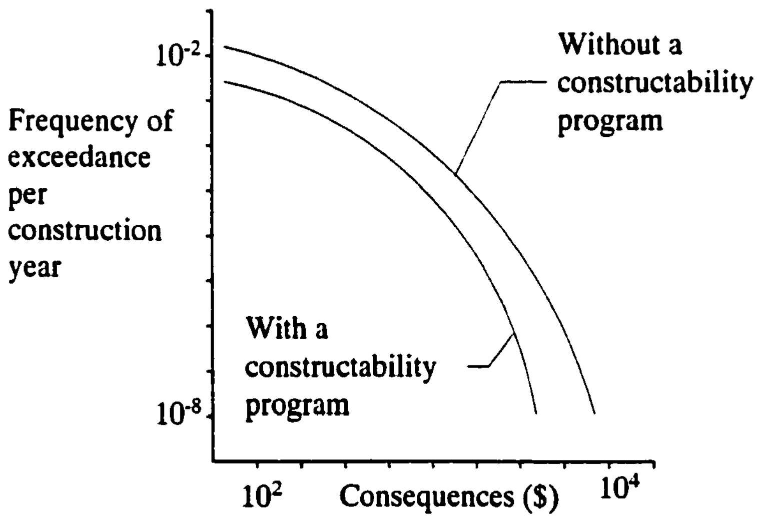

Figure 3-1. Effect of Constructability Program on Risk

Risk is time dependent. Risk profiles that graph risk versus time can show the level of risk changes as a function of time. For example, consider the nuclear waste clean up program at the Hanford nuclear reservation in Washington State. The US Department of Energy is embarked on a 30-year, $50 billion effort to clean up waste

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leftover from the cold war production of nuclear weapons (Seattle Post Intelligencer 2000b). An audit by the US Environmental Protection Agency found that there are at least 1 million gallons of highly radioactive wastes in 67 single walled storage tanks. These tanks were built from the 1940's to 1960's and were designed to last about 20 years. The clean up project has had significant schedule delays due to lack of funding, contractor failings, and lax enforcement. The audit also states "the delays in cleaning up the waste has significantly increased the risk of leaks from old tanks into groundwater or air." The risk of a radioactive exposure to the environment will increase with time due to the higher probability of a storage tank failing. This risk profile is represented in Figure 3-2.

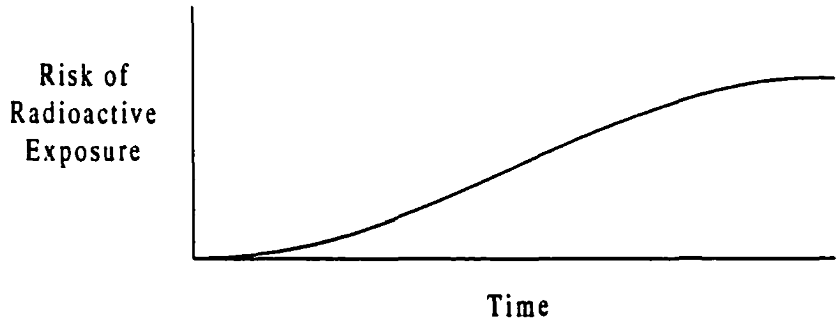

Figure 3-2. Increased Risk as a Function of Time

An expression for risk as a function of time is as follows:

$$\text{Risk}(t) = [P(t), C(t)] \qquad (3\text{-}7)$$

Where t is time and $P(t)$ is probability as a function of time and $C(t)$ is consequence as a function of time.

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3.1.1.7. Risk Classifications

The risk for a system results from the interaction of natural hazards with that system, aging and degradation of the system, and human and organizational factors. Consequently, risk can be classified as voluntary or involuntary, depending on whether or not the events leading to the risk are under the control of the persons at risk, respectively. Society, in general, accepts a higher level of voluntary risk than involuntary risk. For example, people generally accept a higher level of risk by driving a car rather than flying because they are in control of the vehicle. The losses associated with events can be classified as reversible or irreversible such as property and human losses, respectively. Consequences can also be classified by type such as; economic, human, environmental, loss of goodwill and negative publicity. Other classifications of risk are documented in the literature (Wilcox et al. 1996), and (Kumamoto and Henley 1996).

Construction risk can be viewed as above and has physical or capability related aspects (Zack 1997). Where physical risks are those events that prevent one from completing the project or increase the costs and schedule such as acts of God, weather, impracticability, or other things that are beyond the control of the project team. Capability related risks are those that interfere with performing the work but management has a choice in minimizing the risk such as poor quality, safety and equipment selection. These risks have also been classified by the Project Management Institute (PMI) (1996) as: external (uncontrollable) or internal (controllable). This research will use the PMI definitions.

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3.1.1.8. Uncertainty

Central to the concept of risk is the uncertainty associated with the probability and consequence of a risk event. From Ayyub and McCuen (1997) this uncertainty has two types of origins attributed to ambiguity, non-cognitive and cognitive. The non-cognitive uncertainty results from physical randomness, use of limited information, and model uncertainties due to simplifying assumptions. This type of uncertainty can be dealt with by employing current statistical and probabilistic science. Cognitive types of uncertainty result from humans expressing subjective judgements. This uncertainty may be modeled using a fuzzy set theory approach. This type of uncertainty is acknowledged as existing but is considered out of the scope of this research. The reader is referred to Blair (1999) for a dissertation on using a fuzzy set theory approach for the development of costs and schedules for complex engineering systems.

Kumamoto and Henley (1996) describe a risk profile as having "meta-uncertainty". In a risk assessment there are two types of meta-uncertainty one for the uncertainty associated with the probability of an event's occurrence and the other type associated with the consequence of the event's occurrence.

Suffice it to say uncertainty exists in the modeling and project management of a complex structure. This uncertainty is due to the model representing a real system and is also attributed to the humans that express risk in subjective terms. This uncertainty must be recognized and tracked from inception to completion of a project to ensure any changes in a risk profile are understood.

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3.1.2. Risk Engineering

Complex construction projects involve substantial cost and schedule risk. From a business perspective construction is an inherently risky venture. For example, the first contractor to attempt to build Seattle's Kingdome, the largest concrete arch supported roof sports stadium ever built, went bankrupt due to technical, cost, and schedule problems. Yet, the rewards for working in a high-risk industry are the potential for greater profits. The contractor that finished the Kingdome project has gone on to become a very large and profitable contractor in the greater Seattle area. This implies that risk also has opportunities for improvements and financial or competitive advantage.

Risk as defined earlier and in the literature (Kumamoto and Henley 1996) is generally thought of as only the possibility of suffering harm or typically resulting in negative consequences. In project management the project team should maximize the results of positive events and minimize the consequences of adverse events (PMI 1996). Thus, in a project management context, risk should also be thought of as being concerned with opportunities or potential gain as well as threats or negative consequences.

Similarly in Wang and Roush (2000) they introduce the term "Risk Engineering" as follows: "The field of risk assessment has generally focused upon the quantification of the risks associated with a range of negative consequences. We differentiate risk engineering as a subject that addresses the broader topic that includes positive as well as negative consequences." Later in their book Wang and Roush (2000) refer to risk management as: "This management can help to limit the potential

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for negative consequences arising from these uncertainties and maximize the possibilities that results will be better than the target values." These definitions and descriptions that allow project managers to also take advantage of the potential gains or opportunities from identified risk events will be used in this dissertation. This research will include the concepts of risk engineering as presented by Wang and Roush (2000) as an integral part of risk analysis.

3.1.2.1. Opportunities

In practicing risk engineering, consequences are viewed as having a positive or a negative consequence. From the Association for the Advancement of Cost Engineering (AACE), opportunities are defined as uncertain events or scenarios that have a probability of producing a favorable result or improve the probability that a desired outcome will happen (AACE 2000). Negative risk is viewed as having consequences that adversely effect a project's cost. Opportunistic risk is viewed as having the potential to improve or lower the project's cost.

3.2. Principles of Risk Analysis

Risk analysis is a systematic process of evaluating a risk at the systems level. There is a consensus within the technical community that a comprehensive risk analysis consists of risk assessment, risk management, and risk communication (National Research Council 1983) and (Karaszewski 1998). Risk assessment is the process of identifying and evaluating areas of risk. Risk management is the act or practice of dealing with or controlling this risk. Risk communication is the process of

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documenting and exchanging information about the results of risk studies to various interested parties. These aspects of risk studies are described under subsequent sections. The objective of introducing these concepts is to prepare and familiarize users and readers of risk terminology, thereby enhancing their understanding of risk analysis.

A classic risk analysis process is shown in the upper tiers of Figure 3-3. A slight modification to this is the addition of risk engineering. Risk engineering adds to both risk assessment and risk management a broader scope to accommodate potential oppurtunities for gain as well as the potential losses due to a risk event. The dotted box, risk engineering, in Figure 3-3 is shown to highlight the application of risk enginering as a backdrop to risk assessment and management.

A risk analysis delivers construction specific items as shown in the lower tier of Figure 3-3. The formation of a construction plan or strategy along with initial cost and schedule estimates is completed as part of a risk analysis. A final and comprehensive risk assessment can be performed through simulation. Risk management is also developed through modeling techniques that allow various scenarios to be simulated for an understanding of "What ifs" and how risk may be changed or be minimized. During the construction execution phase a risk management plan will help project managers control risks. Risk communication is the exchange of information obtained during the risk analysis. This communication may be among project team members or with the public.

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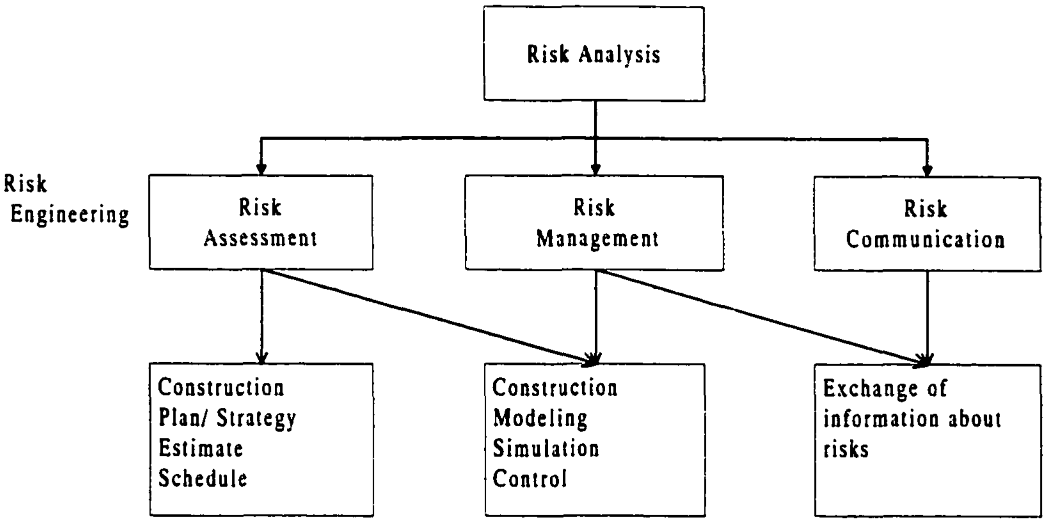

Figure 3-3. Construction Risk Analysis

3.2.1. Risk Assessment

Risk assessment is a technical and scientific process by which the risk of given situations for a system are modeled and quantified. Risk assessment provides qualitative and quantitative data to decision-makers for later use in risk management.

The risk assessment process attempts to answer the following three questions: (1) What can go wrong? (2) What is the likelihood that it will go wrong? (3) What are the consequences if it does go wrong? These questions are derived from Kaplan (1991). In order to perform risk assessments, several methods have been created to help answer these questions. Each of these methods is suitable in certain stages of a system's lifecycle. The characteristics of these methods are shown in Tables 3-1 and 3-2 as adapted from Wilcox et al. (1996). Kumamoto and Henley (1996) describe other methods for reliability, consequence analysis and assessment.

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Table 3-1. Qualitative Risk Assessment Methods

Safety/ Review Audit
Identify equipment conditions or operating procedures that could lead to a casualty or result in Property damage or environmental impacts.
Checklist
Ensure that organizations are complying with standard practices.
What-If
Identify hazards, hazardous situations, or specific accident events that could result in undesirable consequences.
Hazard and Operability study (HAZOP)
Identify system deviations and their causes that can lead to undesirable consequences. Determine recommended actions to reduce the frequency and/or consequences of the deviations.
Preliminary Hazard Analysis (PrHA)
Identify and prioritize hazards leading to undesirable consequences early in the life of a system. Determine actions to reduce the frequency and/or consequences of prioritized hazards.
Risk Assessment Matrix Tables
Frequency and consequences qualitatively described, yet risk is described quantitatively.
Analytic Hierarchy Process (AHP)
Asses risk by quantifying subjective information in a systematic manner.
Consequence Assessment and Cause Consequence Diagrams
Assess consequences and scenarios leading to them.
Expected Monetary Value (EMV) using the Delphi Technique
Collects expert opinion without allowing for individual expert contact.
Influence Diagrams
Diagrammatically represent sources and possible responses to risks.

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Table 3-2. Quantitative Risk Assessment Methods

Simulation
Imitate the operation of a process or system over time, space, or operation cycles.
Failure Modes and Effects Analysis (FMEA)
Identifies the components (equipment) failure modes and the impacts on the surrounding components and the system.
Fault Tree Analysis (FTA)
Identify combinations of equipment failures and human errors that can result in an accident.
Event Tree Analysis (ETA)
Identify various sequences of events, both failures and successes that can lead to an accident.
Success Tree Analysis
Model functions needed in order for system to perform properly.
Accident Progression and Frequency Analysis
Identify the initiating events, their frequency and a systems failure path.
Common Cause Scenarios
Identify seemingly unrelated failures that occur due to a common cause of events.
Sensitivity Factors
Importance factors are applied to systems or components that greatly lead to failure scenarios.
Fuzzy Stochastic Applications
Fuzzy logic and set theory is applied to linguistic terms.
The Risk Premium
Uses contingencies to allow for unforeseen conditions.
Expected Monetary Value (EMV) and Expected Net Present Value (NPV)
Incorporates probability cost assessments and the time value of money.
Risk Adjusted Rate of Return
Adjusts alternatives minimum attractive rate of return depending on alternatives of risk.
Stochastic Dominance
Involves visual inspection of alternative statistics.

Risk assessment for construction projects can be performed by comparing the resource requirements needed to build the projects to the existing industrial capacity and by performing simulations of the construction processes. These techniques highlight the critical areas and bottlenecks of the construction scenarios. When data does not exist or is unavailable, a construction risk assessment can be made in qualitative terms. Where data exists or can be obtained, the risk assessment is

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quantitative. The risk assessment then considers deviations from these construction scenarios that can lead to undesirable or positive consequences. The consequences can be described in terms of adverse or positive impacts to a project's cost and/ or schedule.

The selection of a qualitative or quantitative method depends upon the availability of data for evaluating the hazard and the level of comfort of those analysts that are performing the risk assessments. For example, if plenty of statistical data is available for the particular assessment a quantitative assessment will normally be made. Conversely, if the only data available is incomplete or not directly applicable a qualitative assessment will normally be made.

The methods shown in Table 3-1 and Table 3-2 are divided into how the risk is determined by qualitative or quantitative analysis. The following sections highlight some risk assessment techniques that may be the best suited for use in construction project risk assessment.

3.2.1.1. Qualitative Risk Assessment

Qualitative risk analysis uses expert opinion to evaluate the probability and consequence of a hazard's interaction with a system. Safety review/ audit, checklist, what-if, Hazard and Operability study (HAZOP), Preliminary Hazard Analysis (PrHA), risk assessment matrix tables, Analytical Hierarchy Process (AHP), consequence assessment and cause consequence diagrams, Expected Monetary Value (EMV) using the Delphi technique and influence diagrams are normally considered qualitative techniques. Safety review/ audit, checklist, what-if, HAZOP, PrHA, and

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consequence assessment and cause diagrams are concerned mainly with preventing a mishap or hazard that could lead to an undesirable consequence. Since this research is concerned with both positive and negative risk consequences these will not be discussed further as potential risk assessment tools. EMV monetary value using the Delphi technique may be better suited for decision analysis application because its utility is the ability to select between different alternatives this is discussed later in the chapter. Risk assessment matrix tables, AHP and influence diagrams are particularly suited to project management and are discussed in the following sections.

3.2.1.1.1. Qualitative Risk Assessment Matrix Tables

This method of risk assessment qualitatively describes both the likelihood of occurrence and consequences of an event. Similarly this method can be applied to quantify the effects of a favorable event. From the combination of these two terms a quantitative risk assessment is derived. The quantified risks for various scenarios can be used to perform comparisons among scenarios. The National Aeronautics and Space Administration (NASA) has used risk assessment matrixes to avoid the problem of managers treating the values of probability and risk as absolute judgements (Wiggins 1985). The offshore industry has used risk matrix tables on complex, highly technical, and expensive hydrocarbon development projects for risk assessment (Curole 1997). The Department of Defense offers the use of risk assessment matrixes as a tool to prioritize risk (Defense Acquisition University 1998). Qualitatively, the likelihood of occurrence and consequences of an adverse scenario may be described as shown in Tables 3-3 and 3-4, respectively. Levels of occurrence may be based on

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expert elicitation or actual probability data. Table 3-4 has two categories of consequences, cost and schedule, others such as technical performance, and impact to others could be added.

Table 3-3. Likelihood of Occurrence

Level	Description
A	Improbable, minimal, remote , can assume occurrence will not happen
B	Unlikely, small, yet possible over the life of a program
C	Occasional, likely to occur over life of program
D	Probable, highly likely, will occur at least once over the life of a program
E	Frequent, likely to occur more than once over the life of a program

Table 3-4. Consequences

Description	Schedule	Cost
I. Negligible	Minimal or no impact	Minimal or no impact
II. Acceptable	Milestones slip, use float to recover overall schedule	< 5% growth
III. Marginal	Some critical path items impacted that results in minor delays	5-10 % growth
IV. Critical	Major and lengthy delays to a critical path item	10-15 % growth
V. Catastrophic	Multiple delays to critical path items that result in multiple and lengthy delays	> 15 % growth

The consequences described in Table 3-4 are expressed in terms of schedule delay and cost escalation. These may be determined by using expert elicitation. A better method to quantify the consequences is to develop estimates for the number of the days delayed or dollar value of the cost escalation. The number of days delayed can be found by comparing the original planned schedule to the current planned schedule. The cost escalation can be calculated by using standard estimating procedures.

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The above tables are combined to form the risk matrix. Risk assessment is based on the pairing of the likelihood of occurrence and consequence. Table 3-5 shows this pairing and is considered the risk assessment matrix.

Table 3-5. Risk Assessment Matrix

Likelihood level	Consequence level				
	I	II	III	IV	V
A	1	2	4	8	10
B	3	4	8	13	14
C	5	6	12	16	18
D	7	8	16	20	22
E	9	10	21	24	25

Risk Index	Suggested Criteria
1-5	Acceptable
6-10	Acceptable - with review from management
11-19	Undesirable - decision required
20-25	Unacceptable - alternative solution required

As shown in Table 3-5, a list can be developed that prioritizes and categorizes risk. From this list, attention can be focused on the appropriate areas and system changes, or suggestions are developed. Similar tables can be developed that represent opportunistic risk and positive consequences.

Risk assessment matrixes may be particularly suitable to the construction industry because they can rely on "semi-quantitative" data. Due to the uniqueness of each construction project specific data may not be available, therefore risk probability and consequences may only be approximately described in relative terms. Additionally, construction is typically fast paced once funding is arranged and a quick, yet effective, method of quantifying risk is needed. A risk assessment matrix could

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quickly and inexpensively provide owners, contractors, project managers, and others with an acceptable quantification of risk.

3.2.1.1.1.1. Risk Profiles for Risk Assessment Matrix Tables

Risk assessments found with risk assessment tables may also be shown graphically as qualitative risk profiles. As shown in Figure 3-4 a risk event may be shown as representing a specific risk quadrant. This graphical display shows how the movement of a particular risk event to a different quadrant will change the risk rating. For example, in Figure 3-4 lowering the likelihood, consequences, or both can lower the risk of the event shown.

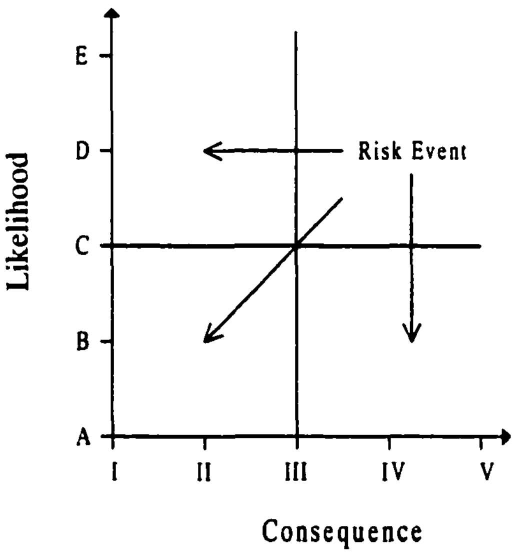

Figure 3-4. Risk Profile of a Qualitative Risk Event

The use of similar graphs to chart risk changes and the direction of movement over time is particularly useful to management. A risk event could be shown over time as moving in one of the directions as shown in Figure 3-4, thus less time and resources need to be devoted to this particular event. Conversely, if the risk event

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were shown to be moving to the upper right management attention would be required to reduce the risk.

3.2.1.1.2. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is generally considered as a decision analysis tool but its applicability as a risk assessment tool has been shown (Mustafa and Al-Bahar 1991).

AHP allows for a decision-maker or a group of experts to perform pair-wise comparisons of criteria to develop the overall priorities or assessments. These comparisons are generally stated verbally, such as "criterion X is less than, equal to, better, or much better than criterion Y." These verbal statements are converted to numerical values by using a table and a numeric weighting is derived. Applying matrix algebra, the alternative choices or assessments that best meet the identified criteria are calculated.

3.2.1.1.3. Influence Diagrams

Influence diagramming involves planning the project, identifying the sources of risk and possible responses to these risks. This information is then presented diagrammatically as arrows connecting geometric shapes. The shapes represent uncertainties and the arrows represent dependencies and information flows. The main advantage of influence diagrams is that the relationship between risk sources and activities in the project can be clearly seen. Being able to see these relationships makes it easier for planners to identify effective responses to these risks.

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In terms of the amount of time and resources it takes to perform a risk analysis, the method of using influence diagrams is considered relatively inexpensive (Smith 1999). The influence diagramming technique requires consideration of the entire project. This information is then displayed in a simple and graphical manner. This technique is suited for construction projects that can be divided into a few major activities and where alternative strategies are being considered (Jeljeli and Russell 1995).

3.2.1.2. Quantitative Risk Assessment

Quantitative analysis relies on statistical methods and databases that determine the probability and consequence of an event. The simulation, Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), success tree, accident progression and frequency analysis, common cause scenarios, sensitivity factors, fuzzy stochastic applications, risk premium, EMV and expected Net Present Value (NPV), risk adjusted rate of return, and stochastic dominance are generally considered quantitative risk assessment techniques. Due to their potential application to the project management field this research describes the application of simulation, FTA, fuzzy stochastic applications and expected NPV in the following sections.

3.2.1.2.1. Simulation

Ang and Tang (1984) define simulation as the process of replicating the real world on a set of assumptions and conceived models of reality. Simulation is the imitation of an operation of a process or system over time or production cycles.

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Simulation is normally used to represent a large, complex, non-existent process or system because it is much less expensive to experiment with a model than the real system. The purpose of simulation is to understand the behavior of a process or system as it evolves and understand the system's behavior under various alternative scenarios. The assumptions made in building the simulation model can be changed to investigate "what if" questions about the real system or process. Simulation is particularly useful to study systems in the design stage, because it is a good tool for predicting the performance or cost of something that has not been built.

Simulation can be of continuous random variables or discrete events. Continuous simulations attempt to quantify the changes in a system over a period of time in response to controls. Examples are weather and flight simulators. Discrete Event (DE) simulation is defined as "the modeling of a system as it evolves over time by a representation in which state variables change instantaneously at separate points in time" (Law and Kelton, 1991). In other words the system changes instantaneously in response to discrete events. For example, simulating the process of parts being manufactured with the discrete steps of: an order arrives at a plant, material is delivered, multiple step manufacturing process, inspection, then shipping to the customer. At each point in the process the variables change, i.e., from raw material to finished product.

Simulation is used as a tool in decision making. A simulation is typically developed to determine a system's performance under alternative methods or environments, with the objective of optimally designing a system. When applied to project or construction risk assessment, DE simulation can be used to analyze

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construction processes and activities. A construction simulation, built on potential construction scenarios will identify "risky" scenarios, resource constraints, and potential bottlenecks. Additionally, using probability distributions to model uncertainties in the underlying basic random variables, DE simulation can be used to statistically assess possible outcomes of cost and schedule. A construction simulation model can account for sequences, construction times, facilities, materials, transportation, labor and equipment.

Simulations are typically performed on a computer due to the large volume of calculations and dependencies required. Advances in computer technology has made simulation easier to use and much more applicable to complex problems. Several off the shelf simulation software programs are available that are conducive to simulate construction projects.

3.2.1.2.1.1. Construction Simulation

Simulation has been used to analyze a large variety of systems. Simulation is a relatively new science having come of age with the advent of the computer (Law and Kelton 1991). It has been applied to construction, manufacturing, public health, transportation, business process reengineering and a host of other industries (Banks et al. 1996). Simulation is particularly suited to construction because it allows experiments in construction operations to evaluate potential impacts or improvements to cost and schedule (Halpin 1977) and (Halpin and Senior 1998).

The purpose of simulation is to understand the behavior of a process or system as it evolves and understand the system's behavior under various alternative scenarios.

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The assumptions made in building the simulation model can be changed to investigate "what if" questions about the real system or process. Simulation is particularly useful to study construction CPM schedules in the planning stage because it is a good tool for predicting the performance or cost of something that has not yet been built. A construction planner may investigate the effects of accelerating certain activities of a construction project by simulating the CPM and performing "what if" drills. For example Woodward (1992) simulated the CPM and found that if the mechanical and electrical portions of the work could be accelerated the commissioning of a plant could start earlier than scheduled. This allowed a plant to come on line earlier than originally planned.

Likewise, simulation can be used to forecast a project's costs. The estimate for each activity is modeled and the uncertainty of the estimate is represented by a probability distribution. As new information becomes available during the life of a project the model can be updated to provide a better simulation of the final costs.

Simulation is also well suited to calculate the consequences of a potential risk event. A given risk source may potentially result in a cost escalation. For example, an environmental concern when building on former industrial sites is uncovering unknown contaminates. The consequences of finding a previously unknown containment are schedule delays and cost escalations. The schedule delays and cost escalations can be easily approximated through the use of simulation.

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3.2.1.2.2. Fault Tree Analysis

Complex systems are often difficult to visualize and the effect of individual components on the system as a whole is even more difficult to evaluate. Two methods of modeling that have greatly improved the ease of assessing system reliability are fault trees and success trees. Fault Tree Analysis (FTA) uses the probability of failure for independent components coupled with the logic that relates the individual components to the ability of the system to function to determine the overall system's reliability. A simple example of this type of modeling is two pipes with two different probabilities of failure connected in series. If the goal of the system is to maintain water flow from one end of the system to the other, then the individual pipes can be related with a Boolean "AND" gate. Since the pipes are connected in series, both pipe #1 and pipe #2 must function for the system to meet its goal. The goal of fault-tree modeling is to determine every point in the logic of a system that might fail. Once these fault nodes have been defined, it is possible to follow all the possible failure scenarios of a system.

Fault tree analysis requires the development of a tree-looking diagram for the system. Therefore, the tree shows failure paths and scenarios that can result in the occurrence of a top event. The construction of the tree should be based on the building blocks and the logic gates. An illustrative example of the reliability of a piping system using fault tree analysis is presented in Ayyub and McCuen (1997).

The outcome of interest from the fault tree analysis is the occurrence probability of the top event. Since the top event was decomposed into basic events, its occurrence can be stated in the form of "AND," and "OR" of the basic events. The

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resulting statement can be restated by replacing the "AND" with the intersection of the corresponding basic events, and the "OR" with the union of the corresponding basic events. Then, the occurrence probability of the top event can be computed by evaluating the probabilities of the unions and intersections of the basic events. The dependence between these events affects the resulting probability.

For large fault trees, the computation of the occurrence probability of the top event can be difficult because of their size. In this case, more efficient approaches need to be used for assessing the reliability of a system, such as the minimal cut set approach. According to this approach, each cut set is defined as a set of basic events where the joint occurrence of these basic events results in the occurrence of the top event. A minimal cut set is a cut set with the condition that the non-occurrence of any one basic event from this set results in the non-occurrence of the top event. Therefore, a minimal cut set can be viewed as a subsystem in parallel to other potential failure paths. In general, systems have more than one minimal cut sets. The occurrence of the top event of the system can, therefore, be due to any one of these minimal cut set. As a result, the system can be viewed as the union of all the minimal cut sets for the system. Ayyub and McCuen (1997) present an example of this minimal cut set approach to determine the reliability of a piping system.

3.2.1.2.2.1. Fault Tree Analysis Applied to Construction

Fault tree analysis can be applied to model construction systems and process. The analysis provides failure probabilities at the system level that are needed for assessing the risks involved in a construction project, e.g., safety, subcontractors

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ability to deliver on time, equipment reliability and production, costs and schedules associated with construction activities. The risk analysis could guide project managers to strategies that should reduce the overall risk. However, since typical construction projects are unique with similar but different values or magnitudes of probability and consequences of risk, this method is cumbersome to apply to the typical and especially a complex project. In Bender (1998) it was found that fault tree analysis when applied to a construction project requires the use of probability data that may be highly subjective. The results could be misleading because of requirements to make several simplifying assumptions and the reliance on hard probability data that was subjectively obtained. This study does point out the benefits of the initial steps of performing a FTA such as hazard definition, defining initiating events, and scenario development. These steps are beneficial to the project team because they highlight areas of risk that may require additional attention.

3.2.1.2.3. Fuzzy Stochastic Applications

Chao and Skibniewski (1999) state that the idea of fuzzy sets and logic is that an artificial logic system can be developed to emulate the linguistic way humans think and judge, yet achieve consistency by following accountable rules. Fetz et al. (1999) found that the power of fuzzy set theory is that it allows a formalization of vague data, a representation of their fuzziness that can be entered into computation and a possibility theoretic interpretation.

In order to account for qualitative factors that affect the project and cognitive or vague uncertainty, fuzzy logic and set theory can be applied. Fuzzy based cost

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estimating and scheduling enables planning experts to describe a project with approximate cost and time data. Many cost and scheduling problems can be simulated and managed by fuzzy inference systems as long as the logic interactions are known. This is possible because fuzzy logic provides a way to compute with words composed of fuzzy IF-THEN rules. Fuzzy logic thus provides a means of performing linguistic computations to quantify risk.

One of the basic ideas of fuzzy logic is that any statement employed in reasoning will have a corresponding confidence level. Fuzzy logic also provides rules for the truth of complex statements. For example, in predicting a project activity duration by eliciting opinions from various managers statements such as experience is approximately greater than 5 years AND training is HIGH may be obtained in relation to staffing requirements for a specific activity. The confidence in such a statement involving AND is the minimum of the confidences in the individual statements which make up the complex statement. If the complex statement involves OR, such as experience is approximately greater than 5 years OR training is HIGH, the confidence in the complex statement is the maximum of the confidences in the individual statements.

Fuzzy sets and logic can be used to capture qualitative domain expert opinion for an achievable and affordable schedule and budget. Although this technique cannot substitute for deterministic scheduling and costing methods, it does complement the set of modeling methods thus enabling a better and more extensive risk assessment in cases of vague and incomplete project information. The use of expert opinion to

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model a construction simulation using a fuzzy stochastic technique can be performed by following the steps below which are laid out in the Figure 3-5.

1. Collect and input subjective information.
2. Quantify subjective information using fuzzy sets.
3. Estimate various parameters of distributions, including maximum and minimum values, and the mean and variances of the parameters.
4. Examine graphical display of distributions. The fitted distribution is affected by selection and membership values of the linguistic variables. If fit is unsatisfactory, update estimated parameters.
5. From satisfactory fit obtain stochastic estimate of the duration.
6. Input results into simulation module.

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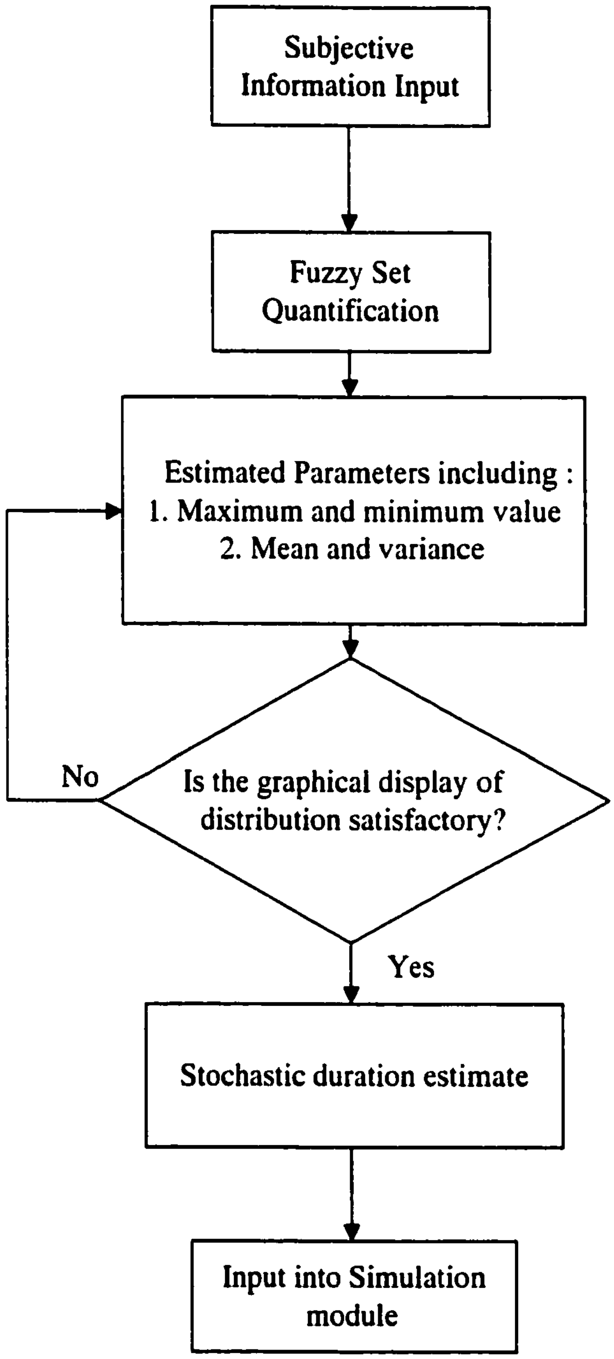

Figure 3-5. Fuzzy Stochastic Application (Blair 1999)

Several problems associated with uncertainty in the construction management field have applied a fuzzy set theory methodology. Most applications apply to estimating the cost (Paek et al. 1993), developing a risk-based cost and schedule

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(Blair 1999), developing the schedule (Ayyub and Haldar 1983), or performing risk-based decision-making (Ayyub and Haldar 1985) and (Blair et al. 2000). The use of fuzzy theory is particularly suited to construction issues because of a lack of hard data and the propensity of construction professionals to express uncertainties and risk factors in linguistic terms rather than mathematical expressions.

A risk profile may be developed through a combination of both fuzzy stochastic techniques and typical quantification of hard data. The fuzzy techniques are well suited to assess the probability of an event. The consequences of the event may be calculated through the use of historical or published cost data. For example, it may be difficult to express the probability of a serious construction accident in crisp terms. Based on the type of work and working conditions, experts could easily quantify the probability of a serious accident in linguistic terms. Through the use of fuzzy techniques these terms could be used to express a probability. The consequence of a serious accident in term of increased insurance rates is easily calculated in monetary terms based on published rates from private and public insurance carriers.

3.2.1.2.4. Expected Net Present Value (NPV)

A NPV analysis is typically considered as a decision tool but sometimes, as a secondary purpose, it is used as a risk analysis to "prove" to management that a particular project is worthy of funding because all risks have been taken into account (Wang and Roush 2000). This analysis generally considers the time value of money and cost associated with the risks or alternatives. Typically five factors are considered in the analysis: capitol investment, operation and maintenance cost, interest rates,

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length of time and salvage value. By using probabilistic terms to represent the uncertainty of these factors a cost risk assessment may be performed. Since NPV is generally thought of as a decision tool, formulas and typical expressions for NPV analysis are presented later in the chapter under the decision analysis section.

The use of NPV can also be used to calculate the consequences of a risk event. This method is particularly suited when the consequences are in monetary terms. For example, when considering either leasing or purchasing equipment the consequences of this decision are expressed in monetary terms. One of the major factors to consider in this decision is the time value of money. A NPV analysis provides the necessary technique to account for this cost. In a risk based analysis the variables that effect this decision can be expressed as a range, probability distribution, or simulated.

3.2.1.3. Methods for Assessment of Probabilities and Consequences

Several methods exist to document the assessment of probabilities and consequences. These may be objective methods that provide an exact percentage or dollar value or they may be subjective and based on a verbal representation such as rare or expensive.

3.2.1.3.1. Objective Methods for Assessment of Probabilities and Consequences

In a perfect risk scenario an objective assessment of probabilities and consequences can be exactly determined (Kumamoto and Henley 1996). Therefore, the best method of establishing associated probabilities and consequences is through the use of representative data that can be used to develop exact probabilities or consequences. This is typically difficult in the construction industry because each

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project is unique in form, function and the humans that build it. Databases for construction projects may be available from in-house (company specific), governmental agencies, such as the Bureau of Labor Statistics (BLS), come from industry sources, such as R.S. Means (R.S. Means 1999) or published in academic literature.

3.2.1.3.1.1. In-house Databases

In-house historical databases are probably the best source of data to assess the probability of an occurrence or consequence of a risk event. However, in many cases these databases are inadequate, unavailable, or supplemented with personal knowledge (Al-Bahar and Crandell 1990). These databases are company and project specific and should not be uniformly applied to new projects.

3.2.1.3.1.2. Governmental Databases

The governmental data is generally overly broad and may be used to gage or forecast overall trends. For example, the number of accidents per thousand hours of work can be obtained from BLS and broken out by specific industry (Ayyub et al. 1999b). Yet, this data is difficult to apply to a specific construction project to assess probabilities of occurrence or consequences of an event because the data considers all types of construction, from residential, road building, heavy civil, to large commercial developments.

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3.2.1.3.1.3. Industrial Databases

Industrial databases focus on the cost of construction. Specific risk events are not individually expressed but are accounted for in the productivity and cost rates quoted. For example, R. S. Means (1999) and others publish construction cost data that is representative of an average cost taken from various projects and locations across the United States. These average values include the effects of risk events but the assessment of probabilities or consequences is not discernable.

3.2.1.3.1.4. Statistics Reported in the Literature

Statistics that are reported in the literature can be used after a careful examination for their applicability to the system under investigation. However, this data is generally very broad and is best suited for understanding and developing trends (Kangari 1995).

3.2.1.3.2. Subjective Methods for Assessment of Probabilities and Consequences

In risk assessment, the methods of probability theory are used to represent engineering uncertainties. However, uncertainty is a vague concept. It refers to events that occur with periodic frequency, such as demands on a piece of equipment, yet also to conditions which are existent but unknown, such as cracks or defects in a weld. It applies to the magnitude of an engineering parameter, yet also to the structure of a model. By contrast, probability is a precise concept. It is a mathematical concept with an explicit definition. The mathematics of probability theory is used to represent uncertainties, despite that those uncertainties are of many forms. The issue of the

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vagary of uncertainty versus the specificity of probability is particularly significant in the discipline of project management. Thus, subjective methods are better suited for the assessment of risk in project management.

In certain situations the application of standard probability distributions may appropriately represent the risk assessment. This technique requires an application of personal knowledge or documented research of both the probability distribution application and the system being represented. Although the results are expressed in terms of hard numbers the selection of appropriate probability density functions and their corresponding range and shape functions requires an application of professional judgement.

Expert elicitation is a valid method to develop risk assessments. Expert elicitation is a formal process of obtaining assessment probabilities and consequences when the information is subjective. The expert elicitation process must be systematically structured and could use a participative method, Delphi or modified Delphi technique, to quantifying the assessment probabilities and consequences.

3.2.1.3.2.1. Expert Elicitation Using a Participative Process

Expert elicitation is a formal process of obtaining information or answers to specific questions about certain issues where the information is highly subjective and lacking. This process is used by other industries. The description of expert elicitation herein was adapted from Ayyub (1992 and 1993). The expert elicitation process consists of the following steps:

1. Selection of issues.

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2. Selection of experts.
3. Issue familiarization of experts.
4. Training of experts.
5. Elicitation of experts about the issues.
6. Aggregation and presentation of results.
7. Discussion and revision by experts.
8. Revision of results and reporting.

The first three steps should be performed prior to a face-to-face meeting of the experts. Steps four through seven should be performed during the meeting. The last step can be performed after the meeting. These steps are briefly described herein.

The issues of interest should be carefully selected to achieve certain objectives. The objective is to qualitatively assess the probabilities and consequences for identified areas of potential risk. Personnel with risk-analysis background that are familiar with the construction, design, operation, and maintenance of the project need to define these issues in the form of specific questions. Also, background materials about these issues need to be assembled. The materials will be used to familiarize and train the experts about the issues of interest as described in steps three and four.

The attendees of the expert elicitation process should be selected on the basis of their familiarity with the design, construction or operation of the project. Also, the attendees should be knowledgeable of the administrative and logistic aspects of operation, inspection and maintenance, the expert elicitation process, and the scope and key objectives of the project. The attendees can be classified as experts, observers and facilitators. All attendees can participate in the discussions during the meeting.

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However, only the experts can provide the needed answers to questions on the selected issues. The experts should be selected for their recognized expertise in certain areas of interest. The panel of experts should have a balance of viewpoints. The diversity and completeness of the panel of experts is essential for the success of the elicitation process. The size of the panel of experts should be about six to fifteen members but practically speaking may number as low as six. The observers provide expertise in the elicitation process, probabilistic and statistical analysis, risk analysis and other support areas. The composition and contribution of the observers are essential for the success of this process. The facilitators are responsible for conducting the expert elicitation process. They can be considered to be a part of the observers if their participation is deemed necessary.

The background materials that was assembled in step one should be sent to the experts about one to two weeks in advance of the meeting with the objective of providing sufficient time for them to become familiar with the issues. The objective of this step is also to ensure that there is a common understanding among the experts of the issues. The background material should include the objectives of the study, description of the issues in the form of a list of questions and their components, description of the process, its equipment and components, the elicitation process, and selection of experts. Also, example results and their meaning, methods of analysis of the results, and lessons learned from previous elicitation processes should be made available to them. It is important to break down the questions or issues in components that can be easily addressed.

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Preliminary discussion meetings between the facilitators and experts might be necessary in some cases to prepare for the elicitation process. These meetings may be performed during the initial meeting of the experts, observers and facilitators. The meeting should be started with presentation of issues and training of experts in providing the answers in an acceptable format that can be used in the analytical evaluation of the unsatisfactory-performance probabilities or consequences. Also, the experts need to be trained in certain areas such as the meaning of probability, central tendency and dispersion measures, consequences, subjective assessment, logic and methods of combining their evaluations.

After presenting an issue without any ambiguity and clear conditions, discussion of the issue should be encouraged, and a form with a statement of the issue should be given to the expert to record their evaluation or input. The experts' judgement along with their supportive reasoning about the issues should be documented.

The collected assessments from the experts should be analyzed and aggregated to obtain composite judgments about the issues. The means, medians, percentile values and standard deviations need to be computed for the issues. Also, a summary of the reasoning provided during the meeting about the issues needs to be developed. Uncertainty levels in the assessed issues should also be quantified.

The aggregated results need to be presented to the experts for a second round of discussion and revision. The experts should be given the opportunity to revise their assessments of the individual issues at the end of discussion. Also, the experts should be asked to state the rationale for their statements and revisions. The revised

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assessments of the experts need to be collected for aggregation and analysis. A comprehensive documentation of the process is essential in order to ensure acceptance and credibility of the results. The document should include complete descriptions of the eight steps, the initial results and revised results.

3.2.1.3.2.2. Expert Elicitation Using the Delphi Method

Sometimes face to face meetings to reach agreements on issues posses undesirable attributes (Lifson 1972). These can be:

1. A senior member of the group, for example a boss or person with a dominant personality can sway opinions in a manner inconsistent with the information presented.
2. People can be unwilling to change opinions stated publicly.
3. People can "grandstand" or "posture" or in other words stick to beliefs that may not be appropriate but show they are actively engaged.

The Delphi technique (Linstone and Turoff 1975) anonymously elicits the opinions of experts concerning uncertain events and the reasoning behind the opinions. It provides feedback to the experts in the form of distributions of their opinions and reasons. The experts are asked to revise their opinions in the light of the information contained in the feedback. This sequence of questionnaire and revision is repeated until no further significant opinion changes are expected. The technique is designed to protect anonymity of the experts' opinions and reasoning.

The Delphi technique has some shortcomings (Sackman 1975). These can be characterized as:

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1. The information and questions provided to experts needs to be carefully reviewed to ensure objectivity.
2. It is difficult to summarize and present to the group a common evaluation scale that is interpreted uniformly be the experts.
3. The benefits of experts participating in active dialogue are missed.
4. It may be difficult and time consuming to explore disagreements between experts.

3.2.1.3.2.3. Expert Elicitation Using a Modified Participative-Delphi Method

Both of the above methods have significant advantages. A combination of the two is proposed to produce expert opinions that are valid.

Step five of the participative method, elicitation of the experts about the issues, should be done in anonymity. This provides an initial starting point free of any other outside opinions besides the individual expert. The results are then presented for discussion and revised until no significant deviations are present. This method allows for individuals to initially remain anonymous bur later gain the benefit of other expert knowledge and opinions. Their first opinion may change based on new information and discussion but because it was given anonymously the individual may be willing to change something that was not said in public.

The other change suggested to the participative method discussed above is the number of experts involved could be as few as three. For the rapidly paced project management world any expert elicitation method needs to be nimble and efficient. This is because project managers are continually confronted with not having enough

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time for all the activities required of them (Laufer 1996). Although some expertise would be lost this would allow for an efficient and practical process that could be embraced by the project team.

3.2.1.4. Assessment of Probabilities

Unless good data is available the above subjective methods are well suited to develop expressions for probability. If data is available the methods to develop appropriate probabilities from existing data are shown in a typical text on statistics and probability, such as, Ayyub and McCuen (1997).

3.2.1.5. Assessment of Consequences

The consequences of a risk event may be considered to denote the magnitude of a loss or gain. In a project management sense the consequences can be expressed as a "consequence triangle". Derived from Roush and Wang's (2000) risk triangle, a consequence triangle shows the three main consequences typically found in project management and is shown in Figure 3-6.

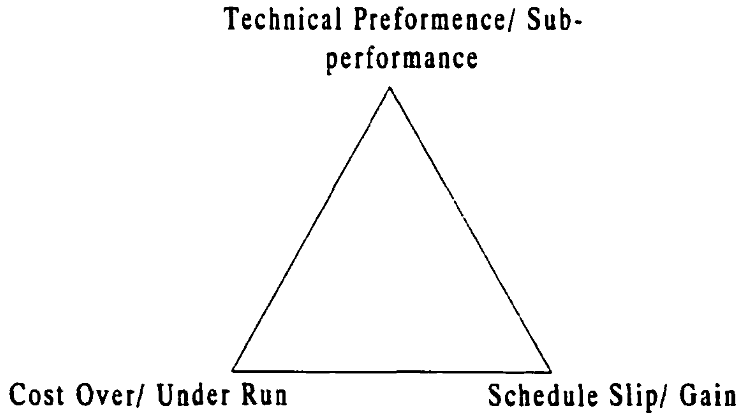

Figure 3-6. Project Management Risk Consequences

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The consequence triangle shows the three most important consequences typically found in project management are; cost, schedule, and technical performance. Of course there are other consequences such as safety, loss of goodwill or reputation, quality, and environmental effects. These consequences could result in costs or gains if not on the current project, on future projects. For example, ignoring environmental effects may result in not gaining approval for future projects.

The magnitude of consequences may be determined as discussed above, through the use of expert opinion. Since a consequence is typically expressed in terms of dollars, days of delay, or accidents quantitative method may be more appropriate and are discussed below.

3.2.1.5.1. Cost Over-run or Under-run Consequence

This consequence occurs due to an occurrence of a risk event that either increases or decreases the cost of building a project. These consequences can be determined by developing estimates of the impacted work or activities. Cost can be estimated roughly by using parametric estimating or similar guides or very accurately produced by developing itemized quantities of materials, equipment and labor. Both methods of estimating require a systematic technique and an application of experience and judgement. These techniques are found in several undergraduate text on estimating (Dagostino and Feigenbaum1996) and (Bledsoe 1992).

3.2.1.5.2. Schedule Slip or Gain Consequence

The consequence of a schedule delay or gain can be due to any number of occurrences. For example, decreased or increased productivity, adverse or favorable

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weather, and increasing or decreasing material prices. These risk sources are further discussed in section 3.2.6.

The magnitude of a schedule delay or gain can be estimated through the use of comparative CPM analysis. Typically a project will begin with an "as planned CPM schedule" this schedule is developed before a project begins. Through the use of existing CPM software such as MS Project (Microsoft 2000) or Primavera (Primavera 2000) "what if" scenarios can be expressed to determine the consequences of certain risk events. Simulation may also be used to develop an estimate of a risk event's occurrence on the schedule.

3.2.1.5.3. Technical Performance/ Sub-performance

Not only do projects need to be delivered on time and within budget but also their performance should meet the established design criteria. Depending on the level of difficulty of a project this may become a major consequence due to such things as trying to work too fast, working in poor weather conditions, or sub-par work items from one vendor or subcontractor causing more work for follow on builders. For example, a project may have been built within cost and schedule budgets but this may have come at the expense of quality.

3.2.1.5.4. Accident Free or Accident Consequence

Safety is also a major consequence because it deals with the health and welfare of people. Having an extremely safe work place has the consequences of lower costs. Conversely having a work place or project that has a high accident rate results in higher cost. These cost generally show up in insurance rates for worker compensation,

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third party liability, and coverage for loss. The magnitude of the consequences is industry and location specific but are easily calculated based on published rates.

The consequences of fatalities are not so easily calculated in monetary terms, how do you put a value on human life? A fatality will certainly hurt productivity, cause insurance rates to increase, may result in loss of public support, and could include a large wrongful death settlement. These consequences may be determined from past data or require assistance from expert opinion.

3.2.2. Risk Management

Risk management is the process by which system operators, project managers, and owners make decisions, changes, and choose different system configurations based on the data generated in the risk assessment. Risk management involves using information from the previously described risk assessment stage to make educated decisions about different configurations, construction scenarios and operational parameters of a system. Risk management is also dynamic as new information about risk events becomes available managers should adjust accordingly.

Risk management makes decisions based on risk assessment and considerations including cost, schedule, technical, political, environmental, legal, reliability, constructability (producibility), safety, and other factors. Although communication between the risk assessment and management is necessary, it is important that risk management is separate from risk assessment in order to lend credibility to the assessment of risk without biasing the evaluation by considering other factors. Especially in a qualitative assessment of risk where "expert judgment"

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plays a role in decisions, it is important to allow the risk assessors to be free of the "political" pressures that managers encounter. However, there must be communication linking the risk assessors and risk managers together. The risk assessors need to assist the risk managers in making a decision. While the managers should not be involved in making any risk assessment, they should be involved in presenting to the assessors what needs to be answered.

Risk management uses the information obtained during the risk assessment phase to model different construction configurations and operational parameters. The modeling process develops "what if" scenarios for risk management to account for possible configurations of material suppliers, fabricators, transportation times, methods, sequencing, and length of construction activities. Modeling such complex processes will result in construction cost and schedule values with associated probability distributions. Given a cost value or schedule duration and associated probabilities, decision-makers will have the appropriate confidence in these values and are better equipped to understand the risks associated with their decisions.

3.2.2.1. Risk Evaluation

Calculating risk involves combining an event's probability and its corresponding consequence. The event's risk can then be expressed by multiplying these two measures together. Risk can be shown either figuratively (acceptable/ unacceptable) or numerically. In both cases, the resulting risks are grouped into a handful of risk categories. The categories range from extremely low-risk to high-risk situations. For a negative risk it is desirable to maximize the number of events that

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occur in the lowest one or two (depending on the situation) risk categories. Events that fall into the high-risk category can be the result of high consequences, high probabilities of occurrence, or both. Negative risk producing events falling into the high-risk categories should be examined to find ways of risk reduction, management or mitigation. Opportunistic risk can be characterized in a similar manner.

3.2.2.2. Risk Acceptance

In order to make decisions based on risk, a level of acceptable risk must be determined. As shown in Figure 3-7, lines of constant show that risk increases as the likelihood and/ or consequence of a risk event increases. Figure 3-7 also shows that when considering risk acceptance curves that show a high consequence with an extremely low likelihood and vice versa may be used to show acceptable risk. Management should determine risk acceptance through a systematic process that may be project specific, based on general corporate, or governmental guidelines. Events that have a higher risk than the set level of acceptable risk should be flagged. Each flagged event should be studied to determine why its risk level is so high. This process can also be applied to risk that presents the potential for a positive gain.

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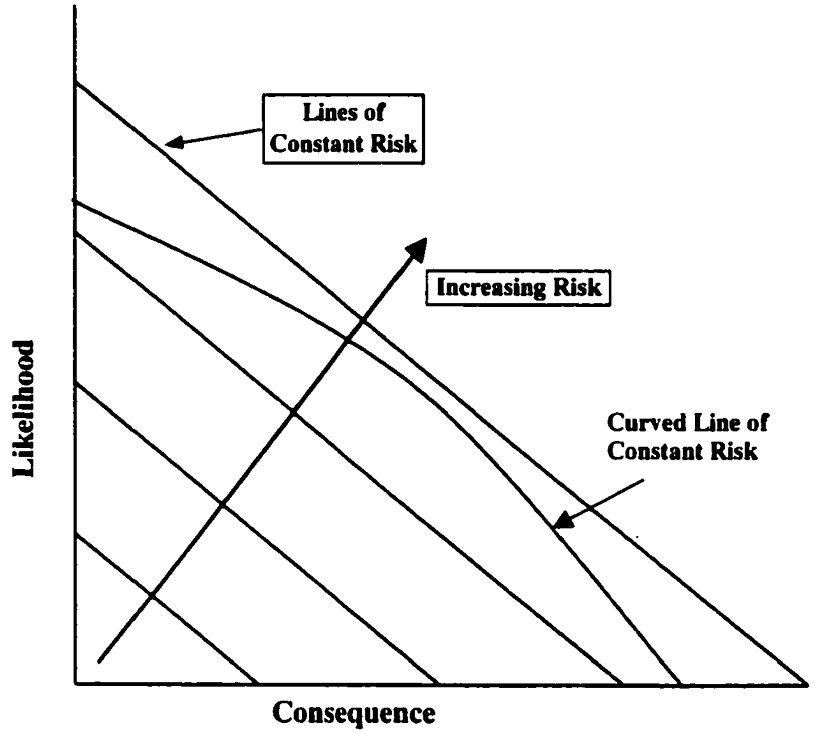

Figure 3-7. Risk Levels (Adapted from Hess and Ayyub 1997)

3.2.2.3. Risk Acceptance Methods

Several methods have been developed to assist in determining risk acceptance. A summary of these methods as adapted from Ayyub and Wilcox (2000) are shown in Table 3-6.

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Table 3-6. Methods for Determining Risk Acceptance

Risk Acceptance Method	Summary
Risk Conversion Factors	This method addresses the attitudes of the public about risk through comparisons of risk categories. It also provides an estimate for converting risk acceptance values between different risk categories. Risk can be categorized by the consequence categories.
Farmer Curve	It provides an estimated curve for cumulative probability risk profile for certain consequences (e.g., cost). Demonstrates graphical regions of risk acceptance/non-acceptance. See Figure 3-1.
Revealed Preferences	Through comparisons of risk and benefit for different activities, this method categorizes society preferences for voluntary and involuntary exposure to risk.
Evaluate Magnitude of Consequences	This technique compares the probability of risks to the consequence magnitude for different industries to determine acceptable risk levels based consequence. This method applies an equation to determine the annual probability of failure that is dependent on variables such as; life of structure and number of people exposed to the risk.
Risk Effectiveness	It provides a ratio for the comparison of cost to the magnitude of risk reduction. On a cost-benefit decision criteria a risk reduction effort should not be pursued if the cost outweigh the benefits. This method is suitable for project management when consequences such as costs are considered but may not coincide with society values about safety.
Risk Comparison	This risk acceptance method provides a comparison between various activities, industries, etc., and is best suited to comparing risks of the same type.

In a project management context most risk events will generally not involve the public, such as, failure consequences to populations or exposing the public to involuntary risk. For example, a new baseball stadium in Seattle finished $100 million over budget the cost risk was borne by investors. Project management risk involves cost, schedule, technical performance, safety, or loss of goodwill. Risk involving cost, schedule, technical performance, and loss of goodwill may be quantified in terms of a

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monetary value and are best suited for the risk effectiveness method of risk acceptance. Safety risk to the workers on a project is not suited for a risk acceptance method that only considers cost. A risk comparison method may be better suited for safety considerations since management will consider these risks separately from monetary risk and generally have a lower tolerance for this type of risk.

3.2.2.3.1. Risk Effectiveness/ Cost Effectiveness of Risk Reduction

Risk effectiveness is expressed in the following equation:

$$\text{Risk Effectiveness} = \frac{\text{Cost}}{\Delta\ \text{Risk}} \tag{3-8}$$

where Cost is the amount required to reduce risk and ΔRisk is the level of risk reduction. The inverse of this relationship is the cost effectiveness and is expressed as:

$$\text{Cost Effectiveness} = \frac{\Delta\text{Risk}}{\Delta\text{Cost}} \tag{3-9}$$

where Cost is the expense of reducing risk and ΔRisk is the level of risk reduction that may be in terms of expected monetary loss.

3.2.2.3.2. Risk Comparison

This method of risk acceptance is best suited to compare risks within the same category. The likelihood of consequences are used to compare risk and justify risk acceptance. This method may be suitable for safety risk on complex construction project.

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3.2.2.4. Risk Acceptability

When considering risk in terms of a monetary outcome there are three general attitudes toward risk (Kumamoto and Henley 1996). These are; 1) Risk-aversive, 2) Risk-neutral, and 3) Risk-seeking. In general these classifications intend to show that people's acceptance of risk ranges from more importance or emphasis on the risk than on the expected monetary gain to more importance or emphasis on the expected monetary gain than the risk. These attitudes toward risk are shown in Figure 3-8.

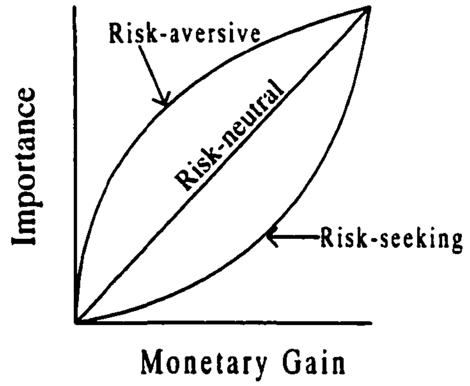

Figure 3-8 Risk-aversive, Risk-neutral, and Risk-seeking

An example of this can be seen in an individual's investment practice. Some investors prefer to buy stock of small companies in the high technology sector. Typically this is considered a risk-seeking stock choice because there is a chance of losing an initial investment but the potential monetary gain can be quite substantial. As shown in Figure 3-8 these investors place more emphasis on monetary gain than the risk involved in the investment. A risk-aversive investment choice would be investing in certificates of deposits. These investments are protected against any principal loss but only result in a low fixed rate of return. As shown in Figure 3-8 these investors place a greater importance on risk than monetary gain.

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In a project management context it can be generally stated that large established companies are risk-aversive, governmental ventures are risk neutral to risk-aversive, and smaller newer companies are risk-seekers. However individual organizations and governmental agencies will have an established culture that views risks and monetary outcomes as shown above. A risk analysis should account for the acceptability of risk according to the established risk attitude.

3.2.2.5. Risk Monitoring and Control

Although increasing productivity or other such measures can reduce the risk exposure to cost and schedule escalation, the responsibility for risk reduction rests with management. Risks must be monitored and controlled once management has established a risk management plan and a project begins. Management may alter planned efforts as more becomes known about the estimated probabilities or the magnitude of the negative or positive consequences of a particular event.

3.2.3. Risk Communications

Risk communications can be defined as the exchange of information among interested parties about the nature, magnitude, significance, or control of a risk (Covello 1996). This definition of risk communication delineates it from risk-message transmittal from experts to non-experts. The exchange of information in risk communication should be an interactive, i.e., two-way, process (National Research Council 1989). However, this definition does not make it easy because technical information about controversial issues needs to be skillfully delivered by risk

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managers and communicators who might be viewed as adversaries by the public. Risk communication between risk assessors and risk managers is necessary to effectively apply risk assessments in decision making. Risk managers must participate in determining the criteria for selecting what risk is acceptable and unacceptable. This communication between the risk managers and risk assessors is necessary for a better understanding of risk analysis in making decisions.

3.2.4. Construction Risk Analysis

Construction is an industry associated with many risks. A sampling of the most prevalent risk will convince any causal observer that the construction process is risky. Some of these risk are safety risks; business risks associated with any venture involved with contracts, multiple agencies, time and money; performance risks associated with producing a final product, working under varying weather conditions; and among others liability risks (CII 1989).

A formal risk analysis applied to the construction process will help manage risks. A risk analysis can be performed for each project phase shown in Figure 2-4. The level of detail performed for the risk analysis is based on the documents produced in these phases, any previous risk analysis, and the degree of risk perceived by management. This risk analysis process shown in Figure 3-9 is continuous throughout each phase until construction begins. As construction begins risk management becomes a greater concern and project managers focus on monitoring and controlling risks.

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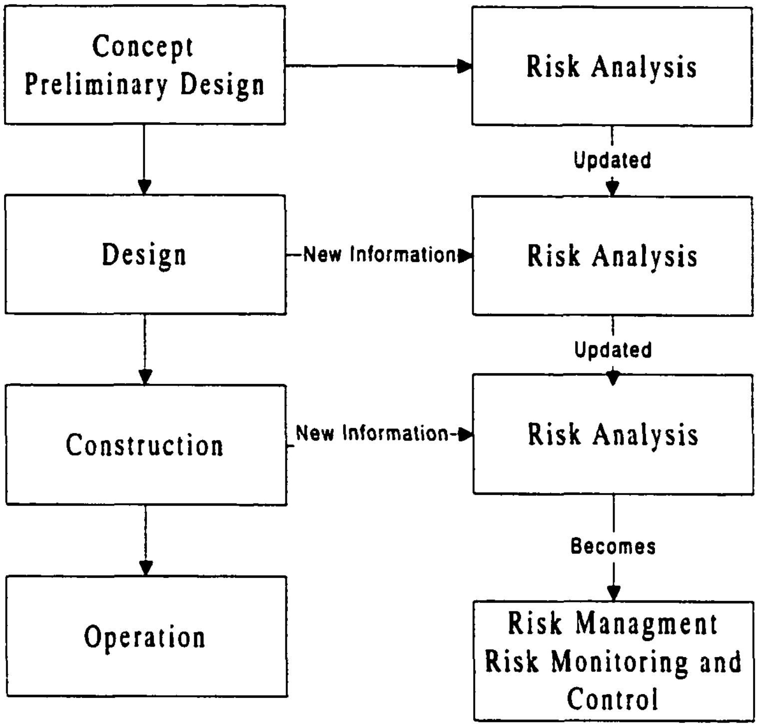

Figure 3-9. Construction Risk Analysis

3.2.4.1. Construction Risk

Construction risk has several sources. When performing a construction risk analysis each source or characteristic of risk needs to be addressed. Table 3-7 lists many of the most common sources of construction risks that should be considered in a structured approach to identifying a project's potential risks. Table 3-7 is structured to also note the positive outcomes from a risk source. Other listings of potential construction risks may be found in the literature (Edwards 1995), (Smith and Bohn 1999), and (Kim and Bajaja 2000).

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Table 3-7. Sources of Common Construction Risk

Risk Source	Description of Risk Source
Cost	Estimate is uncertain because it is based on past and projected costs. Consequences are financial impacts to project and opportunities are for greater profit margins or savings.
Schedule	Schedule is uncertain because it is based on past and predicted performance. Consequences are time delays and opportunities are available to shorten the project length.
Labor Problems	Labor strength and productivity uncertainties. Consequences are more expensive labor costs, quality problems and opportunities are for increased productivity.
Project Management Issues	Uncertain experience levels, cohesiveness of team, and make up from project managers to subcontractors. Consequences of inefficiencies that result in higher cost, technical problems or a damaged reputation. Opportunities for creativity and efficiencies.
Safety Problems	Potential for accidents and consequences of death or higher costs.
Excessive Change Orders	Potential for changes that may cause productivity losses. Consequences of increased cost, schedule delay, and technical performance.
Unforeseen Conditions	Undefined underground or hidden site conditions could cause cost and schedule growth.
Environmental Concerns	Regulatory approvals and mitigation of environmental concerns may be required. Consequences of time delay or cost escalation.
Equipment Issues	Selection of equipment and techniques and potential for equipment failure. Consequences of increased costs, schedule, and opportunity potential for increased efficiencies.
Inflation	Potential for material and labor price increases.
Weather	Potential delays, costs, and technical non-performance from adverse weather.
Complexity	Level of difficulty increases the potential for cost and schedule growth. Consequence of technical non-performance.
Client or Owner Initiated	Potential owner's representatives, architects, engineers, and inspectors are overly critical or difficult to work with. Consequences of increased costs and time. Potential to work with a homogenous project team that is focused on opportunities for total cost savings.
Fire	Probability of fire hazard from work operations, vandalism or lightning may cause cost impacts.
Suppliers	Potential for non-performance from vendors, subcontractors or suppliers that causes impacts to cost and schedule.
Property Loss	Potential for loss due to theft, sabotage or vandalism.
Design	Potential for design to be incomplete or lacking. Opportunity to work with a design that considers construction aspects.

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Table 3-7. (continued) Sources of Common Construction Risk

Risk Source	Description of Risk Source
Quality	Potential for consequence of poor quality and technical non-performance. Opportunity for high quality and additional future work.
Political	Potential loss of support. Opportunities to network and acquire new work.

3.2.4.2. Construction Risk Assessment

A construction risk assessment should be based on one of the systematic processes depicted in Table 3-1 and 3-2. To include the concepts of risk engineering the three questions posed in section 3.2.1 should be rephrased as (1) What can happen to this project? (2) What is the likelihood that it will happen? (3) What are the positive or negative consequences if it does happen? These questions seek answers to a broader scope of risk to include opportunities. Clearly it is advantageous to develop an understanding of the risk associated with a project. This enables planners, designers and constructors to minimize the downside of risk or capitalize on opportunities. A quantitative approach to construction risk assessment is difficult to document because these methods rely on data. The difficulty in obtaining construction data is because each project is unique. What data does exist is based on past projects and may contain significant uncertainty when applied to the current problem. An appropriate method to quantitatively assess a construction project's risk is through simulation. Simulation can be made to account for this uncertainty and builds the projects many times to develop meaningful data. Another quantitative method is through the use of decision trees. A decision tree technique that uses an EMV may guide decisions concerning alternatives with various levels of risk. Certain qualitative risk assessment methods may also be particularly suited to construction projects. Risk

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assessment matrix tables are especially suitable to construction because they can efficiently develop a measure of risk and do not require project specific probability and consequence or opportunity data. The Delphi technique and AHP is useful because experts may be interdisciplinary and are better able to identify and assess potential risk. Influence diagrams are another useful method because they can quickly communicate potential risk to management (Diekmann 1997).

3.2.4.3. Construction Risk Management

The literature has several case studies of construction risk management from general building construction (Baker et al. 1995) to offshore construction (Curole 1997). In the field of project management, risk management is a recognized practice to help managers deliver projects on schedule and within cost (PMI 1997). But in general, the risk management performed in the construction industry has traditionally been through the use of "gut feel" or a series of "rules of thumb" (Al-Bahar and Crandall 1990). This may be due to a lack of understanding of the benefits and cost, the perceived difficulties, or cumbersome processes in developing risk management (McKim 1992) and (Ward 1999).

3.2.4.3.1. Construction Risk Monitoring and Control

An essential function of construction project managers is to control their projects. The control of risk is achieved by executing the risk management activities. Risk monitoring is required to respond to events that occur over the course of a project. This is needed because the original risk assessment and management are

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based on certain assumptions, probabilities, and consequences that may not have been accurately described or estimated.

Risk control can be achieved through updating the risk management plan with new information, identifying alternatives to an unplanned risk event, and mitigating the unplanned risk. Risk monitoring and control should therefore use existing risk management documentation and make them better. Once an appropriate strategy is developed that handles an unplanned or changed risk exposure, management must act to implement the new course.

3.2.4.4. Construction Risk Communication

Construction risk communication may be internal or external to the construction process. Internal communications are among the project team members such as owners, designers, and construction personnel. External risk communications for a construction project may be made to a regulatory body or the public.

Internally the communication of the risk assessment and management functions will result in a construction risk management plan being developed. The development and distribution of this plan should be preformed across several disciplines to ensure maximum input and exposure. The plan will assist team members in selecting appropriate alternatives and prepare for potential risk events.

3.3. Decision Analysis

Decision analysis uses a decision model to optimize objectives of a decision problem. Project management and engineering are professions that require decisions

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to be made for the management of technical, cost, and schedule risks. As projects become more and more complex the need for a systematic method to make theses decisions is even more paramount. Most decision analysis techniques have the following steps or phases (Ayyub and McCuen 1997):

1. Identify the problem and objectives.
2. Develop alternatives.
3. Evaluate the alternatives.
4. Implement the best alternative.

These steps should include the uncertainties associated with the data or alternatives. This section highlights four possible methods that can be used in a risk based decision analysis methodology.

3.3.1. Decision Analysis Using Decision Trees

A decision model for decision-making involving risk analysis and using decision trees requires performing the following steps are adapted from Ayyub and McCuen (1997):

1. Definition of objectives of decision analysis.
2. Definition of decision variables.
3. Definition of decision outcomes.
4. Development of associated probabilities and consequences.
5. Creation of decision trees.
6. Analysis of results.

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The objective of the decision analysis needs to be clearly stated and may have a single or multi-objective focus. The decision variables are the available options or alternatives. The decision outcomes are the events that can happen as the result of a decision. The decision outcomes have both a probability of occurrence and consequence. The probabilities model the random nature and consequences model the magnitude of the outcomes. The construction of the decision trees is the graphical portion of this method and is discussed in the following section. Once the results have been obtained they should be checked for reasonableness and analyzed for sensitivity.

3.3.1.1. Decision Trees

Decision trees are employed to examine all available information for the purpose of decision making. A decision problem is graphically expressed and the diagram shows all the important decision points. Probably the best method to describe decision trees is through an example. Such an example is building the hinged MOB concept as shown in Figures 3-10 and 3-11. The MOB concept is the beginning of a tree. Lines out of this beginning are branches that represent decision nodes (squares) or chance (circles). The tree is populated with utility values and probabilities of a chance node direction. The utility is an expression of a decision makers preference for possible outcomes. The total expected utility for each decision scenario is calculated and the most suitable decisions with respect to the stated objectives are obtained.

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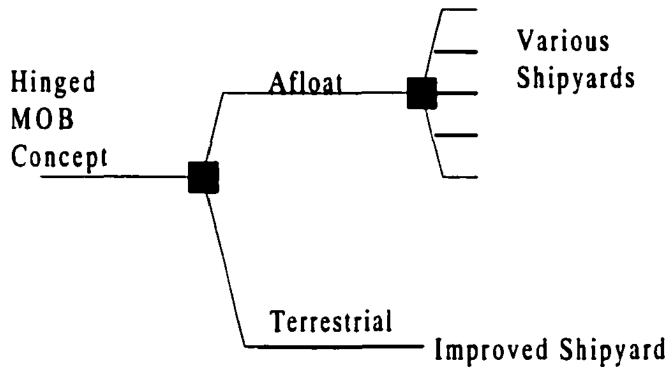

Figure 3-10. Initial Portion of Hinged MOB Concept Decision Tree

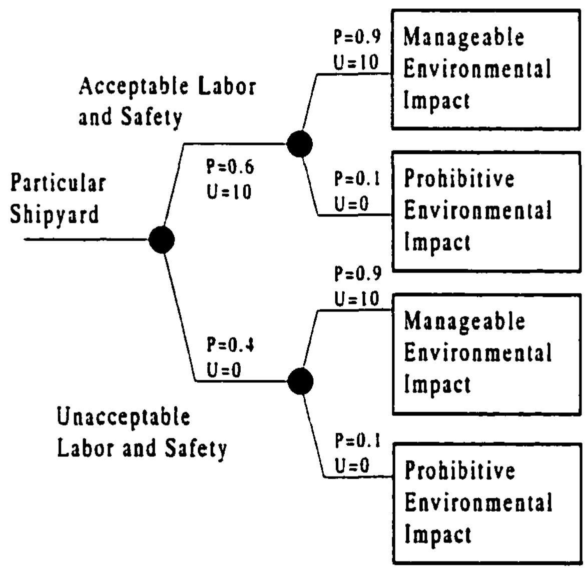

Figure 3-11. Final Portion of Hinged MOB Concept Decision Tree

As shown in Figure 3-10, the decision-maker may choose either afloat or terrestrial assembly for a particular MOB concept. Other decisions such as, which shipyards to employ are also considered. As shown in Figure 3-11, a particular shipyard has certain chance paths associated with it. Once one calculates the total expected utility of each decision path, comparisons may be made and the best decision selected.

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Total utility values are calculated by summing utility values along the tree. At the first chance node probabilities and utility values are given for labor and safety and likewise for the second chance node for environmental impacts. The total expected utility for a particular shipyard is calculated as the sum of the four potential paths. The path that has the highest utility value is the selected decision. An analysis of this result should be performed to ensure the results make sense and the results are not unduly influenced by a slight variation of input data.

3.3.1.2. Expected Monetary Value Using Decision Trees

In a project management context most decisions will be based on monetary considerations. Using decision trees developed with probabilities and benefits a decision is made by selecting the alternative with the highest Expected Monetary Value (EMV) (Clemen 1996). Conversely, if the alternatives represented outcomes that represented costs, the lowest EMV alternative would be selected.

As an example of using a decision tree to assist decision-makers, consider the potentially risky scenario of theft and vandalism occurring at a controversial large project such as a major development in an environmentally sensitive area. The decision of which security measures to use could be analyzed by the use of a decision tree. The security system could consist of only fencing, fencing with a guard dog, or hiring watchmen. An example of this decision tree is shown in Figure 3-12. The decision tree shown is purposely kept simple to demonstrate a method. To illustrate one more level of chance the alternative of providing only a fence with potential losses expressed as a high, medium, or low is shown following this example. The data is

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hypothetical and is used only for illustrative purposes. In this case the EMV is a cost and a decision-maker would select the alternative with the lowest EMV.

As shown Figure 3-12 a decision-maker can choose four possible decisions. Assuming a potential loss of $100,000 from vandalism or theft the risk or expected loss of not doing anything is $100,000 x (0.7) = $70,000. This option does not involve any additional costs, therefore the EMV is $70,000. Cost for other options are calculated considering both the costs to implement the decision and the expected loss. For example, the decision to hire a watchman will result in a cost of $30,000 plus an expected cost of $100,000 x (.02) = $2000, for a total EMV of $32,000. The decision-maker compares all of the EMVs and selects the alternative with the lowest EMV. In this case using a fence and dog for security is the lowest cost alternative.

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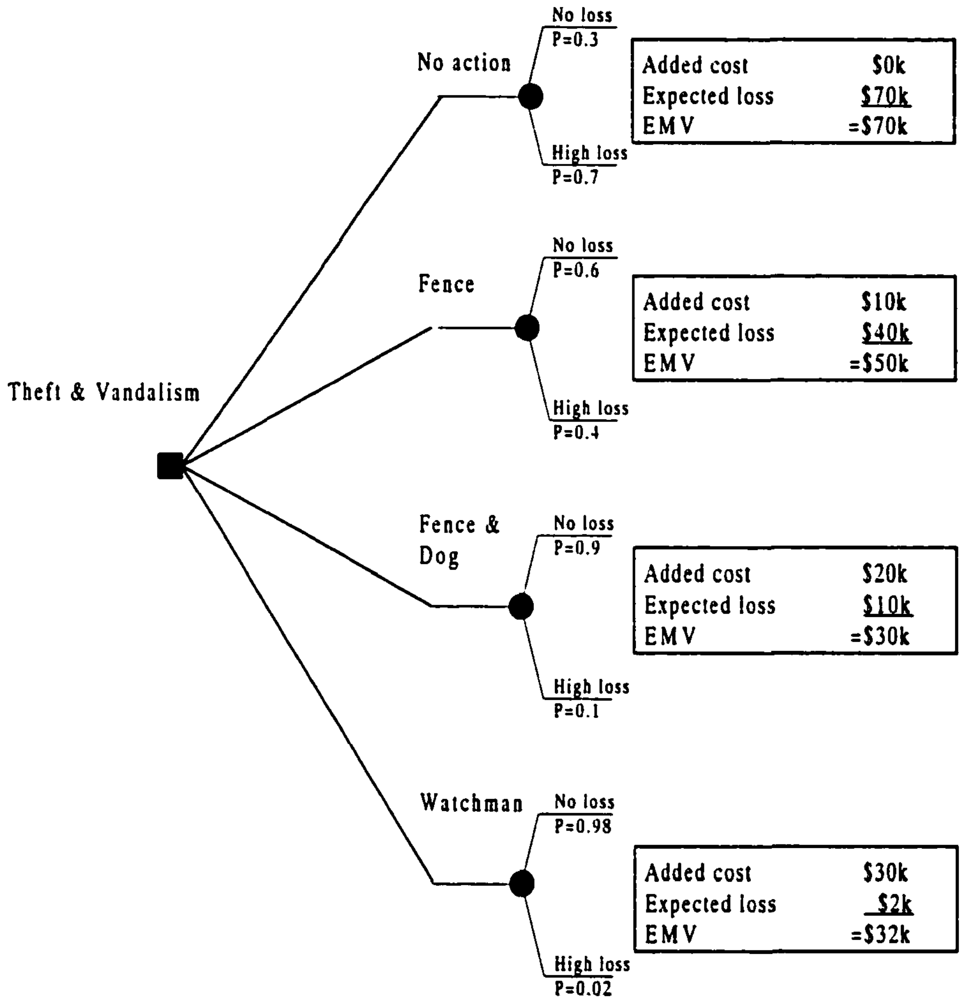

Figure 3-12. Security Decision Tree

Risk profiles for each of these alternatives can be established. A risk profile is the likelihood versus outcome for a particular chance event. Figure 3-13 shows the four potential alternatives and their respective risk profile.

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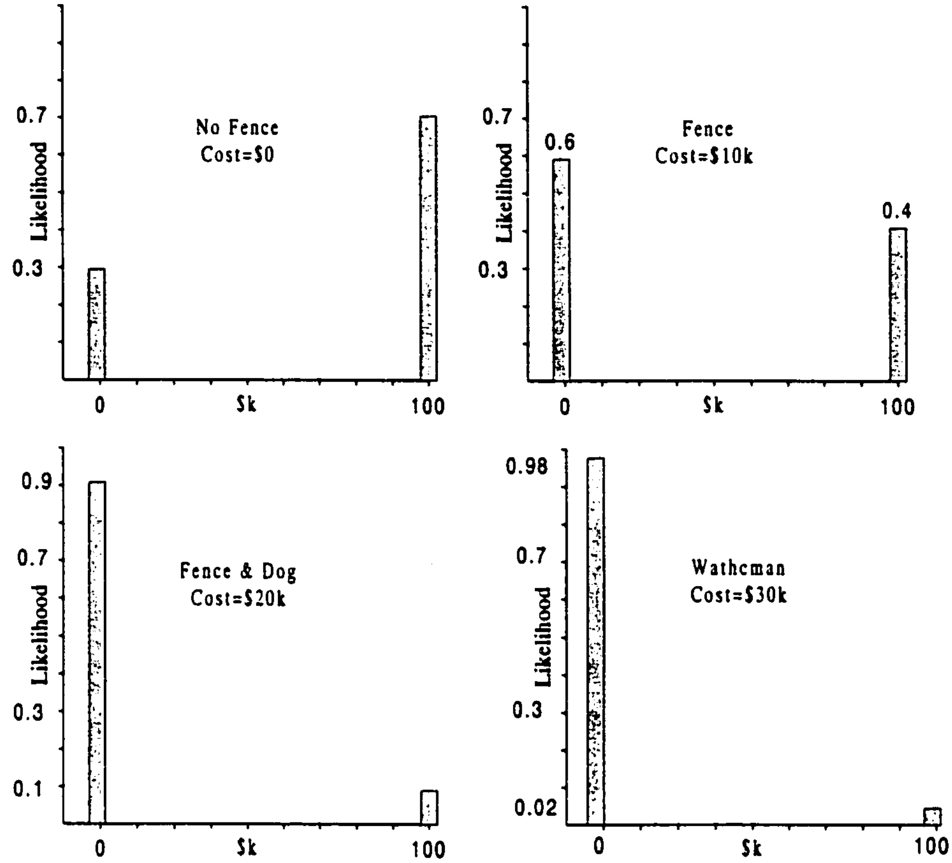

Figure 3-13. Risk Profiles for Security Alternatives

To better reflect the uncertainty, the loss from theft or vandalism in the above example may be expressed as high, medium or low and assigned an appropriate probability. An example of this is shown in Figure 3-14 for only the fence alternative with assumed probabilities and losses.

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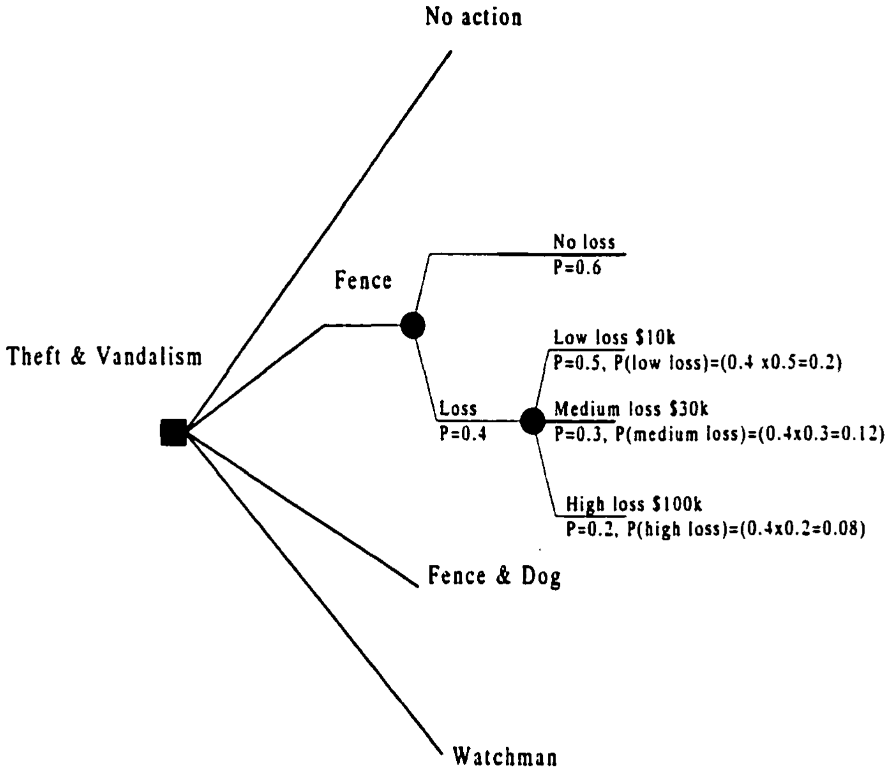

Figure 3-14. Security Decision Tree with Fence Option and Range of Loss

The fence option shown above also has a risk profile that is shown in Figure 3-15. The risk profiles shown in Figure 3-15 can not be compared to those shown in Figure 3-13 because of the different assumptions they are based on.

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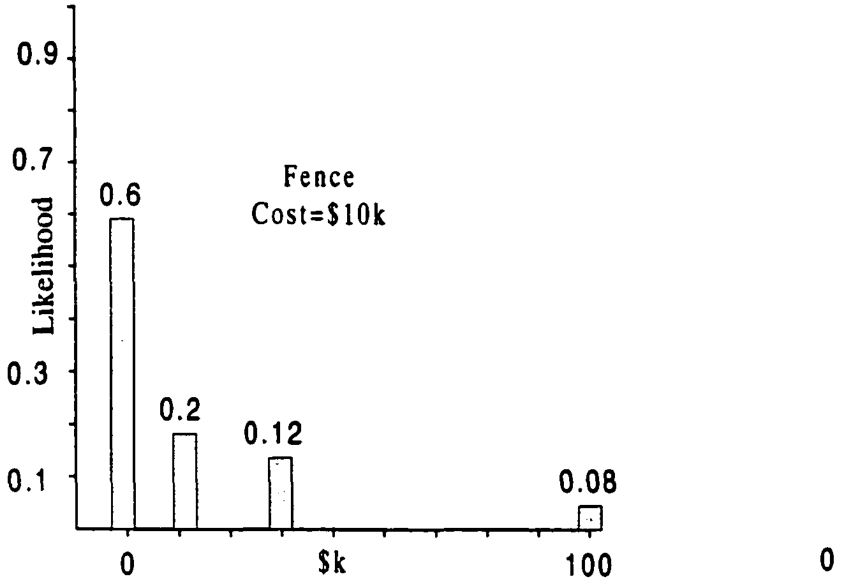

Figure 3-15. Risk Profile for Fence with Range of Loss

In the example above the probabilities and estimated costs are expressed as discrete items. Of course these items are uncertain until they actually happen or the money is spent. This uncertainty can also be represented by a probability distribution that brackets a range of values. For example, the security decision tree with fence alternative and losses represented by a normal distribution is shown in Figure 3-16.

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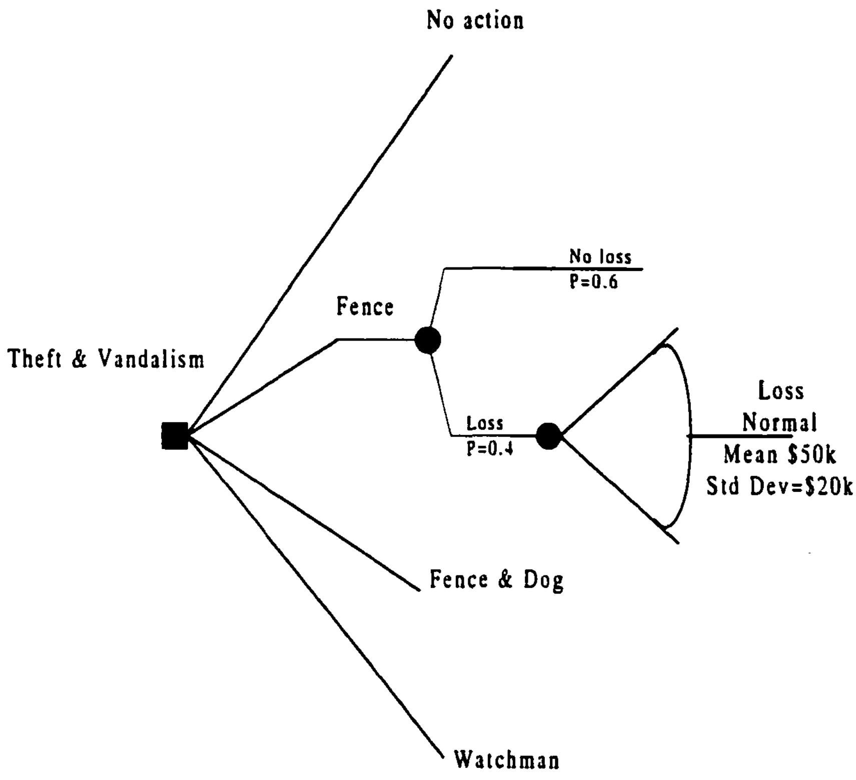

Figure 3-16. Security Decision Tree with Fence Option and Loss Represented by a Normal Distribution

This representation of the loss due to theft or vandalism with a probability distribution as shown in Figure 3-16 is called a “fan diagram”. The fan represents a range of possible outcomes based on the distribution type and selected parameters. The distribution type may be selected based on available data or knowledge of the distribution and the outcomes being modeled. Specific probability models as applied to decision making are presented in Clemen (1996). The risk profile for only the loss portion of this alternative is shown in Figure 3-17.

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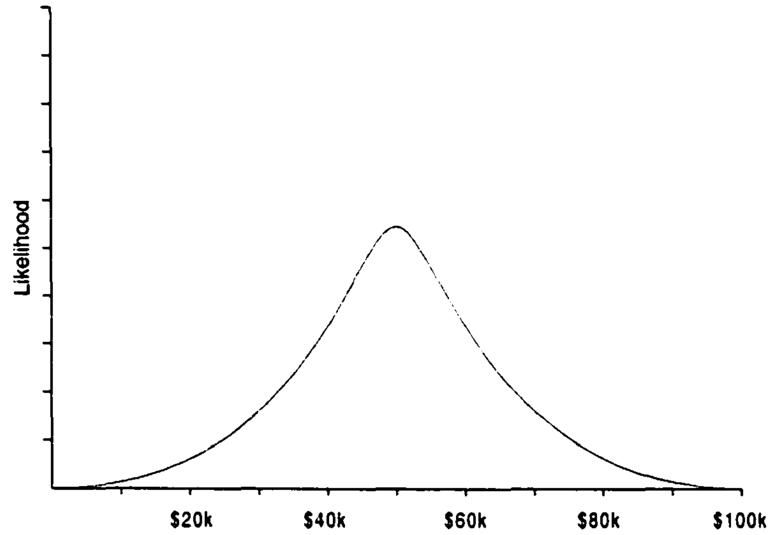

Figure 3-17. Risk Profile for only the Loss Portion of the Fence Option

As can be seen in Figures 3-16 and 3-17 the uncertainty associated with the loss is represented by a probability distribution.

3.3.2. Decision Analysis Using Goal Tree

A goal tree is a success-oriented logic structure that can be used to organize complex systems and their engineering knowledge into a format suitable for problem solving (Wang and Roush 2000). Its appealing feature is that it graphically clarifies a large amount of information into a form that allows decision-makers to see what needs to be accomplished and how to accomplish it. The steps to develop a goal tree are:

1. State the requirements of the problem that needs to be solved. Answer the question "What needs to be done? or What is the goal?"
2. Develop tree branches from the above goal that answer "How can it be done?"
3. If required develop more branches from step number two. Tree construction develops a hierarchy of branches by applying two rules: 1) look directly above in

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the tree structure to reveal "why" any specific goal or sub goal must be achieved; 2) look downward in the tree structure to reveal how a goal or sub-goal is satisfied. An example goal tree is shown in Figure 3-18. The project team is exploring methods to improve the labor productivity on a project. The objective or "what needs to be done" is "improve labor productivity". The second tier in the hierarchy is "how to improve productivity". The second tiers can have third tier branches. As shown in Figure 3-18. The third tier shows how a particular second tier goal is satisfied.

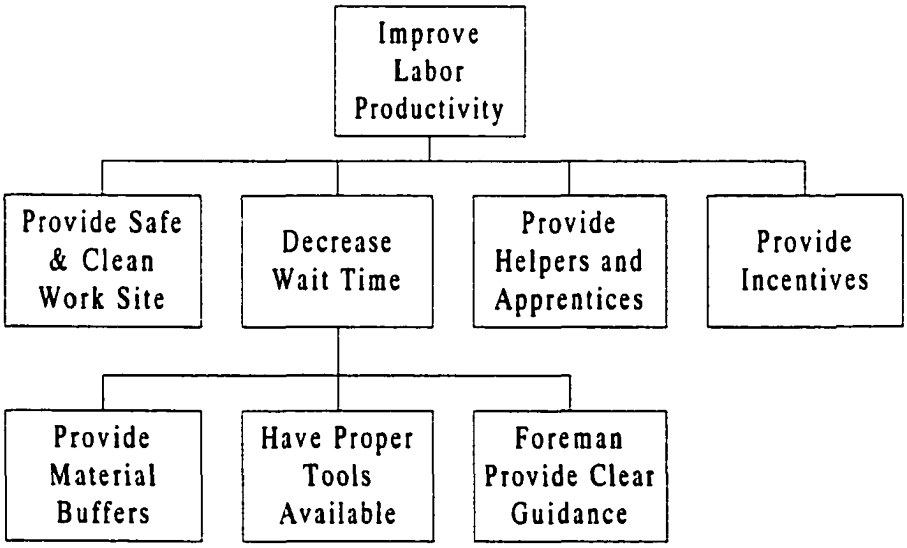

Figure 3-18. Goal Tree Illustrating Worker Productivity

3.3.3. Decision Analysis Using Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is generally considered as a decision analysis tool and was developed to allow decision-makers the ability to select between several alternatives. The basics of AHP were discussed earlier in regards to risk assessment. In terms of decision analysis the basic methodology discussed earlier is

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similar except that alternatives are ranked by using multi-criteria developed from the risk measures found through a risk assessment.

3.3.4. Decision Analysis Using Net Present Value

A Net Present Value (NPV) methodology can be used for decision analysis to select between different alternatives. This analysis is sometimes called Present Worth (PW). This methodology is similar to the NPV analysis discussed earlier in that it accounts for the time value of money. The best alternative is generally selected for having the highest NPV. Typically the alternatives are represented by cash flows using discrete values. In a risk-based decision analysis these discrete values can be represented by a range, probability distribution, or simulation to better represent the uncertainty involved (Newnan et al. 2000) and (Schuyler 1992).

The NPV concept is based on based on equating all cash flows relative to a base or beginning point called the present. The NPV is expressed in the following equation:

$$NPV = -CI + (AR - AC)\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] + \frac{S_N}{(1+i)} \qquad (3\text{-}7)$$

Where CI is the Capitol Investment (CI), or the initial cost of an alternative. AR is the Annual Revenue (AR), if the alternative provides a monetary benefit it may be expressed in annual terms. AC is the Annual Cost (AC), the alternative may have costs associated with it that can be annualized. S_N is any salvage value remaining after N periods of time, where N is the alternative's useful life. The interest rate is *i*,

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where this interest rate is the minimum attractive rate of return. Graphically NPV cash flow diagram is presented in Figure 3-18.

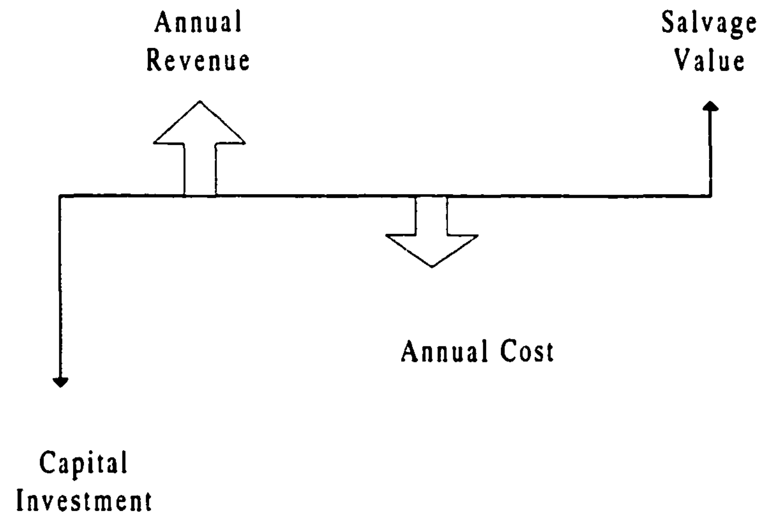

Figure 3-18. NPV Cash Flow Diagram

In a project management context equation 3-7 and Figure 3-18 would typically be applied using a shorter incremental period such as months.

The NPV method is particularly suited for evaluating concepts or alternatives in the feasibility phase of a project. This is because owners and financiers are able to understand the costs associated with a potential investment. As more infrastructure projects are being financed by joint public-private ventures this type of analysis will be applied to more complex engineering projects. For example, a new Tacoma Narrows bridge is estimated to have a construction cost of about $450 million dollars (WSDOT 2000) and is being finance by a joint public- private venture. In equation 3-7, the $450 million represents the CI, tolls are the AR, maintenance costs are the AC, the salvage value may be represented as a disposal or replacement cost, the interest rate is tied to the bond rates that will finance the project. In a risk based

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decision analysis values for these variables would be represented by a range of values or a probability distribution to reflect the uncertainty in developing accurate estimates of construction, maintenance, and replacement cost.

3.3.5. Comparisons of Decision Analysis Methods

A comparison of decision analysis tools is presented in Table 3-9.

Table 3-9. Decision Analysis Tools

Method	Advantage	Disadvantage
Decision Trees	Visual, shows decision paths. Relatively simple to implement for problems with limited decision paths and discrete probability assumptions.	Requires accurate probability data. Can become cumbersome for a large number of decisions or decisions with several alternatives.
Goal Tree	Simple graphical display of alternatives to meet an objective or goal.	Does not include likelihood of event and magnitude of cost or benefits.
Analytic Hierarchy Process (AHP)	Accommodates both hard data and personal judgement. Provides mathematically based relative weights of criteria.	Decision criteria need to be well understood or inaccurate results will occur.
Net Present Value	Relatively simple method to calculate the cost of alternatives or proposals.	Relies of several hard data sources and assumptions.

3.4. Construction Risk Analysis Needs

What is needed is a risk analysis methodology that allows construction mangers to employ risk assessment and management along side or in conjunction with typical construction management functions. This methodology should embrace the concept of risk engineering and be continuous through each phase of the construction process as shown in Figure 3-9. For risk techniques to be embraced by the construction industry it must be relatively simple yet able to assist managers to deliver

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projects within budget and schedule. Finally a risk-based methodology combined with cost control is needed to obtain a synergistic (the whole is better or greater than the sum of the parts) strategy to control complex construction costs.

3.4.1. Continuous Process

Just as construction is a continuous process from feasibility to final completion, the risk techniques employed to help manage complex projects are required to be dynamic or continuous throughout the process. Risk management is not a one-time event. This is because new project information becomes available as the project progresses. This information allows a fine-tuning of any previously developed risk management plans. A risk methodology for project management could be updated through either computer simulation models or a continuous application of existing methods.

3.4.2. Risk Engineering

From a project management perspective risk should be viewed as "risk is good." This is because project managers should not only take a classic view of risk as "a potential for harm" but also look at risk as an opportunity to create positive consequences. By understanding, evaluating and controlling risk a project manager may avoid negative impacts but also turn opportunities to their advantage.

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3.4.3. Systematic and Simple

Major decisions and the ability to control risk are best performed when the factors and circumstances that effect them are made visible or highlighted. This requires that the processes used to control risk are logical, methodical, and consistent. In construction project management, because of the lack of available data, this particularly true when applying a qualitative method.

A methodology to apply risk techniques does not have to be so complicated that it is difficult for people to communicate or carry out. Research has shown that complex systems or methods applied to control construction processes do not work (Diekmann et al. 1987). This is because if the people that are needed to carry out the complex systems find that it is too complicated and requires too much effort they resort back to rules of thumb or intuition. Additionally, the construction project management business is fast paced and a less complicated system can be more nimble and adaptable to change.

3.4.4. Risk Techniques Combined With Combined Cost Control Techniques

The application of risk techniques combines well with cost control techniques because they have the same goal in mind. Both are tools project managers can apply to avoid potential problems or seize potential opportunities. By combining these techniques into a single methodology project managers can enjoy a synergistic effect.

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4. PROPOSED METHODOLOGY FOR RISK BASED COST CONTROL

In this chapter the proposed methodology of a risk-based cost control system is presented. This proposed methodology combines risk analysis and cost control techniques. The risk analysis is continuous throughout all phases of a project and focuses on events that may increase cost. Additionally the uncertainty associated with certain events must be considered because estimates, budgets and schedules are developed with various levels of uncertainty. The risk-based cost control methodology presented includes applying risk-based techniques to the development of estimates or schedules and controlling costs on complex projects.

This risk approach to cost control will identify risks in the earliest stages of concept feasibility through to the completion of a project. The risk assessment method used in an earlier phase will be updated based on new information obtained as a project progresses and applied to cost control.

4.1. Risk-Based Approach to Cost Control

The primary benefit of using a risk-based approach to cost control is in the assessment of project cost and schedule targets, understanding the uncertainty affecting them, and ensuring they are achieved as a project progresses. As shown in

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Figure 4-1 risk-based methods are applied in both the planning and execution phase of a project. Risk methods that account for uncertainty are used to develop realistic budgets and schedules or targets in the planning phase. Risk methods combined with conventional cost control methods are used during project execution to monitor and control the project's direction. The ultimate goal of applying risk methods to control cost is shown as the last block in Figure 4-1, projects delivered within budget and schedule.

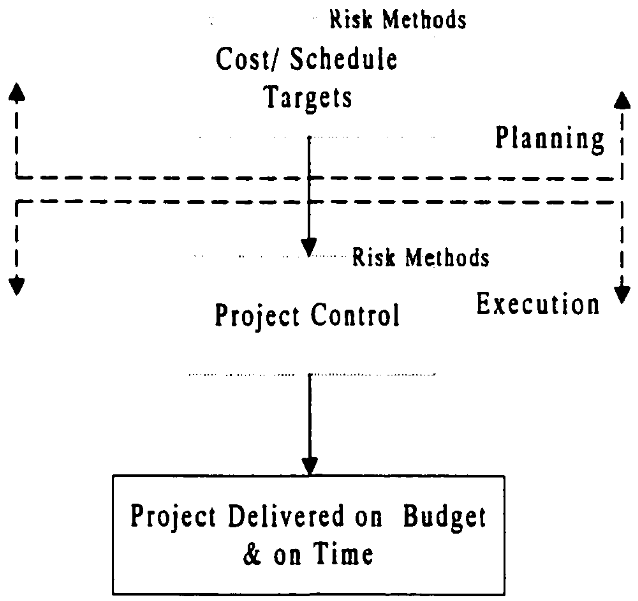

Figure 4-1. Top Level Risk-based Cost Control

4.1.1. Planning Phase

In the top portion of Figure 4-1, an estimate and schedule become the project targets and are developed with risk methods. The targets are produced based on the

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documentation developed in the feasibility, design or construction planning phase as shown in Chapter two, Figure 2-1.

4.1.1.1. Risk Analysis

Methods to apply risk analysis in the planning phase is applied to both the cost and schedule estimates. The primary objectives during this phase of the risk analysis is to develop an understanding of the uncertainty involved in the project and produce realistic cost and schedule targets. Risk analysis is an important aspect during this phase, it is the foundation for planning and controlling potential risk during the execution phase. Additionally, this two step method provides a holistic coverage of risk for the entire life of the project from planning to construction completion.

4.1.1.2. Cost Estimate

All estimates that make up a project's cost will be uncertain. To account for this uncertainty a risk analysis is performed to develop a cost estimate based on risk methods. The primary risk of any cost estimate is due to estimating uncertainty and a risk analysis helps to ensure realistic cost targets are achievable. A risk assessment is a tool for quantifying the frequency and consequences of potential risks. These tools are some of those presented in Chapter three and range from qualitative to computerized simulation models. In the concept or preliminary design phase the risk analysis is crucial to establishing if a project should be pursued further. During the design phase the risk analysis should be used to assist the decision-makers in the selection of materials, scope, timing, and other characteristics that may impact cost. In the construction phase a risk analysis should be performed based on any previous

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analysis and by construction personnel responsible for planning prior to building the project. During the construction of a project risk techniques can help managers control a project's cost.

4.1.1.3. Schedule Planning

Applying risk analysis to scheduling is just as important as applying it to cost estimating. This is because cost and schedule uncertainties are interrelated. For example, both cost and schedule are linked to the productivity rate of labor. The labor productivity rate is generally one the most difficult rates to approximate (Barrie and Paulson 1984), thus the actual rate could have a pronounced effect on both cost and schedule.

4.1.2. Project or Construction Execution Phase

Several methods of cost control were introduced in Chapter two. Of these, the earned value method provides the most objective and quantitative method for controlling cost. An earned value technique that applies the knowledge gained from a risk analysis and can account for uncertainties in project management is presented.

4.1.2.1. Overview

In Chapter two, section 2.3 the major project uncertainties of estimated cost, planned schedule, forecasted cost at completion, and management actions were introduced. These uncertainties can all contribute to actual costs being different than planned. Other seemingly minor or "soft" cost influences can also contribute to cost escalation. These soft influences or drivers could be derived from or are the

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cumulative effect of real project occurrences such as: a difficult inspector, designer or owner, excessive change orders, ripple effects, uncooperative subcontractors, or a poor design. The "soft" cost drivers are identified in a risk analysis and their known effects as a project progresses can be used to help diagnose where and why potential problems may occur. Additionally these cost drivers may modify an earned value technique to better estimate costs at completion. The risk-based approach to earned value is used to fill the gaps between how a project is trending and the final completion in terms of cost and schedule. For example, in the classic earned value curves shown in Figure 4-2 the gap in data between point A and point B could be modified by risk analysis data.

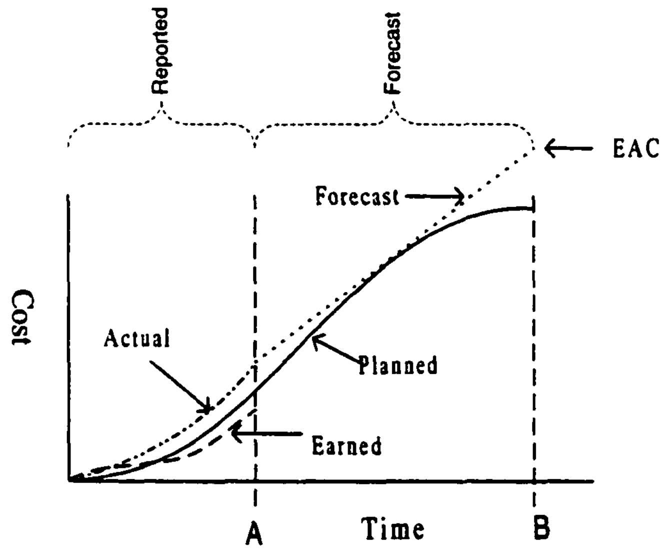

Figure 4-2. Classic Earned Value Curves

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4.1.2.2. Risk Analysis

Just before construction begins a final risk analysis should be performed by those responsible for planning the actual construction of the project. Likewise, as discussed above, an estimate and schedule are produced in a similar manner. This risk analysis is developed into a risk management plan and a strategy to accomplish the construction project. The final estimate and schedule become the budget and planned schedule of work. As shown in Figure 4-3 planning develops into a plan/ strategy or risk assessment develops into risk management. The key in this process is that estimated costs and schedules are developed into budgets and schedules with the help of risk analysis techniques. This risk analysis work performed early in a project's cycle can be used as a starting point for further risk analysis work once a project has begun.

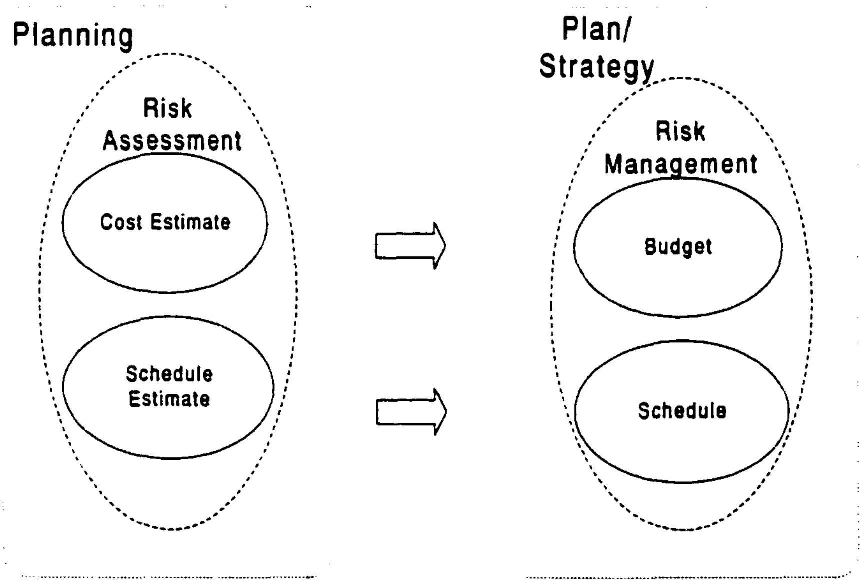

Figure 4-3. Risk Assessment Becomes Risk Management

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During construction execution the budget and plan are compared to the actual cost and milestone accomplishments. This comparison method is the basis for most cost control and forecasting techniques discussed earlier. For example, in Figure 4-2, an earned value system allows managers to control costs between points A and B. It also will forecast what costs may be at point B based on actual cost at point A.

The difficulty in this cost and forecasting method is that it only applies known variances after they occur and applies a choice of linear equations or statistics to forecast the cost at completion.

The point of departure for this research is to combine the techniques of risk analysis, cost control, and simulation to anticipate problem areas between points A and B, as shown in Figure 4-4. Identified soft cost drivers from the risk analysis will be used to help control cost during a project's execution. A risk assessment in the construction execution phase should not be cumbersome and only needs to be an update of an existing risk assessment. Details of which risk analysis techniques that are best suited to capture the soft cost drivers and how best to combine these with simulation and earned value methods is presented in the following section.

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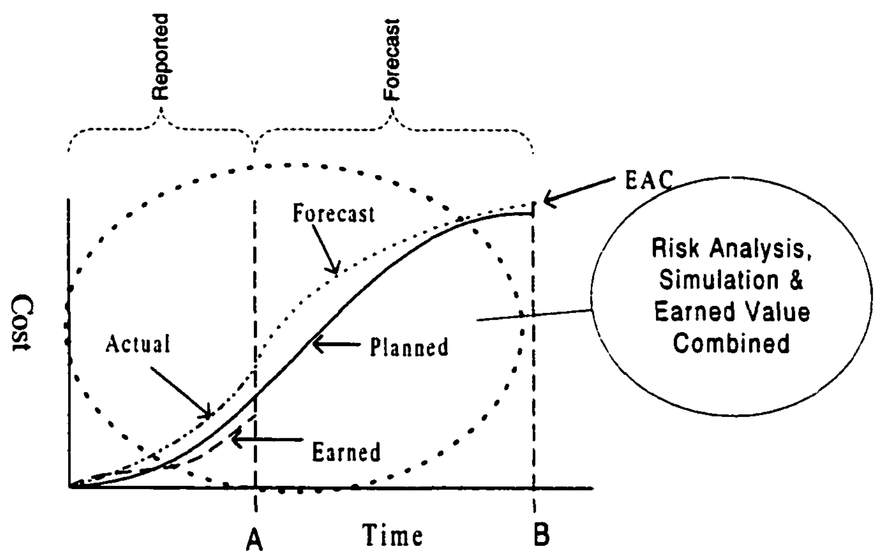

Figure 4-4. Risk Assessment Applied During Project Execution

4.2. Suitable Risk Methods For Cost Control

Suitable risk methods for cost control needs are defined and are presented in this section. As shown earlier in Tables 3-1 and 3-2 there are several risk methods that are both qualitative or quantitative that could be applied to the cost control problem.

A successive risk analysis has been developed in conjunction with the phases of a construction project. This risk analysis is a dynamic process and is a combination of both qualitative and quantitative risk methods. The generic structure of this risk analysis for cost control is shown in Figure 4-5. In the risk assessment phase the probabilities and consequences of risks or opportunities are identified and a determination of risk is developed. Then risk ratings are compared to risk acceptance levels and a decision analysis process is used to assist management. The basic structure shown in Figure 4-5 is applied in both the planning and execution phases of a

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project. The activities in the boxes represent risk assessments and the activities in the arrow represent risk management functions.

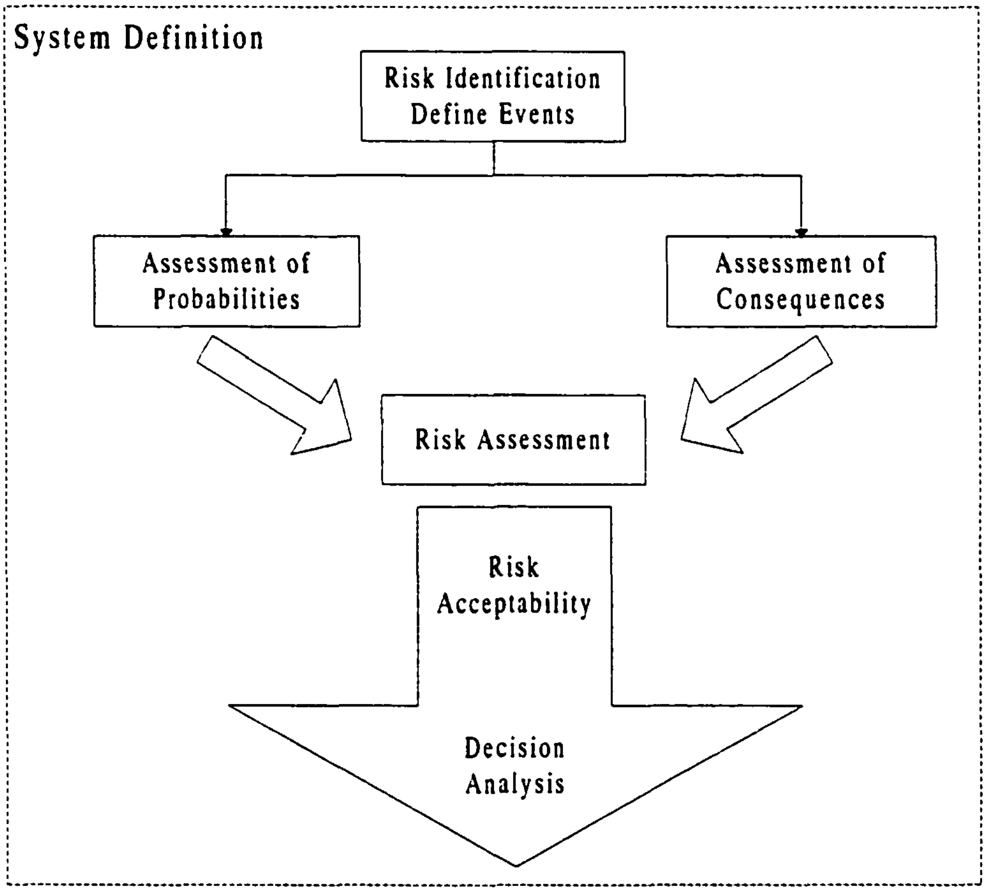

Figure 4-5. Generic System Definition of Risk-based Cost Control

4.2.1. Planning Phase

Applying the results of a qualitative method to simulation during the planning (feasibility or preliminary design) phase of a project makes a qualitative and quantitative risk assessment. This method accounts for the uncertainty in estimated cost and schedules. The qualitative method of the risk assessment is performed using

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a two step process. First a check list approach is used to identify potential risk and then a risk matrix technique is applied using expert judgement to quantify the risk. By using two methods of risk assessment potential areas of risk that effect the cost and schedule are accounted for. Additionally, other areas of potential risk are highlighted and can be managed.

This portion of the risk assessment is focused on the development of cost and schedule estimates that include the effects of uncertainty and potential risks. Cost and schedule risks are best suited for methods that apply a quantitative method since the estimate and schedule are developed by a quantitative analysis. A simulation of the construction processes using probability density functions to represent the uncertainty in the cost or activity duration estimates is used. Yet, to accurately and fully account for potential risks a qualitative risk assessment method provides input to the quantitative analysis.

A generic flow chart of this qualitative and quantitative process is shown in Figure 4-6. The process begins with a review of the project scope and a Work Breakdown Structure (WBS) development. Risk is then identified and assessed via a risk matrix table. Results from this assessment are used to help build simulation models for cost and schedule development. If a risk is assessed as too high or unacceptable it must be mitigated in the planning phase. Similarly if an opportunity is identified and assessed as having a high potential to save money it should be taken advantage of during the planning phase. Once these risks have been mitigated, or taken advantage of, there are two outputs from this process: 1) risks and uncertainty are monitored in the execution phase 2) simulation is used to estimate cost and

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schedule targets. This risk assessment method is simultaneously applied to both cost and schedule issues, but for clarity is described separately in the following sections.

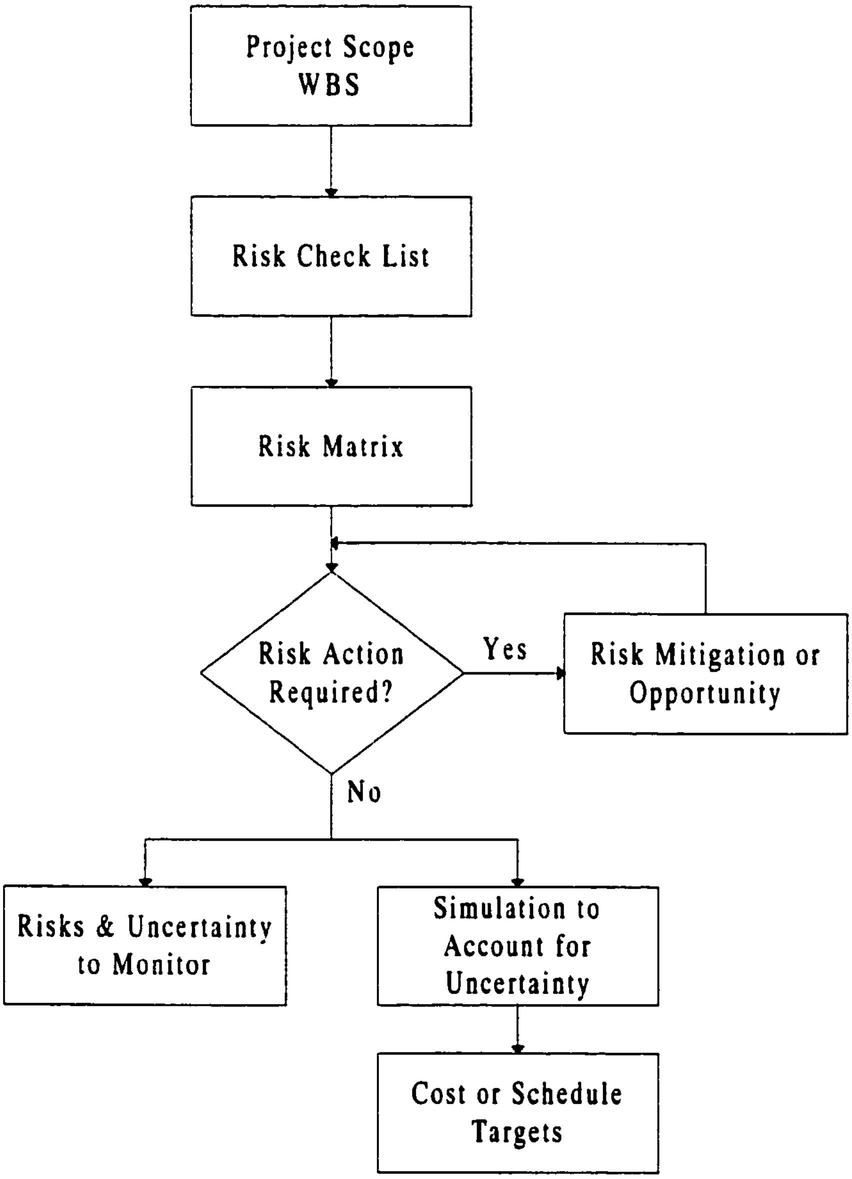

Figure 4-6. Combined Planning Phase Qualitative and Quantitative Risk Assessment

4.2.1.1. Cost Risk Assessment

Construction project costs are typically estimated by developing a single value or "point estimate". A point estimate does not include the effects of uncertainty and is

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simply based on the summation of a number of point estimates for items of work. A point estimate does not include a range of values, standard deviation and variance, or confidence intervals. A better risk-based estimate would model uncertainty and provide results that include statistical parameters.

There are several methods that can be used to quantitatively model the uncertainty associated with developing a risk-based cost estimate. These are simulation, fuzzy set theory, probabilistic risk assessment method using fault trees, and the Expected Monetary Value (EMV) method. These methods of developing risk-based costs are established in the literature and are not a focus of this research. What is presented is a methodology to combine one of these quantitative methods with a qualitative method that provides a broader coverage of risk.

A methodology utilizing simulation is presented because simulation techniques are readily adapted to the construction industry. This is because construction projects have multiple and interrelated activities that can be easily modeled. Once a point estimate is developed, uncertainty can be probabilistically expressed by using probability density functions. Finally, simulation can be easily performed on current state of the art desktop computers.

One difficulty of using simulation to develop cost risk is determining what factors, parameters, or range of values should be applied to the probability distributions used to represent the uncertainty of cost. The proposed method is to apply both a risk check list to identify and risk matrix to quantify the potential risk. The simulation model can then use this information to develop appropriate cost ranges modeled by the probability distributions.

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Other methods of using a risk assessment to develop costs are not used because of their limited practical application to construction projects. For example, when using fault trees, detailed input data is required. Since each construction project is unique this data is typically difficult to obtain in crisp quantified terms.

4.2.1.1.1. Data Requirements for Cost Risk Assessment

The process for developing the cost risk data is presented in Figure 4-7. The first step in establishing a cost estimate is to breakdown the project using a Work Breakdown Structure (WBS). Once this is done a point estimate can be developed for each individual work package. Replacing a point estimate for a work package with a probability density function can better approximate the cost of each work package by accounting for uncertainty. Care will be required to use the appropriate density function and associated parameters. To assist in this selection a risk check list and matrix process is used. The selection of which probability density function is best suited for certain construction operations has been demonstrated by AbouRizk and Halpin (1992) and Law and Kelton (1991) recommend several alternative distributions. This estimated cost or target of the project shown in the last block of Figure 4-7 has been quantified to account for uncertainty and potential risks. This process also highlights risks or opportunities that may be mitigated or taken advantage of during the planning process.

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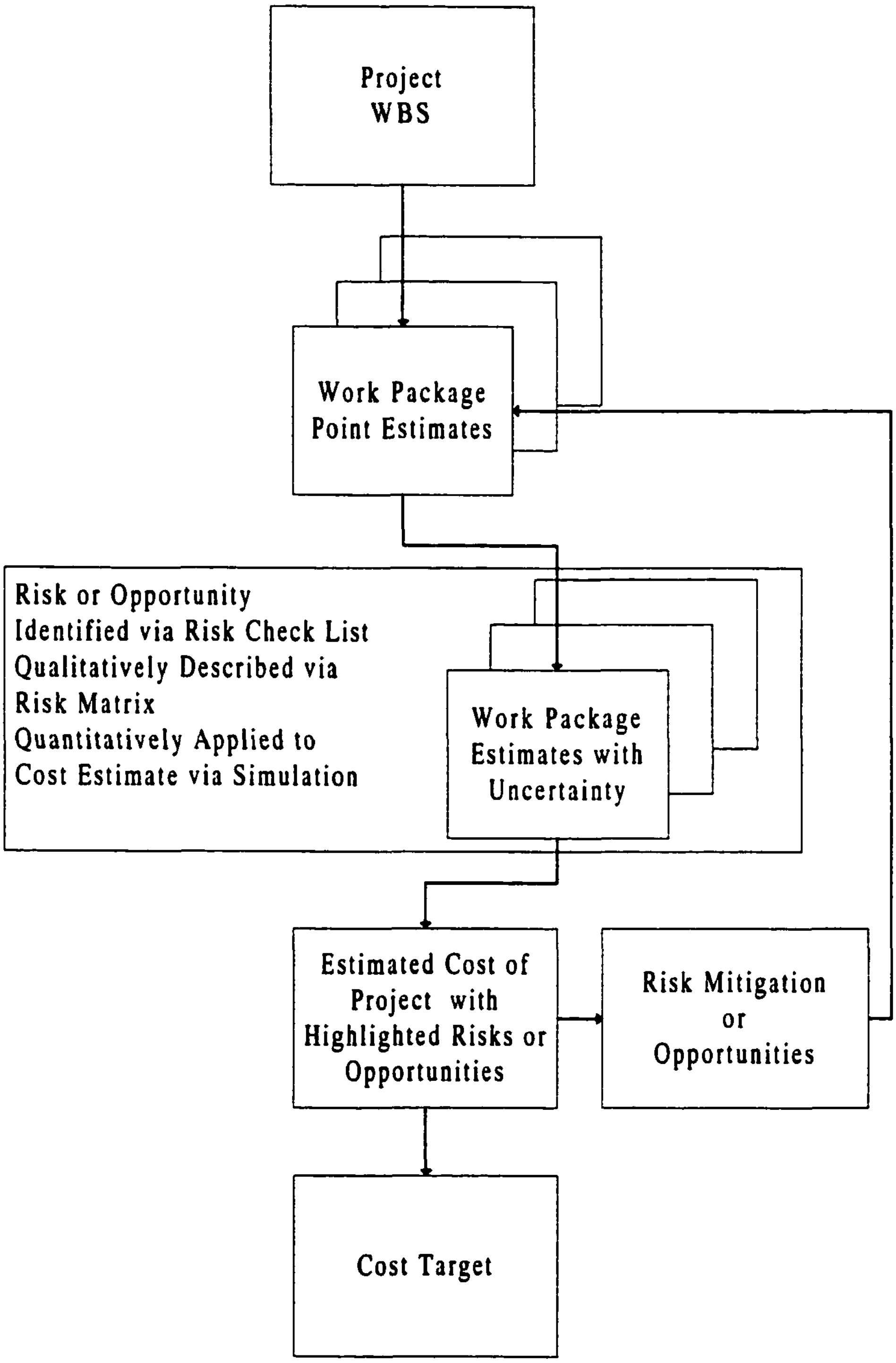

Figure 4-7. Cost Risk Data and Process

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4.2.1.2. Schedule Risk Assessment

Construction project schedules are typically estimated by breaking down the project into definable activities. Each activity is estimated to take a discrete amount of time or a "point estimate" for the time an activity will take. The total time for a project using the Critical Path Method (CPM) is the sum of all critical activities (activities that any delay will cause a project to be delayed). This method does not account for any uncertainty in the activities. A point estimate does not include a range of values, standard deviation and variance, or confidence intervals. A better risk-based schedule would model uncertainty and provide results that include statistical parameters.

There are several methods that can be used to quantitatively model the uncertainty associated with developing a risk-based schedule estimate. These are simulation, fuzzy set theory or a probabilistic risk assessment method. These methods of developing risk-based schedules are established in the literature and are not a focus of this research. What is presented is a methodology to combine one of these quantitative methods with a qualitative method that provides a broader coverage of risk.

A methodology utilizing simulation is presented because simulation techniques are readily adapted to the construction industry and combines well with the CPM of scheduling and simulation. This allows one model to be developed to obtain the results for both the estimated cost and schedule. Once a point estimate is developed, uncertainty can be probabilistically expressed by using probability density functions. Simulation is easily performed on the current state of the art desktop computer.

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One difficulty of using simulation to develop schedule risk is determining what factors, parameters, or range of values should be applied to the probability distributions used to represent the uncertainty of the schedule. The proposed method is to apply both a risk checklist and matrix to identify and quantify the potential risk. The simulation model can then use this information to develop appropriate schedule ranges modeled by the probability distributions.

Other methods of using a risk assessment to develop schedules are not used because of their limited practical application to construction projects. For example, when using a probabilistic method such as fault trees, detailed input data is required. Since each construction project is unique this data is typically difficult to obtain.

4.2.1.2.1. Data Requirements for Schedule Risk Assessment

The process for developing the schedule risk data is presented in Figure 4-8. This process is purposely similar to that shown in Figure 4-7 so they can be analyzed simultaneously. The only real difference between the two processes is the input data for either cost or schedule. The first step in establishing a schedule estimate is to break down the project using a Work Breakdown Structure (WBS). To effectively apply a cost control system, this WBS needs to be the same as the one used to breakdown costs (Fleming and Hoppelman 1996). A point estimate for the duration of each activity can be developed for each individual work package. Replacing a point estimate for a work package with a probability density function better approximates the cost of each work package by accounting for uncertainty. Care will be required to use the appropriate probability density function and associated parameters. To assist

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in this selection the same risk check list and matrix process used to define the cost risk described earlier is applied. The estimated or target schedule for the project shown in the last block of Figure 4-8 has been quantified to account for uncertainty and potential risks.

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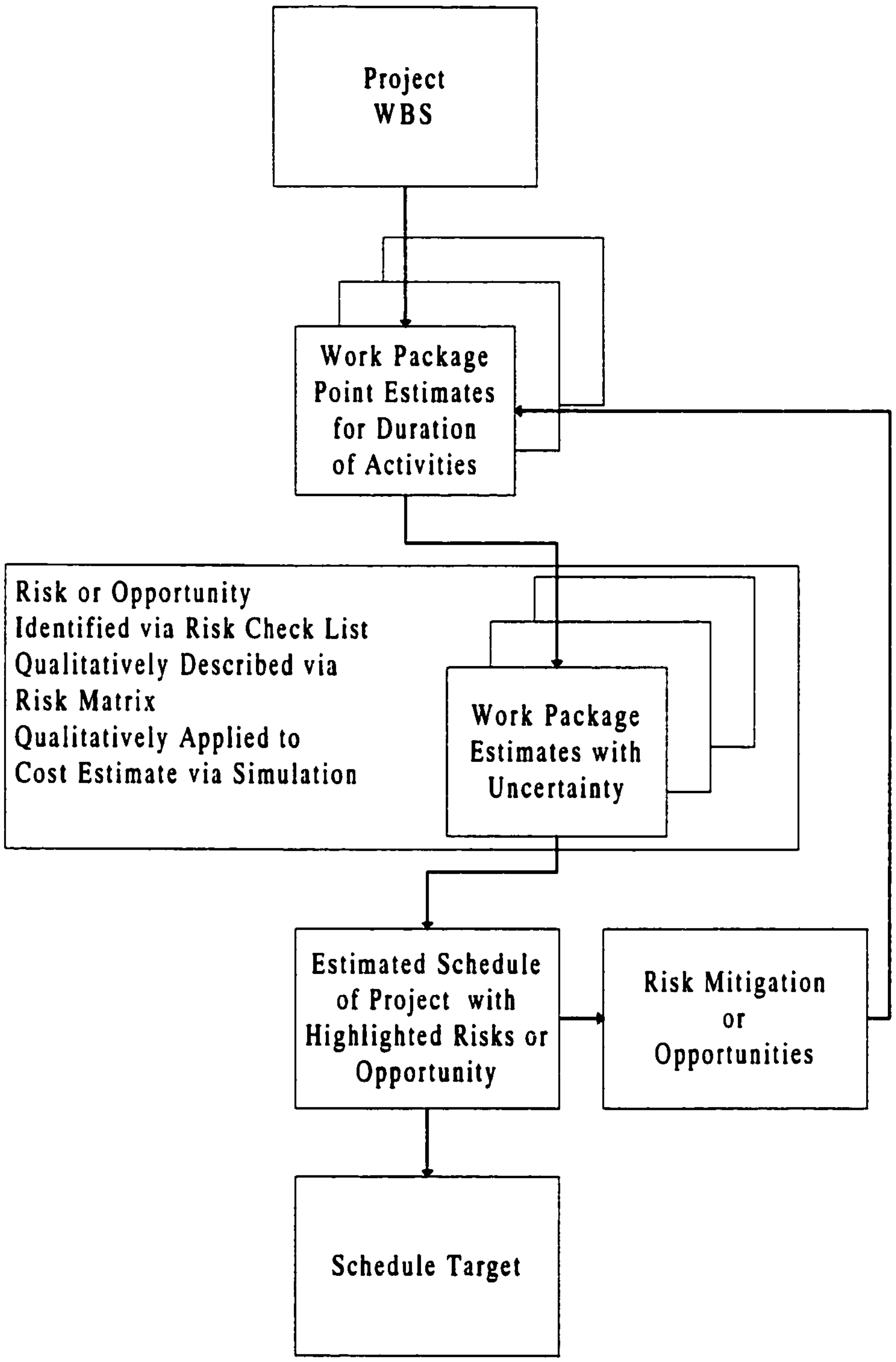

Figure 4-8. Schedule Risk Data and Process

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4.2.1.3. Cost and Schedule Risk Acceptability Method

Once the potential risks are highlighted from the risk matrix a method of risk acceptability is required. The project team should propose to management the level of acceptable risk. The method for establishing acceptable risk should be based on criteria and guidelines established for a particular company or organization. These criteria should be relatively generic so that they can be applied to projects typical for the organization.

Risks that have the potential to cause significant cost impacts should be targeted for reduction or control. This methodology uses a two step process for determining risk acceptability: 1) all risk above a certain qualitative threshold should be targeted for reduction or opportunity, 2) all risks, except safety, should be evaluated by the cost effectiveness of risk reduction.

Management needs to set the thresholds for risk levels and cost effectiveness. Risk events with an acceptable cost effectiveness are deemed acceptable and mitigation efforts or opportunities will be pursued. Negative risks that are deemed unacceptable and not cost effective will likely make a project non-viable.

Safety risk is treated separately because society views fatalities much differently than monetary losses. Again a two step process will be used to determine safety risk acceptability. First, safety risk events are categorized and prioritized by the magnitude of the consequences. This method is similar to the risk totem pole (Grose 1987). Secondly the cost effectiveness of risk reduction method will be used but the threshold of acceptability will be much lower. Safety risks that are deemed unacceptable and can not be mitigated will make a project non-viable.

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4.2.1.4. Cost and Schedule Decision Analysis Method

There are three major decisions to be made in the planning process. The first one answers the question, "What risk should be mitigated or opportunities pursued in the planning phase?" The second decision area helps to set up the simulation for the development of cost and schedule targets. Third, a decision is required to determine if a project should be pursued furthered into the execution phase.

As shown in Figures 4-7 and 4-8 the output form the risk based cost and schedule development also includes highlighted risk or opportunities. High negative risks and opportunities should be acted on during the planning phase. This should have the effect of reducing cost and schedule and therefore the original estimate must be redone. Finally cost and schedule targets are developed that include the effects of mitigating high negative risk and seizing opportunities.

As shown in Figure 4-7 and 4-8 the results of the risk assessment from the risk matrix are applied to the cost or schedule estimate via a simulation method. The risk assessment provides information for the determination of the appropriate range to use in the probabilistic representation of various cost or activities. The range is the measure of dispersion of a distribution about a mean value. For example, if a construction operation is represented by a triangular distribution the range of values may be arbitrarily selected from 90% to 115% of the mean. Though the results of the risk assessment this range can better represent the risk involved and is increased or decreased accordingly. For example, an activity with a high negative risk might use a range between 95% and 125% to reflect the potential for an adverse consequence.

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The decision to go further with the project will be made once the risks have been highlighted and final target costs and schedules are known. Generally the most important risk issues are costs and schedules. This may be simply a matter of comparing the cost and schedule targets to the available resources. For a private owner or governmental agency this is performed by comparing the targets to funding required to make the project economically viable or funding available. A constructor considering building a project will compare the schedule targets with the requirements, the cost targets with the resources available, their ability to perform the work, amount of bonding capacity, and the risks involved.

A methodology for using Net Present Value (NPV) will be used to determine if the project should be pursued further. This method is selected because it is relatively simple to apply, yields a monetary value that includes the time value of money, and can account for the uncertainty in a project (Wang and Roush 2000).

4.2.2. Project or Construction Execution Phase

The methods used during this portion of the project are dynamic or continuous because the project is active and new information is continually available.

4.2.2.1. Project Execution Phase Risk Assessment

The initial risk assessment work performed in the planning phase should be continued in the execution phase. The risk checklist, consequence and likelihood assessments are reviewed and updated to provide a risk assessment during the execution phase. The new information available to the project team is used to update

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previous risk assessments. The risk methods applied in this phase are shown in Figure 4-9.

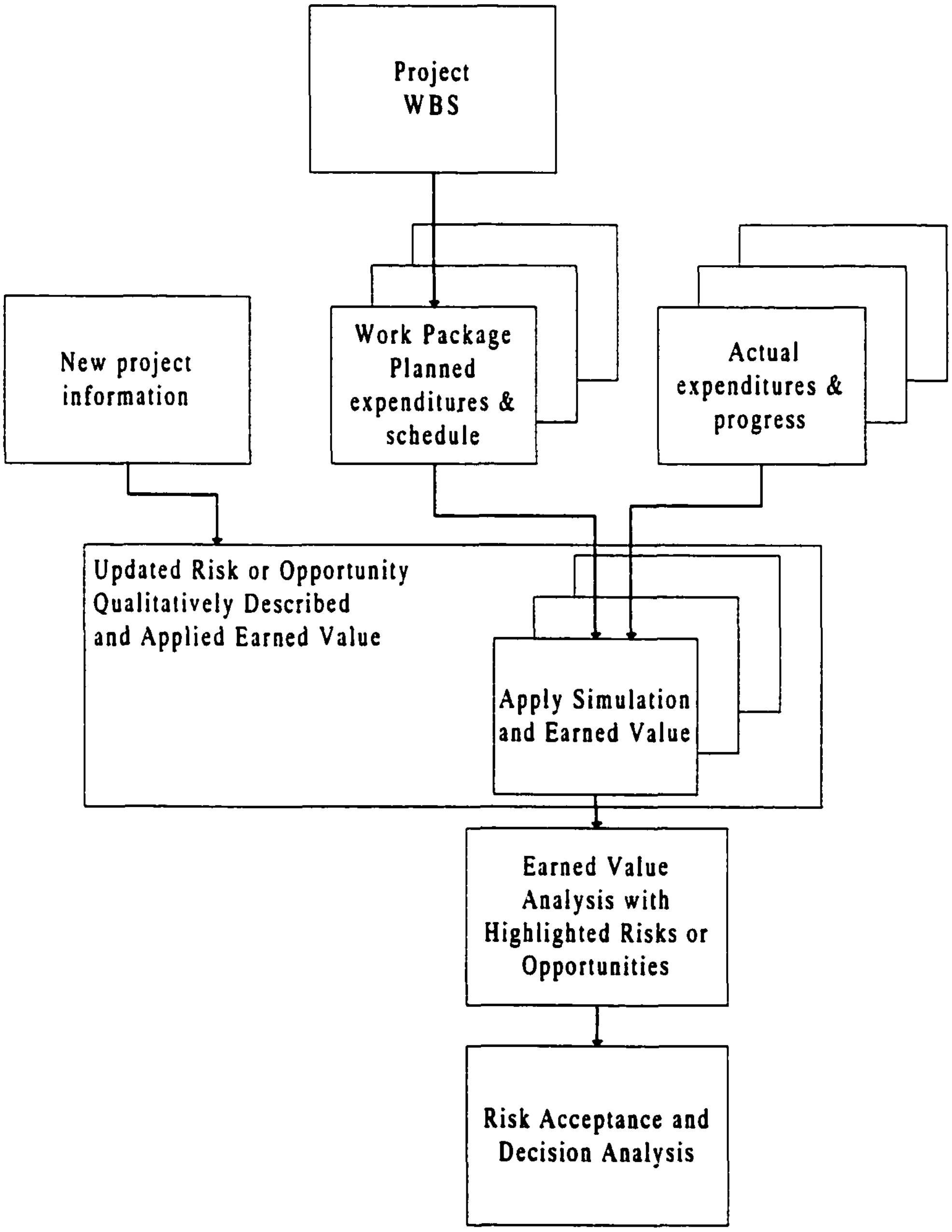

Figure 4-9. Execution Phase Risk Analysis

There are several differences between the process shown is Figure 4-9 and the similar processes shown in Figures 4-7 and 4-8. In the execution phase of a project

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new information that effects the project is generated. This new information may be changes to the final construction documents, actual cost quotes versus estimates, feedback from vendors and other data. This information should reduce the uncertainty that a previous risk assessment was made with. Therefore the previously performed risk assessment needs to be updated. Actual project information such as costs incurred and milestone accomplishment (earned value techniques) can now be used to help monitor the project's cost, schedule and risks. As shown in Figure 4-9 there is one output from the simulation block, the earned value analysis with highlighted risk or opportunities to monitor. From this information, risk acceptability criteria are applied and a decision analysis process is used to control project cost.

4.2.2.1.1. Execution Phase Risk Acceptability Method

A strategy to reflect the level of risk that is deemed acceptable to the project team is needed. This process should be based on the specifics of the project but within the general guidelines established by a corporation or governing body.

A two step method is used to aid in the management of the identified risk above an acceptable level. The first step is to tentatively describe acceptable and unacceptable risk levels. For example, if the output of the risk matrix describes risk as low, medium or high, all high level risks may be tentatively deemed unacceptable. The second step is to determine the cost effectiveness of risk reduction for all identified risks. Management will determine a level of acceptable risk based on the cost effectiveness of risk reduction.

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4.2.2.1.2. Execution Phase Decision Analysis Method

A risk-based decision analysis provides a framework for project managers to bring known risks under control, reduced, or minimized. Where appropriate, decision trees or goal trees will be used to assist decision-makers.

4.3. Proposed Cost Control Methodology

The overall proposed methodology that applies risk analysis for cost control is highlighted in Figure 4-10. The methodology is broken up into two separate and distinct phases. As shown in Figure 4-10 the top portion relates to planning and the bottom section relates to execution. The main difference between these two is that planning uses a risked-based approach to develop costs and schedule targets, while execution uses a risk-based approach to control project costs.

The methodology has several central themes that enable it to provide the tools necessary to control costs. These are:

- Through early risk identification and assessment, as shown in the top portion Figure 4-10, project managers will have a warning of the potential negative or opportunistic risks on a project. This early identification of risk events is paramount in the case of controlling costs because it affords decision-makers an opportunity to take corrective actions or seize opportunities.

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- Combines a novel blend of risk and cost control methodologies that synergistically assist project management in controlling costs. As shown the lower portion of Figure 4-10 risk analysis, earned value, and simulation are combined.
- Provides a continuous process that monitors initial assessments throughout the life of a project. Risk assessment and cost control data are updated during the life of a project as shown in the lower left portion of Figure 4-10.

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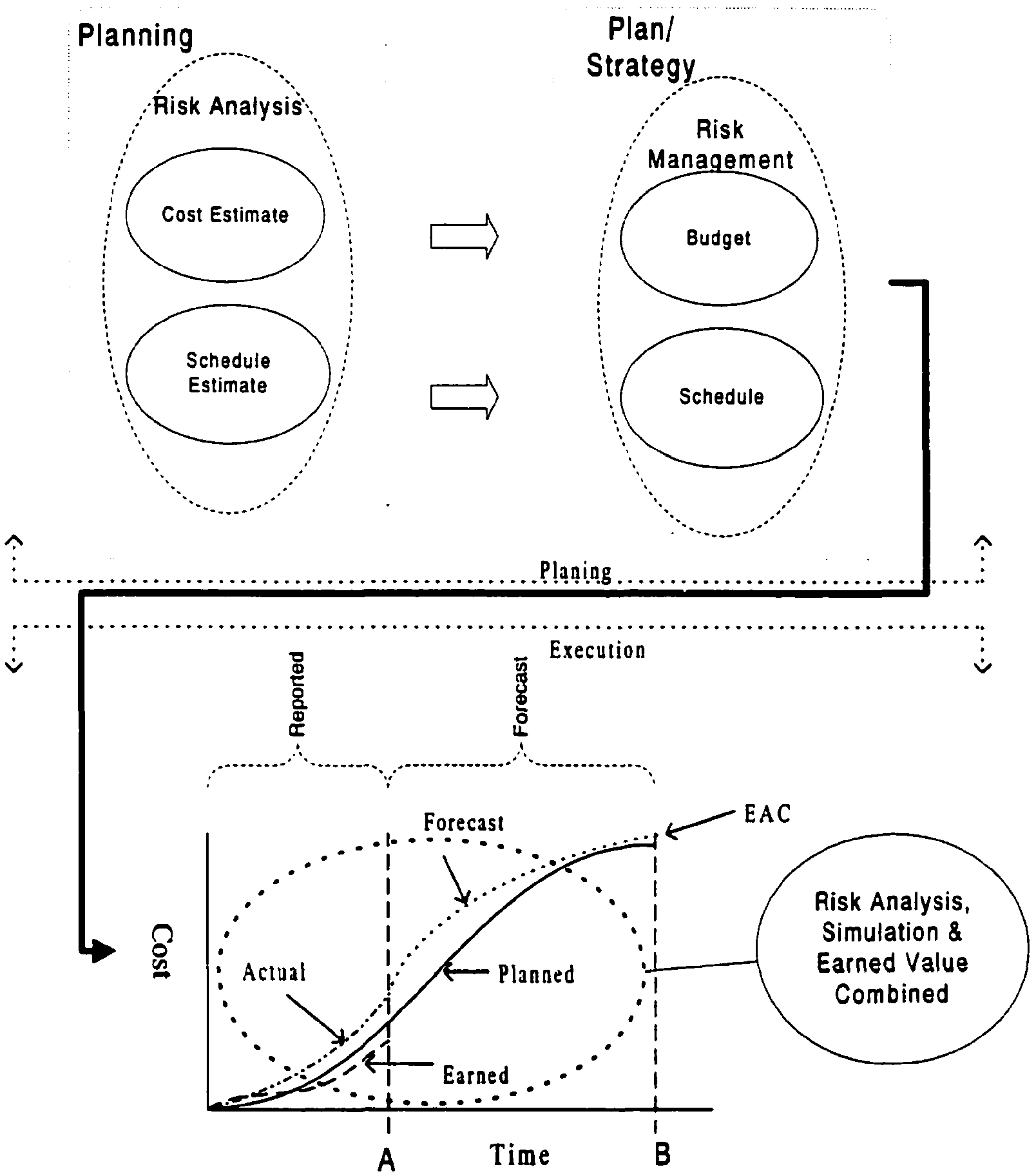

Figure 4-10. Proposed Methodology

4.3.1. Proposed Methodology Framework

This risk-based cost control methodology includes a system that encompasses and accommodates: a system definition, assessment of probabilities and consequences, risk assesment, risk profiles, risk acceptability, and planned actions through decision

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analysis. This framework applies to both the planning and execution phases shown in Figure 4-10.

4.3.2. System Definition

The methodology of combining cost control techniques and earned value is established within a framework of a systems definition. This framework is shown in Figure 4-11 and includes the entire methodology. The dashed line that encompasses the shown process represents the cost control systems definition that defines boundaries and interactions among the various components of the methodology.

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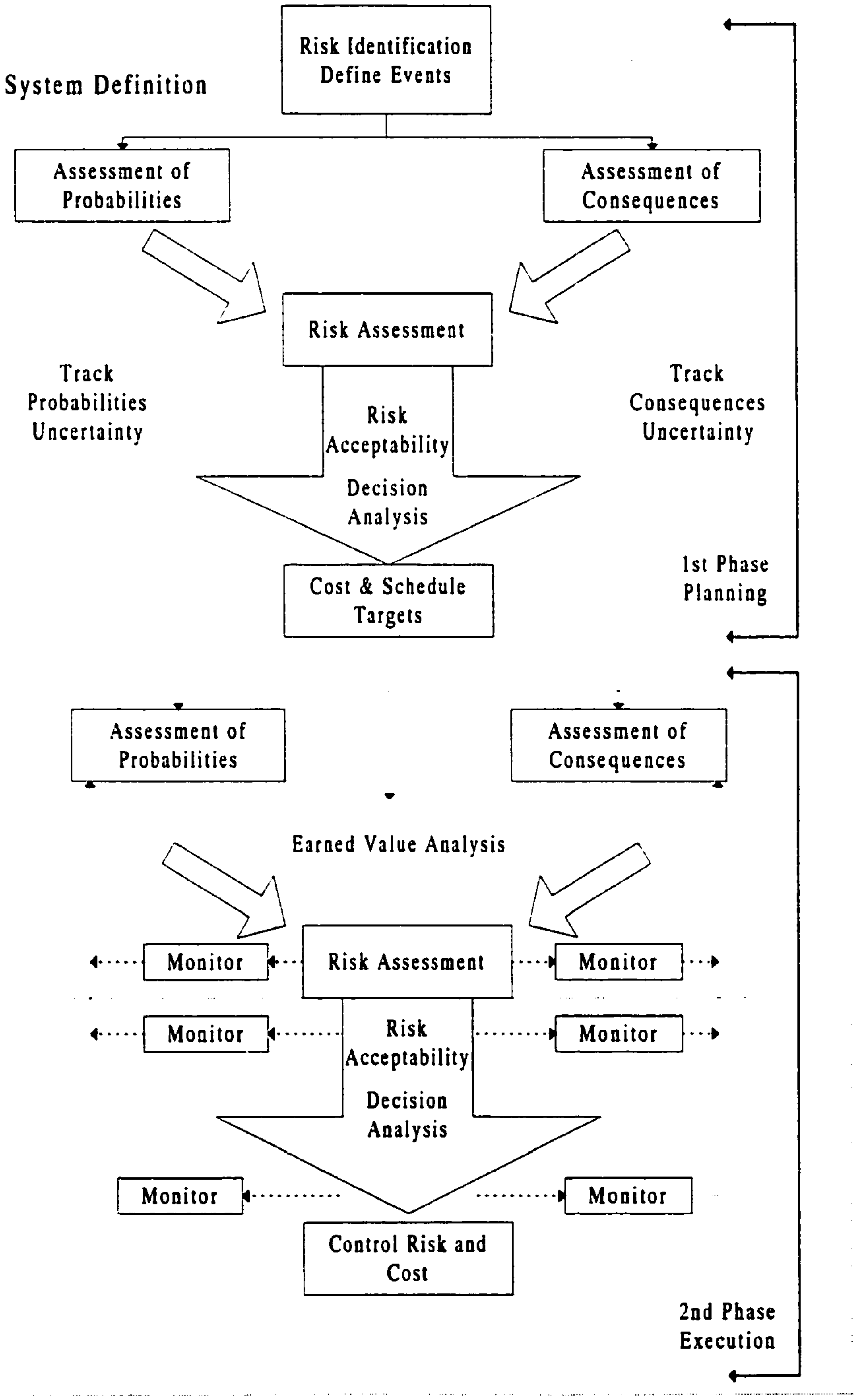

Figure 4-11. System Definition of Risk-based Cost Control

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As shown in Figure 4-11 the system has a two-phase hierarchical structure. The objective of the first phase is to use the project information to: 1) identify risk for mitigation and opportunities to take advantage of, 2) develop target cost and schedule, 3) assist in determining a project's viability. In the planning phase the risks are identified, risk events, associated probabilities, and consequences are defined. Referring back to the definition of risk engineering these consequences include both negative and positive effects to the project. The probabilities and consequences of a risk event are combined to form a risk assessment and representative risk profile. Once risk profiles are defined, a risk management methodology formulates a risk management plan that includes the procedures for risk acceptability and decision analysis.

The second phase of this process is repeated again but with some changes. New information is used to update a risk assessment and is shown in Figure 4-11 as lightly dotted lines from the first assessment of probabilities and consequences blocks to the second set of assessment of probabilities and assessment of consequences block. The lightly dotted lines represent items that are monitored or updated throughout the life of a project. The cost and schedule targets form the base line of the earned value analysis that is combined with the risk assessment to better assess overall project risk and control costs. The objective and output from the second phase are decisions used to control project costs.

The systems definition includes:

- The architecture of the system.
- The interactions of the components of the system.

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- Criteria for evaluating a components completeness.
- The boundaries of the system.

4.3.2.1. Architecture of the System

The system architecture is designed to produce a management tool for project cost control. This is accomplished through:

- Information Collection
- Risk Analysis
- Earned Value Analysis
- Simulation

4.3.2.1.1. Information Collection

An important theme and consideration in the methodology is information collection. What, when to collect, and the value of information collected all need to be considered.

4.3.2.1.1.1. What Information

The basic architecture of the methodology begins with an information gathering process. Available documents such as plans, specifications, requirement assessments, and other documents that describe the scope of the project are used to establish the construction requirements. Additional documented material such as historical data, industrial capabilities, and resource availability is required to understand the risks involved with a complex project. The information generated from both the requirements versus the capabilities and historical data is used as the

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foundation for the risked-based development of cost and schedule targets. As the project progresses into the execution phase new information is collected to validate previous assumptions or is used to help better quantify risk and cost issues. This information is from field reports, actual cost data, and risk assessment reports collected from the ongoing project.

4.3.2.1.1.2. When to Collect Information

An important consideration and theme of the methodology is when to collect information required to assess risk, make decisions and control costs. The phase of the project dictates when and how information is collected.

There is a dilemma in decision making that concerns the amount of information required to make a decision. Decision-makers would prefer to have all the information available to make a decision but by the time this information becomes available the decision may have been "overcome by events" or moot. Therefore decisions must be made with a level of uncertainty. Risk analysis helps to reduce this uncertainty by forecasting potential project issues.

In the planning phase most information will come from the sources described above. The information acquired during the planning phase needs to be acquired as early in the planning phase as possible. This allows for the maximum ability to influence planning and execution processes. Much of this early information may still be quite vague or conceptual. The important issue here is that risk issues are identified and vetted within the project team early enough to take corrective action.

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During the execution phase project managers are faced with an even more perplexing decision dilemma. In the execution phase project managers are typically faced with decisions that need to be resolved right away. In making these decisions the project manager may not be afforded the time to develop a detailed analysis and ends up jumping from one crisis to the next. In these cases most project managers may rely on professional judgement and intuition. To avoid this crisis management, project managers need information periodically updated in the execution phase to be able to anticipate problems or opportunities. This periodic information will most likely be collected monthly. It will be used to update the existing risk assessment and earned value analysis. The actual periodicity of information collection will depend on the value of the information and the cost to collect it.

4.3.2.1.1.3. Value of Information

Should you hire a broker or should you use an on-line discount broker to make your stock transactions? When making stock trades with a broker you pay more for each stock trade but gain the brokers knowledge and information. When using a discount broker you pay less per trade but do not receive any recommendations for a particular stock. In paying a broker a stock trader is paying for the information provided or the expected value of information.

The expected value of information can be zero, positive, or perfect (Clemen 1996). If the trader ignores the broker's advice and puts his money elsewhere the information has zero expected value. If the trader heeds the advice of the broker and the information leads to a greater than expected return then the value of

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the information is positive. If the broker can provide information that resolves all uncertainty and every choice has a known outcome the value of the information is perfect.

In a project management context the expected value of information is an important consideration. First, all information gathering can be expensive and time consuming. Secondly, the appropriate information for the decision at hand needs to be gathered. By considering the expected value of this information, better decisions can be made about how much information to obtain or what information is required.

The expected value of information can be calculated through the use of influence diagrams and decision trees (Clemen 1996). These methods are relatively straightforward but require a substantial investment to obtain the data required to populate the diagrams and trees.

The amount of resources devoted to information gathering should be based on an application of Pareto's Law (20% of the elements effect 80% of the outcome) and the magnitude of the Expected Monetary Value (EMV) of the decision at hand. This means a qualitative determination for the expected value of information will need to be determined. For example, the "Big Dig" tunnel project under the Boston harbor is several billion dollars over budget and expected to cost about $13.5 billion. Most of the additional expense has to do with encountering unexpected soil conditions. In hindsight, millions of dollars could have been applied to site and soil investigations. The expected value of information in this case had an obviously high value and the decision at hand (do more investigative and design work versus amount planned) should have anticipated potentially high negative consequences.

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4.3.2.1.2. Risk Analysis

The risk analysis process used in this methodology is repeated from the planning to the execution phase to ensure completeness and simplicity of application. The actual quantification of risk may change as new information is provided during the execution phase of the project. This requires that the assessment of probability and consequences will be monitored for changes until the project is completed. Likewise uncertainty will be tracked for changes. This monitoring is required because decisions are typically made with a certain amount of uncertainty. Should the assessment of probability, consequences, or uncertainty change previous decisions may need to be revisited.

4.3.2.1.3. Earned Value

The earned value analysis is performed in the execution phase and is represented as the dotted lined box around the assessment of probabilities, assessment of consequences, and risk assessment functions shown in the lower portion of Figure 4-11. This commingling of risk assessment and earned value is designed for each technique to symbiotically assist each other. The risk assessment focuses interest on items that are most susceptible to cost escalation and could benefit from an earned value analysis. The earned value analysis provides new information that may be used to update a previous risk assessment.

4.3.2.1.4. Simulation

The simulation of the system is the glue that links the two-stage process together and makes the system manageable. Risk assessment, cost and schedule

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models developed in the planning phase only need to be updated in the execution phase. A risk-based decision analysis used in the execution phase is required to account for new information and provide actions to control costs.

4.3.2.2. Interactions of the Components of the System

The components of the system that are shown in Figure 4-11 all interact together because they are all linked to the risks, cost or schedule of a project. The system is a dynamic process, as the project progresses from feasibility to final completion new information is used to help quantify risks and control costs. Therefore, certain information needs to be tracked and updated periodically. This information is earned value cost data, uncertainty, assessment of probabilities and consequences. As a project moves toward completion uncertainty about risk assessment should decrease and the value of this information increases.

The main interaction of the systems is between the two stages. The output from the first risk analysis is used in the second stage or execution phase as the main input for the risk and earned value analysis. The output of cost and schedule targets is used to define a baseline for a project's execution. Additionally, the risk assessment performed in the execution phase is based on any previous risk assessment work and updated information. As shown in the lower portion of Figure 4-11, in the execution phase there is a constant monitoring of risk assessment data, risk acceptability, and decisions made to ensure the project is progressing satisfactory.

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4.3.2.3. Criteria for Evaluating a Components Completeness

Criteria to measure the completeness of the components of the system are required. These criteria are technique or process specific and are broken down between the two stages shown in Figure 4-11.

4.3.2.3.1. Planning Phase

This is the first phase of the risk analysis shown in Figure 4-11. It sets the stage for the methodology.

4.3.2.3.1.1. Planning Risk Identification

A generic risk checklist is used to help identify typical project risk. The risk identification process is complete when this checklist has been reviewed against available project information and possible risk events have been documented.

4.3.2.3.1.2. Planning Risk Assessment

The risk assessment begins with a review of identified risks and generic lists of project probabilities and consequences. The criteria for risk assessment completion is when consensus is reached among risk assessors, risk has been rated, and profiled.

4.3.2.3.1.3. Planning Risk Acceptability

The criterion for this step is to set the level of acceptable risk. It is completed once this level has been set and the risks above this level are flagged and prioritized.

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4.3.2.3.1.4. Planning Decision Analysis

The decision analysis in this step is focused on: 1) mitigation of risks or taking advantage of opportunities 2) setting the range of variables and parameters to represent the uncertainty in the estimated cost and schedules 3) assist in determining project economic viability. The criteria for completion are to: 1) identified risks or opportunities to be acted on 2) ensure each major identified work package estimate is represented by an appropriate probability density function 3) a recommendation of project viability based on risk is made.

4.3.2.3.1.5. Planning Cost and Schedule Target Development

The cost and schedule development must ensure that the simulation of project activities is validated and verified. This process is completed when the simulation is reviewed to ensure it represents the actual process and produces accurate results.

4.3.2.3.2. Execution Phase

This is the second stage of the risk analysis that includes earned value analysis as shown in the bottom Figure 4-11.

4.3.2.3.2.1. Execution Phase Risk Identification

The risks identified in the first stage are reviewed for validity and updated with new information. The risk identification process is complete when this risk checklist and previously established risk events have been reviewed and compared to updated project information.

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4.3.2.3.2.2. Execution Phase Risk Assessment

The risk assessment begins with a review of identified risk events. This process also includes are review of the probabilities and consequences of risk and their corresponding uncertainties identified in the planning phase. The risk assessment requires monitoring to track any changes in the uncertainty of the probabilities and consequences. The criteria for risk assessment completion are when the new information is reviewed, a consensus among risk assessors is reached, and risk has been rated and profiled.

4.3.2.3.2.3. Execution Phase Earned Value Analysis

This analysis considers actual reported project information. The criteria for completion are timely updated information, a graphical representation of the data, and projected costs at completion have been developed.

4.3.2.3.2.4. Execution Phase Risk Acceptability

The criterion for this step is to set the level of acceptable risk. It is completed once this level has been set. The criterion for risk level selection is based on dollar value, schedule milestones, technical requirements, and safety. The assessment of probabilities and consequences are monitored against the acceptable level of risk to ensure any changes have not made a risk profile unacceptable.

4.3.2.3.2.5. Execution Phase Decision Analysis

The decision analysis in this step is focused on providing management with the appropriate actions for cost control. The criteria for completion are to ensure each major identified cost issue has an identified choice of resolutions or alternatives.

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4.3.2.3.2.6. Cost Control

This process is completed when management takes the necessary action to implement the decisions recommended from combined earned value, risk, and decision analysis. The criteria for completing this function are that the actions taken are reviewed and monitored to ensure the solutions to decrease the risk or increase the opportunity of cost control are working.

4.3.2.3.3. Summary for Evaluating a Components Completeness

The criteria for the systems completeness are summarized in Table 4-1.

Table 4-1. Criteria for a Components Completeness

System Component	Criteria for Completeness
Planning Phase	
Risk Identification	Risk checklist compared to project information and risk events defined and profiled.
Risk Assessment	Identified risks have been rated.
Risk Acceptance	Level of risk acceptability is set; risks above this level are flagged and prioritized.
Decision Analysis	Mitigate negative risk or take opportunities, determine variables for probability density functions, assist in determination of project's viability.
Cost and Schedule Targets	Simulation has been verified and validated.
Execution Phase	
Risk Assessment	Risk checklist reviewed, compared to new information, and risk events updated. Assessment of probabilities, consequences and uncertainty are tracked until project completion.
Earned Value Analysis	Updated information and estimated completion costs are shown graphically.
Risk Acceptance	Threshold of risk set. Probabilities and consequences monitored against the threshold.
Decision Analysis	Alternatives for cost control are selected.
Cost Control	Cost control actions are reviewed for effectiveness.

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4.3.2.4. Boundaries of the System

The system is bounded by the scope of the project. For example, in the MOB case study the methodology is only applied to the construction of the hull. The methodology only seeks to control costs during a project's execution, the actual cost of feasibility studies, designs, and operation are not considered.

The risks that could cause cost issues are bounded by the reasonableness of the level of effort required to control the risk. For example, costs escalation risks may be from rising material prices. Material that has a price increase but insignificantly effects the project would not be suitable for risk analysis. For a specific example consider the cost of lumber, it can have significant fluctuations but if the project is a high rise building very little wood would be installed and this risk would be insignificant.

4.3.3. Planning Phase Methodology

Since the methodology spans two distinct phases in a project's life the planning and execution phases will be presented separately.

4.3.3.1. Planning Risk Identification

A complex construction project will contain risks with the potential for negative and positive consequences. This section presents a checklist method to help project team members identify potential risks and develop risk event scenarios for their projects. Figure 4-12 shows the process of identifying risk in the planning phase

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of a project. The risk identification is performed by team members who review the projects documentation, breakdown the work and compare it to a risk checklist.

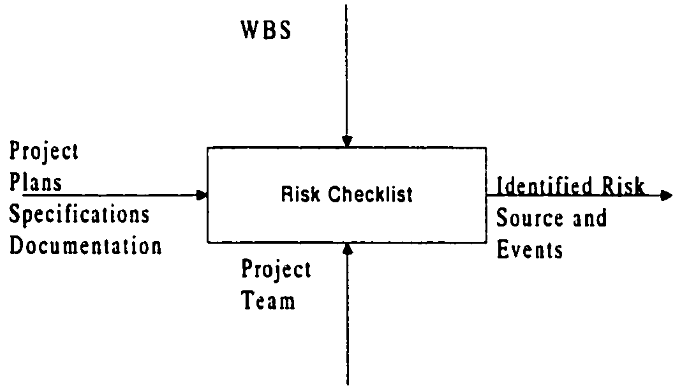

Figure 4-12. Planning Risk Identification

The risk checklist is not designed to replace critical thinking but only to encourage it. The checklist also helps to ensure nothing was left out. Knowledge of the project, possible methods, and strategy are fundamental to correctly identifying the risks associated with the project.

4.3.3.1.1. Project Team

The project team as used through out this dissertation is defined as; a group of individuals brought together to plan and help manage the construction of a complex project. The make up of the project team will depend on what method of project delivery system is being used. For example, in government procurement the project team may be composed of government and contractor personnel from several backgrounds. In a negotiated procurement in the private sector the project team may be composed of owners representatives, designers, builders, and others. The project team should have diverse backgrounds and experiences to understand the full nature of the risks involved in the project. At a minimum it should contain a representative

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from the owner or governmental agency, the designer and builder. Depending on the size of the project the number of people and organizations involved in the planning and management could become quite large, but for simplicity in this dissertation this group is referred to as the project team.

4.3.3.1.2. Risk Checklist

Risk checklists are presented in two tables, Table 4-2 for negative risks and Table 4-3 for opportunistic risks. The risk checklists shown in these tables should be considered generic. Other checklists developed for specific industries may be more detailed or efficient. For example, a project being built specifically for the disposal of hazardous waste may include several other sources of risk specific to the hazardous waste remediation industry.

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Table 4-2. Risk Checklist for Sources of Potential Negative Risk

Risk Source	Potential Events
Cost Escalation	Budget or bid unreasonable. Failure to account for bid items or requirements to fully complete project. Failure to meet budget.
Schedule Delay	Unreasonable schedule. Delays from others e.g. owners, suppliers, subcontractors, or consultants. Delayed permit process or site access. Failure to meet milestones.
Labor Problems	Availability and productivity issues. Unskilled labor force. Strikes or "working to rules".
Project Management Issues	Inexperienced project managers. Lack of cohesiveness in team. Inappropriate contract type or construction delivery method.
Safety Problems	Personal accidents from minor to fatal. Damages to property. Structural failure.
Excessive Change Orders	Poor design, capricious owner, new requirements. Fast track construction.
Unforeseen Conditions	Underground or hidden site conditions.
Environmental Concerns	Required regulatory approvals take longer than anticipated. Mitigation of environmental concerns cost more than anticipated.
Equipment Issues	Equipment failure. Selection of inefficient equipment.
Inflation	Material, equipment, labor, and overhead cost increases.
Weather	Adverse weather. Time of year work is scheduled causes low productivity. Extreme events e.g. hurricane, lightening strikes, or floods.
Complexity	Level of difficulty or technically challenging. Mistakes or rework.
Client or Owner Initiated	Potential owner's representatives, architects, engineers, and inspectors are overly critical or difficult to work with. Bankruptcy of owner. Loss of political support. Late payments.
Fire	Operations that require open flame or sparks. Work requiring explosives.
Suppliers	Non-performance from vendors, subcontractors or suppliers. Working with unknown suppliers. Defective materials.
Property Loss	Theft, sabotage, or vandalism.
Design	Incomplete design causes expensive changes and delays.
Quality Problems	Rework. Failure to meet specifications. Systems not working or fitting together properly.

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Table 4-3. Risk Checklist for Sources of Potential Opportunistic Risk

Risk Source	**Potential Events**
Cost Efficiencies	Activities cost less than anticipated. Use method that requires fewer resources. Perform work under budget.
Schedule Efficiencies	Activities take less time than anticipated. Change CPM logic. Use over time, shift work or extra crews. Complete work ahead of schedule.
Labor Efficiencies	Increased use of equipment, modular units, robots, or new technologies.
Project Management	Better job site layout, appropriate level of resources, technological productivity enhancements. Experienced team that have work together before.
Equipment Management	Purchase or lease more productive equipment.
Weather	Schedule work activities to take advantage of windows of opportunity.
Suppliers	Opportunities for strategic partnerships.
Design	Constructability improvements.

Each of the risk sources shown in Tables 4-2 and 4-3 should be reviewed and sources of potential risk should be further decomposed to expose the root causes and events that trigger a risk source. For most construction projects nearly every item in the Tables 4-2 and 4-3 pose at least a very small amount of risk. A risk analysis should narrow its focus to the risk events that pose the greatest challenges or opportunities. In an application of Pareto's Law (20% of the elements effect 80% of the outcome), only those risk that are potentially significant should be further studied. Similar to the procedure to establish critical cost elements presented in the range estimating section of Chapter two, an event's significance can easily be determined by applying a rule-of-thumb. This rule states that an item can be considered critical if it has the ability to cause a variation on the cost by 0.5 % (Curran 1989). Using this rule if a risk event has the potential to cause a $5,000 variation in cost on a $1,000,000

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project it should be considered further. This rule of thumb has been successfully applied to thousands of projects of all types in size from $100,000 to $12 billion (CII 1989).

For example, a long-term project may be exposed to the risk of inflation, specifically the rising cost of petroleum products. If the project has a substantial transportation or equipment fuel costs this item should be highlighted for further study. If an analysis shows the fuel costs could cause a variation in the total costs by 0.5 % this risk should be identified for further analysis. Conversely opportunities to take advantage of potential cost savings should be similarly investigated.

4.3.3.2. Assessment of Probabilities and Consequences

Once risk events are selected for the possible occurrence on a specific project the appropriate assessment of probabilities and consequences is performed. This is followed by an assessment of risk profiles. The assessment identification and profiling initially performed in the planning phase is monitored to detect any changes in a risk profile until a project's completion.

4.3.3.3. Specific Probabilities Common to Construction

The typical risk sources in a complex construction project that are precipitated by events are shown in Tables 4-2 and 4-3. These potential events have a probability of occurrence associated with them. Tables 4-4 and 4-5 lists some common probabilities that will need to be determined once negative or opportunistic risk events have been identified.

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Table 4-4. Negative Risk Probability Assessments for Complex Construction Projects

Negative Risk Item	**Assess the Probability of:**
Cost Escalation	Exceeding contract price or budget. Failing to account for bid items. Failing to account for items to produce a complete and usable facility.
Schedule	Exceeding contract completion date. Delays form suppliers, owners, subcontractors, consultants or transportation systems.
Labor	Labor shortages. Lower than normal productivity. Strike. "Working to rule"
Project Management	Inexperienced team members. Poor relationships between team members. Unfavorable contract type.
Safety	Accident that raises rates. Accident requiring work stoppage Accident involving a fatality. Accident causing property damage.
Excessive Changes	Poor design. Capricious owner. New requirements. Fast track construction with incomplete drawings.
Unforeseen Conditions	Occurring from underground or excavation work. Occurring from hidden work.
Environmental	Encountering conditions that will require mitigation efforts. Regulatory approvals costing more the anticipated.
Equipment	Equipment failure. Improper equipment selection.
Inflation	Material price increases. Labor cost increases. Equipment cost increases. Overhead cost increase.
Weather Delays	Delays due to adverse weather. Delays due time of year work is performed. Delays due to extreme events.
Complexity	Mistakes or rework. Technically difficult. Inexperienced with type of work.
Client Initiated	Difficult owners representative, inspector or engineer. Financial difficulties. Late payments. Loss of political support.
Fire	Operations that require open flame or sparks starting a fire. Work requiring explosives start a fire.
Subcontractors/ Suppliers	Non-performance from subcontractor or supplier. Default by major subcontractor or supplier. Defective materials
Property Loss	Theft, vandalism, sabotage or terrorism.
Design	Delays due to design errors. Excessive changes.
Quality	Rework or mistakes. Work not compliant with specifications. Missed tolerances.

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Table 4-5. Opportunistic Risk Probability Assessments for Complex Construction Projects

Opportunistic Risk Item	**Assess the Probability of:**
Cost	Delivering work items for less than expected. Using a method that requires fewer resources.
Schedule	Accomplishing activities in less time than expected. Changing the CPM logic to successfully shorten the duration. Using Over time, shift work, or extra crews successfully
Labor Efficiencies	Successfully applying the use of more equipment, modular units, and robots.
Project Management	Experienced team able to work together. Successfully applying technological improvements. Increasing productivity through better jobsite layout. Successfully balancing resources.
Equipment Management	Successfully applying new equipment or methods.
Weather	Successfully taking advantage of weather windows.
Suppliers	Forming strategic partner ships that create lower costs and higher quality.
Design	Applying knowledge of constructability.

Tables 4-4 and 4-5 are not used to assess the probability of the occurrence of a specific event. It is used to trigger the thinking of what probabilities need to be determined. The probabilities shown in Table 4-6 can be used by project team members to describe the probability of occurrence in a qualitative manner.

Table 4-6. Qualitative Expressions for Probability of Risk Events

Level	Description
A. Implausible	Minimal, remote, improbable, can assume occurrence will not happen on the project.
B. Unlikely	Small chance, yet possible over the life of a project.
C. Likely	Occasional, may occur over life of project.
D. Highly Possible	Probable, highly likely, should occur at least once over the life of a project.
E. Certainty	Will occur maybe more than once over the life of a project.

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4.3.3.4. Uncertainty Associated with a Probability Assessment

An important consideration in the assessment of probability is the uncertainty involved in its assessment. The probability assessment may change over the life of a project and therefore needs to be tracked from its original assessment until a project's completion.

4.3.3.5. Specific Consequences Common to Construction

The typical risk sources in a complex construction project that are precipitated by events are shown in Tables 4-2 and 4-3. The potential events have a consequence associated with their occurrence. Tables 4-7 and 4-8 lists some common negative and positive consequences that will need to be determined once a risk event has been identified. These tables should be used to help assess the consequences of a specific event's occurrence.

Tables 4-7 and 4-8 do not quantify the magnitude of the consequences in terms of hard data such as, dollars or schedule impacts converted to dollars per day or month. The magnitude of the consequences must be approximated from project specific information. Similarly the magnitude of technical performance must be estimated from project specific information. The consequences of higher or lower costs will depend on the size of the project and magnitude of the risk event. For example, for the risk of excessive change orders the cost consequences will be determined based on the magnitude of the project and the volume of changes. Cost escalation from schedule delays will be based on the additional costs incurred from direct and indirect cost associated with the delay. For example, if a project is delayed

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due to a strike, a cost per day based on the actual expenditures or estimated cost due to such items as facilities, salaried personnel, and extended overhead can be determined. The cost of a damaged reputation is difficult to quantify but should be considered. For example, if a strategic client (one who considers the builder as the sole provider) is presented with a major cost or schedule delay, this client may choose other providers for their future projects. Similarly opportunities present positive consequences that will require approximation.

Table 4-7. Specific Negative Consequences Common to Complex Construction Projects

Negative Risk Item	**Negative Consequence in terms of:**
Cost Escalation	Higher cost. Loss of goodwill. Reduced technical performance from inappropriate cost reduction.
Schedule	Liquidated damages in dollars. Higher cost. Loss of goodwill. Reduced quality from congestion.
Labor	Higher cost. Schedule delays. Lower quality.
Project Management	Higher cost in dollars. Schedule delays. Loss of goodwill. Technical non or sub-performance.
Safety	Higher cost. Schedule delays. Injuries. Fatalities.
Excessive Changes	Higher cost. Schedule delays. Loss of goodwill. Technical non or sub-performance.
Unforeseen Conditions	Higher cost. Schedule delays.
Environmental	Higher cost. Schedule delays.
Equipment	Higher cost. Schedule delays. Technical sub-performance.
Inflation	Higher cost.
Adverse Weather	Higher cost. Schedule delays. Technical non or sub-performance.
Complexity	Higher cost. Schedule delays. Quality problems.
Client Initiated	Higher cost. Schedule delay.
Fire	Higher cost. Schedule delay.
Subcontractors/ Suppliers	Higher cost. Schedule delay. Technical non or sub-performance.
Property Loss	Higher cost. Schedule delay.
Design	Higher cost. Schedule delay.
Quality	Higher cost. Schedule delay. Technical non or sub-performance.

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Table 4-8. Specific Positive Consequences Common to Complex Construction Projects

Opportunistic Risk Item	**Positive Consequence in terms of:**
Cost	Lower cost. Shorter schedule.
Schedule	Shorter schedule. Lower cost.
Labor Efficiencies	Shorter schedule. Lower cost. Improved technical performance.
Project Management	Shorter schedule. Lower cost. Increased goodwill. Greater technical performance.
Equipment Management	Shorter schedule. Lower cost. Improved technical performance.
Weather	Shorter schedule
Suppliers	Lower cost. Shorter schedule. Improves technical performance.
Design	Lower cost. Shorter Schedule. Improved technical performance.

Since trying to estimate the actual dollar value of consequences for complex construction projects is difficult a table that describes consequences in terms of a percentage of the total cost can be used. Table 4-9 is a table that qualifies both negative and positive consequences in terms of cost. The range between negative and positive consequences is skewed. This is to reflect the effects of market forces in the competitive business of construction. Typically there is not a lot of margin or room for exaggerated profits in a construction endeavor but there is plenty that can go wrong and drive up prices. This is reflected in Table 4-9 with the maximum consequence categories with the potential to overrun cost greater than 25% versus the ability to achieve cost savings greater than 10%.

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Table 4-9. Qualitative Cost Consequences

Description	Cost impacts
Negative Consequence	*Negative impacts*
I. Negligible	Minimal or no impact
II. Acceptable	< 5% growth
III. Marginal	5-10 % growth
IV. Critical	10-25 % growth
V. Catastrophic	> 25 % growth
Positive Consequence	*Positive impacts*
-I. Negligible	Negligible or no saving
-II. Minimal	< 1% saving
-III. Marginal	1-5 % saving
-IV. Favorable	5-10 % saving
-V. Outstanding	> 10 % saving

Other consequence tables for schedule, technical performance, and safety is presented in Tables 4-10 through 4-12. In Table 4-10 the consequences of schedule delays or improvements are shown as a percentage increase or decrease. Table 4-11 presents a qualitative assessment of the consequences for technical performance. This table is generic and would require substantial modifications based on the type of project. Table 4-12 provides a qualitative range of safety consequences.

Table 4-10. Qualitative Schedule Consequences

Description	Schedule Impacts
Negative Consequence	*Negative Impacts*
I. Negligible	Minimal or no schedule impact.
II. Acceptable	Minor activity delays use float to recover schedule, <1%.
III. Marginal	Some impacted activities, minor delays, 1-5%.
IV. Critical	Lengthy delay to critical path, > 5%.
V. Catastrophic	Multiple and lengthily delays to critical path, > 25%.
Positive Consequence	*Positive Impacts*
-I. Negligible	Negligible or no time saving
-II. Minimal	Minor schedule reduction <1%.
-III. Marginal	Some schedule reduction. 1-5%.
-IV. Favorable	Significant schedule reduction, 5-10%.
-V. Outstanding	Substantial schedule reduction, >10%.

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Table 4-11. Qualitative Technical Performance Consequences

Description	Technical Performance Impacts
Negative Consequence	*Negative Impacts*
I. Negligible	Minimal or no performance impact.
II. Acceptable	Very minor appearance or aesthetic issues.
III. Marginal	Aesthetic issues that require rework.
IV. Critical	Structural, mechanical, and other costly rework required.
V. Catastrophic	Major rework of items that impact other activities, lingering sub-performance issues.
Positive Consequence	*Positive Impacts*
-I. Negligible	Negligible or no technical improvement.
-II. Minimal	Minor performance and quality enhancements.
-III. Marginal	Some technical performance improvements.
-IV. Favorable	Significant quality and performance enhancements.
-V. Outstanding	Both immediate and long-term life cycle cost reduction and performance enhancements.

Table 4-12. Qualitative Safety Consequences

Description	Safety Impacts
Negative Consequence	*Negative Impacts*
I. Negligible	Minimal or no impact.
II. Acceptable	Minor injuries no "loss time".
III. Marginal	Loss time accident.
IV. Critical	Disability injury or fatality.
V. Catastrophic	Multiple fatalities.
Positive Consequence	*Positive Impacts*
-I. Negligible	Negligible or no improvements.
-II. Minimal	Minor safety improvements.
-III. Marginal	Safety improvements that improve safety awareness.
-IV. Favorable	Safety improvements that reduce hazardous exposure.
-V. Outstanding	Significant reduction in hazardous operations.

4.3.3.6. Uncertainty with Consequence Assessment

There is some ambiguity associated in the above categories of consequences. This is acceptable because the verbal descriptions categorize a narrow range. The magnitude of the consequences and therefore the assessment of the consequences also

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contain some uncertainty. This uncertainty needs to be tracked from the original assessment until the completion of the project. The tracking will enable project managers to control cost by understanding an assessment that has changed.

4.3.3.7. Planning Risk Assessment

Risk is defined in Section 2.2 as a combination of both the occurrence probability and the occurrence consequence. The methodology to combine these two and form a risk assessment is by using a risk assessment matrix table. This assessment is made by the project team and is diagramed in Figure 4-13. The output from this risk assessment is a risk rating and profile development of the identified risk for a specific project.

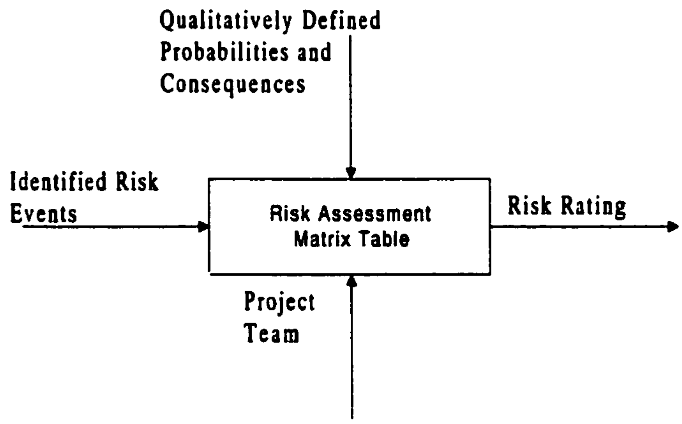

Figure 4-13. Planning Risk Assessment Process

Using a risk assessment table may be considered a highly subjective method of risk assessment (Smith 1999). This is because the results of the risk assessment are typically based on an expert's opinion and are not exact. For example, the risk assessment would not express the risk as "there is a 0.45 probability that a fire can occur that causes $100,000 in damages". The results from a risk assessment matrix

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table are expressed in a linguistic term such as acceptable risk or high risk. Special care is needed to assure the risk assessments are not overly vague or the results may prove to be confusing or meaningless. Additionally, the risk assessment needs to be reviewed to ensure it has not been biased.

The use of risk assessment tables has been shown to be an appropriate method of risk assessment particularly when dealing with project management or construction (Defense Acquisition University 1998), (Al-Bahar and Crandell 1990) and (Baker et al. 1995). This is because exact data for the determination of the assessment of probabilities and consequences is not easily determined or available. This method also allows project team members to use their logic, judgement, and experience in the assessment of risk. Probably the best feature of this application is its simplicity. Busy project personnel typically do not have the time, resources or skills needed to perform an assessment that requires the development of hard data.

4.3.3.8. Risk Assessment Matrix Table

Using the risk identified earlier and the assessment of probabilities and consequences as shown in Tables 4-4 through 4-12, a risk assessment is made using Tables 4-13 or 4-14.

4.3.3.8.1. Negative Risk Assessment

Matching Table 4-4 negative items of risk, Table 4-6 an expression for probability of these item's occurrence, Table 4-7 negative consequences, and either one of Tables 4-9 through 4-12 for an expression of the negative consequences in terms of a percentage of total project cost develops a negative risk assessment. Once a risk item

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is quantified in these terms Table 4-13 is used to express the risk assessment for the particular item. This table is a negative risk assessment table. It is used to combine the occurrence probability with the occurrence consequence to establish a risk assessment of a particular event. For example, assume labor availability has been identified as potential risk source. From Table 4-4 a probability of a labor shortage will need to be assessed, from Table 4-6 an expression of this probability is found, assume the project team terms the probability "Highly Possible". From Table 4-7 an expression of possible consequences in terms of higher cost, schedule delay or both is made, then from Table 4-9 an expression of the consequences is made, assume it is "Critical". From the matching of "Highly Possible" and "Critical" and using Table 4-13 the risk of labor availability is "High Risk". This risk information identifies areas to concentrate on and helps determine the appropriate variables when determining final cost and schedule targets.

Table 4-13. Negative Risk Assessment Matrix Table

Likelihood level	Negative Risk Assessment				
	I Negligible	II Acceptable	III Marginal	IV Critical	V Catastrophic
A. Implausible	N	L	L	L	M
B. Unlikely	L	L	L	M	H
C. Likely	L	L	M	H	H
D. Highly Possible	L	L	M	H	H
E. Certainty	L	L	M	H	H
Risk Assessment Guide					
N = Essentially no risk, can assume risk will not occur.					
L = Low risk, minor project cost escalation.					
M = Medium risk, average project cost escalation					
H = High risk, certain or if occurs will result in significant cost escalation.					

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4.3.3.8.2. Opportunistic Risk Assessment

Matching Table 4-5 opportunistic items of risk, Table 4-6 an expression for probability of these item's occurrence, Table 4-8 positive consequences, and either of Tables 4-9 through 4-12 an expression of the positive consequences in terms of a percentage of total project cost develops a opportunistic risk assessment. Once a risk item is quantified in these terms Table 4-14 is used to express the risk assessment for the particular item. For example, assume equipment selection has been identified as a potential opportunistic risk source. From Table 4-5 the probability of successfully applying new equipment will need to be expressed, from Table 4-6 an expression of this probability is found, assume the project team terms the probability "Likely". From Table 4-9 an expression in terms of lower cost, shorter schedule or both is made, then from Table 4-9 an expression of the consequences is made, assume it is "Favorable". From the matching of "Likely" and "Favorable" and using Table 4-14 the opportunistic risk of selecting better equipment is "Medium Risk". This medium risk is identified as having an average cost saving and it may be worth trying to take advantage of the saving. This opportunistic risk information may identify areas available to capitalize on. For example management may "run the numbers" or develop a better estimate for the cost and benefits of this risk. This information also helps to determine the appropriate variables when determining final cost and schedule targets.

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Table 4-14. Opportunistic Risk Assessment Matrix Table

Likelihood level	Opportunistic Risk Assessment				
	-I Negligible	-II Minimal	-III Marginal	-IV Favorable	-V Outstanding
A. Implausible	N	L	L	L	M
B. Unlikely	L	L	L	M	H
C. Likely	L	L	M	H	H
D. Highly Possible	L	L	M	H	H
E. Certainty	L	L	M	H	H
Risk Assessment Guide					
N = Essentially no risk, can assume risk will not occur.					
L = Low risk, minor project cost saving, may not be worth the effort to pursue.					
M = Medium risk, average project cost saving, may be worth pursuing					
H = High risk, certain or if occurs will result in significant cost saving. Rewarding to pursue.					

4.3.3.8.3. Output From Risk Assessment Matrix Tables

The output of a risk assessment made with using Tables 4-13 and 4-14 will be qualitative. This output will also be shown graphically as a risk profile. The risk profiles of the previous two examples, i.e. labor availability and equipment selection are shown in Figure 4-14. For the labor availability example of high risk the risk profile show that a reduction of the consequence, likelihood, or both will lower the risk. In the equipment selection example increasing the likelihood of occurrence can most easily raise the opportunistic risk.

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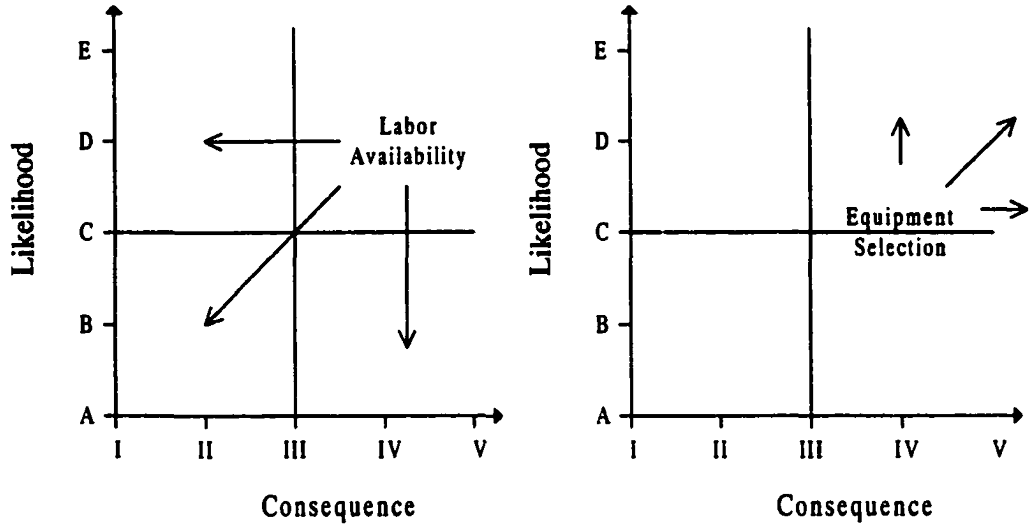

Figure 4-14. Risk Profiles for Labor Availability and Equipment Selection

4.3.3.9. Planning Risk Acceptability

Risk management involves establishing the level of acceptable risk. Once the risk assessment has been made a determination of risk acceptability can be performed. This process is shown in Figure 4-11 as flowing from the risk assessment. The arrow in Figure 4-11 represents a change from risk assessment methodologies to risk management methodologies.

Comparing the risk rating to the established guidelines or policies develops risk acceptability. Additionally, to help determine risk acceptance quantitative estimates are required to establish a magnitude of the consequences. These estimates can be used to develop expressions for the cost effectiveness of risk reduction as presented in Chapter three.

The managers of those who made the risk assessment make the risk acceptability determination. This process is shown in Figure 4-15. The output of this

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process is a prioritized list of events that have an unacceptable level of risk or provide favorable opportunities.

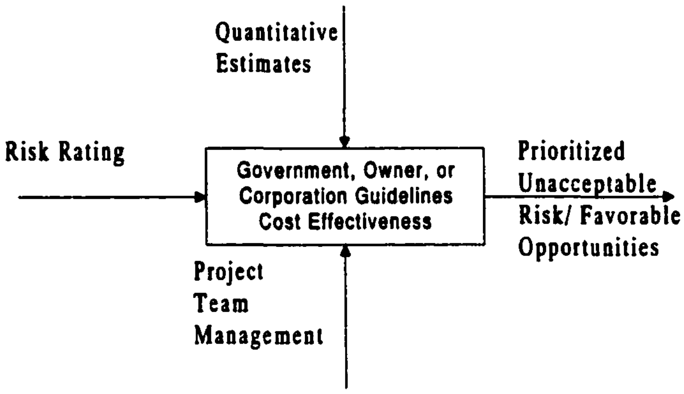

Figure 4-15. Risk Acceptability Process

The output from this process is three fold. First, management to control risk uses the information. Secondly, the information is used to establish the appropriate shape, range and other such parameters used when applying probability density functions in the cost and schedule simulation to establish these targets. Negative risks should be minimized and the opportunistic risks should be maximized. Third, a determination of a project's viability is at least partially based on the outcome of risk acceptability in the planning phase.

4.3.3.10. Planning Decision Analysis

Three major categories of decisions are required in the planning phase. The first major decision area is deciding how to reduce negative risk that has been deemed unacceptable and exploit opportunistic risk that shows promise. Decisions will need to be made by management to determine the appropriate course of action to reduce or eliminate the unacceptable risks. These decisions may effect the scope, design,

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procurement method, and could be implemented in the planning or execution phase of a project. If these risk mitigation or opportunities are used in the planning phase their effects are applied to develop cost and schedule targets.

The second decision is to decide on the appropriate shape, range and other such parameters used when applying probability density functions in the cost and schedule simulation. The type and shape of probability density functions used to represent the uncertainty in cost and schedule models should be made by using the information available from the risk assessment, documented knowledge of probability density functions, and personal judgement. The range of a probability density function can be established based on the risk ratings and how these rating effect the specific activities being modeled. The use of tables should be used as a guide, but judgement and knowledge of specific construction activity should temper the use of a table. An example look up table is presented in Table 4-15.

Table 4-15. Ranges for Probability Density Functions Based on Risk Rating

Negative Risk Rating	Range	
	Minimum	Maximum
High	95%	125%
Medium	90%	120%
Low	90%	110%
None	N/A	N/A
Opportunistic Risk Rating		
High	85%	100%
Medium	90%	105%
Low	95%	105
None	N/A	N/A

An example of using a risk assessment to help define the characteristics of a probability density function is as follows. Once a point estimate for cost or schedule has been developed for an activity, the activity can be modeled by a probability

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density function to account for uncertainty. Assume a triangular density function is being used to represent an activity such as assembling large components of a MOB module while at sea. This activity is estimated to take 10 days. Assume this activity contains some elements of the work that has been assessed as "high risk". Using Table 4-12 the range for representing this value is 95% for the minimum or 10 x (95%) = 9.5 days and 125% for the maximum or 10 x (1.25) = 12.5 days. This range is shown graphically in Figure 4-16.

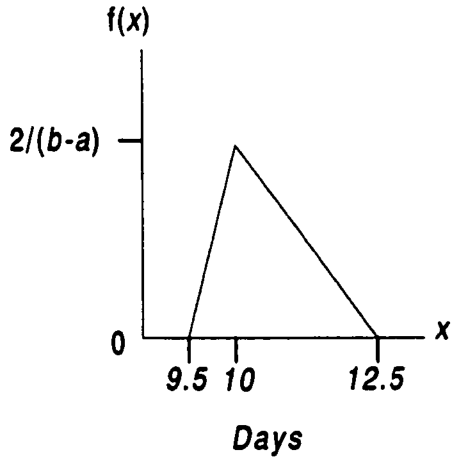

Figure 4-16. Triangular Distribution

The range for the minimum and maximum values for probability density function shown in Figure 4-16 is not skewed uniformly between negative and opportunistic risk. This is due to the greater potential for cost to exceed their target than is the potential for cost to be less than their target (Mullholland and Christian 1999).

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The third major decision of deciding a project's economic viability will be made once cost and schedule targets that account for uncertainty are developed. The risk assessments, profiles, and acceptability analysis can assist in this decision.

4.3.3.11. Cost and Schedule Target Development With Simulation

To develop accurate and realistic cost and schedule targets a simulation of the construction process is developed using the knowledge learned during the risk analysis process. The simulation model is constructed to reflect how the actual project will be built.

Once final cost and schedule targets are developed a decision to move forward with the project is required. This will generally be made based on the cost of a project but certainly the results of the risk analysis will also influence the decision. Other factors such as, national priorities, political forces, and economic growth may influence the decision.

4.3.4. Execution Phase Methodology

The execution phase of a project begins once a project owner or governmental agency has given the go ahead for the project. Referring back to Figure 4-11, this is shown in the lower half of the figure. During this phase contracts have been awarded and parties are under certain obligations to provide various tasks. Actual construction begins in this phase and a cost control methodology is required to ensure costs remain within the target. This section presents a cost control methodology that combines risk and earned value analysis techniques to control project cost.

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The beginning of the execution phase has traditionally been seen as a "hand off" from design to construction. The hand off terminology is intended to signify that the designers have less of a role and the builders are more involved in the project. It also signifies a shift of the responsibilities for certain risks from one party to another. During this hand off new personal and organizations are brought in to work on the project. These people and organizations may have techniques or solutions that could add to previous risk analysis work.

During the planning phase a project's risks have been identified, assessed, and incorporated into a risk management plan. New information available in the execution phase of a project may only require the original risk assessment to be expanded or updated to reflect any changes in uncertainty, assessment of consequences and probability, or new risk events. The risk assessment in this phase is now preformed along side an earned value analysis. Risk acceptability and decision analysis is preformed in the execution phase as a means to control project costs.

The combined process of risk assessment and earned value analysis is shown in Figure 4-17. This combined process is shown as being comprised of establishing and updating both the risk assessment and earned value processes. Baselines for risk and costs are established as soon as possible in the execution phase. Each month as new project information and earned value data becomes available these analyses are updated. The processes shown in Figure 4-17 are discussed in the following sections.

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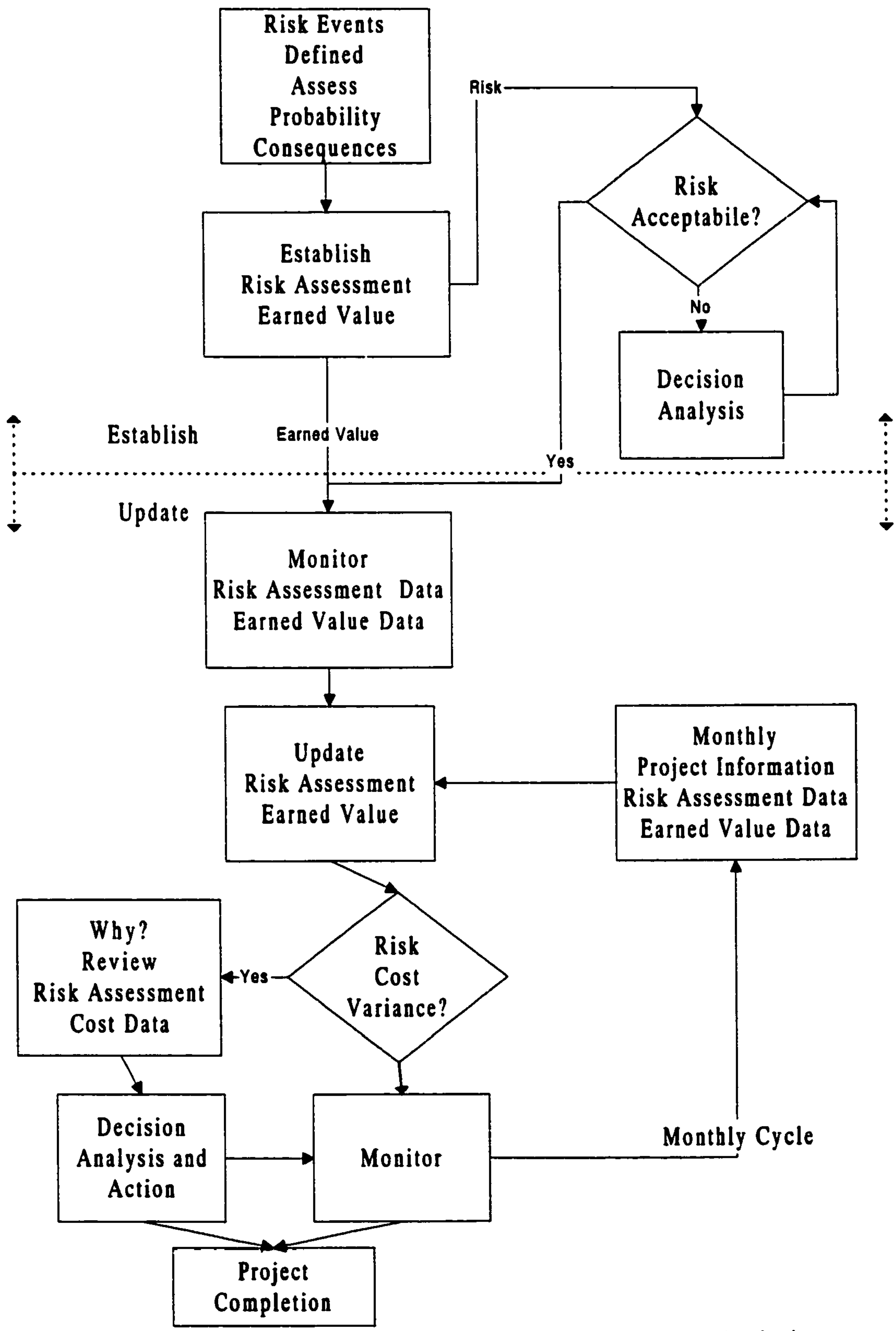

Figure 4-17. Combined Risk Assessment and Earned Value Analysis

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4.3.4.1. Execution Phase Define Risk Events

The project execution team will identify potential risks using the tables presented earlier, any previous risk studies, and project documentation. Although high negative risks and high opportunistic risks should have been acted on during the planning phase before the execution of a project has begun, some may remain and others may have cropped up.

4.3.4.2. Execution Phase Assessment of Probabilities and Consequences

With the addition of new people and organizations a new assessment of the probabilities and consequences of identified risks is required. The assessment of probabilities and consequences can be performed as discussed earlier, through the use of tables and applied judgement. At a minimum, the previous risk assessment will need to be updated. Special attention should be paid to the assessment of probabilities and consequences to ensure these expressions are accurately captured. These assessments will require updating as the project progresses.

4.3.4.3. Execution Phase Establish Risk Assessment and Earned Value

To combine risk assessment and earned value analysis means to perform these activities together. As shown in Figure 4-17 both techniques contain an initial set up or establishment process followed by an updating process.

A classic risk assessment will be performed early in this phase to help the project team assess risk areas. This risk assessment may only be an update of the existing assessment or depending on the conditions a more comprehensive assessment

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will be required. The updating of risk information is continuous for the life of a project.

Earned value analysis has two distinct phases. The set up or establishment of the baseline is required to base performance against. Once a project begins data will be recorded and results analyzed.

Project team members should perform a risk assessment or update before any construction begins. This assessment should begin by reviewing existing documentation such as plans, specifications, contracts, and previous risk analysis work. Risk ratings from this assessment are reviewed for risk acceptability.

The risk assessment in the execution phase should not be viewed as a redundant step. Several things will have changed from the planning phase to the execution phase. The people and organizations involved on the project will have changed and at a minimum new people and organizations will have been added. These new people and organizations may be contractors, subcontractors, engineers, consultants, inspectors, governmental officials, suppliers, and owner's representatives. These new people and organizations should be represented or at least considered when performing a new or updated assessment.

New information also requires that a new or updated risk assessment be performed. The new information may be accepted bids, approved environmental documents with new requirements, amendments to contractual requirements, changes to risk profiles, uncertainty, and other conditions that have changed.

The organizational structure of the project changes when shifting from planning to execution. During a planning phase owners and designers have the

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greatest ability to influence or control costs. The total ability to influence costs is decreased in the execution phase, but this ability to control cost is mostly borne by the contractor or builder. In fact the contract type will most likely be structured to shift the risk of cost growth to the contractor or builder (Ostwald 2000).

An earned value analysis involves both establishing the baseline and measuring actual performance against this baseline. As early as possible in the project execution phase the planned budget should be established and charted as cumulative cost versus time.

The contract type for the project will determine what the baseline budget will be based on. The cost and schedule targets developed by using risk methods in the planning phase should be used if the contract is a derivative of a cost reimbursable type contract. The targets may have to be modified due to design changes, market conditions, price quotes, or mandated conditions. If the project has been competitively bid, the baseline budget will be established using the winning bid.

The risk assessment provides insight to items of various levels of risk. These items should be broken out or reduced to manageable levels in the earned value analysis. This allows managers to identify potential origins of variances. The earlier cost problems or opportunities are identified the better. This allows project managers enough time to correct a problem or seize an advantage to affect the outcome of a project.

The budget baseline or planned value of the work in earned value terminology is best organized and analyzed by using spreadsheet software. These spreadsheets can be easily updated and graphically show trends.

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4.3.4.4. Execution Phase Risk Acceptability

Once a new or updated risk assessment has been performed the management team responsible for project execution will establish risk acceptability levels. Risk acceptability is performed during the establishment portion of the execution phase. This is required early in a projects execution life cycle in order to receive the full benefit of mitigating potential harm or capitalizing on opportunities. Once potential risk are flagged a decision analysis process is used to decide on a best course of action. Risk acceptability should be based on established criteria from a governmental agency, owner, builder, designer, or a team of personnel from these organizations. The primary methodology for determining a risk acceptance will be made using the technique of risk effectiveness or cost effectiveness of risk reduction.

Risk acceptability is shown as a decision block in the upper right portion of Figure 4-17. If an identified risk is acceptable it only needs to be monitored during the construction process. An identified risk event that is unacceptable or an opportunity attractive enough must be mitigated or the opportunity taken advantage of. A decision analysis process is used to identify the best solution. Once these events have been acted on they should be monitored for the life of the project.

4.3.4.4.1. Risk Acceptability Chart

A graph of risk levels using a qualitative method of risk assessment is presented in Figure 4-18. The graph shows risk profiles of all of the identified risks and may also assist in developing risk acceptability. For example risks L_1 and L_2 may

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be considered acceptable without further analysis. Risks with different consequences will be categorized and considered separately from other risks.

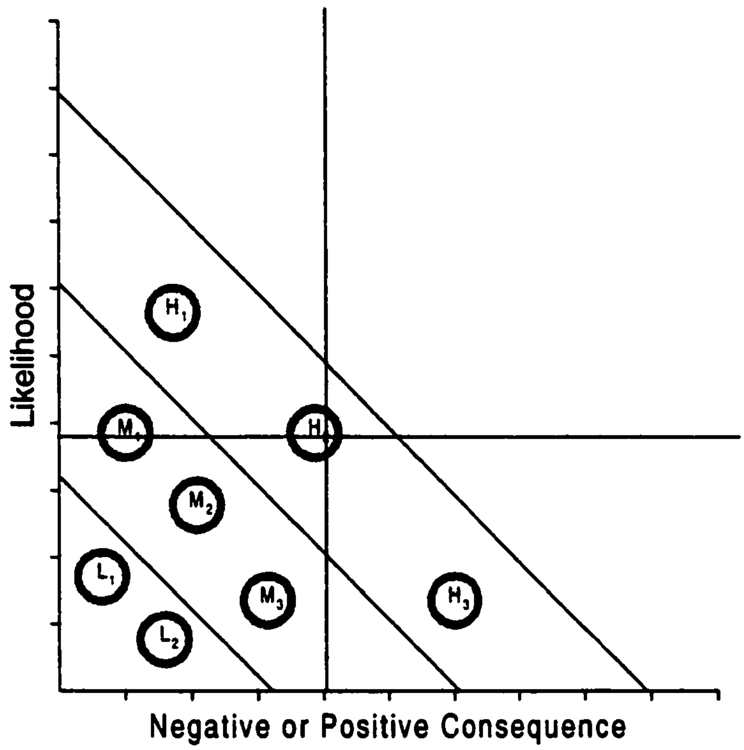

Figure 4-18. Qualitative Risk Levels

Figure 4-18 not only shows the risk levels but it is divided into quadrants to show each considered risk profile. This risk profile is important when risk mitigation or opportunities are being considered. For example, in Figure 4-18 the high risk identified as H_1 may be made acceptable by only reducing the likelihood of occurrence.

A table such as Table 4-16 should accompany Figure 4-18. This table allows project managers to quickly identify high risk sources and understand the relationship between likelihood and consequences when used in conjunction with Figure 4-18.

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Table 4-16 only shows negative risk but this table could be combined with opportunistic risk or a separate opportunistic risk table could be developed.

Table 4-16. Sample Identified Risks Table

Risk	Risk Reduction Direction
L_1 Inflation, cost increases	Acceptable.
L_2 Equipment failure	Acceptable.
M_1 Safety, working at heights	Lower likelihood.
M_2 Complexity, difficult layout	Lower likelihood, consequence or both.
M_3 Changes, unfamiliar with designer	Lower consequence.
H_1 Weather, crane pick delays from wind	Lower likelihood.
H_2 Labor, shortage of ironworkers	Lower likelihood, consequence or both.
H_3 Environmental, construction along waterfront	Lower consequence.

From Figure 4-18 and Table 4-16 project managers should propose to management a strategy for risk management. This strategy will base risk reduction or opportunity selection on the level of risk and a cost effectiveness approach to manage the risk. The following sections provide guidelines for monetary and safety risk mitigation requirements. Safety is considered separately because of the special emphasis placed on safety by society. Guidelines for risk with other consequences could also be developed. Conversely, these guidelines should be developed for opportunistic risk.

4.3.4.4.2. High Monetary Risk

High risk items must be mitigated. The high risk areas represent areas where mitigation efforts should be focused. Efforts to bring down the risk level of a specific item should focus on the most economical method, specifically to reduce the likelihood, consequence, or both.

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4.3.4.4.3. Medium Monetary Risk

Medium risk represents items where risks may be mitigated if cost effective. The risk mitigation efforts should focus on the items in this category that will provide the greatest benefit. Strategies for risk reduction should be based on lowering the likelihood of occurrence, consequence of an event, or both. Should a risk in this category not be reduced it must be carefully monitored during the construction process.

4.3.4.4.4. Low Monetary Risk

Low risk items are typically not mitigated unless it is simple and very cost effective to do so. If they are not mitigated they are annotated for careful monitoring during the life of a project.

4.3.4.4.5. High Safety Risk

Management focuses the most attention on these risk areas where risk must be mitigated. Risk mitigation measures must be implemented to bring down the level of risk.

4.3.4.4.6. Medium Safety Risk

These risks represent areas where risk events will generally be mitigated. Exception to mitigation may be based on the practicality of mitigation efforts.

4.3.4.4.7. Low Safety Risk

These risks represent areas where risk events may be mitigated. The cost effectiveness of risk reduction should be considered in this decision.

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4.3.4.5. Execution Phase Decision Analysis

In the risk acceptability step risks are identified as acceptable, those that may be mitigated/ taken advantage of, or must be mitigated/ taken advantage of. As shown in Figure 4-17 if a risk is not acceptable a decision analysis process is used to determine a course of action. The decision process is used to decide how a particular risk is best mitigated or taken advantage of. Once a decision has been made and an acceptable level of risk is reached the project team should monitor the project information and earned value data to ensure an appropriate decision was made.

4.3.4.5.1. Decision Analysis to Determine Mitigation or Opportunity Strategy

For those risks that must or should be mitigated or taken advantage of a goal tree methodology is used to determine the appropriate strategy. A goal tree technique is used in this portion of the execution phase for several reasons:

- Time is of the essence.
- Availability of accurate data.
- Systematical and simple.

Time is of the essence during the execution phase because a decision must be made early enough to effect the project's outcome. This window of opportunity is greatest at the beginning of a project and decreases proportionally with the time remaining on a project.

The typical complex construction project will be one of a kind or significantly different from past projects, therefore accurate data on past projects may not be available to populate a similar decision analysis that required probabilistic data.

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Goal trees are a systematic process that exposes several options for management to consider. To aid in rapid decision making they are swiftly and simply constructed.

4.3.4.6. Execution Phase Update Risk Assessment and Earned Value

This risk assessment process should be dynamic or constantly evaluating risks for the life of the project. Once a project is progressing managers need a dynamic risk assessment process that will not be too time consuming and should be scheduled at regular intervals. This constant assessment of risk includes updating risk profiles and should coincide with the updating of the earned value charts.

In Figure 4-17 this updating of information is depicted in the lower right hand portion of the figure. Earned value data and risk assessment data is shown as being collected monthly. The type of data collected for earned value analysis is the actual cost of performing the activities to date and the physically accomplished value of the activities performed to date (earned value). This data will be used to update the established spreadsheets.

The risk assessment data that needs to be collected is a review and reassessment of identified risk profiles. Additionally the uncertainties associated with these risk profiles will need to be updated. As a project becomes closer to completion the uncertainty associated with the risk profiles should be reduced. This reduction of uncertainty will help project managers make decisions.

As shown in the lower center portion of Figure 4-17 once the earned value and risk assessment data is updated a variance may be observable. If a variance occurs the reasons for it must be understood and action take to correct the situation. If a variance

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does not occur when the monthly update is made the risk profiles and earned value data continues to be monitored through monthly updates.

The updating process is illustrated with the following example. Suppose a project after an update of the earned value data shows a variance that indicates the project is trending on schedule but over cost. A review of the risk assessment may provide clues to why the project is costing more than anticipated. Assume the risk assessment has identified a potentially poor design, labor shortages, and a high level of difficulty. The potential impact of these risk sources should be less uncertain in the execution phase because more information is now known. All of these risk sources should be checked to determine which ones are and why they are causing cost overruns. The risk profiles for these events should be reviewed, either the probability of occurrence or consequences may have been understated. The adjusted risk profile will provide clues for the appropriate action to be taken, e.g. reduce probability, consequences or both. Once an understanding of what is causing a variance is understood a decision analysis problem can be developed.

4.3.4.7. Execution Phase Cost Control

In this stage of a project's life cycle management takes action to correct an observed variance. Once the project managers have an understanding of why a variance has occurred a decision analysis process can be employed to assist in decision-making. Referring back to Figure 4-17, as shown in the lower left portion a decision and action is required to correct a variance. The technique of using a goal or decision tree will be used to assist project managers in decision making. Once a

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decision has been made and action taken the results must be monitored for their effectiveness. This process continues until a project is completed.

In developing a decision model several questions need to be answered to formulate a goal tree. These questions are shown in Table 4-17 and provide a foundation for finding a solution to a project variance.

Table 4-17. Questions to Formulate a Decision Objective

Question	Question
1	Which specific area (s) are causing a cost or schedule variance?
2	How much will the variance effect the final cost or schedule?
3	Do these areas also show a variance in risk assessment?
4	How have the risk profiles changed?
5	What are the reasons for the cost, schedule, or risk variance?
6	What should the objective be to correct the variance?
7	What alternatives can be taken to correct the variance?
8	What specific action should be taken if a changed risk profile indicates an unacceptable negative risk or an opportunity has arisen?

To demonstrate the decision technique using a goal tree, the example from the last section, and the above questions are presented. Assume project management has determined that labor shortages has caused the costs to exceed the budget. The projected variance using earned value techniques is a 5% cost overrun. Also assume from the risk assessment a risk profile indicated there was a high probability of labor shortages causing a moderate cost increase. New information has changed the risk assessment and risk profile now reflects a certainty that labor shortages will occur more than once on this project. The cost variance has been determined to come from on site project managers that have used too much overtime to keep the project on schedule. Management has determined the objective of the decision problem is to reduce the effects of labor shortages. Some methods to reduce the occurrence of a

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labor shortage are offering higher prevailing wages or benefits, increasing productivity, developing alternatives to the currently planned method of work, and shift work. Other methods that may reduce the cost consequences of labor shortages are allowing the schedule to slip and reducing quality. Of course these measures may also have ripple effects that incur other cost later in a project. The final question is "What specific action should be taken to correct this problem?" A goal tree is shown in Figure 4-19 that graphically presents this decision objective.

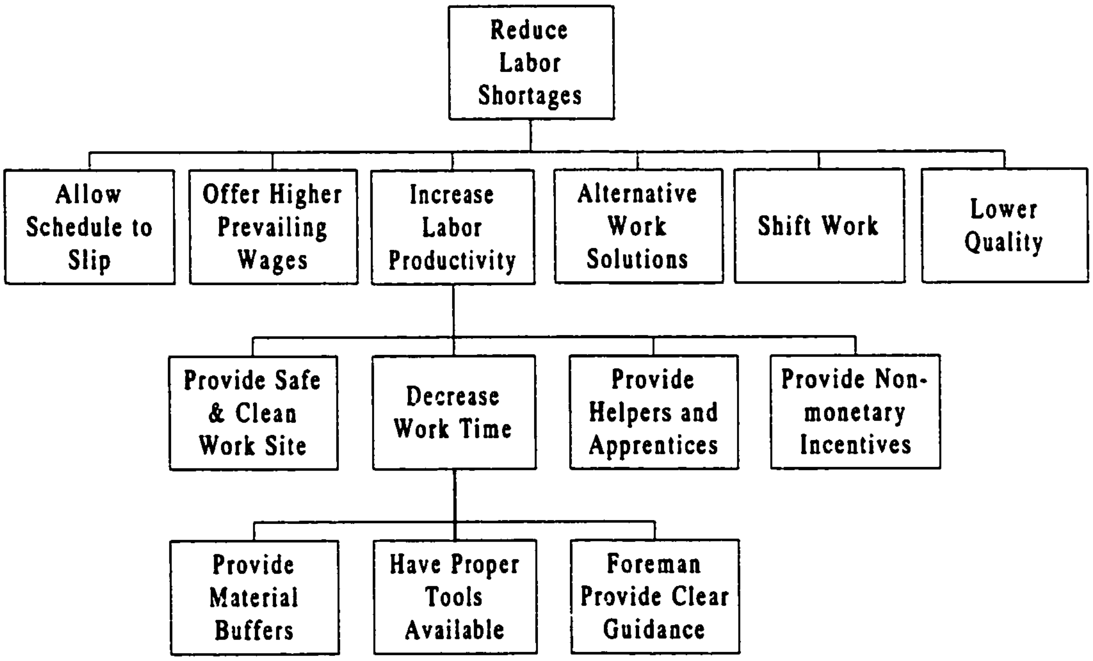

Figure 4-19. Goal Tree for Labor Shortage Decision

The above goal tree has been expanded from the original list of alternatives by including sub alternatives in the tree. Expressing the decision problem in a graphic form provides a clear view of the alternative solution to the problem. By applying a goal tree in combination with the updated risk profile management has solutions to this problem that will reduce the probability of occurrence or consequences of labor

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shortages. Management may select several of the least costly alternatives that reduce the likelihood of occurrence.

The advantage of goal trees is speed and simplicity. Unfortunately goal trees do not provide an expected monetary value or a probability of success. This is acceptable due to the short window of opportunity and the lack of accurate data in the execution phase. Should time allow and accurate data is available decision trees should be used to help decision-makers decide between alternatives. The application of decision trees was discussed in Chapter three.

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5. RISK-BASED COST CONTROL CASE STUDY

The application of a risk-based cost control methodology is applied to building the proposed MOB. Earlier chapters presented the MOB concept and its point estimates for cost and schedule. The proposed methodology of a risk-based cost control system as presented in Chapter four will be demonstrated with the MOB.

The proposed methodology was presented as being performed by the project team in Chapter four. The project team has been identified as project managers from these organizations: owners or governmental agencies, designers, and builders. For this case study the author fulfills the role of the project team.

5.1. Planning Phase of Risk-based Cost Control

During the planning phase the main objectives are to identify potential risk, mitigate or take advantage of these risks, and develop realistic cost and schedule targets.

5.1.1. Background of MOB Construction Industrial Capabilities

Before an assessment of the probabilities and consequences of constructing a MOB is presented, this section will provide background material on the US industrial capacity to build a MOB. This material is adapted from Ayyub et al. (1999b and 1999c).

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5.1.1.1. US Industrial Capacity to Build a MOB

An extensive literature review of construction techniques coupled with meetings including MOB personnel and individuals in the marine, offshore and construction industries related to the MOB was conducted to quantify the capacity of the marine and offshore industry. A baseline of the construction, marine and offshore industry's ability to construct the MOB was defined.

5.1.1.1.1. Material Production Capacities.

A comparison of the material available or that can be produced by the steel industry and the steel needs for a MOB concept revealed that steel will not be a critical issue in the construction of a MOB. It was determined that the amount of steel produced in the US is an order of magnitude larger than the steel required to build a MOB.

5.1.1.1.2. Shipyard Capacities.

From a total of 49 shipyards considered in the US, 42 were identified as practical facilities to construct at least the smallest components of the MOB. The most important characteristics of shipyards were categorized into tables for ease of selection when building proposed construction scenarios (Ayyub et al. 1999b). These characteristics were; number and length of building positions, employment, crane capacity and type of work the shipyard normally engages in. A construction scenario for building the hinged concept requires 20 shipyards, much less than the total capacity and therefore sufficient shipyard capacity exists in the US to build a hinged MOB.

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5.1.1.1.3. Shipyard Labor

Due to both decreased demand for US ships and improved efficiencies in shipbuilding the US shipbuilding labor force has been declining since World War II. The amount of shipyard labor required each year to build a MOB module was quantified and compared to the projected available shipyard workers. These comparisons were made using production indices and data from the Bureau of Labor Statistics (BLS 1998) and Maritime Administration (MARAD 1997). Because the production indices are from raw data applied to a specific problem and the referenced data was very broad the comparisons employed conservative assumptions. The estimated labor for building a hinged MOB concept is about 27,100 workers per year. The estimated labor available to build a MOB is between 16,500 and 30,000 workers per year. This later range applies a conservative approach that considers expected commercial and naval backlog. Therefore, the available labor is marginally sufficient to build the hinged MOB.

5.1.1.1.4. Offshore Industry Capacities

The offshore industry is composed of many of builders, suppliers, specialty contractors, subcontractors, and other related industries. The three largest US based, worldwide constructors for the offshore industry are; Aker Gulf Marine, the J. Ray McDermott, and Brown and Root Energy Services. These companies were studied as potential erectors and assemblers of MOB components. Although many other offshore constructors exist, these three establish the upper limit in terms of single facility capacity and heavy lift ability. Each facility is capable of erecting, assembling

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smaller blocks into large grand blocks of the upper hull, and loading the grand blocks onto barges for offshore assembly to the lower hull and columns. Due to the weather sensitive nature of offshore assembly a weather window or "season" exist for assembly of grand blocks to the lower hull structure. Based on the scale of the combined three facilities, certainly in conjunction, the three could build, launch, and assemble the grand blocks in a season. Each site is analyzed to determine if it could by itself build, launch and assemble the required number of grand blocks to complete a single concepts module during a season. Table 5-1 presents a qualitative judgement if a single facility could erect, load-out, and assemble a hinged concept's grand blocks during a single season. This qualitative judgement is based on this concept's size and number of grand blocks compared to a facility's; size, waterfront and transportation abilities, employment, number and capacities of heavy lift cranes.

Table 5-1. Grand Block and Load-out Capacity

Concept	Aker Gulf Marine	JR McDermott	Brown & Root
Hinged	Likely	Likely	Unlikely

5.1.1.1.5. Offshore Labor

The nature of offshore construction, fabrication, and assembly requires a skilled work force. Historical data shows the strength of this labor force is cyclical and can swell as seen in the late 1970s to early 1980s. Therefore, labor resources for MOB construction will only be at a premium during a boom period and should be adequate during all other periods.

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5.1.1.1.6. Personnel Safety

Shipbuilding and repair, by its very nature, is fraught with hazards and has very high rates of illnesses and injuries. The illness and injury rate of shipbuilding and repair workers is among the highest of similar industries as shown in Figure 5-1.

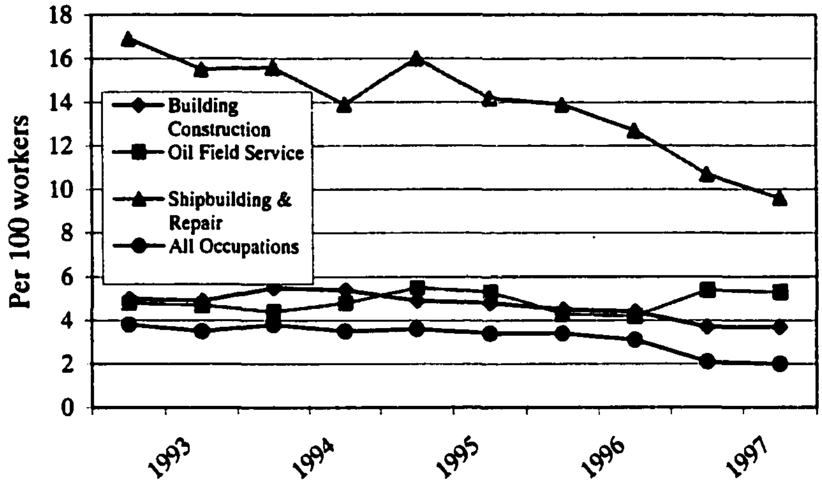

Figure 5-1. Injury and Illnesses Per 100 Workers

The conclusion drawn from Figure 5-1, as applied to MOB construction, is that safe practices must be accounted for during the design and construction of something this large and that safety should be considered in a risk assessment.

5.1.1.1.7. Environmental Concerns

Most of the MOB will be built in and around the waterfront, an area of significant environmental concern. The MOB will be a US government acquisition and therefore must abide by the National Environmental Policy Act (NEPA) (Code of Federal Regulations 1969). The areas of environmental concern that will require studies or

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mitigation before or during MOB construction are; dredging, construction of new graving docks, or construction of new facilities.

5.1.1.1.8. Project or Construction Management

Any proposed scenario of MOB construction involves several facilities concurrently producing blocks or components for final erection and assembly at a single location. This process requires a management structure in place to maximize coordination, schedule adherence, and minimize rework. An assembly scenario would require a lead design and shipyard or offshore constructor to fulfill this management role. Due to the complexity and potential for schedule delays when ten or more shipyards are working on a single project, the construction management is analyzed as a potential negative risk in MOB construction. Conversely, the ability to build components around the country is also seen as an opportunistic risk that could allow project managers the ability to build several components simultaneously.

5.1.2. Planning Phase Risk Identification

The method used to identify risk sources for the construction of a MOB was to compare the MOB design documentation to the US industrial capacity to build a MOB. A risk checklist was also used in this process to help identify risks. This process is shown in Figure 5-2.

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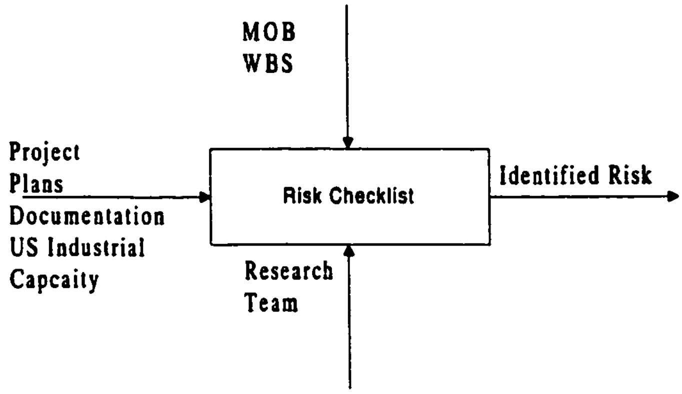

Figure 5-2. MOB Risk Identification

The hinged MOB concept was broken down into major structural components and categorized by WBS as presented in Chapter two. In Ayyub et al. (1999b) a research team, as shown in Figure 5-2, was used instead of a project team due to the nature of the study being a research project versus an actual construction project. For this dissertation the research team's results have been augmented and adapted by the author. A review of the MOB construction data and using the risk checklist as a backdrop the identified risks of building the MOB are presented in Table 5-2.

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Table 5-2. Identified Risk for Hinged MOB Construction

Negative Risk Source	*Potential Events*
Cost Escalation	1. Cost estimate is unrealistic. 2. Failure to account for all requirements. 3. Failure to meet budget 10-25%. 4. Failure to meet budget >25%.
Schedule Delay	1. Schedule estimates is unrealistic. 2. Delays form others e.g. government, subcontractors, etc. 3. Delay in funding process.
Labor Problems	1. Insufficient work force. 2. Insufficient skilled work force.
Project or Construction Management	1. Coordination of several sites building components. 2. Appropriate contract type.
Safety	Working the shipbuilding industry is hazardous. 1. Major or multiple serious accidents. 2. Serious accident.
Environmental Concerns	Cost impacts due to environmental mitigation requirements.
Equipment/ Facility Issues	1. Insufficient cranes. 2. Insufficient shipbuilding facilities.
Inflation	Cost increases from inflation due to lengthy construction.
Weather	1. Loss of components when transporting or connecting. 2. Schedule impacts due to weather.
Complexity	Cost problems associated with being the largest ocean structures ever built.
Suppliers	1. Ability to produce enough raw materials. 2. Vendors producing at maximum capacity.
Quality Problems	Components built at separate facilities requiring rework at assembly sites.
Opportunistic Risk Source	***Potential Events***
Project or Construction Management	1. Potential to spread the construction work of components to several sites thus allowing schedule flexibility and resource leveling. 2. Develop terrestrial construction method. 3. Use of latest technology and management techniques to build more efficiently.

The list presented in Table 5-2 represents the major risk identified in the construction of a MOB platform. There were not sufficient resources or

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documentation available to develop a highly detailed list of risks because of the limited scope of the research and conceptual nature of the MOB documentation.

5.1.3. Planning Phase Probability and Consequence Assessment

A qualitative assessment of the likelihood of occurrence and the consequences of an event will be presented in this section. The author has qualitatively made the probability and consequence assessments.

5.1.3.1. Planning MOB Construction Probabilities Assessment

This section will present a qualitative assessment of the probabilities of the risk identified in building a MOB. The probabilities that need to be assessed and their qualitative expression for probability are shown in Table 5-3. Table 5-4 is a legend for the qualitative descriptions of probability expressed in Table 5-3.

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Table 5-3. MOB Construction Probability Risk Assessment

Negative Risk Source	***Assess Probability of:***	***Probability Expression***
Cost Escalation	1. Cost estimate is unrealistic. 2. Failure to account for all requirements. 3. Failure to meet budget 10-25%. 4. Failure to meet budget >25%.	1. D Highly Possible 2. D Highly Possible 3. C Likely 4. B Unlikely
Schedule Delay	1. Schedule estimates is unrealistic. 2. Delays from others. 3. Delay in funding.	1. D Highly Possible 2. D Highly Possible 3. B Unlikely
Labor Problems	1. Insufficient work force. 2. Sufficiently skilled work force.	1. C Likely 2. B Unlikely
Project or Construction Management	1. Late deliverables and coordination problems from several sites building components. 2. Contract type causes discord.	1. D Highly Possible 2. C Likely
Safety	1. Major or multiple serious accidents. 2. Serous accident.	1. C Likely 2. D Highly Possible
Environmental Concerns	Cost impact due to environmental mitigation requirements.	D Highly Possible
Equipment/ Facility Issues	1. Insufficient cranes. 2. Insufficient shipbuilding facilities.	1. B Unlikely 2. B Unlikely
Inflation	Unplanned cost increase from lengthy construction period	B Unlikely
Weather	1. Loss of components when transporting or connecting components. 2. Schedule impacts due to weather.	1. B Unlikely 2. D Highly Possible
Complexity	Cost problems associated with being the largest ocean structures ever built.	C Likely
Suppliers	1. Ability to produce enough raw materials. 2. Vendors overwhelmed.	1. B Unlikely 2. B Unlikely
Quality Problems	Components built at separate facilities and not fitting together at assembly sites.	C Likely

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Table 5-3. (continued) MOB Construction Probability Risk Assessment

Opportunistic Risk Source	***Potential Events***	
	Assess Probability of:	***Probability Expression***
Project or Construction Management	1. Potential to spread the construction work of components to several sites thus allowing schedule flexibility and resource leveling. 2. Develop terrestrial construction method that decreases cost. 3. Latest technology and management techniques reduce cost.	1. C Likely 2. C Likely 3. C Likely

Table 5-4. Qualitative Expression of Probability

Probability Level	***Description***
A. Implausible	Minimal, remote , improbable, can assume occurrence will not happen on the project
B. Unlikely	Small chance, yet possible over the life of a project
C. Likely	Occasional, likely to occur over life of project
D. Highly Possible	Probable, highly likely, will occur at least once over the life of a project
E. Certainty	Will occur maybe more than once over the life of a project

5.1.3.2. Planning MOB Construction Consequence Assessment

This section will assess the specific consequences of potential risk events when building a MOB. The consequences are categorized according to cost, schedule, safety and technical performance. The qualitative expressions for these consequences are presented in Tables 5-5 through 5-8.

The assessed consequences are shown in Table 5-9. Although some risk events could have multiple consequences, each was categorized by the consequence having the potential for the largest magnitude or ultimate effect. For example,

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environmental concerns could cause schedule delays and mitigation efforts may cause a cost escalation but both are categorized together as a cost consequence category because a schedule delay also has cost impacts. Table 5-9 reflects the risk events organized by their consequence category.

5.1.3.2.1. Cost Consequences

Risk events that were considered as having cost consequences are; cost escalation, labor problems, environmental concerns, inflation, and weather impacts that could cause a loss of a component. These consequences were expressed as shown in Table 5-5.

Table 5-5. MOB Qualitative Cost Consequences

Description	Cost impacts
Negative Consequence	*Negative impacts*
I. Negligible	Minimal or no impact
II. Acceptable	< 5% growth
III. Marginal	5-10 % growth
IV. Critical	10-25 % growth
V. Catastrophic	> 25 % growth
Positive Consequence	*Positive impacts*
-I. Negligible	Negligible or no saving
-II. Minimal	< 1% saving
-III. Marginal	1-5 % saving
-IV. Favorable	5-10 % saving
-V. Outstanding	> 10 % saving

5.1.3.2.2. Schedule Consequences

Risk events that were considered as having schedule consequences are; schedule delay, construction management, weather impacts to the schedule, equipment and facility issues. These consequences were expressed using Table 5-6.

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Table 5-6. MOB Qualitative Schedule Consequences

Description	Schedule Impacts
Negative Consequence	*Negative Impacts*
I. Negligible	Minimal or no schedule impact.
II. Acceptable	Minor activity delays use float to recover schedule, <1%.
III. Marginal	Some impacted activities, minor delays, 1-5%.
IV. Critical	Lengthy delay to critical path, > 5%.
V. Catastrophic	Multiple and lengthly delays to critical path, > 25%.
Positive Consequence	*Positive Impacts*
-I. Negligible	Negligible or no time saving
-II. Minimal	Minor schedule reduction <1%.
-III. Marginal	Some schedule reduction, 1-5%.
-IV. Favorable	Significant schedule reduction, 5-10%.
-V. Outstanding	Substantial schedule reduction, >10%.

5.1.3.2.3. Safety Consequences

Risk events that are considered as having safety consequences are the safety concerns. These consequences were expressed using Table 5-7.

Table 5-7. MOB Qualitative Safety Consequences

Description	Safety Impacts
Negative Consequence	*Negative Impacts*
I. Negligible	Minimal or no impact.
II. Acceptable	Minor injuries no "loss time".
III. Marginal	Loss time accident.
IV. Critical	Disability injury or fatality.
V. Catastrophic	Multiple fatalities.
Positive Consequence	*Positive Impacts*
-I. Negligible	Negligible or no improvements.
-II. Minimal	Minor safety improvements.
-III. Marginal	Safety improvements that improve safety awareness.
-IV. Favorable	Safety improvements that reduce hazardous exposure.
-V. Outstanding	Significant reduction in hazardous operations.

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5.1.3.2.4. Technical Performance Consequences

Risk events that were considered as having technical performance consequences are; complexity, suppliers and quality problems. These consequences were expressed using Table 5-8.

Table 5-8. MOB Qualitative Technical Performance Consequences

Description	Technical Performance Impacts
Negative Consequence	*Negative Impacts*
I. Negligible	Minimal or no performance impact.
II. Acceptable	Very minor appearance or aesthetic issues.
III. Marginal	Aesthetic issues that require rework.
IV. Critical	Structural, mechanical, and other costly rework required.
V. Catastrophic	Major rework of items that impact other activities, lingering sub-performance issues.
Positive Consequence	*Positive Impacts*
-I. Negligible	Negligible or no technical improvement.
-II. Minimal	Minor performance and quality enhancements.
-III. Marginal	Some technical performance improvements.
-IV. Favorable	Significant quality and performance enhancements.
-V. Outstanding	Both immediate and long-term life cycle cost reduction and performance enhancements.

5.1.3.2.5. Opportunistic Risk Consequences

The consequences of these events were expressed in terms of cost consequences using Table 5-5.

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Table 5-9. MOB Construction Consequence Assessment

Negative Risk Source	***Assess Consequence of:***	***Consequence Expression***
Cost Consequences		
Cost Escalation	1. Cost estimate is unrealistic. 2. Failure to account for all requirements. 3. Failure to meet budget 10-25%. 4. Failure to meet budget >25%.	1. IV Critical 2. III Marginal 3. IV Critical 4. V Catastrophic
Labor Problems	1. Insufficient work force. 2. Sufficiently skilled work force	1. IV Critical 2. IV Critical
Environmental Concerns	Cost impact due to environmental mitigation requirements.	IV Critical
Inflation	Unplanned cost increase from lengthy construction period	II Acceptable
Weather	1. Loss of components when transporting or connecting components.	1. V Catastrophic
Schedule Consequences		
Schedule Delay	1. Schedule estimates is unrealistic. 2. Delays from others. 3. Delay in funding.	1. IV Critical 2. IV Critical 3. IV Critical
Project or Construction Management	1. Late deliverables and coordination problems from several sites building components. 2. Contract type causes discord.	1. III Marginal 2. III Marginal
Weather	2. Schedule impacts due to weather.	2. III Marginal
Equipment/ Facility Issues	1. Insufficient cranes. 2. Insufficient shipbuilding facilities.	1. II Acceptable 2. III Marginal
Safety Consequences		
Safety	1. Major or multiple serious accidents. 2. Serous accidents.	1. V Catastrophic 2. IV Critical
Technical Performance Consequences		
Complexity	Cost problems associated with being the largest ocean structures ever built.	III Marginal
Suppliers	1. Ability to produce enough raw materials. 2. Vendors over whelmed.	1. III Marginal 2. III Marginal
Quality Problems	Components built at separate facilities requiring rework at sites.	III Marginal

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Table 5-9. (continued) MOB Construction Consequence Assessment

Opportunistic Risk Source	***Potential Events***	
Cost Consequences		
Project or Construction Management	1. Potential to spread the construction work of components to several sites thus allowing schedule flexibility and resource leveling. 2. Develop terrestrial construction method that decreases cost. 3. Latest technology and management techniques reduce cost.	1. -IV Favorable 2. –III Marginal 3. –IV Favorable

5.1.4. Planning MOB Construction Risk Assessment

A qualitative expression for risk can be made using a risk assessment matrix table once the risk events have been identified and an assessment of probabilities and consequences has been made. The risk assessment process is shown in Figure 5-3.

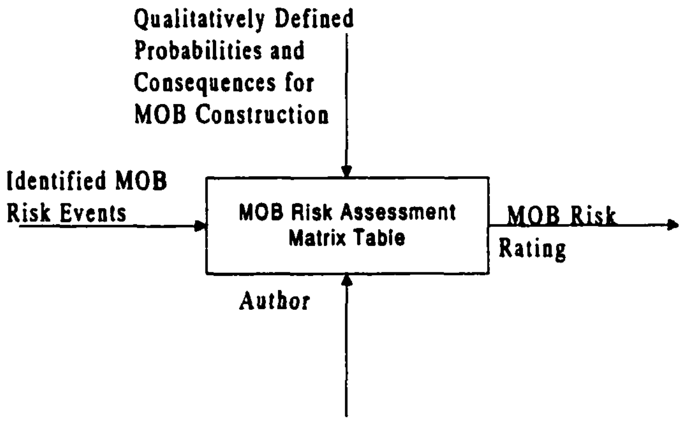

Figure 5-3. Planning MOB Construction Risk Assessment

Tables 5-10 and 5-11 show the negative and opportunistic risk assessment matrix tables. The previous probability and consequence assessments are combined in

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these risk assessment matrix tables by the author. The output from the risk assessment table is the ratings of risk for particular risk events. The negative risk assessments are shown in Table 5-12. This table was made by combining Tables 5-3, 5-9, and 5-10. Similarly Tables 5-3, 5-9, and 5-11 are combined to form an opportunistic risk rating.

Table 5-10. Negative Risk Assessment Matrix Table

Likelihood level	Negative Risk Assessment				
	I Negligible	II Acceptable	III Marginal	IV Critical	V Catastrophic
A. Implausible	N	L	L	L	M
B. Unlikely	L	L	L	M	H
C. Likely	L	L	M	H	H
D. Highly Possible	L	L	M	H	H
E. Certainty	L	L	M	H	H
Risk Assessment Guide					
N = Essentially no risk, can assume risk will not occur.					
L = Low risk, minor project cost escalation.					
M = Medium risk, average project cost escalation					
H = High risk, certain or if occurs will result in significant cost escalation.					

Table 5-11. Opportunistic Risk Assessment Matrix Table

Likelihood level	Opportunistic Risk Assessment				
	-I Negligible	-II Acceptable	-III Marginal	-IV Favorable	-V Outstanding
A. Implausible	N	L	L	L	M
B. Unlikely	L	L	L	M	H
C. Likely	L	L	M	H	H
D. Highly Possible	L	L	M	H	H
E. Certainty	L	L	M	H	H
Risk Assessment Guide					
N = Essentially no risk, can assume risk will not occur.					
L = Low risk, minor project cost saving, may not be worth the effort to pursue.					
M = Medium risk, average project cost saving, may be worth pursuing					
H = High risk, certain or if occurs will result in significant cost saving. Rewarding to pursue.					

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Table 5-12. Planning Phase Identified Risk for Hinged MOB Construction

Potential Events	*Probability*	*Consequence*	*Negative Risk Rating*
Negative Risk			
Cost Escalation 1. Cost unrealistic 2. Account for all requirements 3.10-25% Budget shortfall 4. >25% Budget shortfall	1. D Highly possible 2. D Highly possible 3. C Likely 4. B Unlikely	1. IV Critical 2. III Marginal 3. IV Critical 4. V Catastrophic	1. High 2. Medium 3. High 4. High
Schedule Delay 1. Schedule unrealistic 2. Delays by others 3. Funding delay	1. D Highly Possible 2. D Highly Possible 3. B Unlikely	1. IV Critical 2. IV Critical 3. IV Critical	1. High 2. High 3. Medium
Labor Problems 1. Sufficient quantity 2. Sufficient quality	1. C Likely 2. C Likely	1. IV Critical 2. III Marginal	1. High 2. Medium
Construction Management 1. Coordination 2. Discord	1. D Highly Possible 2. C likely	1. III Marginal 2. III Marginal	1. Medium 2. Medium
Safety 1. Major & multiple 2. Serious	1. C Likely 2. D Highly Possible	1. V Catastrophic 2. IV Critical	1. High 2. High
Environmental Concerns	D Highly Possible	IV Critical	High
Equipment Issues 1. Insufficient Cranes 2. Insufficient facilities	1. B Unlikely 2. B Unlikely	1. II Acceptable 2. III Marginal	1. Low 2. Low
Inflation	B Unlikely	II Acceptable	Low
Weather 1. Component loss 2. Schedule impacts	1. B Unlikely 2. D Highly Possible	1. V Catastrophic 2. III Marginal	1. High 2. Medium
Complexity	C Likely	III Marginal	Medium

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Table 5-12. (continued) Identified Risk for Hinged MOB Construction

Potential Events	***Probability***	***Consequence***	***Negative Risk Rating***
Negative Risk			
Suppliers 1. Enough material 2. Venders over whelmed	1. B Unlikely 2. B Unlikely	1. III Marginal 2. III Marginal	1. Low 2. Low
Quality Problems	C Likely	III Marginal	Medium
Opportunistic Risk			***Positive Risk Rating***
Construction Management 1. Resource leveling at several sites 2. Terrestrial construction 3. Apply new technology and management	1. C Likely 2. C Likely 3. C Likely	1. -IV Favorable 2. –III Marginal 3. –III Marginal	1. High 2. Medium 3. Medium

5.1.4.1. MOB Construction Planning Risk Profiles

Using Table 5-12 risk profiles of negative risk and opportunistic risk are shown in Figures 5-4 and 5-5 respectively.

5.1.4.1.1. Negative Risk Profiles

Risk profiles can show all risk events or show a separate profile for each category of a risk source. In Figure 5-4 all the identified risks are shown on the same profile chart. Referring back to Table 5-12 the underlined letters represent the letters of risk events shown in Figure 5-4. The risk events are shown as square dashed lines representing the imprecision of their risk assessment. Included in Figure 5-4 are rough

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"iso-risk lines" or lines intended to show constant risk. As shown, the risk is skewed to place a heavier emphasis on the negative consequences.

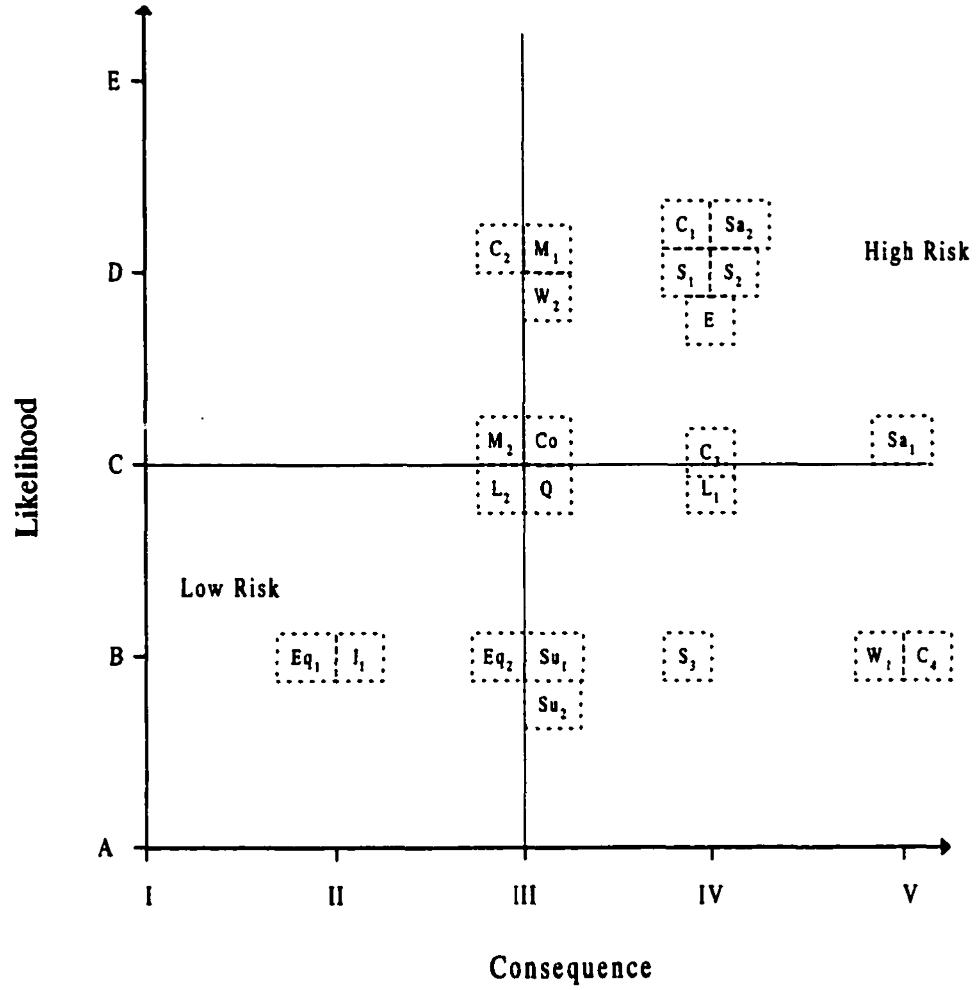

Figure 5-4. Planning Negative Risk Profiles

5.1.4.1.2. Opportunistic Risk Profiles

The three identified opportunistic risks are profiled in Figure 5-5. As seen in Figure 5-5 the opportunity of resource leveling has the highest potential to achieve a greater return.

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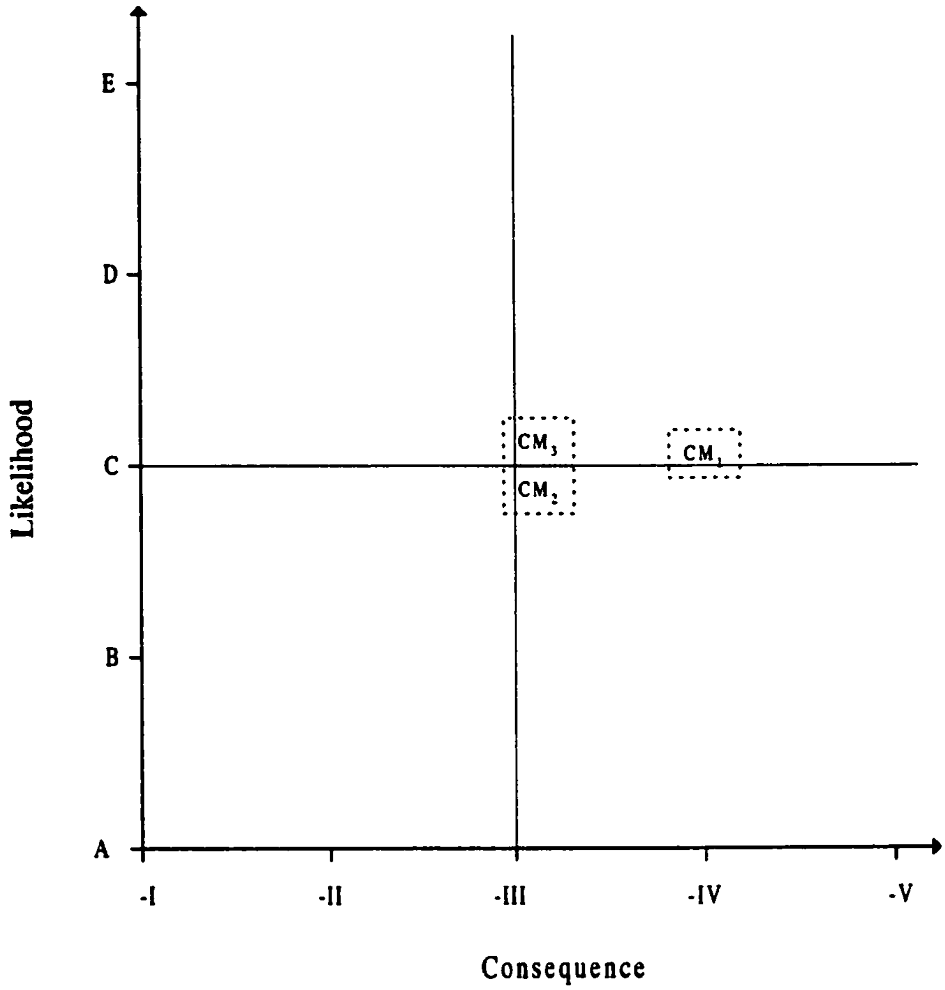

Figure 5-5. Planning Opportunistic Risk Profiles

5.1.4.1.3. Risk Profiles by Consequence Category

For the purpose of understanding risk acceptance it may be better to compare risk that have the same consequences. The negative risk portion of Table 5-12 is reconfigured to categorize risk by consequence as was done in Table 5-9. Table 5-13 shows negative risks categorized by consequences.

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Table 5-13. Identified Negative Risk for Hinged MOB Construction by Consequence Category

Potential Events	***Probability***	***Consequence***	***Negative Risk Rating***
Cost Consequence			
Cost Escalation 1. Cost unrealistic 2. Account for all requirements 3.10-25% Budget shortfall 4. >25% Budget shortfall	1. D Highly possible 2. D Highly possible 3. C Likely 4. B Unlikely	1. IV Critical 2. III Marginal 3. IV Critical 4. V Catastrophic	1. High 2. Medium 3. High 4. High
Labor Problems 1. Sufficient quantity 2. Sufficient quality	1. C Likely 2. C Likely	1. IV Critical 2. III Marginal	1. High 2. Medium
Environmental Concerns	D Highly Possible	IV Critical	High
Inflation	B Unlikely	II Acceptable	Low
Weather 1. Component loss	1. B Unlikely	1. V Catastrophic	1. High
Schedule Consequence			
Schedule Delay 1. Schedule unrealistic 2. Delays by others 3. Funding delay	1. D Highly Possible 2. D Highly Possible 3. B Unlikely	1. IV Critical 2. IV Critical 3. IV Critical	1. High 2. High 3. Medium
Construction Management 1. Coordination 2. Discord	1. D Highly Possible 2. C likely	1. III Marginal 2. III Marginal	1. Medium 2. Medium
Weather 2. Schedule impacts	2. D Highly Possible	2. III Marginal	2. Medium
Equipment Issues 1. Insufficient Cranes 2. Insufficient facilities	1. B Unlikely 2. B Unlikely	1. II Acceptable 2. III Marginal	1. Low 2. Low

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Table 5-13. (continued) Identified Risk for Hinged MOB Construction

Potential Events	***Probability***	***Consequence***	***Negative Risk Rating***
Safety Consequence			
Safety 1. Major & multiple 2. Serious	1. C Likely 2. D Highly Possible	1. V Catastrophic 2. IV Critical	1. High 2. High
Technical Performance Consequence			
Complexity	C Likely	III Marginal	Medium
Suppliers 1. Enough material 2. Venders over whelmed	1. B Unlikely 2. B Unlikely	1. III Marginal 2. III Marginal	1. Low 2. Low
Quality Problems	C Likely	III Marginal	Medium

The risk profiles for the risks as categorized by consequence are shown in Figures 5-6 through 5-9.

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5.1.4.1.3.1. Planning Risk Profiles with Cost Consequences

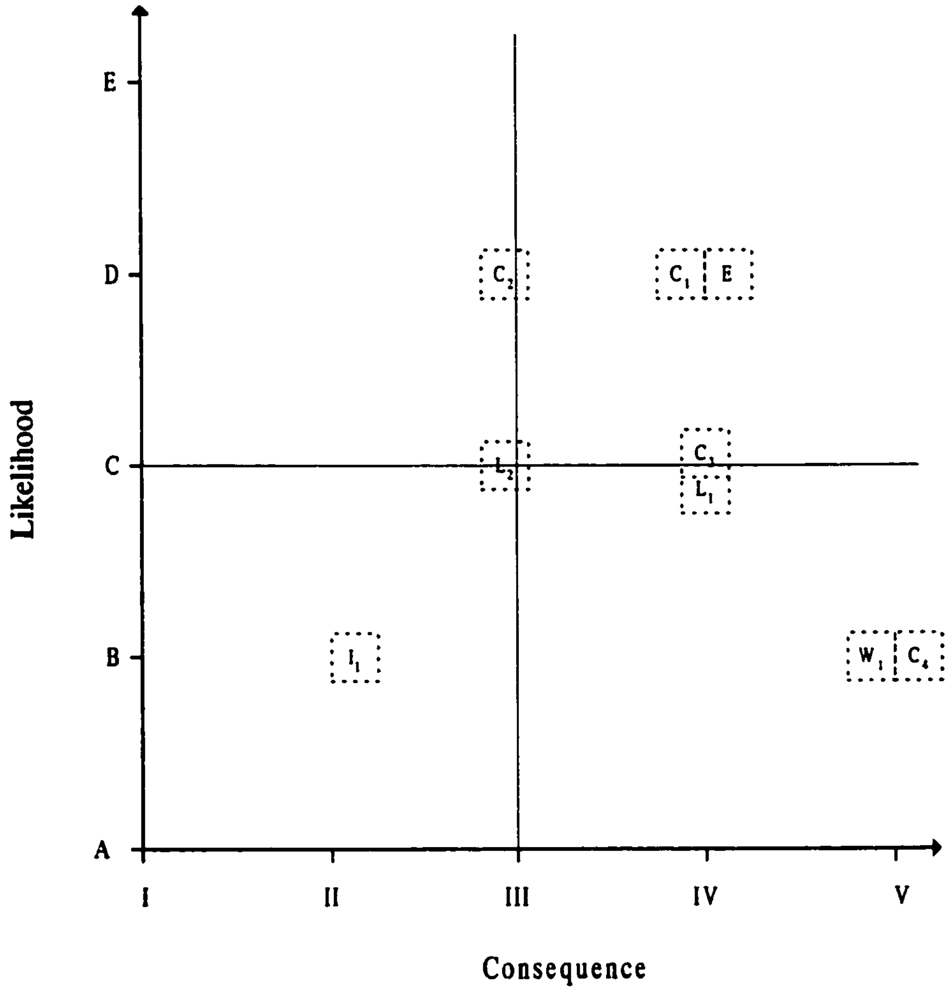

Figure 5-6. Planning Risk Profiles with Cost Consequences

The cost risk of Cost (C_n) C_1, C_3, C_4, Environmental (E), Labor (L_1), and Weather (W_1) are all high risk and should receive special attention in the planning phase. The risk of C_2 and L_2 are medium risk. The risk of Inflation (I_1) is a low risk.

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5.1.4.1.3.2. Planning Risk Profiles with Schedule Consequences

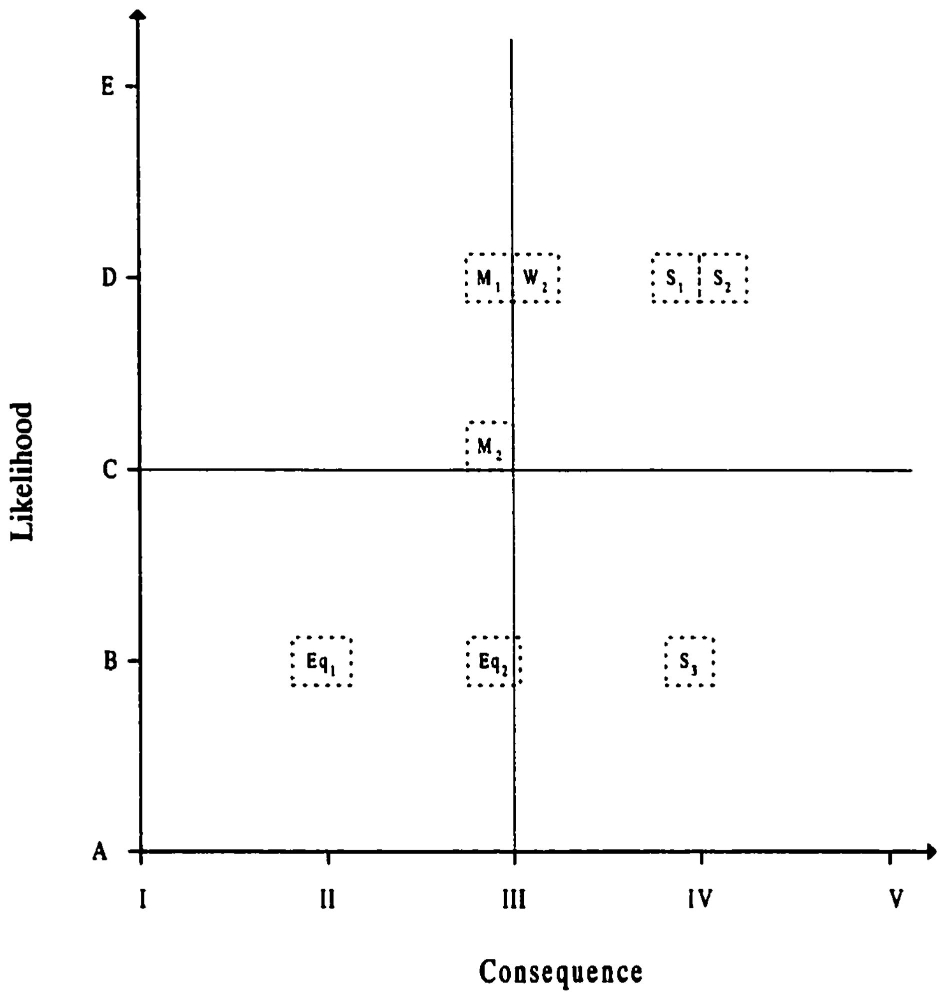

Figure 5-7. Planning Risk Profiles with Schedule Consequences

The risk of Schedule (S_n) S1 and S_2 are high risk and should be mitigated in the planning phase. The risk of construction Management (M_1), W, and S_3 are medium risk. Both Equipment and facility (Eq) are low risk.

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5.1.4.1.3.3. Planning Risk Profiles with Safety Consequences

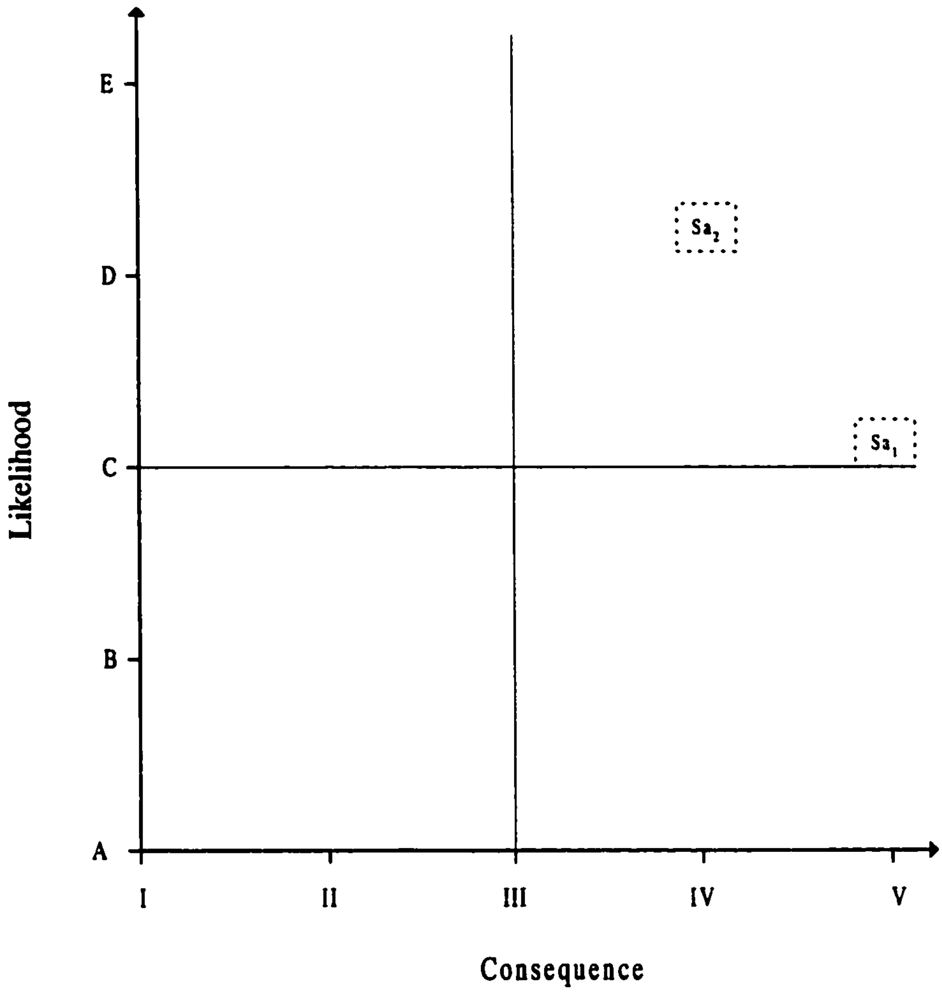

Figure 5-8. Planning Risk Profiles with Safety Consequences

The identified safety risks should be mitigated in the planning phase because they are unacceptably high.

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5.1.4.1.3.4. Planning Risk Profiles with Technical Performance Consequences

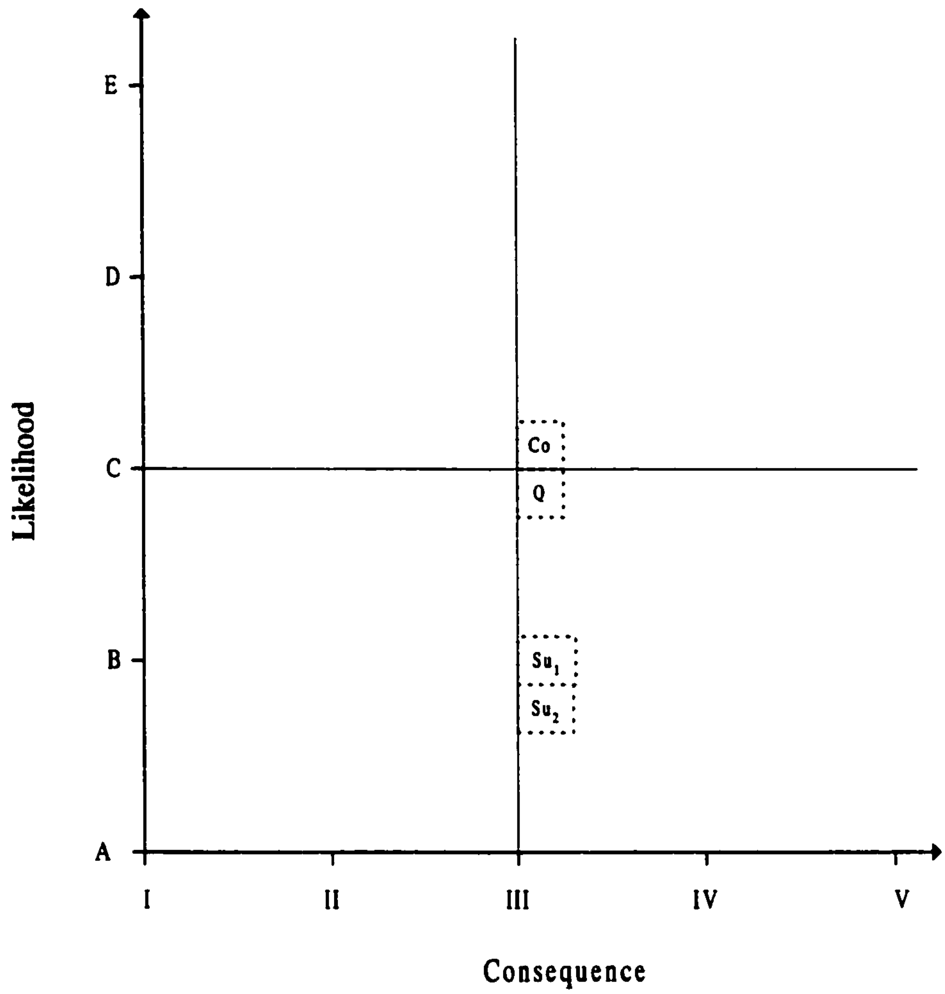

Figure 5-9. Planning Risk Profiles with Technical Performance Consequences

The risks from Suppliers (Su) are low. The issues of Quality (Q) and Complexity (Co) are medium risk.

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5.1.5. Planing MOB Construction Risk Acceptability

In this section risk ratings will be prioritized and an acceptable level of risk will be established. The process for determining risk acceptability is shown in Figure 5-10.

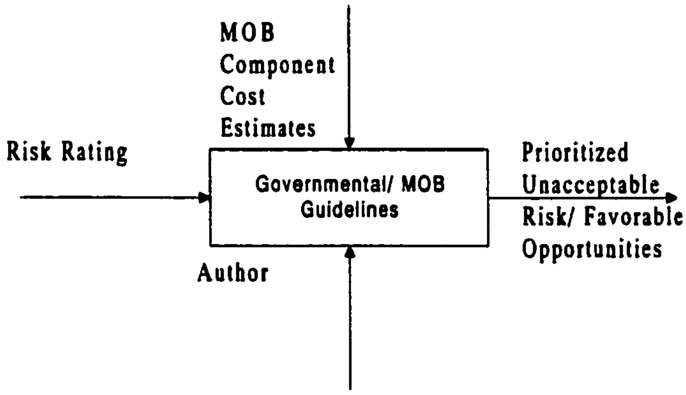

Figure 5-10. MOB Construction Risk Acceptability

The author, using documented guidelines and the presented charts of risk profiles, prioritized the risk ratings. From this information the risks were separated, prioritized, and categorized as; 1) high risk must be mitigated in the planning phase 2) medium risk should be mitigated in the planning phase if cost effective, and 3) low risks should monitored in the execution phase. Prioritization was based on cost, schedule, safety, and technical risks as being paramount. A prioritized list of the identified risks is shown in Table 5-14.

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Table 5-14. Planning Phase Prioritized Risk for Hinged MOB Construction

Potential Events	*Negative Risk Rating*	*Risk Acceptability*
Negative Risk		
Cost Escalation 1. Cost unrealistic 3.10-25% Budget shortfall 4. >25% Budget shortfall	1. High 3. High 4. High	1. Unacceptable 3. Unacceptable 4. Unacceptable
Schedule Delay 1. Schedule unrealistic 2. Delays by others	1. High 2. High	1. Unacceptable 2. Unacceptable
Safety 1. Major & multiple 2. Serious	1. High 2. High	1. Unacceptable 2. Unacceptable
Weather 1. Component loss	1. High	1. Unacceptable
Labor Problems 1. Sufficient quantity	1. High	1. Unacceptable
Environmental Concerns	1. High	1. Unacceptable
Cost Escalation 2. Account for all requirements	2. Medium	2. Mitigated in cost effective
Schedule Delay 3. Funding delay	3. Medium	3. Mitigated in cost effective
Construction Management 1. Coordination	1. Medium	1. Mitigated in cost effective
Weather 2. Schedule impacts	2. Medium	2. Mitigated in cost effective
Complexity	1. Medium	1. Mitigated in cost effective
Quality Problems	1. Medium	1. Mitigated in cost effective
Construction Management 2. Discord	2. Medium	1. Mitigated in cost effective

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Table 5-14. (continued) Planning Phase Prioritized Risk for Hinged MOB Construction

Potential Events	***Negative Risk Rating***	***Risk Acceptability***
Negative Risk		
Labor Problems 2. Sufficient quality	2. Medium	1. Mitigated in cost effective
Suppliers 1. Enough material 2. Venders over whelmed	1. Low 2. Low	1. Monitor in execution phase
Equipment Issues 1. Insufficient Cranes 2. Insufficient facilities	1. Low 2. Low	1. Monitor in execution phase 2. Monitor in execution phase
Inflation	1. Low	1. Monitor in execution phase
Opportunistic Risk	***Positive Risk Rating***	
Construction Management 1. Resource leveling at several sites 2. Terrestrial construction 3. Apply new technology and management	1. High 2. Medium 3. Medium	1. Choose in planning phase 2. Choose if cost effective 3. Choose if cost effective

5.1.6. Planning MOB Construction Risk Decision Analysis

The decision analysis in this section is focused on determining the risks that have been identified in the previous sections as requiring mitigation and a decision analysis process to determine the most appropriate alternative for mitigation. Also risks that have been identified for possible mitigation if cost effective may require a decision analysis process to determine if it is economically prudent to mitigate the

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risk. Additionally the appropriate probability density functions and ranges to use in a simulation of cost and schedule targets needs to be determined. Finally, based on the project risks, a recommendation to pursue the project further is required.

5.1.6.1. Risks Requiring Mitigation

The risk assessment identified several risk areas that must be addressed in the planning phase.

5.1.6.1.1. Cost and Schedule

The cost and schedule risk will be analyzed through a simulation of the cost and schedule to develop target values that reflect an appropriate level of uncertainty. Although in a strict sense the risks of a cost escalation is not mitigated but the target values developed have a higher level of certainty than those presented in Chapter two. The fact that target cost and schedules represent realistic estimates tend to keep projects within an established budget (Kerzner 1992) and (Laufer 1996).

5.1.6.1.2. Safety

Safety was assessed as a high risk and these safety risks must be mitigated during the planning phase. This is because safety is not just a cost issue it effects the lives of people. The risk analysis only points out that safety concerns must be addressed in the planning phase but not the specific safety issues e.g. falling from heights, working in confined spaces, etc. In Ayyub et al. (1999b) a preliminary hazard analysis was performed. The results of this analysis indicate areas where mitigation efforts can be applied in the planning and execution phases of MOB construction.

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5.1.6.1.3. Weather Caused Component Loss and Delays

Should a hurricane or tropical storm occur during the assembly or transportation of the MOB components there is the potential for a catastrophic loss. This risk is severe enough that the schedule of MOB construction operations will need to be timed to windows of opportunities that minimize this loss. The schedule developed in the planning phase must conservatively account for these construction windows. In Ayyub et al. (2000) a weather risk analysis methodology is presented that provides decision-makers with the information to make operational construction decisions.

Although not as high a risk as a component loss the delays due to weather will result in schedule increases. This risk is also mitigated by conservatively accounting for weather windows in the construction schedule as discussed above.

5.1.6.1.4. Labor Problems

There is a risk of not having a sufficient quantity of labor in the shipbuilding industry available to build the MOB. Labor cost for construction projects typically represent 40 to 50% of the total cost of construction (Adrian 2000). Thus any problems associated with labor will have a significant effect on the cost of a MOB. This uncertainty was accounted for in the cost and schedule efforts discussed above and methods to help ensure productivity efficiencies are discussed in Ayyub and Bender (1999).

Labor problems may also manifest if the quality of the skilled worker is sub-par. Typically the shipyard and offshore construction industries require certain work

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to be performed by experience journeyman. If these skills are lacking in the work force quality, productivity, and cost containment may suffer. The uncertainty for this item is accounted for in the cost and schedule target development.

5.1.6.1.5. Environmental Concerns

The potential risks associated with environmental concerns are schedule delays that tend to increase costs from expensive mitigation efforts. The best method to mitigate this risk is through the planning and design process that seeks alternatives to avoid this risk. Some strategies for avoiding this risk are to avoid facilities that would require dredging, new facility construction, and avoid particularly environmental sensitive areas, e.g. the Chesapeake Bay. The requirements and methods to objectively account for this risk are presented in Ayyub et al. (1999c).

5.1.6.1.6. Construction Management

The main risk source in this area is construction coordination. This coordination risk may be considered a double-edged sword. The volume of work required to build a MOB will overwhelm any one single shipyard or offshore construction facility. Therefore, the work will need to be spread over several facilities, which will increase the coordination requirements. On the other hand if a large number of facilities are building components and if any one facility is late with deliverables the potential consequences may be easier to mitigate by shifting plans. In developing the strategy to build a MOB a large number of facilities, (20) were used to build or assemble components for the hinged MOB (Ayyub et al. 1999b).

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Another potential risk area in construction management involves the contracting and construction delivery methods. Several alternatives exist to deliver projects. These methods should be explored and studied to provide a method that offers a competitive price, fairly distributes risks, and fosters good working relationships. The construction delivery method and contract type is not within the scope of this study but it is recognized that these will cause some risk in the execution phase if not planned for appropriately.

The construction management risks were modeled as part of the target cost and schedule development. These uncertainties were built into the simulation model to account for the risk of coordination, the benefit of using several facilities and an undetermined construction delivery method.

5.1.6.2. Potential Risk Mitigation Requiring an Economic Analysis

The medium risk identified in the areas of cost, schedule, weather, and labor have been addressed in the above sections along with similar high risk sources.

5.1.6.2.1. Complexity

This risk area involves the level of difficulty involved in the MOB project. During the planning phase efforts should be made to reduce the complexity of building a MOB. These efforts may include such items as mock-ups, laboratory tests, and other studies that will increase the likelihood of an economical success. Of course the level of complexity is a relative term that may not be fully understood until construction starts but the risk-based cost and schedule target development helps to account for this uncertainty.

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5.1.6.2.2. Quality

A potential source of risk is quality and tolerance control. The MOB construction scenario involves large components being built at one facility and assembled at another. The components should fit together without rework or require additional adjustments to ensure a proper fit. A management methodology and statistical techniques to help minimize this risk are presented in Ayyub et al. (1999b).

5.1.6.2.3. Project or Construction Management

A project of this magnitude will have a large amount of coordination and scheduling issues that need to be managed. If deliverables are behind schedule that are on the critical path they will lengthen the duration of construction and result in increased costs. The uncertainty of this effort is accounted for in the target cost and schedule simulation.

5.1.6.2.4. Weather Caused Delay

The construction scenario of building a MOB is to assemble large components at sea. This concept is similar to the current practices in the offshore industry. Additionally, the transportation of components from the fabrication site to the assembly site will be by barge or tow. The assembly and transportation of such large components requires calm seas and weather. A study of the risk of bad weather or seas causing a delay or controlling the windows of opportunity is presented in Ayyub et al. (2000).

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5.1.6.2.5. Complexity

A complex project by its very definition can be considered as difficult to understand, very large, and composed of many different parts. For the construction of a MOB, its complexity will create risks in the coordination between the designers and builders, fabrication, outfitting, transportation of components, performing heavy lifts, and other similar construction and coordination issues. Several of these risk complexity issues can be mitigated during the planning phase and are outlined in Ayyub and Bender (1999).

5.1.6.3. Risk that Require Monitoring During Execution

5.1.6.3.1. Suppliers

An analysis of potential industrial facilities indicated there are enough suppliers of raw materials and vendors to build a MOB (Ayyub et al. 1999b). Some of these suppliers and vendors may be working at their capacity and this risk should be monitored in the execution phase.

5.1.6.3.2. Equipment

Both of the identified risks of having sufficient crane and facility capacities are low. The documented capacities and volume of facilities evidence this (Ayyub et al. 1999b). These risks need to be monitored to ensure the final construction strategy accounts for any limitations in this area.

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5.1.6.3.3. Inflation

This identified risk is because a MOB will take several years to build. If double-digit inflation, as seen in the 1970's, reoccurs this will have a significant effect on the cost of construction. Recent trends of the 1980's and 1990's indicate inflation will remain low but this risk should be monitored during the execution phase.

5.1.6.4. Potential Risk Opportunities

As discussed previously there are potential project management benefits to spreading the manufacturing and building of blocks and components of a MOB to many different facilities. This would allow flexibility in scheduling and resource leveling. The MOB is so large that it must be built at several sites, increasing the number of sites to a maximum level should improve productivity. The downside to building components at a large number of sites is the increased coordination issues. The cost and schedule simulation includes the effects of incorporating a large number of sites. Additionally, other construction management issues that could potentially reduce the cost requirements are presented in Ayyub and Bender (1999) and Ayyub et al. (2000).

A novel concept of building the MOB completely ashore or terrestrially is appealing because this method would avoid the risks and expense of afloat operations. This method of construction is fully discussed in several MOB reports (Ayyub et al. 1999b), (Ayyub et al. 1999c) and (Ayyub et al. 2000).

There are several new technologies being applied to the shipbuilding industry that could successfully be applied to build a MOB e.g. robotic construction, use of

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high strength steels and welding. Additionally advances in management initiatives e.g. group technology and simulation based design have made shipbuilding more efficient and should be applied to the construction of a MOB. These techniques and initiatives are outlined in Ayyub and Bender (1999). Individual techniques and initiatives that are not intuitively obvious should be tested for their cost effectiveness before they are implemented.

5.1.7. Planning MOB Cost and Schedule Target Development

The majority of the work presented in this section, specifically the simulation, cost, and schedule development is adapted from Ayyub et al. (1999c).

5.1.7.1. Mob Construction Model and Simulation Setup

The model construction and simulation process starts with a decision on the type of simulation that should be used of either discrete event or continuous. Factors that should be considered in this decision include what is being modeled, characteristics, time steps, ordering, routing, and statistical detail. The model for the hinged MOB concept is developed so those individual components can be monitored. These components have assigned attributes such as construction time and cost. The intervals between the events depend on the duration of the activities. In addition to general statistics of the system, individual statistics of the components are tracked. The modeling of a MOB's construction requires simulation of discrete items and not flows and thus discrete event modeling is used.

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The Discrete Event (DE) simulation technique is used to probabilistically assess possible outcomes of cost and schedule by using statistics to account for the effects of variances and randomness. The model accounts for sequences, construction times, shipyards, materials, transportation and fabrication and assembly.

An example of a simplified MOB construction model using several shipyards is shown in Figure 5-11. The blocks in the Figure 5-11 represent major activities that have a random duration in length. Material deliveries are an uncertain process, generated by a random number technique and represented by a probability distribution. The selection of which technique and distribution to use is not a trivial process since it greatly affects output. Likewise other activities such as the construction duration of the braces, columns, and hulls, transportation and assembly are all processes that have a random duration. The techniques and rationale for the selection of a particular statistical distribution to represent randomness during modeling was presented in an earlier section.

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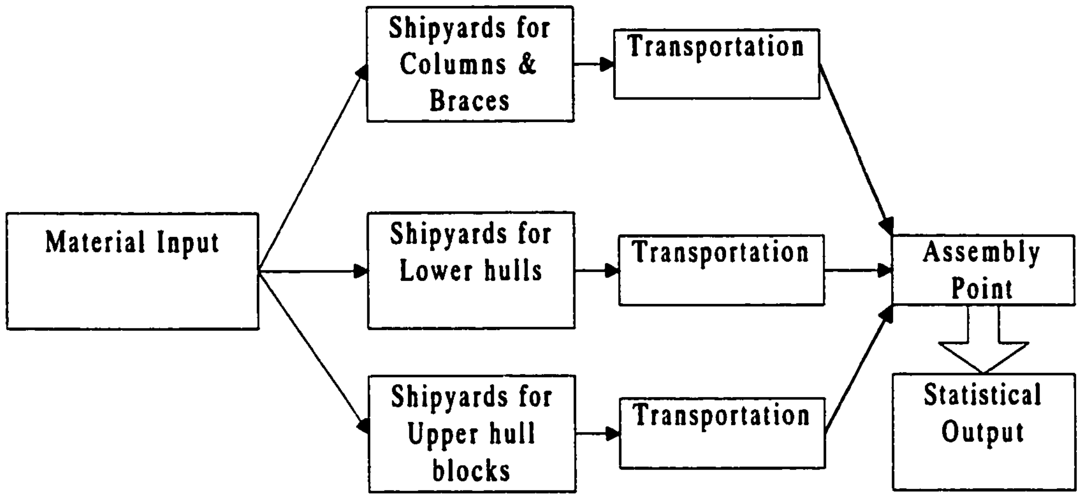

Figure 5-11. Generic Module Construction and Assembly Model

The three shipyards shown in Figure 5-11 is modeled as blocks with attached attributes for estimated construction times associated with each process. The construction times represent a range of estimates based on some type of statistical distribution. This distribution is required to model the uncertainty of a particular shipyard capability. Similarly, the transportation blocks represent the time required for the components to be barged or floated to a common assembly site. The duration of these discrete events account for uncertainty by using a random length of time based on a specific type of statistical distribution. Final assembly of the MOB must account for uncertainty associated with the estimated duration. Probabilistic output for cost and schedule is derived from performing many runs of the simulation.

An example of input and output randomness is shown in Figure 5-12. The various inputs of material, shipyard construction, transportation and assembly are modeled by a particular distribution. The simulation model using adapted off the shelf

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software compiles the inputs to match a MOB's critical path of construction and outputs statistical representations of projected cost, schedule or other desired parameters. A detailed model for the hinged concept has been developed to explore impacts to cost and schedule.

The power of simulation resides in allowing a modeler to experiment or vary the discrete events and develop "what if" scenarios to determine optimal system characteristics. For instance, what if a shipyard was added to or removed from the system shown in Figure 5-11? Sensitivity analyses can be performed on variables for each event. To develop meaningful statistics many experimental runs of the MOB construction process are made.

Figure 5-12 is a simplified representation of the probabilistic and stochastic processes of the model represented in Figure 5-11. A computer performs the actual calculations for the required number of simulation runs and storage of complex interactions. This computerized technique allows a hierarchical building approach to simulation and complex models can be made to look simple. The model in Figure 5-11 is only the "top level" in the entire MOB construction model. Hierarchical blocks break down the model into greater detail. The simulation is graphical and can be animated. For example, while running a simulation, the model in Figure 5-11 could show on a computer screen material moving into a shipyard, components being outputted, transported, and finally shown assembled in accordance with the timing parameters established by the model. Animation can be used as a communication tool to understand both the processes and identifying areas for improvement.

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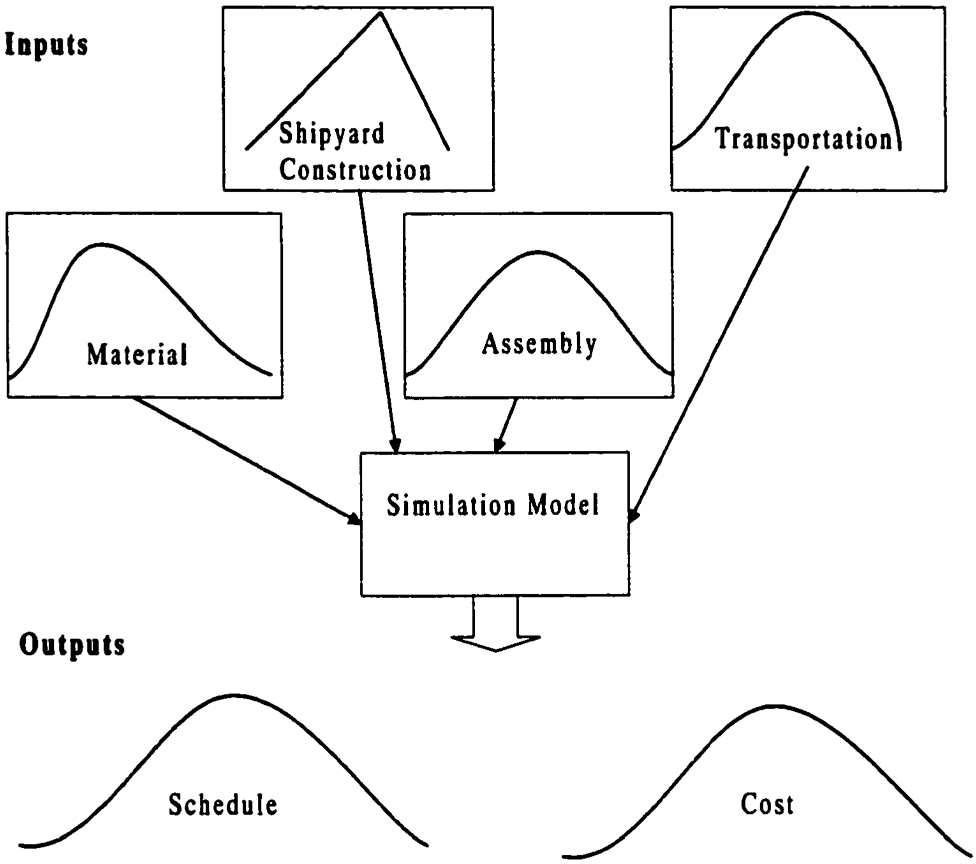

Figure 5-12. Random Input and Random Output for Process Shown in Figure 5-11

5.1.7.2. Steps in the MOB Simulation Study

The sections that follow provide simulation steps for the MOB concept and model.

5.1.7.2.1. MOB Construction Simulation Problem and Objective Statement

The construction of the MOB is a monumental task that requires a very large expenditure of resources. The objective of MOB construction simulation is to determine the best approach for construction in terms of cost and schedule. Proposed

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construction scenarios are simulated with a goal of providing reliable cost and schedule targets.

5.1.7.2.2. Analysis of Input Distribution

Since this research considers complex projects that may not have been considered before, historical data to model construction is not available. For example, a MOB has not been built from which the duration of construction can be measured and used as data on a model. Law and Kelton (1991) recommend the Triangular or Beta distributions to estimate a random duration when sample data does not exist. The Triangular distribution is also suggested when a most likely value can be given (Banks et al. 1995). In Chapter two, most likely values or point estimates for a MOB were developed and are used as a starting point in the simulation of the MOB construction.

Thus in keeping with current probabilistic theory and to keep models simple during development a triangular distribution was used for initial model development. The Triangular distribution used a most likely value that was derived in Chapter two. The shape of the Triangular distribution was based on the authors construction experience, studies of comparing construction estimates to actual duration, the results of the risk assessment, and applying this to a MOB construction scenario. Building a MOB is a high risk venture. Generally estimates tend to be overly optimistic and a majority of construction projects fail to finish on schedule as originally estimated (Mullholland and Christian 1999). Therefore the location parameter (lower limit) was taken as 90% of the estimate and the shape parameter (upper limit) was taken to be 125% of the estimate found in Chapter two.

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Once models were verified, not all input distributions were modeled with a Triangular distribution. When possible, personal knowledge, a review of construction modeling research, and combined with an understanding of particular distribution's characteristics a process was modeled by a more appropriate distribution.

Construction processes that involved the building, fabrication, and erection of components were modeled with a Beta distribution. The selection of the Beta distribution was based on, it is appropriate for use in the absence of adequate data, and the findings of AbouRizk and Halpin (1992) recommended that Beta distributions should be used to model duration input data for simulation of repetitive construction processes. Additionally, by using appropriate shape parameters, the distribution generally shows actual times take longer than estimated. The finite lower and upper bounds were found similar to the Triangular distribution above. These bounds are based on the construction duration of a specific process found in Chapter two, modified by 95% and 125% to derive the maximum and minimum limits as shown in Table 5-15. This is due to the activities involved in the building, fabrication, and erection of the components are considered high risk because they are susceptible to cost escalation, schedule delay, environmental concerns, labor problems and safety concerns. The ranges represented in Table 5-15 have been determined by the author but in practice these ranges could be set by the project team. The shape parameters in the Beta distributions are assumed to be 3 and 1.5. These values are used to develop a shape that is skewed toward a more conservative duration since these activities are high risk. The shape of a Beta distribution will look similar to that shown in Figure 5-13 using the shape parameters of α_1=3 and α_2=1.5.

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Table 5-15. Ranges for Probability Density Functions Based on Risk Rating

Negative Risk Rating	Range	
	Minimum	Maximum
High	95%	125%
Medium	90%	120%
Low	90%	110%
None	N/A	N/A
Opportunistic Risk Rating		
High	85%	100%
Medium	90%	105%
Low	95%	105
None	N/A	N/A

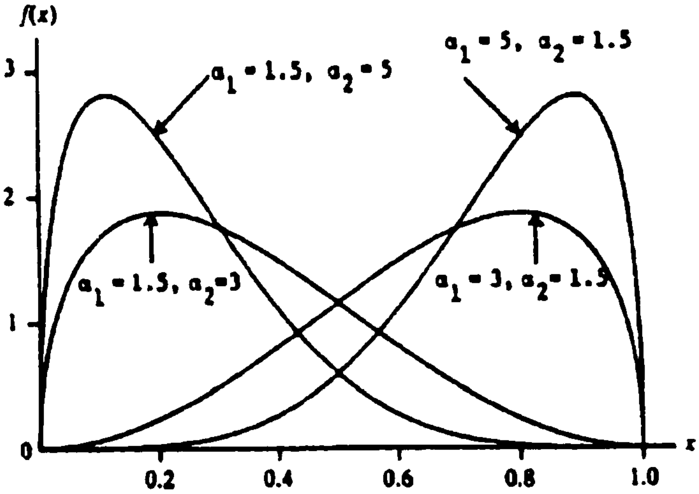

Figure 5-13. Sample Beta Distribution

Assembly of components and outfitting of modules were modeled with a Triangular distribution as discussed in initial model development. This is due to having limited experience with assembling large components offshore and applying the roughest estimating distribution possible. Additionally these activities were not considered a repetitive construction process suitable for a Beta distribution since these events only occurred between one and six times during the construction of a module. Since these activities are particularly subjected to weather caused delays, complexity

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and quality problems, they are considered a medium risk and the ranges for the probability distributions were between 90% and 120% as shown in Table 5-15.

To model the input duration data for the transportation of components from a building site to an erection or assembly site a Gamma distribution was assumed. This is due to the shape of the Gamma distribution, generally skewed to the left and about the mean but unbounded on the right. This approximation of transportation time is reasonable because of the high confidence in the estimate, yet it also accounts for potential weather or mechanical problems that may lengthen transit time. Additionally, Law and Kelton (1991) recommend a Gamma distribution to model arrival times and time to complete a task. In modeling the transportation time the minimum value (scale location) is 90% of the estimated value and the shape of the Gamma distribution assumed a shape parameter of $\alpha = 3$. This shape and minimum value was selected because of the high risk of a component loss at sea and the medium risk of weather caused delay. Figure 5-14 shows an example of this distributions shape using $\alpha=3$. For example, if the transportation estimate was 19 days the minimum value (0 in Figure 5-14) is 17 days.

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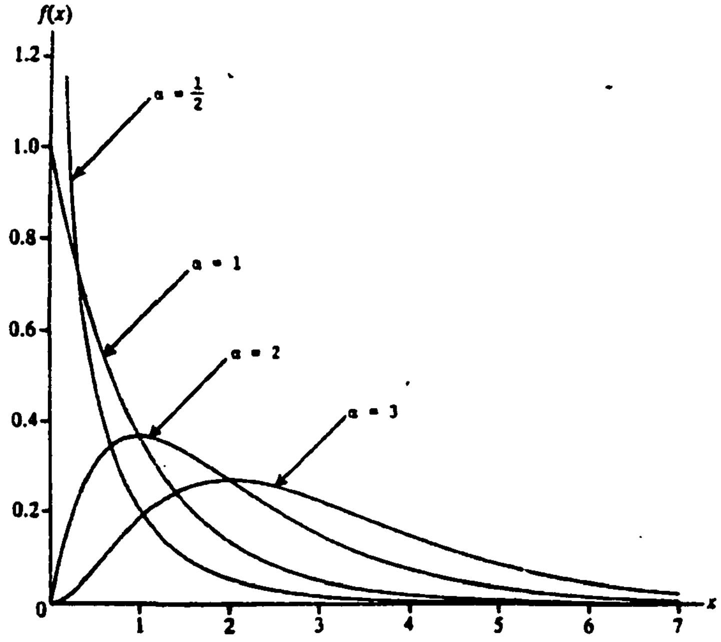

Figure 5-14. Sample Gamma Distribution

The probability distributions, their assocated shape, and ranges represent the risk identified in the risk assessment. These distributions are used to account for the uncertianty in the development of cost and schedule targets.

5.1.7.2.3. MOB Model Building

Several software vendors provide programs available for both discrete and continuous event simulations. One such software product is Extend™ by Imagine That, ® Inc. Extend is a general-purpose graphically oriented, discrete event, and continuous simulation software product. Discrete event modeling using Extend was done to simulate MOB construction. The Extend software was selected because it is easy to learn and apply yet it is robust enough to completely model the details of the MOB construction process. Additionally its graphical features make it a useful communication tool to present and document a MOB's construction simulation.

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Models in Extend were constructed to resemble the critical path of construction. Using a hierarchical building structure, the models look simple but details down to which shipyards are producing what blocks is modeled.

5.1.7.2.4. Model Scenario

A MOB's construction is based on the capacity of the US marine industry and will most likely be built by building large components ashore and assembling them at sea. To include the project management opportunities and risks involved in building a MOB the model contains many possible combinations of using shipyards and offshore industrial facilities to construct portions of the MOB. Shipyard and offshore facility selection was based on the facility capacities and locations presented in Ayyub et al. (1999b).

5.1.7.2.4.1. Afloat Assembly Model

This model uses most of the shipyards in the country to build blocks and major components of the MOB. Final assembly of the major components occurs at sea in the Gulf of Mexico (GOM).

5.1.7.2.4.2. Lower Hulls

The lower hulls required for a MOB module is built at separate shipyards and then transported to the GOM. Several shipyards are capable of building these large hulls. The model simulated construction and transportation of these structures at a particular shipyard and transported to the GOM.

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5.1.7.2.4.3. Braces

The braces for this model are built at a smaller shipyard. These are facilities that typically build or repair marine products. The braces are built at a regional facility close to the assembly site and are transported by barge.

5.1.7.2.4.4. Columns

The columns are built at various shipyards generally along the East and Gulf coast. Since the columns are fairly simple yet massive, two shipyards construct the blocks for assembly along side a pier. Once assembled the columns are attached to the lower hulls using a float over technique. Transportation of the columns was assumed to be performed wet.

5.1.7.2.4.5. Upper Hulls

The upper hulls are constructed from large blocks and panels that are produced at as many shipyards as possible. Shipyards on all coast of the country were used in this model. The blocks and panels are then transported to a site on the GOM for assembly into grand blocks.

5.1.7.2.4.6. Final Assembly

The final assembly of a MOB module is performed at sea using a float over technique.

5.1.7.2.5. MOB Model Validation

Validation attempts to answer the question "Was the right model built or used that truly represent the real system?" The critical path method was employed to

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schedule construction scenarios. Based on this critical path, a model was built by the author and critiqued by a colleague. Then necessary changes were then made to the model. This iterative and collaborative approach to model building helped to ensure the right model was built. From this iterative process more would be understood about the model and compared to the proposed MOB construction scenario to ensure an accurate representation was developed. This iterative process generally took several cycles for completion.

5.1.7.2.6. MOB Modeling Software Adaptation

The Extend software was adapted to perform the simulations for the MOB construction scenario. The attributes of cost and schedule were assigned to each discrete item that modeled the building of a MOB module. As the model "built" the MOB module the attributes were modeled using a particular input distribution and the software accumulated the attribute to develop the total cost and schedule results. Many simulation runs were performed and meaningful statistics were developed.

5.1.7.2.7. Verification of MOB Simulation Program

The MOB construction model was "debugged" and verified in a similar manner to the iterative validation process described above. The model was originally constructed as simple as possible, then complexity was introduced as more was understood about the model and confidence in the model grew. Additionally after each step in the modeled construction process histograms were displayed to ensure the software accounted for the activities duration. For example, if the lower hulls required about six months to complete and transportation required about a month, after each of

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these steps a display would indicate whether an attribute for duration was logically increasing and the results were checked for accuracy. A continuous display of output during model building ensured the model was following the critical path and was a true representation of the construction process. To ensure the model worked correctly, results had to approximate the schedule completion times and cost found in Chapter two.

5.1.7.2.8. Concept and Scenario Simulation Model Layouts

Learning curve efficiencies were applied to each activity that used a repetitive process during construction. The learning efficiencies were applied to building braces, column, blocks, and to erecting blocks or decks. The value of the learning efficiencies ranged from none for the first article to 95% for the last set of items. For example, if the first set of blocks to build the first Grand Block (GB) took 100 days the blocks for second GB took 97.5 days and the last set of blocks for the last GB took 95 days. The learning curve efficiencies are based on the shipbuilding experience of the US Navy (NAVSEA 1999).

This section presents a top-level diagram of the model to give the reader an understanding of what was modeled. The critical path for the construction scenario was modeled. The model has some common components and input distributions. Similar activities within the model use the same input distributions. The following sections present these similar activities and input distributions.

The critical path for the hinged concept and scenario is building the lower hulls and then assembling the grand blocks on to the module. This process is shown in

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Figure 5-15 and is the basis for the model produced with the Extend software. The heavy lines signify the critical path and the light lines indicate simple precedence. Activity duration and the values that were used to build the CPM schedule in Figure 5-15 is shown in Table 5-16. Only the top level is shown in Figure 5-15. For example, block "Build Blocks for GB1" contains several lower level blocks that represented construction at various shipyards.

5.1.7.2.8.1. Lower Hull Construction

Each lower hull's construction duration was modeled as a Beta distribution. Lower hulls were modeled as a complete component. For example, if a lower hull was estimated to take 14 months, only the total construction time was simulated, not the details or actual process to build a lower hull.

The lower hull's total construction cost are modeled as a normal distribution as mandated by the Central limit theorem given all the different cost components that constitute the entire lower hull. The mean and standard deviation of the normal distribution are consistent with the precision of the estimates given Chapter two.

The lower hulls are built concurrently at the Avondale and Newport New shipyards. Once completed they are towed out to sea for column connection prior to the float over of the first grand block. The model accounts for lower hull building and transportation time.

5.1.7.2.8.2. Block and Panel Construction

Block and panel construction duration was modeled as a beta distribution. This construction was modeled by assigning blocks and panel construction to the

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proposed facilities identified in Chapter two. Each block's construction was modeled as a total unit, not the individual steps.

All block and panel's total construction cost is modeled as a normal distribution as mandated by the Central limit theorem. The mean and standard distribution of the normal distribution are consistent with the precision of the estimates given in Chapter two.

Blocks and panels that combine to form the upper hull are built, erected and assembled in groups according to the grand blocks they form. Thirteen shipyards are used to build blocks or panels.

5.1.7.2.8.3. Column and Brace Construction

Columns for the hinged concept are built at two separate shipyards, with four built at Charleston and four built at Philadelphia. They are transported to the main block assembly site for assembly into the columns prior to assembly at sea with the lower hulls and grand blocks. The braces for this scenario could be built at the TDI Halter shipyard in Point Escatawpa, MS.

5.1.7.2.8.4. Component Transportation

Transportation of the various components, for example blocks built in Baltimore, MD and transported to Ingleside, TX, was modeled using a Gamma distribution. Components were queued until enough components were built to load out a barge. Based on the findings in Ayyub et al. (1999b) an adequate supply of barges was assumed. For cost purposes, component transportation is included in total block costs.

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5.1.7.2.8.5. Block and Panel Erection

Combining blocks and panels to form grand blocks was modeled using a Beta distribution. Erection productivity was based on schedules presented in Chapter two. The blocks and panels are assembled to form decks while a module is in the improved facility.

5.1.7.2.8.6. Component Assembly

The assembly of components performed afloat was modeled by a Triangular distribution. A Triangular distribution is used for modeling costs of component assembly.

The blocks are transported to Ingleside, TX for erection and assembly of the grand blocks. The grand blocks are assembled to the columns in deeper water of the Gulf of Mexico.

5.1.7.2.8.7. Outfitting

A Triangular distribution was used to model the schedule for outfitting the modules. A uniform distribution is used to model costs for outfitting in the simulation. The maximum and minimum values of the uniform distribution are consistent with the precision of the estimates given in Chapter two.

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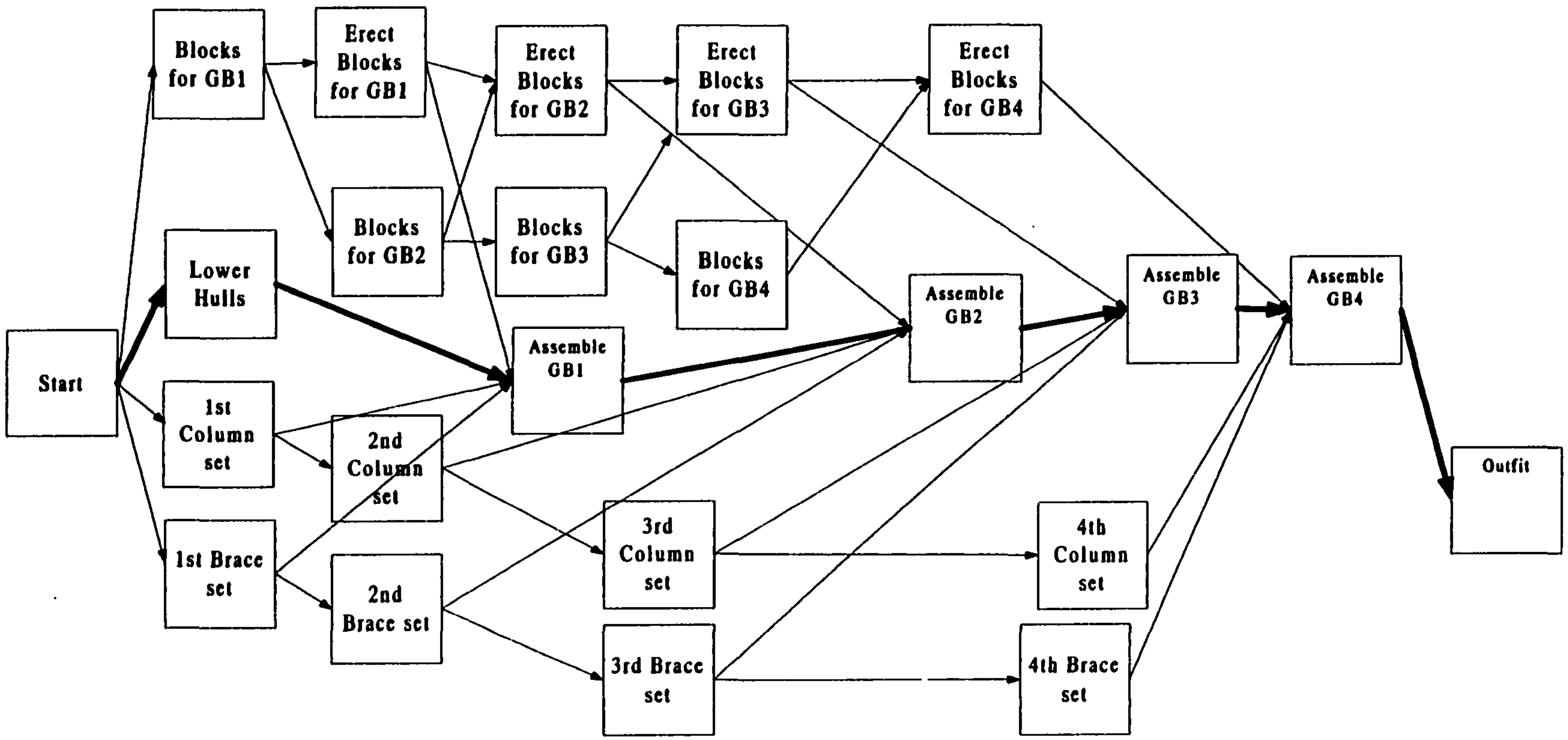

Figure 5-15. Top Level Layout of Hinged Concept with Afloat Assembly

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Table 5-16. Hinged Concept with Afloat Assembly CPM Analysis

Activity ID	Activity Description	Average Duration (Months)	Predecessor	Early Start	Early Finish	Late Start	Late Finish	Total Float	Comment
A	Lower Hulls	14	-	0	14	0	14	0	**Critical**
B	1st Column set	3.5	-	0	3.5	9	12.5	9	
C	2nd Column set	3.5	B	3.5	7	12.5	16	9	
D	3rd Column set	3.5	C	7	10.5	16	19.5	9	
E	4th Column set	3.5	D	10.5	14	19.5	23	9	
F	Build 1st set of 3 braces	1.5	-	0	1.5	12.5	14	12.5	
G	Build 2nd set of 3 braces	1.5	F	1.5	3	15.5	17	14	
H	Build 3rd set of 3 braces	1.5	G	3	4.5	18.5	20	15.5	
I	Build 4th set of 3 braces	1.5	H	10.5	14	19.5	23	9	
J	Build Blocks for GB1	3	-	0	3	5	8	5	
K	Build Blocks for GB2	3	J	3	6	8	11	5	
L	Build Blocks for GB3	3	K	6	9	11	14	5	
M	Build Blocks for GB4	3	L	9	12	15.5	18.5	6.5	
N	Erect Blocks for GB1	4.5	J	3	7.5	8	12.5	5	
O	Erect Blocks for GB2	4.5	K, N	7.5	12	12.5	17	5	
P	Erect Blocks for GB3	4.5	L, O	12	16.5	14	18.5	2	
Q	Erect Blocks for GB4	4.5	M,P	16.5	21	18.5	23	2	
R	Grand Block 1 Assembly	3	A,B,F,N	14	17	14	17	0	**Critical**
S	Grand Block 2Assembly	3	C,G,O,R	17	20	17	20	0	**Critical**
T	Grand Block 3 Assembly	3	D,H,P,S	20	23	20	23	0	**Critical**
U	Grand Block 4 Assembly	3	E,I,Q,T	23	26	23	26	0	**Critical**
V	Outfit	6	U	26	32	26	32	0	**Critical**

5.1.7.3. MOB Construction Statistical Analysis and Simulation Results

The central limit theorem, when used in MOB construction simulation, implies that no matter what the underlying distribution is, the simulated schedule duration or cost mean will tend to a normal distribution (Smith 1991) as long as the assumption of the theorem are met for a large number of input variables without a dominating distribution type. The central limit theorem states that if the number of random variables $X_1, X_2, \cdots, X_n$ with means $\mu_1, \mu_2, \cdots, \mu_n$, and variances $\sigma_1^2, \sigma_2^2, \cdots, \sigma_n^2$, is large, X, the sum of the random variables, is approximately normal, regardless of the shape of distribution of each X_i, with mean $\hat{\mu}$ and variance $\hat{\sigma}^2$ given by

$$\hat{\mu} = \mu_1 + \mu_2 + \cdots + \mu_n \quad (5\text{-}1)$$

$$\hat{\sigma}^2 = \sigma_1^2 + \sigma_2^2 + \cdots + \sigma_n^2 \quad (5\text{-}2)$$

This result is applied to the construction scenario for the hinged MOB concept's critical path for schedule duration and all activities for cost, where X_i, representing the duration or cost of the *i*-th activity, is a random variable, and X is the concept's total duration or cost. In simulating total schedule duration, only activities on the critical path are considered while in simulating total cost, all activities are considered. The hinged concept's schedule duration can be approximated by a the sums of the means and variances of the activities on the critical path. Total cost can be approximated by a normal distribution with the mean and variance of the sums of the means and variances of the hinged concept's activities. The probability associated with completing the project a within certain time or cost limits can be computed using

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standard normal distribution formula. The central limit theorem is to compute schedule and cost risk probability.

For 2000 cycles, the simulation results for the hinged concept are given in Table 5-17. Results for other MOB concepts may be found in Ayyub et al. (1999c). For comparison, the results for the original point estimate developed in Chapter two are shown in Table 5-18. The schedule for building an entire MOB was extrapolated assuming a simple non-statistical derived schedule overlap of 50%. This assumption is reasonabie because it considers the findings in Cybulsky et al. (2000) that indicate a schedule overlap for building MOB modules could range from a very conservative 30% to a highly aggressive 80%.

Table 5-17. Hinged MOB Construction Simulation Results

Hinged Concept	Schedule Results		Cost Results	
	Mean	Standard Deviation	Mean (million $)	Standard Deviation
Module	36 (months)	1.3	843	14
Entire MOB	9 (years)	NA	4,215	NA

Table 5-18. Hinged MOB Construction Point Estimate

Hinged Concept	Schedule Results	Cost Results ($ million)
Module	32 (months)	767
Entire MOB	8 (years)	3,834

The results of Table 5-17 show a surprisingly small standard deviation. This is in part due to the conservative assumptions applied to the range of the probability density functions used in the simulation of activities. As can be seen in the comparision of the results between a point estimate (32 months) and a risk-based,

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statistically derived estimate (36 months) the schedule gained 4 months for a single MOB module. Decision makers should have confidence the the later value (36 months) because it accounts for construction uncertainty. Additionally a large number of simulation runs (2000) were run and this provides a high degree of persicion and accuracy (Ayyub et al. 1999c). Finally, the relatively narrow range of distributions from 90% to 125% contributed to the low standard of deviation.

5.1.8. Final Planning Phase Decision Analysis

Once the risk-based cost and schedule targets have been developed a final decision analysis is required to determine if a project should proceed to the execution phase. This decision is typically an economic one but should be assisted by the risk analysis work performed up to this stage. The proposed methodology in Chapter four assumes a project's future will be based on an economic decision. Thus, a NPV decision analysis method should be employed to help make this decision.

For the MOB several other factors such as national priorities, political, potential alternatives, and governmental spurred economic growth will factor into the decision to actually build a MOB. The decision to build a MOB is not as suited for a risk based NPV approach as a project such as a mass transit tunnel would be. This decision analysis technique is demonstrated to exercise the proposed methodology but it is recognized that the decision to build a large military platform is more than economic.

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5.1.8.1. NPV Analysis

There are several assumptions that need to be made to apply a NPV equation to the MOB. The NPV analysis is applied to one module. This is because it allows decision-makers to review the NPV of a discrete MOB unit or module. The Capitol Investment (CI) of the MOB is assumed to be the target cost found in the planning phase. There is not any expected Annual Revenue (AR) and Annual Costs (AC) to maintain the MOB is one percent of the initial cost. The MOB is being designed for a 40-year useful life (N) and the assumed salvage (S) value after 40 years is 1/5th of the original cost. The interest (i) rate is the 30 year treasury rate as of September 20, 2000 it was approximately 5.9% (Seattle PI 2000c). The NPV is expressed in the following equation:

$$NPV = -CI + (AR - AC)\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] + \frac{S_N}{(1+i)} \qquad (5\text{-}3)$$

Substituting in equation 5-3 the NPV for a single module becomes:

$$NPV = -843 + (0 - 8.43)\left[\frac{(1+0.059)^{40} - 1}{0.059(1+0.059)^N}\right] + \frac{40}{(1+0.059)} \qquad (5\text{-}4)$$

Solving: NPV = \$-933.68 million

The NPV method is suited for evaluating concepts or alternatives in the feasibility phase of a project. Applying an NPV analysis to the MOB results in a more realistic cost because the time value of money, annual costs, and salvage value is also included. Decision-makers can use this derived cost to assist in their decision process.

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5.2. Execution Phase of Risk-based Cost Control

This phase of the project begins once the project owner or governmental agency has approved the project. Actual construction begins in this phase. Because the MOB has not been built the presented MOB case study is presented as an example of how the methodology should be applied. In this section various assumptions and construction scenarios will be employed to demonstrate the proposed methodology.

As presented in Chapter four the proposed execution methodology is also presented in Figure 5-16. This section will follow the proposed methodology as outlined in this figure.

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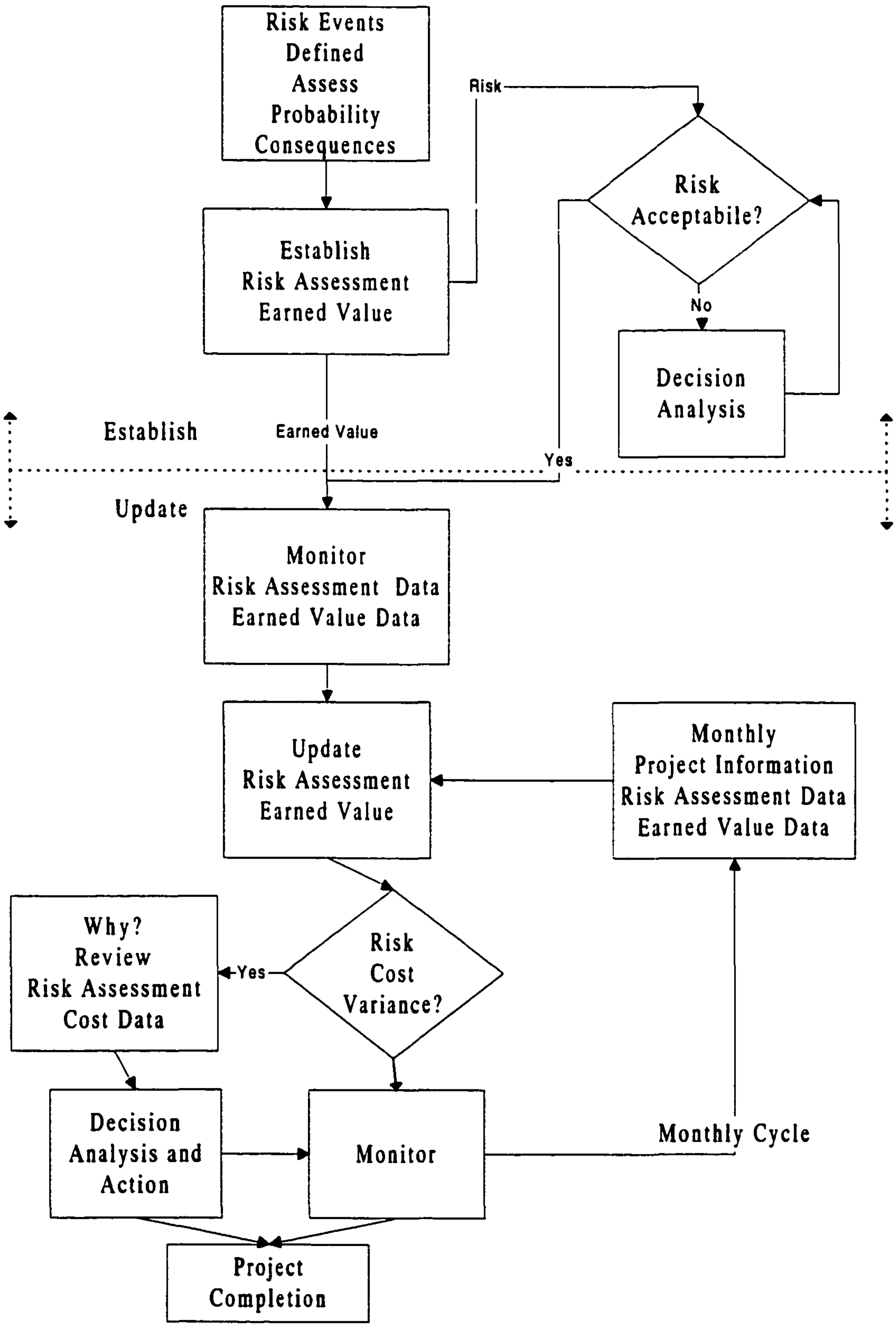

Figure 5-16. Execution phase Combined Risk Assessment and Earned Value

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5.2.1.1. Execution Phase Define Events

During the planning phase the risks of building a MOB were identified. It is assumed that not all of the identified risks still exist into the execution phase. This is because one of the objectives during the planning phase is to mitigate or take advantage of risks. Therefore if a risk event was identified in the planning phase it may not be present or significantly reduced in the execution phase.

During the execution phase new people and organizations will come together to work on building a MOB. These new people and organizations should combine to augment the existing project team that updates or develops a new list of potential risk events. In addition several decisions effecting risk will have been made that increase the risk to certain parties or that change the total risk. For this dissertation the author updated the existing risk events identified in the planning phase.

The identified risk events from the planning phase are mostly assumed to carry over to the execution phase. These risk events are shown in Table 5-19. These events would have been identified similar to the process performed in the planning phase or an updated of the existing identified risk events would have been performed by the new project team.

One of the risk areas where events have changed from the planning phase are in the failure to meet budget events. These events while less uncertain now have a tighter tolerance and an additional range was added. The opportunistic risk event of terrestrial construction was dropped because it is assumed the construction scenario will use the float over technique of assembling components at sea.

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Table 5-19. Identified Risk for Hinged MOB Construction

Negative Risk Source	***Potential Events***
Cost Escalation	1. A cost estimate is unrealistic. 2. Failure to account for all requirements. 3. Failure to meet budget <5%. 4. Failure to meet budget 5-10%. 5. Failure to meet budget >10%.
Schedule Delay	1. Schedule estimates is unrealistic. 2. Delays form others e.g. government, subcontractors, etc. 3. Delay in funding process.
Labor Problems	1. Insufficient work force. 2. Insufficient skilled work force.
Project or Construction Management	1. Coordination of several sites building components. 2. Appropriate contract type.
Safety	Working the shipbuilding industry is hazardous. 1. Fatality. 2. Serious injury.
Environmental Concerns	Cost impacts due to environmental mitigation requirements.
Equipment/ Facility Issues	1. Insufficient cranes. 2. Insufficient shipbuilding facilities.
Inflation	Cost increases from inflation due to lengthy construction.
Weather	1. Loss of components when transporting or connecting. 2. Schedule impacts due to weather.
Complexity	Cost problems associated with being the largest ocean structures ever built.
Suppliers	1. Ability to produce enough raw materials. 2. Vendors producing at maximum capacity.
Quality Problems	Components built at separate facilities requiring rework at assembly sites.
Opportunistic Risk Source	***Potential Events***
Project or Construction Management	1. Potential to spread the construction work of components to several sites thus allowing schedule flexibility and resource leveling. 2. Use of latest technology and management techniques to build more efficiently.

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5.2.1.2. Execution Phase Assessment of Probabilities

Similar to the process used in the planning phase the assessment of probabilities is performed in a qualitative manner and is performed by the project team. For this dissertation the assessment of probabilities is performed by the author and is presented in Table 5-20. The qualitative expressions for the probability assessment are found in Table 5-4.

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Table 5-20. MOB Execution Phase Assessment of Probabilities

Negative Risk Source	***Assess Probability of:***	***Probability Expression***
Cost Escalation	1. Cost estimate is unrealistic. 2. Failure to account for all requirements. 3. Failure to meet budget <5%. 4. Failure to meet budget 5-10%. 5. Failure to meet budget >10%.	1. B Unlikely 2. C likely 3. D Highly Possible 4. C Likely 5. B Unlikely
Schedule Delay	1. Schedule estimates is unrealistic. 2. Delays from others. 3. Delay in funding.	1. B Unlikely 2. C Likely 3. B Unlikely
Labor Problems	1. Insufficient work force. 2. Sufficiently skilled work force.	1. B Unlikely 2. B Unlikely
Project or Construction Management	1. Late deliverables and coordination problems from several sites building components. 2. Contract type causes discord.	1. D Highly Possible 2. B Unlikely
Safety	1. Major and multiple accidents. 2. Serous accident.	1. B Unlikely 2. D Highly Possible
Environmental Concerns	Cost impact due to environmental mitigation requirements.	C Likely
Equipment/ Facility Issues	1. Insufficient cranes. 2. 2. Insufficient shipbuilding facilities.	1. B Unlikely 2. B Unlikely
Inflation	Unplanned cost increase from lengthy construction period	B Unlikely
Weather	1. Loss of components when transporting or connecting components. 2. 2. Schedule impacts due to weather.	1. B Unlikely 2. C Likely
Complexity	Cost problems associated with being the largest ocean structures ever built.	C Likely
Suppliers	1. Ability to produce enough raw materials. 2. Vendors over whelmed.	1. B Unlikely 2. B Unlikely
Quality Problems	Components built at separate facilities and not fitting together at assembly sites.	C Likely

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Table 5-20. (continued) Execution Phase Assessment of Probabilities

Opportunistic Risk Source	***Potential Events***	
	Assess Probability of:	***Probability Expression***
Project or Construction Management	1. Potential to spread the construction work of components to several sites thus allowing schedule flexibility and resource leveling. 2. Latest technology and management techniques reduce cost.	1. C Likely 2. C Likely

5.2.1.3. Execution Phase Assessment Consequences

Similar to the process used in the planning phase the assessment of consequences is performed in a qualitative manner and is performed by the project team. For this dissertation the assessment of consequences is performed by the author and is presented in Table 5-21. Risk events are categorized by their consequences as shown in Table 5-22. The qualitative expressions for the consequence assessment are found in Table 5-5 through 5-8.

The consequences for most of the risk events have not changed from the planning phase. This is due to the magnitude of an event remaining the same unless specific actions are taken in the planning phase to reduce the consequences. It was assumed the planned construction scenario from the planning phase to the execution phase did not change many consequences. For example, the consequence of a component loss due to weather is catastrophic. To reduce the magnitude of this loss smaller components or spare components could be built. The consequence remained

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the same to the execution phase because the construction scenario did not change to account for these alternatives.

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Table 5-21. MOB Construction Execution Phase Consequence Assessment

Negative Risk Source	***Assess Consequence of:***	***Consequence Expression***
Cost Consequence		
Cost Escalation	1. Cost estimate is unrealistic. 2. Failure to account for all requirements. 3. Failure to meet budget <5%. 4. Failure to meet budget 5-10%. 5. Failure to meet budget >10%.	1. IV Critical 2. III Marginal 3. II Acceptable 4. III Marginal 5. IV Critical
Labor Problems	1. Insufficient work force. 2. Sufficiently skilled work force	1. IV Critical 2. IV Critical
Environmental Concerns	Cost impact due to environmental mitigation requirements.	IV Critical
Inflation	Unplanned cost increase from lengthy construction period	II Acceptable
Weather	1. Loss of components when transporting or connecting components.	1. V Catastrophic
Schedule Consequence		
Schedule Delay	1. Schedule estimates is unrealistic. 2. Delays from others. 3. Delay in funding.	1. IV Critical 2. IV Critical 3. IV Critical
Project or Construction Management	1. Late deliverables and coordination problems from several sites building components. 2. Contract type causes discord.	1. III Marginal 2. III Marginal
Weather	2. Schedule impacts due to weather.	2. III Marginal
Equipment/ Facility Issues	1. Insufficient cranes. 2. Insufficient shipbuilding facilities.	1. II Acceptable 2. III Marginal
Safety Consequence		
Safety	1. Major and multiple accidents. 2. Serous injury accident.	1. IV Critical 2. III Marginal
Technical Performance Consequence		
Complexity	Cost problems associated with being the largest ocean structures ever built.	III Marginal
Suppliers	1. Ability to produce enough raw materials. 2. Vendors overwhelmed.	1. III Marginal 2. III Marginal
Quality Problems	Components built at separate facilities requiring rework at assembly sites.	III Marginal

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Table 5-21. (continued) MOB Construction Consequence Assessment

Opportunistic Risk Source	*Potential Events*	
Project or Construction Management	1. Potential to spread the construction work of components to several sites thus allowing schedule flexibility and resource leveling. 2. Latest technology and management techniques reduce cost.	1. -IV Favorable 2. –IV Favorable

5.2.1.4. Execution Phase Establish Risk Assessment

By combining the assessment of probabilities and consequences a risk assessment is made using Table 5-10 for negative risk and Table 5-11 for opportunistic risk. The execution phase risk assessment is shown in Table 5-22.

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Table 5-22. Identified Negative Risk for Hinged MOB Construction by Consequence Category

Potential Events	*Probability*	*Consequence*	*Negative Risk Rating*
Cost Consequence			
Cost Escalation 1. Cost unrealistic 2. Account for all requirements 3.<5% Budget shortfall 4. 5-10% Budget shortfall 5. >10% budget shortfall	1. B Unlikely 2. C Likely 3. D Highly Possible 4. C Likely 5. B Unlikely	1. IV Critical 2. III Marginal 3. II Acceptable 4. III Marginal 5. IV Critical	1. Medium 2. Medium 3. Low 4. Medium 5. Medium
Labor Problems 1. Sufficient quantity 2. Sufficient quality	1. B Unlikely 2. B Unlikely	1. IV Critical 2. IV Critical	1. Medium 2. Medium
Environmental Concerns	C Likely	IV Critical	High
Inflation	B Unlikely	II Acceptable	Low
Weather 1. Component loss	1. B Unlikely	1. V Catastrophic	1. High
Schedule Consequence			
Schedule Delay 1. Schedule unrealistic 2. Delays by others 3. Funding delay	1. B Unlikely 2. C Likely 3. B Unlikely	1. IV Critical 2. IV Critical 3. IV Critical	1. Medium 2. High 3. Medium
Construction Management 1. Coordination 2. Discord	1. D Highly Possible 2. B Unlikely	1. III Marginal 2. III Marginal	1. Medium 2. Low
Weather 2. Schedule impacts	2. C Likely	2. III Marginal	2. Medium
Equipment Issues 1. Insufficient Cranes 2. Insufficient facilities	1. B Unlikely 2. B Unlikely	1. II Acceptable 2. III Marginal	1. Low 2. Low

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Table 5-22. (continued) Identified Risk for Hinged MOB Construction

Potential Events	***Probability***	***Consequence***	***Negative Risk Rating***
Safety Consequence			
Safety 1. Major & multiple 2. Serious	1. C Unlikely 2. D Highly Possible	1. IV Critical 2. III Marginal	1. High 2. Medium
Technical Performance Consequence			
Complexity	C Likely	III Marginal	Medium
Suppliers 1. Enough material 2. Venders over whelmed	1. B Unlikely 2. B Unlikely	1. III Marginal 2. III Marginal	1. Low 2. Low
Quality Problems	C Likely	III Marginal	Medium
Opportunistic Risk			***Positive Risk Rating***
Construction Management 1. Resource leveling at several sites 2. Apply new technology and management	1. C Likely 2. C Likely	1. -IV Favorable 2. –IV Favorable	1. High 2. High

5.2.1.5. MOB Execution Phase Risk Profiles

For the purpose of performing risk comparisons it is better to compare risk that have the same consequences. Figures 5-18 through 5-22 show the risk profiles according to consequence category and type of risk e.g. negative or opportunistic. To track risk that have continued from the planning phase these risks are also shown along with the execution phase risks.

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5.2.1.5.1. Execution Phase Risk Profiles with Cost Consequences

The risks with cost consequences have changed because the risk-based cost targets will have increased the confidence in the estimate and accounted for uncertainty in the costs. The negative risk profiles with cost consequences is shown in Figure 5-17.

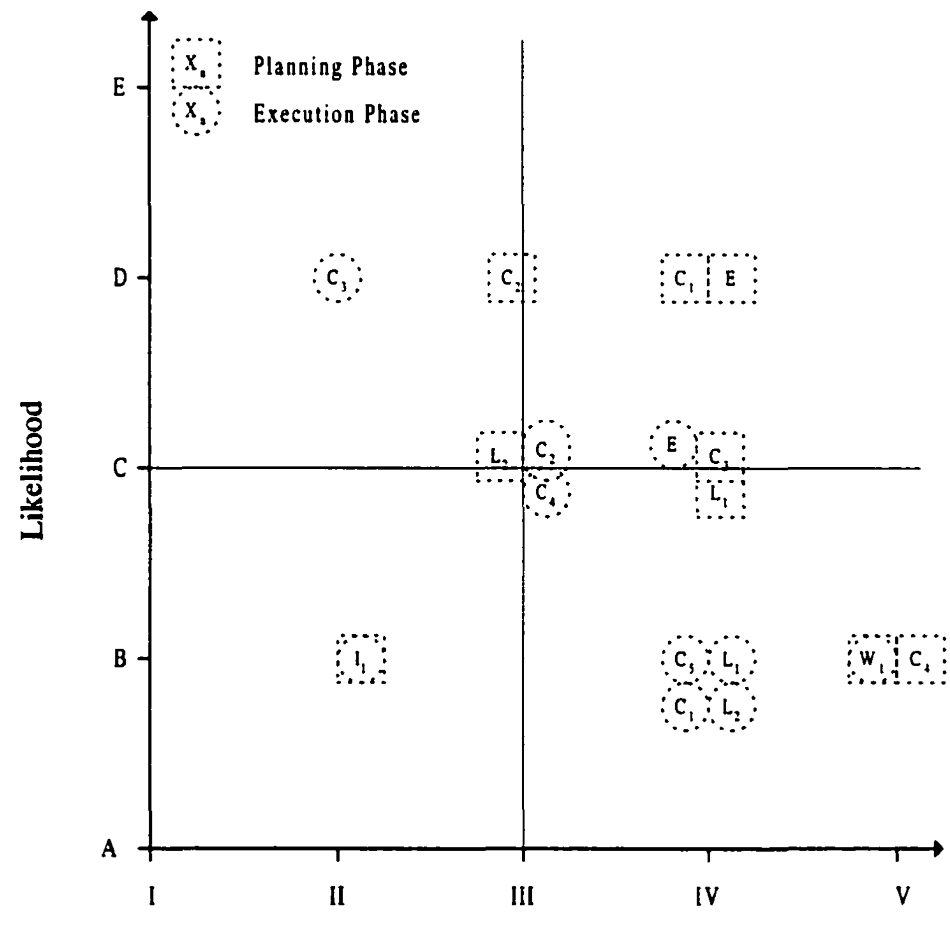

Figure 5-17. Execution Phase Cost Consequence Risk Profile

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5.2.1.5.2. Execution Phase Risk Profiles with Schedule Consequences

The risks with schedule consequences have changed because the risk-based schedule targets will have increased the confidence in the schedule and accounted for uncertainty in the duration of activities. The negative risk profiles with schedule consequences is shown in Figure 5-18.

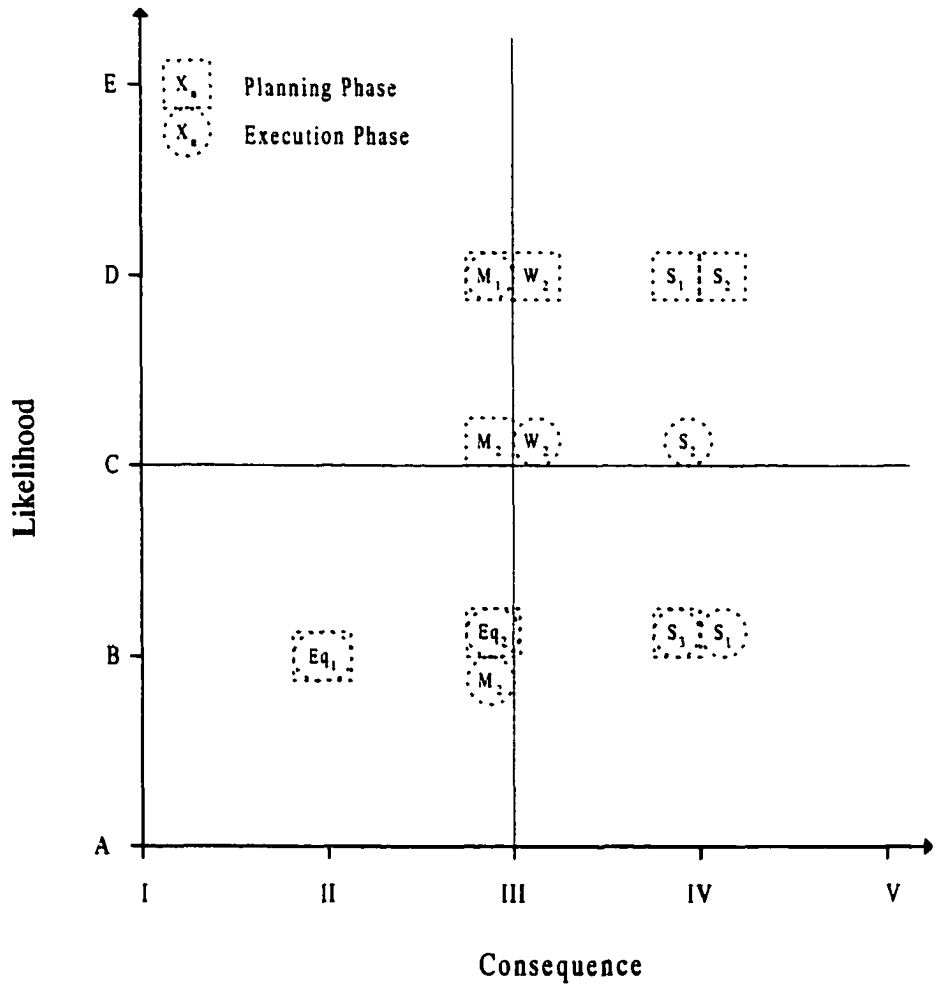

Figure 5-18. Execution Phase Schedule Consequence Risk Profiles

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5.2.1.5.3. Execution Phase Risk Profiles with Safety Consequences

The risks with safety consequences have changed because the in planning phase efforts were made to reduce the likelihood of an accident by performing and implementing a preliminary hazard analysis. The negative risk profiles with safety consequences is shown in Figure 5-19.

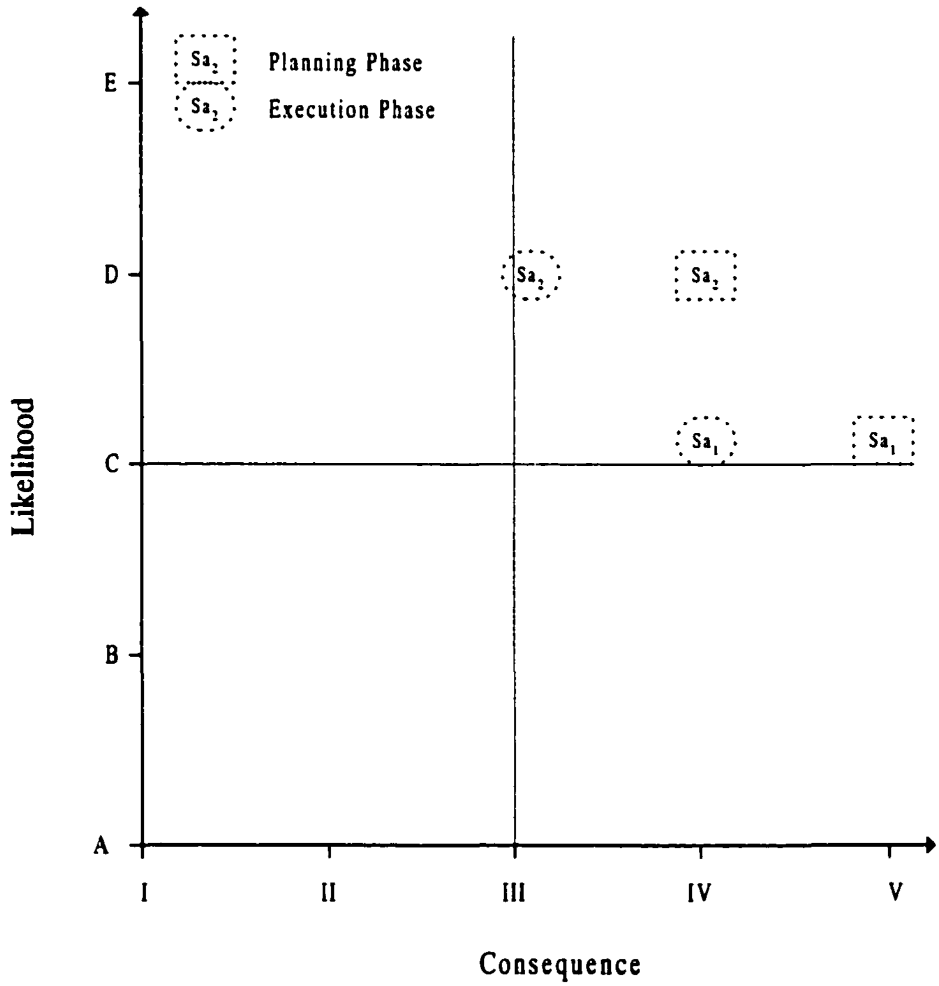

Figure 5-19. Execution Phase Safety Consequence Risk Profiles

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5.2.1.5.4. Execution Phase Risk Profiles with Technical Consequences

The risks with technical performance consequences have remained the same. The negative risk profiles with technical performance consequences is shown in Figure 5-20.

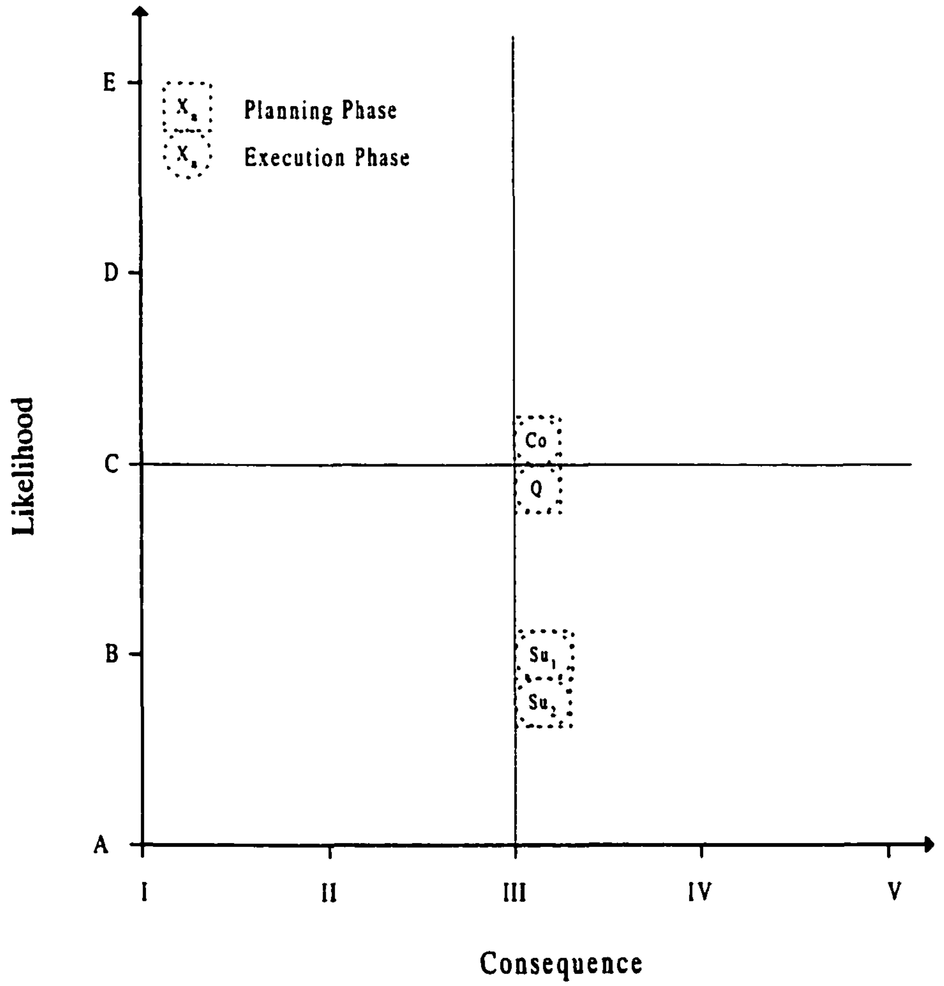

Figure 5-20. Execution Phase Technical Performance Consequence Risk Profiles

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5.2.1.5.5. Execution Phase Opportunistic Risk Profiles

The opportunistic risk profiles are shown in Figure 5-21. The opportunistic risk of terrestrial construction has dropped out between phases because it is assumed the afloat technique is used. The opportunistic risk of applying new technologies and management has improved because it is assumed that these efforts will produce significant savings.

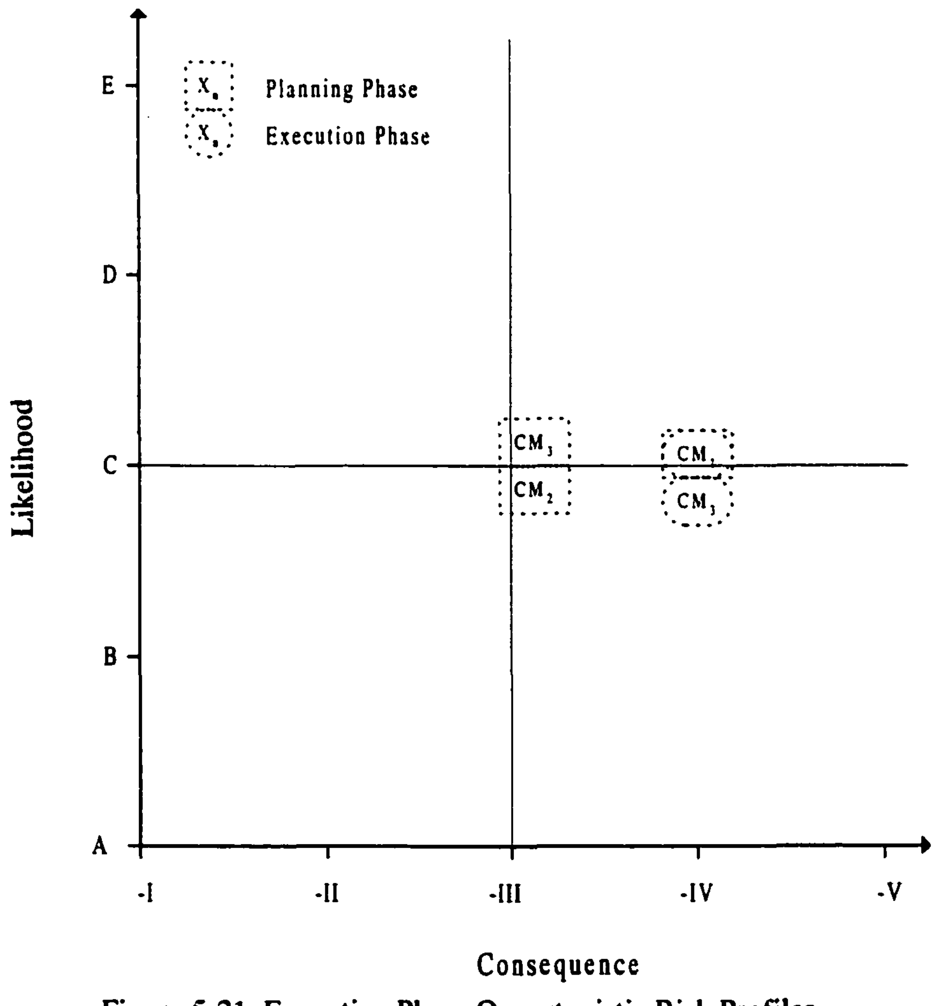

Figure 5-21. Execution Phase Opportunistic Risk Profiles

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5.2.1.6. Execution Phase Establish Earned Value

The earned value analysis should be established once the cost and schedule targets are known. The basic steps to set up the analysis will have been performed during the development of the cost and schedule estimates, by establishing a Work Breakdown Structure (WBS). For the hinged MOB concept this was done in Chapter two. Table 5-23 is the start of the earned value data establishment that is used to establish the planed value of the work scheduled. This table only shows the first ten months because the work is scheduled over 36 months and the columns would not all fit on one page. A complete table is found in Appendix A.

Table 5-23. Establish Earned Value Analysis Planned Value

WBS	Item	Millions of $ per Month									
	Month	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10
11011	P L Hull	2	4	8	10	10	12	14	12	8	
11012	S L Hull			2	4	8	10	10	12	14	12
11510	S Columns					1	1	1	1	2	2
11520	P Columns										
11410	Braces 1				1	1	2	2			
11420	Braces 2								1	1	2
11430	Braces 3										
11440	Braces 4										
13610	U Hull 01	3	6	9	10	10	12	13	12	12	10
13620	U Hull 02							3	6	9	9
13630	U Hull 03										
13640	U Hull 04										
13650	U Hull 05										
14000	Assembly										
	Column Sum	5	10	19	25	30	37	44	44	48	36
	Cumulative	5	15	34	59	89	126	170	214	262	298

Table 5-23 is developed from the target cost, schedule and spreading the estimated cost of components over the estimated schedule activity. The dollar amounts are rounded to the nearest million for simplicity. From the data in a

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completed table (Appendix A) similar to Table 5-23 a graph is produced that establishes the planned value of the work. This graph is shown in Figure 5-22 and is used to compare the actual cost of the work and earned value with the planned value.

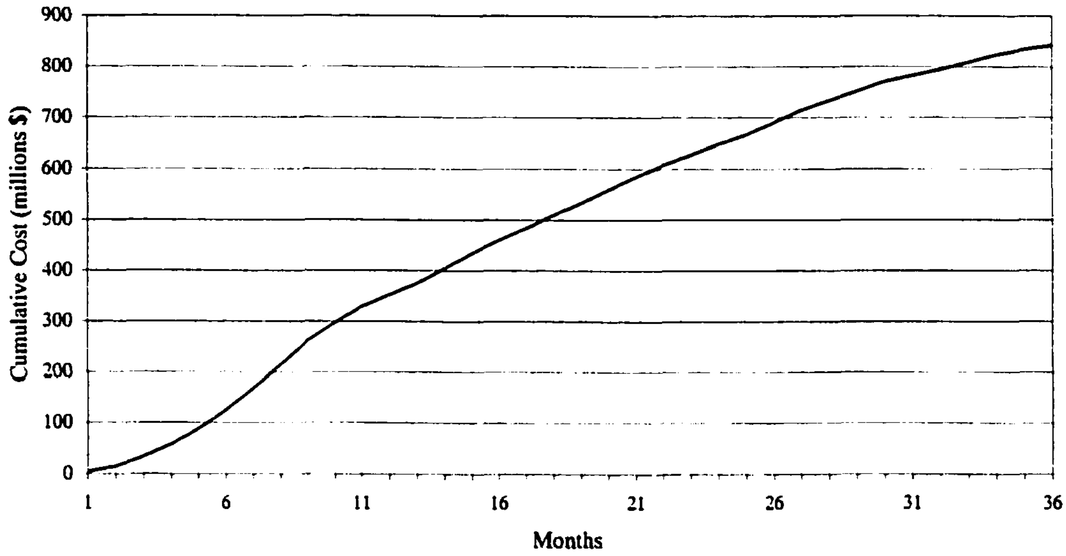

Figure 5-22. Planned Value of the MOB Construction Work

Figure 5-22 will be updated during the execution phase to develop trends in the cost and schedule for the MOB project.

5.2.1.7. Execution Phase Risk Acceptability

Risk acceptability is shown as a decision block in the upper right portion of Figure 5-16. If an identified risk is low enough it is acceptable and it only needs to be monitored during the construction process. An identified risk event that has an unacceptable risk profile or an opportunity attractive enough must be mitigated or the opportunity taken advantage of. A decision analysis process is used to identify the best solution. Once these events have been acted on they should be monitored for the life of the project.

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Risk profiles of all the identified risks for the execution phase are shown in Figure 5-17 through 5-21. These risk profile charts will be used to make an initial qualitative risk acceptability determination. Further risk acceptability is determined by calculating the cost of risk reduction or the benefit of an opportunistic risk.

5.2.1.7.1. Risk Acceptability With Cost Consequences

Using Figure 5-17 and the risk assessment made in the execution phase Table 5-24 is developed to propose an initial risk acceptability and direction for risk reduction.

Table 5-24. MOB Identified Risks with Cost Consequences

Risk	Risk level	Acceptability	Risk Reduction Direction
C_1 Cost Unrealistic	Medium	Mitigate if cost effective	Reduce consequence
C_2 Account for all requirements	Medium	Mitigate if cost effective	Reduce likelihood
C_3 <5% budget shortfall	Low	Mitigate if cost effective	Reduce likelihood
C_4 5-10% budget shortfall	Medium	Mitigate if cost effective	Reduce consequence
C_5 >10% budget shortfall	Medium	Mitigate if cost effective	Reduce consequence
L_1 Sufficient quantity	Medium	Mitigate if cost effective	Reduce consequences
L_2 Sufficient quality	Medium	Mitigate if cost effective	Reduce both likelihood & consequences
E Environmental	High	Must Mitigate	Reduce both likelihood & consequences
I Inflation	Low	Acceptable	Monitor
W_1 Weather component loss	High	Must Mitigate	Reduce consequences

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5.2.1.7.1.1. Risks With Cost Consequences That Must Be Mitigated

The risk areas of environmental concerns and loss of a component must be mitigated. Table 5-24 indicated what direction to move a specific risk's likelihood or consequence to provide the most risk reduction.

5.2.1.7.1.2. Risks With Cost Consequences That Should Be Mitigated If Cost Effective

The risk areas of cost and labor should be mitigated if cost effective. Although the cost risk of having a budget shortfall of 5% or less is low, prudent management will still want to investigate any possible risk mitigation efforts that are cost effective to reduce the risk of a budget shortfall.

5.2.1.7.1.3. Risks With Cost Consequences That Should Be Monitored

Only the inflation risk is low enough that it only needs to be monitored during the execution phase. Should inflation become a problem during the construction of a MOB this risk should be lowered if cost effective.

5.2.1.7.2. Risk Acceptability With Schedule Consequences

Using Figure 5-18 and the risk assessment made in the execution phase Table 5-25 is developed to propose an initial risk acceptability and direction for risk reduction.

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Table 5-25. MOB Identified Risks with Schedule Consequences

Risk	Risk level	Acceptability	Risk Reduction Direction
S_1 Schedule Unrealistic	Medium	Mitigate if cost effective	Reduce consequences
S_2 Delay by others	High	Must Mitigate	Reduce both likelihood & consequences
S_3 Funding delay	Medium	Mitigate if cost effective	Reduce consequences
M_1 Coordination	Medium	Mitigate if cost effective	Reduce both likelihood & consequences
M_2 Discord	Low	Acceptable	Monitor
W_2 Schedule impacts	Medium	Mitigate if cost effective	Reduce both likelihood & consequences
Eq_1 Cranes	Low	Acceptable	Monitor
Eq_2 Facilities	Low	Acceptable	Monitor

5.2.1.7.2.1. Risks With Schedule Consequences That Must Be Mitigated

The risk event of schedule delay by others must be mitigated since it is a high risk and threatens to cause schedule problems. Both the likelihood and consequences of this risk must be reduced.

5.2.1.7.2.2. Risks With Schedule Consequences That Should Be Mitigated If Cost Effective

The risk that should be mitigated if cost effective are; an unrealistic schedule, funding delay, coordination problems, and impacts from weather. Table 5-25 can be used to assist in determining whether to reduce the likelihood of occurrence, the consequence or both to reduce the risk to an acceptable level.

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5.2.1.7.2.3. Risks With Schedule Consequences That Should Be Monitored

It is assumed the contract type and delivery method was selected to reduce this risk to acceptable levels. The equipment risk of a shortage of cranes and facilities is easily mitigated because there is an ample supply of equipment and facilities.

5.2.1.7.3. Risk Acceptability With Safety Consequences

Using Figure 5-20 and the risk assessment made in the execution phase Table 5-26 is developed to propose an initial risk acceptability and direction for risk reduction.

Table 5-26. MOB Identified Risks with Safety Consequences

Risk	Risk level	Acceptability	Risk Reduction Direction
Sa_1 Major & Multiple injuries	High	Must Mitigate	Reduce both likelihood & consequences
Sa_2 Serious injuries	Medium	Must Mitigate	Reduce both likelihood & consequences

5.2.1.7.3.1. Risks With Safety Consequences That Must Be Mitigated

The risk of the loss of a life or a serious disabling injury is held to a higher acceptability threshold than a monetary risk. Therefore all safety related risk should be reduced to a lower level.

5.2.1.7.4. Risk Acceptability With Technical Performance Consequences

Using Figure 5-21 and the risk assessment made in the execution phase Table 5-27 is developed to propose an initial risk acceptability and direction for risk reduction.

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Table 5-27. MOB Identified Risks with Technical Performance Consequences

Risk	Risk level	Acceptability	Risk Reduction Direction
Co Complexity	Medium	Mitigate if cost effective	Reduce both likelihood & consequences
Su_1 Enough material	Low	Acceptable	Monitor
Su_2 Venders overwhelmed	Low	Acceptable	Monitor
Q Quality problems	Medium	Mitigate if cost effective	Reduce both likelihood & consequences

5.2.1.7.4.1. Risks With Technical Performance Consequences That Should Be Mitigated If Cost Effective

The risks that should be mitigated, if cost effective, are the complexity of building a MOB and quality problems. Table 5-27 indicates that reducing both the likelihood of occurrence and the consequence of these events is the best method for risk mitigation.

5.2.1.7.4.2. Risks With Technical Performance Consequences That Should Be Monitored

Both of the risk events that concern suppliers are low risk and should only be monitored during the execution phase.

5.2.1.8. Execution Phase Decision Analysis

As shown in Figure 5-16 if a risk is not acceptable it must be mitigated or mitigated if cost effective to avoid potential problems in the execution phase.

A goal tree technique is used to determine an appropriate strategy for risk mitigation. The goal tree method is used because of its simplicity, ease, and speed of

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application. To determine the cost effectiveness of various alternatives cost estimates will need to be developed and applied to determine the effectiveness of risk reduction.

5.2.1.8.1. Decision Analysis For Risks That Must Be Mitigated

From the risk acceptability phase the risk that must be mitigated are presented in Table 5-28. These are presented without regard to consequence since they must be mitigated.

Table 5-28. MOB Risks That Must Be Mitigated

Risk	Risk Level
E Environmental concerns	High
W_1 Weather Component loss	High
S_2 Schedule delay by others	High
Sa_1 Major and multiple injuries	High
Sa_2 Serious injuries	Medium

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5.2.1.8.1.1. Risk of Environmental Concerns

The goal is to reduce the risk of environmental concerns. The possible methods of achieving this goal are shown in Figure 5-23.

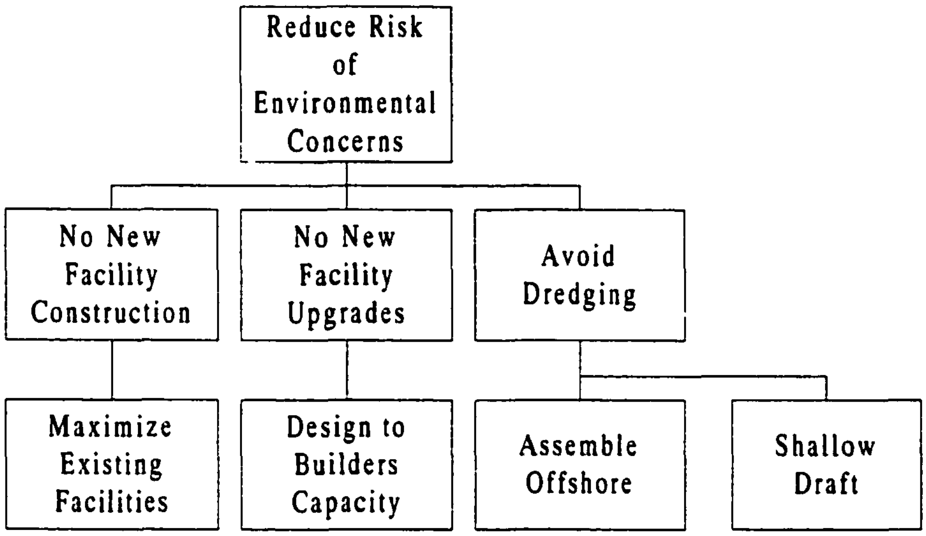

Figure 5-23. Reduce Risk of Environmental Concerns

The identified methods of reducing the risk of environmental concerns attempt to reduce the likelihood of an environmental problem escalating the cost of the MOB. Efforts to curtail the consequences of environmental costs would focus on minimizing the amount of potential environmental mitigation efforts.

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5.2.1.8.1.2. Risk of Weather Causing a Component Loss

There is a potential for the entire loss of a major component when transporting or assembling components at sea. The goal is to reduce the risk of a component loss. Based on the risk profile this can best be done by reducing the consequences of this event. Figure 5-24 is a goal tree that provides potential methods to reduce the risk of a component loss.

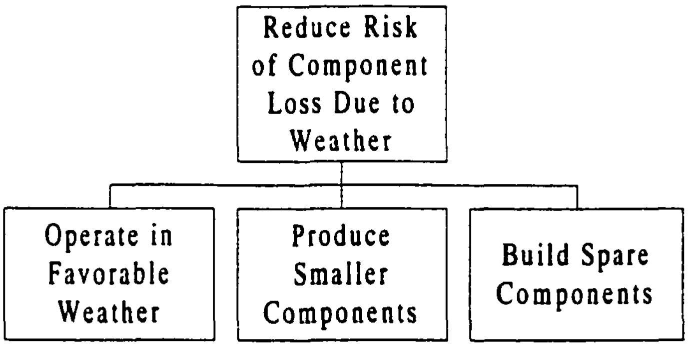

Figure 5-24. Reduce Risk of Component Loss Due to Weather

Only operating in favorable weather will lower the likelihood of a component loss but will also likely increase the schedule length. Both building smaller and spare components will reduce the consequences of this event but will add to the cost of building a MOB.

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5.2.1.8.1.3. Risk of Schedule Delay Caused by Others

There is a potential for delays to the MOB construction schedule from delays caused by subcontractors, transporters, competition from competing industries, lack of direction from governmental organizations, and other organizations. The goal is to reduce the risk of delays caused by others. Based on the risk profile this can best be done by reducing both the likelihood and consequences of this type of event.

Figure 5-25 is a goal tree that provides potential methods to reduce the risk of delays caused by others.

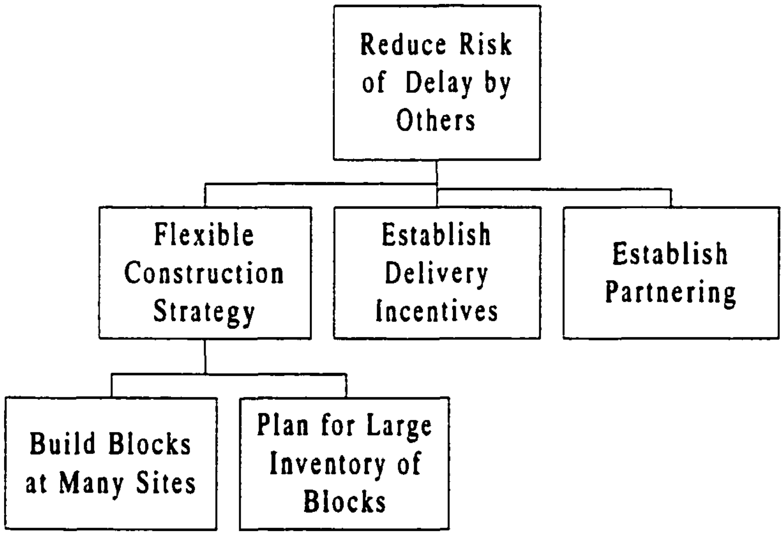

Figure 5-25. Reduce Risk from Delay by Others

Building the MOB with a flexible schedule should reduce both the likelihood and consequence of an event. Providing delivery incentives should reduce the likelihood of delays from others. Partnering is a process that builds teamwork among project managers and should reduce the likelihood of delays.

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5.2.1.8.1.4. Risk of Major and Multiple Serious Accidents

Building the MOB will require thousands of people working in one of the more hazardous industries. There is a potential for a major accident that could cause multiple fatalities or injuries. Additionally, because the entire MOB will take several years there is a potential for several fatalities to occur. The goal is to reduce the risk of major and multiple injury accidents. Based on the risk profile this can best be done by reducing both the likelihood and consequences of this type of event. Figure 5-26 is a goal tree that provides potential methods to reduce the risk of major and multiple injury accidents.

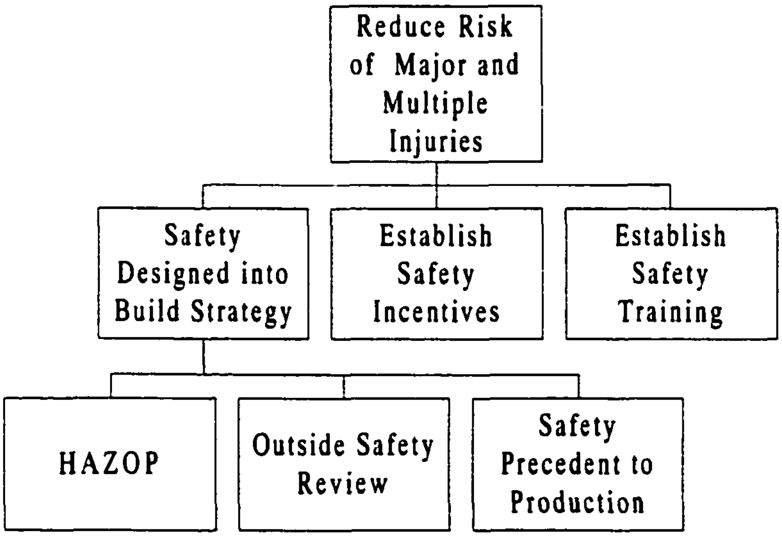

Figure 5-26. Safety Goal Tree

All of the identified safety alternatives should reduce both the likelihood and consequences of a safety problem.

5.2.1.8.1.5. Risk of Serious Injuries

This risk is similar to the above safety risk. The difference is the magnitude of the accident, a serous injury will result in lost time and a potentially a disabling injury.

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The goal tree shown in Figure 5-26 will also provide potential solutions to reduce this risk.

5.2.1.8.2. Decision Analysis For Risks That Should Be Mitigated if Cost Effective

From the risk acceptability phase the risk that should be mitigated if cost effective are presented in Table 5-29. These are presented without regard to consequence since they should be mitigated based on the cost of the risk reduction.

Table 5-29. MOB Risks That Should Be Mitigated If Cost Effective

Risk	Risk Level
C_1 Cost unrealistic	Medium
C_2 Account for all requirements	Medium
C_3 <5% budget shortfall	Low
C_4 5-10% budget shortfall	Medium
C_5 >10% budget shortfall	Medium
L_1 Sufficient labor quantity	Medium
L_2 Sufficient labor quality	Medium
S_1 Schedule unrealistic	Medium
S_3 Funding delay	Medium
M_1 Coordination	Medium
Co Complexity	Medium
Q Quality	Medium

These risks will only be mitigated if cost effective. Therefore, the cost of risk reduction must be worth the expenditure of resources to achieve the risk reduction. For example the cost to develop a cost estimate accurate within 1% must be balanced against the risk reduction achieved by having such an accurate estimate.

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5.2.1.8.2.1. Risk of Using an Unrealistic Cost or Schedule

The target estimate and schedule developed in the planning phase is only that, an estimate. The estimate and schedule for a MOB is difficult to develop because a MOB or similar floating structure has not been built before. The risk that the estimated cost and schedule are not accurate has been reduced through the simulation techniques used in the planning phase but there is still a potential for an inaccuracy of +/- 10%. The goal is to reduce this risk of an unrealistic cost and schedule estimate. Figure 5-27 presents a goal tree that provides potential solutions to reduce the risk of unrealistic costs and schedule.

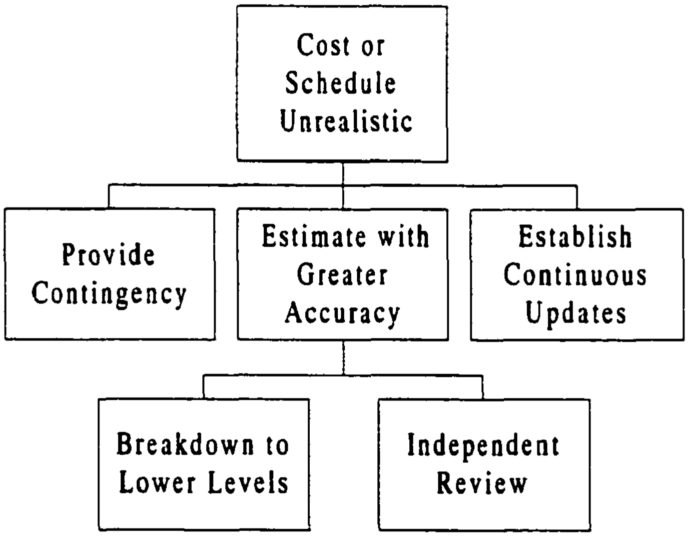

Figure 5-27. Reduce Risk of Unrealistic Cost

The three alternatives for reducing the risk of an unrealistic cost; providing a contingency, a more accurate estimate, and continuous updates all have cost associated with them and these costs will need to be determined to decide on the effectiveness of reducing this risk.

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5.2.1.8.2.2. Risk of a Budget Shortfall

In Table 5-29 there are three risks of differing degrees of a budget shortfall. These risks may come from spending more on items than anticipated. The solutions to these risks are similar and the degree that they are pursued will depend on their cost and an expected lowering of risk. Figure 5-28 presents alternatives to reduce the risk of a budget shortfall.

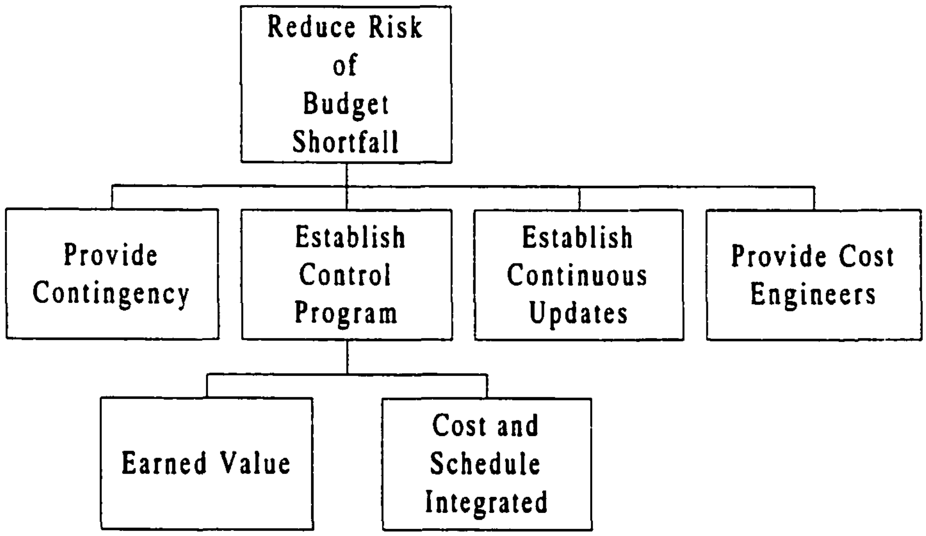

Figure 5-28. Reduce the Risk of a Budget Shortfall

The proposed methodology seeks to reduce this risk by providing a control program with continuous updates.

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5.2.1.8.2.3. Risks of a Labor Quantity and Quality

The risks of not having enough labor or not having an appropriate skill level of labor are similar enough to be considered together. These risks may come from the volume of work required, competition with other endeavors, the concentration of work in specific areas, and the limited supply of qualified shipyard workers. The solutions to these risks are similar and Figure 5-29 presents alternatives to reduce the risk of Labor.

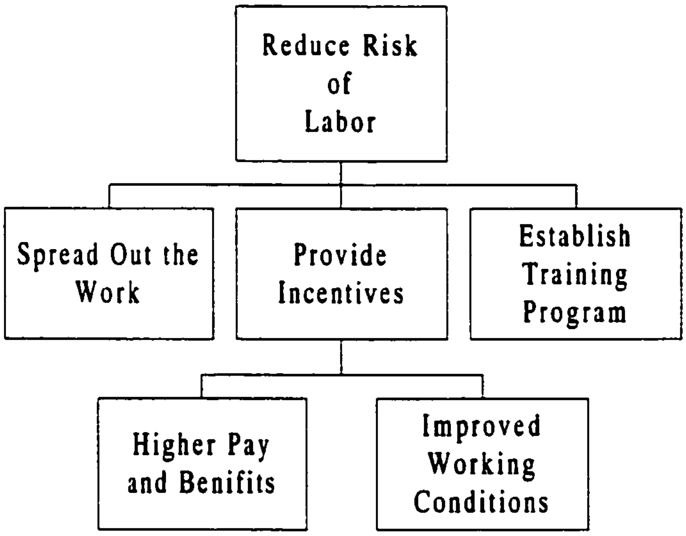

Figure 5-29. Reduce the Risk of Labor

Spreading the work may reduce the likelihood and consequences of this event. Providing incentives and establishing a training program should reduce the likelihood of occurrence for this event.

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5.2.1.8.2.4. Risk of a Funding Delay

For the MOB all of the required funding will be spread over several years and may not be from approved budgets. There is a potential that in future years funding could be delayed. Should a funding delay occur the schedule of building the MOB will be extended. From a review of the risk profile for this risk it may be best to reduce the consequence of this event. Figure 5-30 shows a goal tree to reduce the risk of a funding delay.

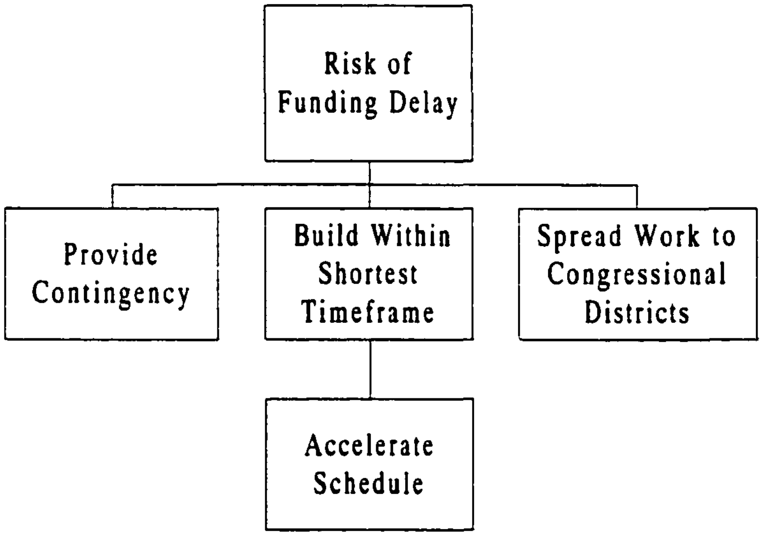

Figure 5-30. Reduce Risk of a Funding Delay

The cost associated with accelerating the schedule may be substantial. Prudent business practice necessitate providing a contingency and obtaining congressional support can not be ignored in a project the size of a MOB.

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5.2.1.8.2.5. Risk of Coordination

The MOB is such a large project that it will require the components to be built at several locations. The effort to coordinate such a massive project creates the risk that the coordination effort could become too large for an efficient management system. From the risk profile reducing both the likelihood and consequences of this event is the best way to reduce the risk of coordination. Figure 5-31 shows several alternatives for reducing the risk of coordination.

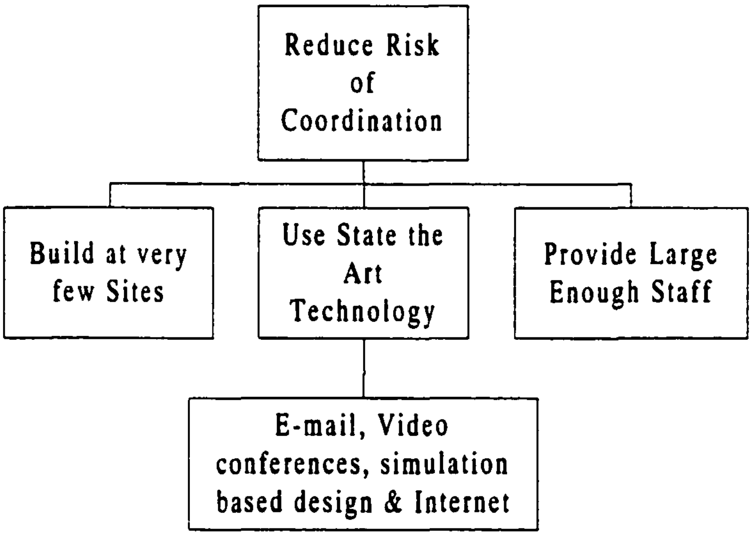

Figure 5-31. Reduce the Coordination Risk

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5.2.1.8.2.6. Risk of Complexity

The MOB is an extremely large but relatively simple structure. The hinged concept is based on mostly proven technology. The connectors between the modules and the propulsion systems are the greatest technical challenges. There are some risks associated with the construction of a MOB because of the volume and size of the construction effort makes this a complex endeavor. Efforts will be required to reduce the risk of complexity by keeping the construction in line with the current best practices. Figure 5-32 shows some alternatives to reducing this risk.

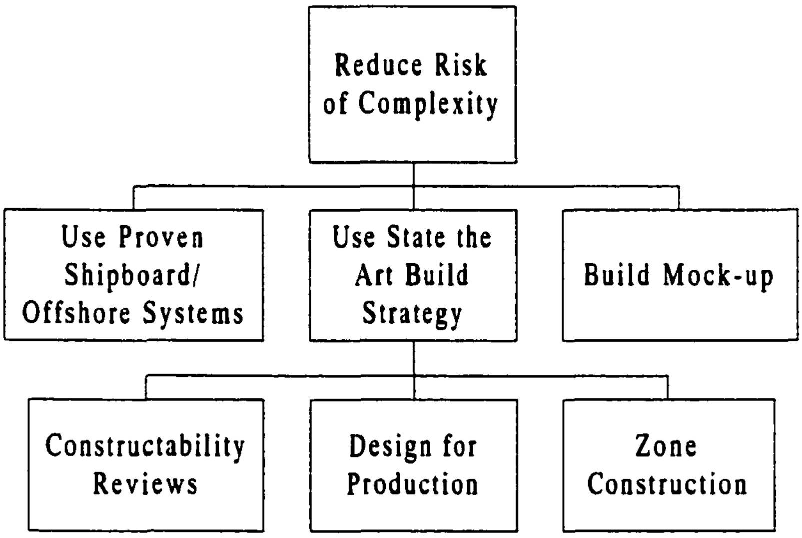

Figure 5-32. Reduce Risk of Complexity

The risk reduction alternative of using a state of the art build strategy is presented in Ayyub and Bender (1999)

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5.2.1.8.2.7. Risk to Quality

In an environment to keep cost under control and a project on schedule sometimes the quality of a project suffers. The risk to quality is that a marginal product is developed or the components will be sent to assembly sites that require rework. From the risk profile the best method to achieve a lowering of this risk is to lower the likelihood and consequence of risks to quality. As shown in Figure 5-33 there are several alternatives that can lower the risk to quality.

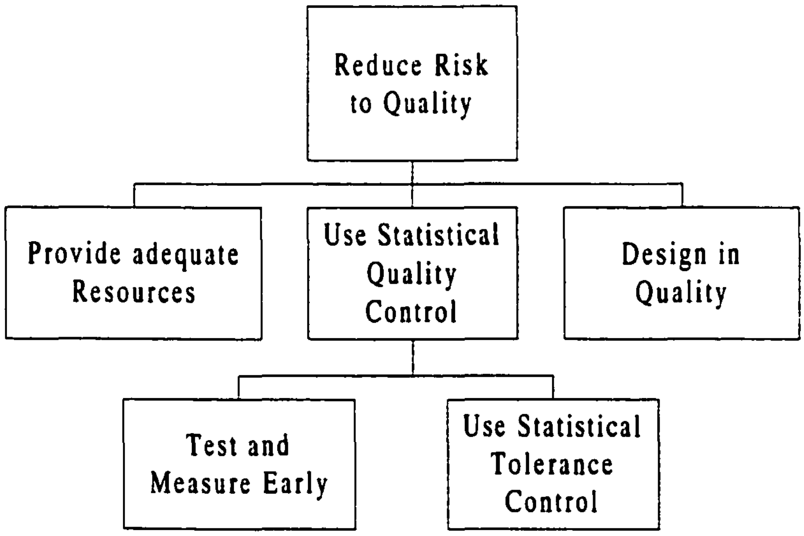

Figure 5-33. Reduce Risk to Quality

In Ayyub et al. (1999b) the alternative of statistical quality control technique is developed further.

5.2.1.9. Execution Phase Update Risk Assessment and Earned Value

Once the MOB construction project is under construction the risk assessment and earned value process needs to be updated at regular intervals. This will provide

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managers with an early warning if costs are escalating. This updating of information is shown in the lower right hand portion of Figure 5-16.

The type of earned value data collected is the actual cost of the work and the earned value of the work performed. Cost data can be obtained from actual receipts and reports generated in the field. The data for the earned value of the work performed will come from estimates made in the field. The updated risk assessments should be made coincident with the earned value updates. These risk assessments will be qualitative and should be made by the project team.

The project team will focus their efforts on finding any variances in either the earned value analysis or the risk assessment. As shown in the lower center portion of Figure 5-16 if a variance is observed it must be understood why it occurs before any actions are taken to try and control it.

Although a MOB has not been built there are only a finite number of possible cost and schedule scenarios that can develop when building a MOB. These scenarios are outlined in Table 5-30.

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Table 5-30. MOB Possible Cost and Schedule Scenarios

Number	Cost and Schedule Variance Scenario	Potential for Risk Assessment Variance
1	Ahead cost Ahead schedule	Risk probably overstated
2	Ahead cost On schedule	Risk probably overstated
3	On cost Ahead schedule	Risk with cost consequences
4	On cost On schedule	Risk with cost consequences
5	Ahead cost Behind schedule	Risk with schedule consequences
6	Behind cost Ahead schedule	All identified risk
7	On cost Behind schedule	Risks with schedule consequences
8	Behind cost On schedule	All identified risks
9	Behind cost Behind schedule	All identified risks

Of course these scenarios can fluctuate from month to month and a trend may take several months to develop. The clues to which scenario is developing is in the updating of the risk assessment. For example if the MOB project is behind in cost but on schedule, all of the identified risks with cost consequences should be scrutinized for possible variances. Any variances in the risk assessment should be investigated as possible sources of cost escalation. This potential for a variance in the risk assessment is shown in the last column of Table 5-30.

5.2.1.10. Execution Phase Cost Control

In this stage of a MOB's execution phase management takes action to correct an observed variance. Once the project managers have an understanding of why a variance has occurred a decision analysis process can be employed to assist in

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decision-making. Referring back to Figure 5-16, as shown in the lower left portion a decision and action is required to correct a variance. The technique of using a goal or decision tree will be used to assist project managers in decision making. Once a decision has been made and action taken the results must be monitored for their effectiveness. This process continues until a project is completed.

Since a MOB has not been built a hypothetical scenario will be presented that exercises the cost control process. The scenario assumes the MOB has been under construction for nine months, earned value data has been collected, labor shortages, and an environmental issue are causing a cost escalation.

The scenario assumes the proposed methodology has been put into practice and monthly updates of the earned value data is indicated in Table 5-31 for the actual cost of the work and Table 5-32 for the earned value of the work performed to date. Table 5-33 is provided to give a quick comparison of the total cumulative values for the planned, actual, and earned value of the work. Using the data from these tables earned value charts are made and are shown in Figures 5-34 and 5-35. Figure 5-35 is an enlarged version of Figure 5-34 and only shows the first ten months of the MOB construction.

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Table 5-31. MOB Earned Value Data Actual Cost of Work

WBS	Item	Millions of $ per Month									
	Month	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10
11011	P L Hull	1	3	9	11	12	13	14	13	12	
11012	S L Hull			3	8	11	12	12	14	15	13
11510	S Columns					1	1	2	2	2	2
11520	P Columns									1	1
11410	Braces 1				1	2	3	2			
11420	Braces 2							1	2	3	2
11430	Braces 3										1
11440	Braces 4										
13610	U Hull 01	3	6	10	11	11	13	14	13	13	11
13620	U Hull 02							3	7	10	10
13630	U Hull 03										
13640	U Hull 04										
13650	U Hull 05										
14000	Assembly										
	Column Sum	4	9	22	31	37	42	48	51	56	36
	Cumulative	4	13	35	66	103	145	193	244	300	336

Table 5-32. MOB Earned Value Data Earned Value

WBS	Item	Millions of $ per Month									
	Month	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10
11011	P L Hull	2	3	7	11	11	12	12	13	9	
11012	S L Hull			1	3	9	12	10	12	13	12
11510	S Columns					1	1	1	1	2	2
11520	P Columns									1	1
11410	Braces 1				1	1	1	2	1		
11420	Braces 2							1	1	1	2
11430	Braces 3										1
11440	Braces 4										
13610	U Hull 01	3	5	8	10	11	12	13	13	10	10
13620	U Hull 02							3	5	9	7
13630	U Hull 03										
13640	U Hull 04										
13650	U Hull 05										
14000	Assembly										
	Column Sum	5	8	16	25	33	38	42	46	45	36
	Cumulative	5	13	29	54	87	125	167	213	258	294

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Table 5-33. MOB Planned, Actual and Earned Value Cumulative Cost

Item	Millions of $ Cumulative per Month									
Month	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10
Planned	5	15	34	59	89	126	170	214	262	298
Actual	4	13	35	66	103	145	193	244	300	336
Earned Value	5	13	29	54	87	125	167	213	258	294

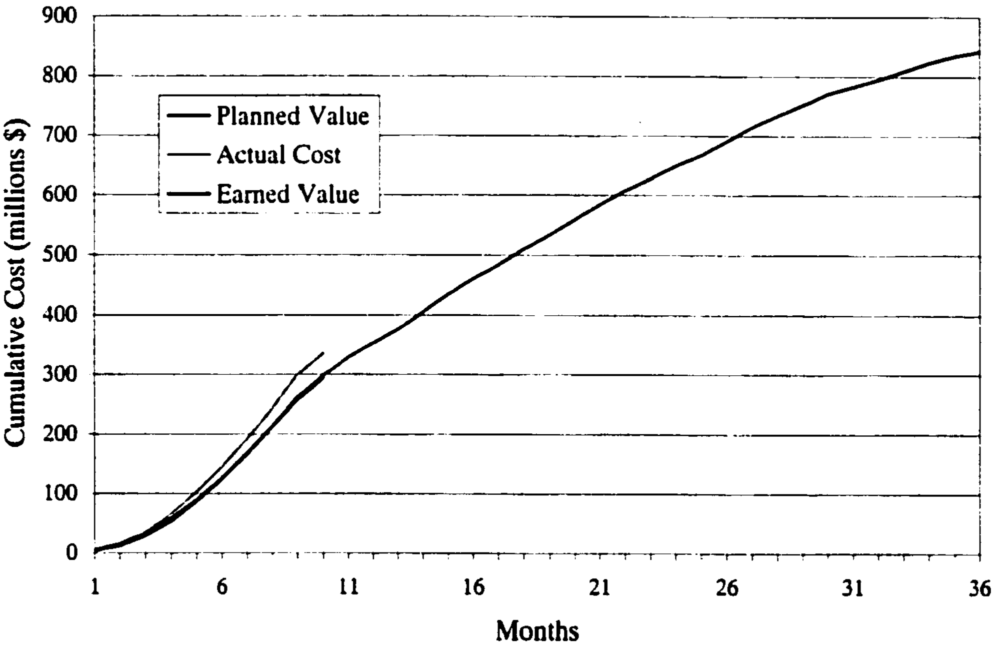

Figure 5-34. Earned Value Chart for MOB at 10 Months

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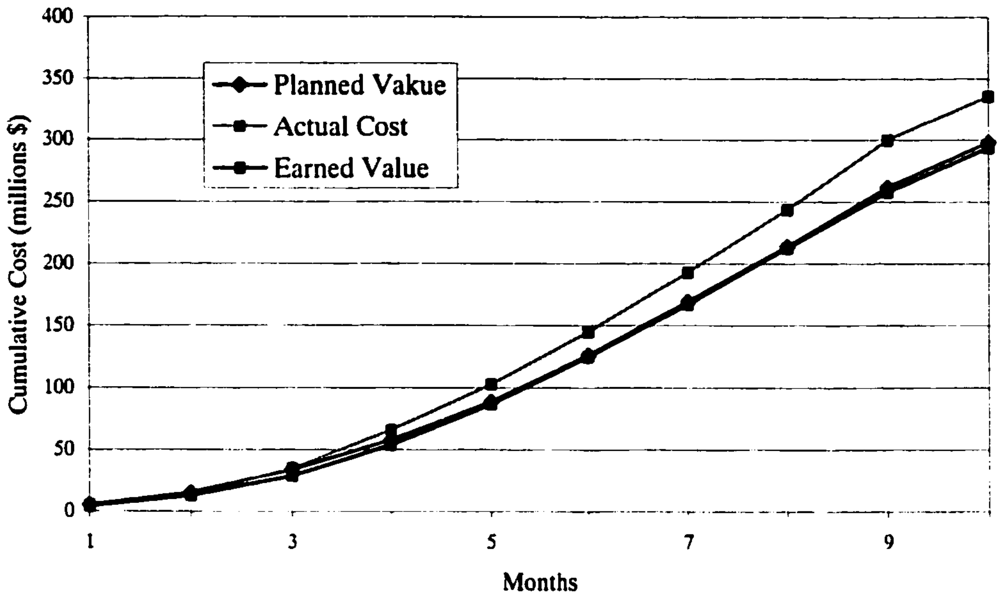

Figure 5-35 Earned Value Chart for MOB only with 10 Months of Data

As shown in Table 5-33 and Figures 5-34 and 35 after ten months the MOB is experiencing a cost overrun and is slightly behind schedule.

Table 5-33 only shows the total cumulative costs for the MOB. To provide more insight to the actual components status tables and charts could be developed for each major component. For example, Table 5-34 combines earned value data for the lower hull sections into one table. From the data in Table 5-34 earned value charts are made for the specific components. Figure 5-36 shows the earned value chart for the port lower hull, Figure 3-37 shows the earned value chart for the starboard lower hull, and Figure 5-38 shows the earned value chart for both of the hulls combined. From these charts it is easily seen that for both lower hulls the actual cost are running higher than planned. The earned and planned value is virtually indistinguishable from each other indicating the lower hulls are being built on schedule.

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Table 5-34. MOB Earned Value Data for Lower Hull

WBS	Item	Millions of $ per Month									
	Month	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10
1101 1	P L Hull Planned	2	4	8	10	10	12	14	12	8	
	Cum Planned	*2*	*6*	*14*	*24*	*34*	*46*	*60*	*62*	*70*	
	P L Hull Actual	1	3	9	11	12	13	14	13	12	
	Cum Actual	*1*	*4*	*13*	*24*	*36*	*49*	*63*	*76*	*88*	
	P L Hull Earned Value	2	3	7	11	11	12	12	13	9	
	Cum EV	*2*	*5*	*12*	*23*	*34*	*46*	*58*	*71*	*80*	
1101 2	S L Hull Planned			2	4	8	10	10	12	14	12
	Cum planned			2	6	14	24	34	46	60	72
	S L Hull Actual			3	8	11	12	12	14	15	13
	Cum Actual			3	11	22	34	46	60	75	88
	S L Hull Earned Value			1	3	9	12	10	12	13	12
	Cum EV			1	4	13	25	35	47	60	72
1101 0	Both hulls Cum Planned	2	6	16	30	48	70	94	118	140	152
	Both hulls Cum Actual	1	4	16	35	58	83	109	136	163	176
	Both hulls Cum EV	2	5	13	27	47	71	93	118	140	152

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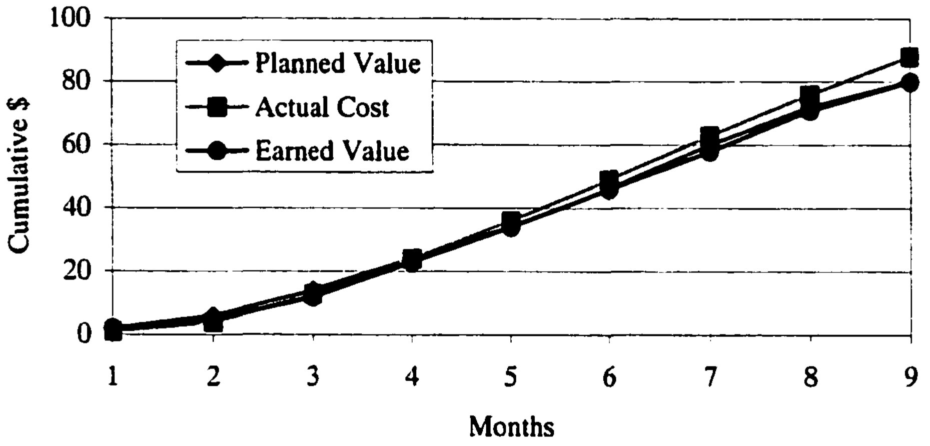

Figure 5-36. Earned Value Chart for Port Lower Hull

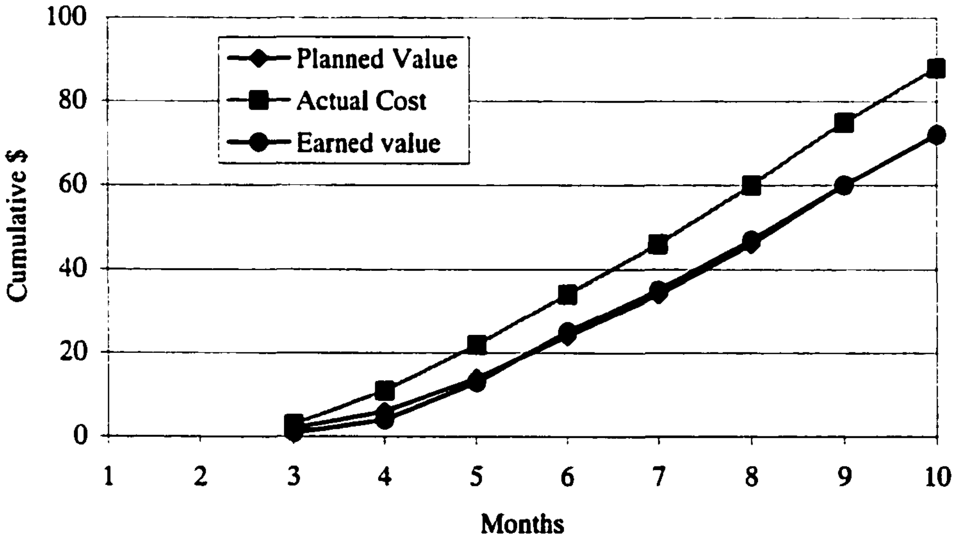

Figure 5-37. Earned Value Chart for Starboard Lower Hull

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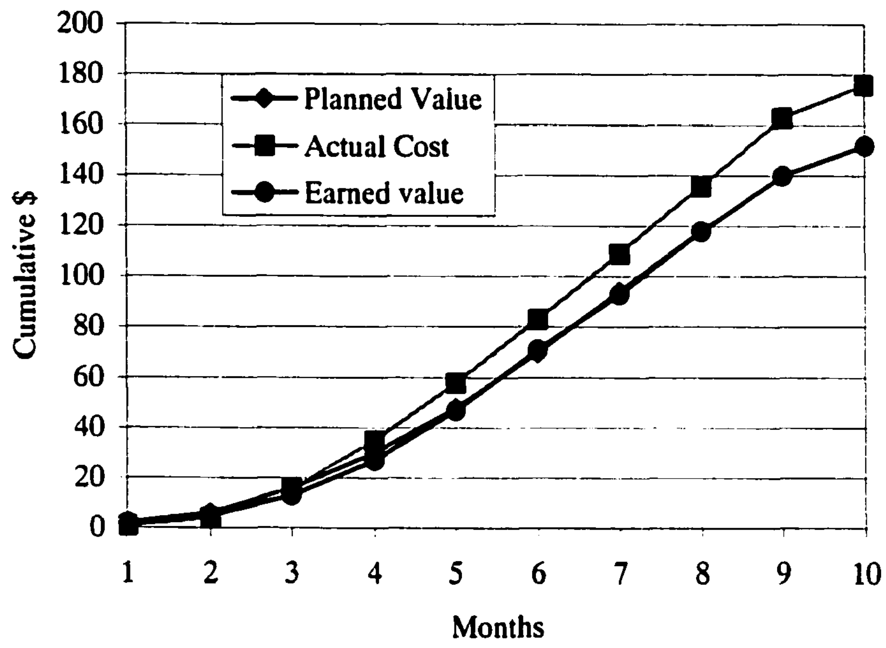

Figure 5-38. Earned Value Chart for Both Lower Hulls

By tracking the earned value data management can see trends developing and take actions to prevent or minimize a cost escalation. Using Figures 5-34 and 5-35 management knows it must do something to control cost. Developing similar charts such as those shown in Figures 5-36, 5-37, and 5-38 can lend insight to specific problem areas.

Referring back to Table 5-33 and studying the earned value charts the scenario for ten months of construction is that the MOB is basically on schedule but it is costing more than planned and a budget over run is eminent. Reviewing the past risk assessments, particularly those concerning cost may help to find the reasons for the cost over run.

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For this hypothetical case study of labor shortages and an environmental issue causing escalating costs, management needs to apply the questions shown in Table 5-35.

Table 5-35. Questions to Formulate a Decision Objective

Question	Question
1	Which specific area (s) are causing a cost or schedule variance?
2	How much will the variance effect the final cost or schedule?
3	Do these areas also show a variance in risk assessment?
4	How have the risk profiles changed?
5	What are the reasons for the cost, schedule, or risk variance?
6	What should the objective be to correct the variance?
7	What alternatives can be taken to correct the variance?
8	What specific action should be taken if a changed risk profile indicates an unacceptable negative risk or an opportunity has arisen?

5.2.1.10.1. Cost and Schedule Variance

A comparison of data from planned values to actual cost and earned value data indicate costs are over running and the MOB is about on but just a little behind schedule. Specifically the cost increases are from labor shortages mostly occurring in building the lower hulls but also in building the blocks for the upper hull. An environmental mitigation effort to dredge a deeper channel at the grand block assembly site has also begun to cost more than expected.

5.2.1.10.2. Variance Impacts to Final Cost and Schedule

The earned value equations presented in Chapter two are used to estimate the final costs and schedule based on the collected data at the 10-month point. The Estimate At Completion (EAC) is given as a range and found by finding a final estimate based on Cost Performance Index and Schedule Performance Index.

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The CPI is given as:

$$CPI = \frac{\text{Earned Value}}{\text{Actual Cost}} \quad (5\text{-}5)$$

Where earned value and actual cost are cumulative costs to date. Using values from Table 5-33 and substituting, equation 5-5 becomes:

$$CPI = \frac{\$294\text{ million}}{\$336\text{ million}} = 0.88 \quad (5\text{-}6)$$

The SPI is a metric to forecast the expected completion date and is found by:

$$SPI = \frac{\text{Earned Value}}{\text{Planned Value}} \quad (5\text{-}7)$$

Using values from Table 5-33 and substituting, equation 5-7 becomes:

$$SPI = \frac{\$294\text{ million}}{\$298\text{ million}} = 0.99 \quad (5\text{-}8)$$

The EAC_C can be determined using CPI as follows:

$$EAC_C = \frac{\text{Total Planned Value}}{CPI} \quad (5\text{-}9)$$

Where EAC_C is the Estimate At Completion and is found using CPI. Substituting into equation 5-9 the EAC_C is:

$$EAC_C = \frac{\$843\text{ million}}{0.88} = \$958\text{ million} \quad (5\text{-}10)$$

The CPI and SPI can be used in conjunction to statistically forecast a range for the EAC. A second EAC using these indices is EAC_{CS} and is found by:

$$EAC_{CS} = \frac{\text{Total Planned Value}}{(CPI)(SPI)} \quad (5\text{-}11)$$

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Substituting into equation 5-11 the EAC_{CS} is:

$$EAC_{CS} = \frac{\$\,843\text{ million}}{(0.88)(0.99)} = \$968\text{ million} \qquad (5\text{-}12)$$

The expected range of final cost at completion for building one MOB module is between $958 to $968 million.

The estimated completion period using the SPI is found by:

$$\text{Estimated completion period} = \frac{\text{Planned completion period}}{\text{SPI}} \qquad (5\text{-}13)$$

Substituting into equation 5-12 the estimated completion is:

$$\text{Estimated completion period} = \frac{36\text{ months}}{0.99} = 36\text{ months} \qquad (5\text{-}14)$$

The result above was rounded to the nearest month and the MOB project appears to be on schedule.

5.2.1.10.3. Variance in Risk Assessment

Coincident with a review and evaluation of the earned value data, management also performs a risk assessment. The risk assessment is a review of the previously made risk assessment augmented with the identification of any new risks. For this case study the review should focus on why costs are actually higher than anticipated. Table 5-36 presents the previously identified risk events with cost consequences. Although these may not be the only areas that may cause cost escalation they would represent the most likely candidates.

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Table 5-36. Previously Identified MOB Construction Risks with Cost Consequences

Potential Events	***Negative Risk Rating***
Cost Escalation 1. Cost unrealistic 2. Account for all requirements 3.<5% Budget shortfall 4. 5-10% Budget shortfall 5. >10% budget shortfall	1. Medium 2. Medium 3. Low 4. Medium 5. Medium
Labor Problems 1. Sufficient quantity 2. Sufficient quality	1. Medium 2. Medium
Environmental Concerns	High
Inflation	Low
Weather 1. Component loss	1. High

A review of the earned value analysis indicates that unless something is done to rein in costs a budget shortfall is not any longer a medium risk, obviously the likelihood of this event occurring has changed.

An investigation into why the cost overruns are occurring indicates that there is an insufficient amount of skilled labor to perform the work typical of shipyards. This shortage of labor has increased the use of overtime to meet the established schedule.

Another problem area causing cost growth is in the area of environmental remediation. The assembly site for combining large blocks into grand blocks is at a site along the Gulf of Mexico that needs to be dredged wider and deeper. Since this is an existing industrial site contaminates in the dredge spoils were expected but not at the volume currently being reported. The cost for this remediation is expected to rise.

Based on the new information a new risk assessment is made for the risk events that have a potential for cost consequences. This new risk assessment is made

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with the existing risk assessment matrix tables presented earlier in the chapter and is performed by the author. The new risk assessment is shown in Table 5-37.

Table 5-37. Reassessment of MOB Construction Risks with Cost Consequences

Potential Events	***Probability***	***Consequence***	***Negative Risk Rating***
Cost Consequence			
Cost Escalation 1. Cost unrealistic 2. Account for all requirements 3.<5% Budget shortfall 4. 5-10% Budget shortfall 5. >10% budget shortfall	1. B Unlikely 2. C Likely 3. NA 4. NA 5. D Highly possible	1. IV Critical 2. III Marginal 3. NA 4. NA 5. IV Critical	1. Medium 2. Medium 3. NA 4. NA 5. High
Labor Problems 1. Sufficient quantity 2. Sufficient quality	1. E Certainty 2. B Unlikely	1. IV Critical 2. IV Critical	1. High 2. Medium
Environmental Concerns	E Certainty	IV Critical	High
Inflation	B Unlikely	II Acceptable	Low
Weather 1. Component loss	1. B Unlikely	1. V Catastrophic	1. High

Some of the risks rated in Table 5-37 has changed from their last assessment performed at the beginning of execution phase. This is to be expected since the most recent risk assessment is based on new information and this information has a higher value. There are two cost risk events C_3 and C_4 that are currently not applicable since the earned value analysis indicates a potential cost overrun of 15% is presently projected. The cost risk event C_5 of a budget shortfall greater than 10% now has a higher risk rating because of the information provided by the earned value

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information. The risk rating of the events of a labor shortage and environmental concerns has changed to high based on new information.

5.2.1.10.4. Risk Profiles

Since there are variances in the risk assessment from the beginning of the execution phase to the ten-month point there are also changes to the risk profiles. The risk profiles for risk events with cost consequences are shown in Figure 5-39.

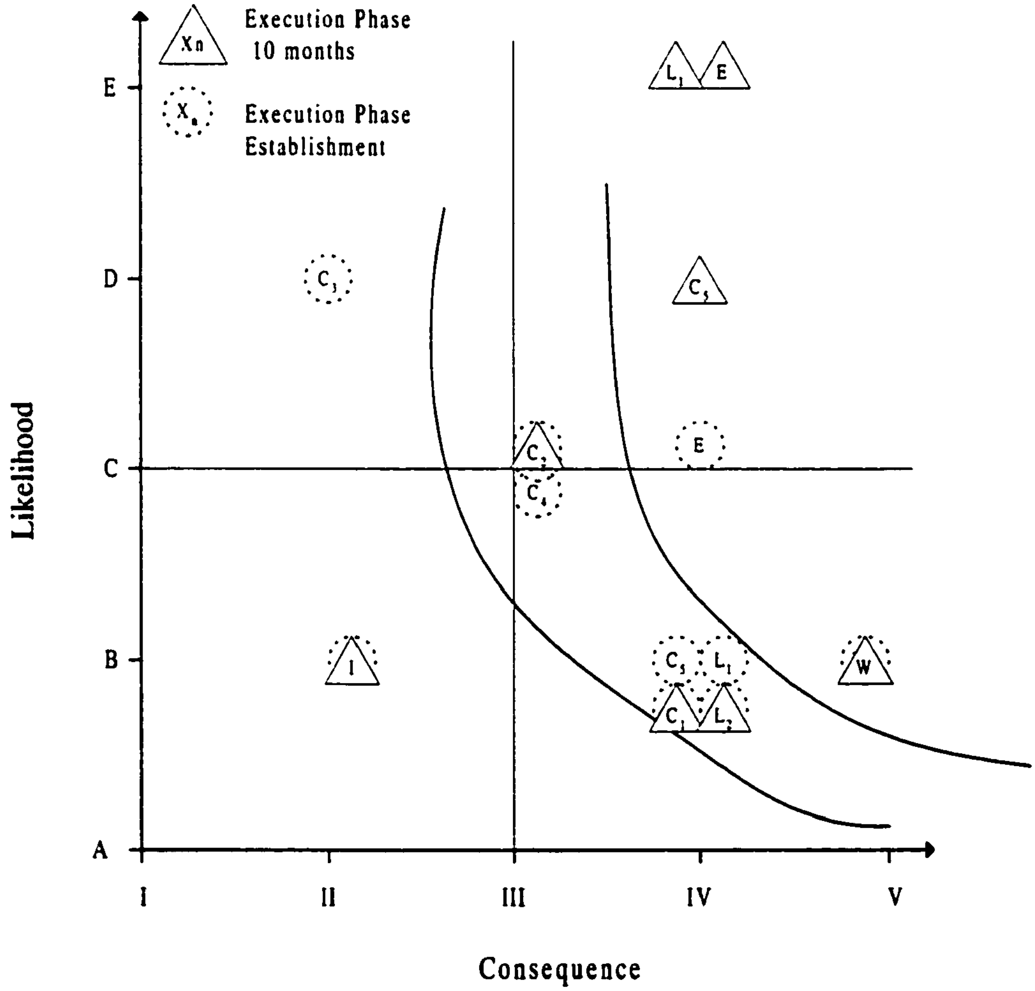

Figure 5-39. MOB Risk Profile for Events with Cost Consequences After 10 months

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As can be seen in Figure 5-39 the risk event of C_5 a budget shortfall of greater than 10% has changed to a higher risk. The risk events of labor shortages L_1 and environmental concerns E has changed to higher risk categories.

5.2.1.10.5. Reasons for Cost and Risk Variance

The reason there is a variance for the cost risk event of a budget shortfall greater than 10%, sufficient labor, and environmental concerns is due to cost overruns occurring from labor shortages and additional environmental remediation efforts.

5.2.1.10.5.1. Objectives to Correct Variances

To correct the variance of a budget shortfall greater than 10% the areas of labor shortages and environmental concerns must be addressed. There are two objectives that need to be expressed. Labor shortages need to be reduced and environmental concerns need to be mitigated.

5.2.1.10.6. Alternatives to Correct Variances

A decision technique of using a goal tree as used in previous sections is used to assist decision-makers during the execution of building a MOB.

5.2.1.10.6.1. Labor Shortages

New information has changed the risk assessment and the risk profile now reflects a certainty that labor shortages will occur more than once on this project. The cost variance has been determined to come from on site project managers that have used too much overtime to keep the project on schedule. The objective of the decision problem is to reduce the effects of labor shortages. Some methods to reduce the

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continuing occurrence of a labor shortage are offering higher prevailing wages or benefits, increasing productivity, developing alternatives to the currently planned method of work, and shift work. Other methods that may reduce the cost consequences of labor shortages are allowing the schedule to slip and reducing quality. Of course these measures may also have ripple effects that incur other costs later in a project. The final question is "What specific action should be taken to correct this problem?" A goal tree is shown in Figure 5-40 that graphically presents this decision objective.

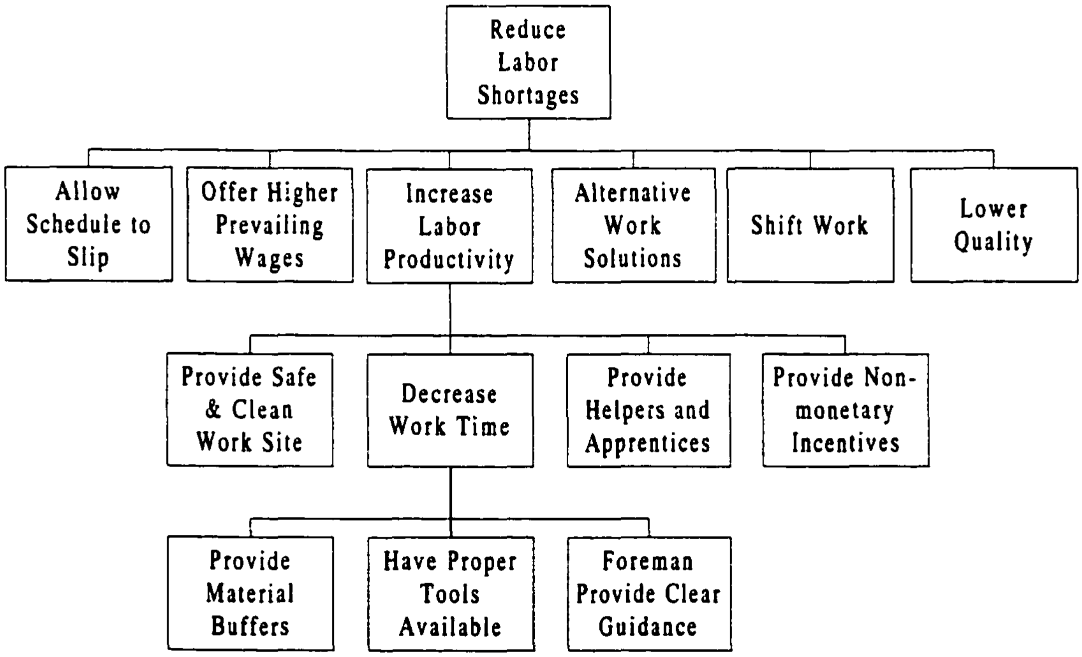

Figure 5-40. Goal Tree for Labor Shortage Decision

A review of the risk profile shown in Figure 5-39 indicates that reducing both the likelihood and consequence of this event is required to reduce the risk. Therefore, an alternative that seeks to reduce both of these may be the best choice.

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Allowing the schedule to slip would certainly avoid the additional cost of overtime currently causing a cost escalation. A delay in the schedule would also cost more than initially planned. Just the overhead cost of an extended schedule for a project the size of building a MOB could amount to several millions of dollars per month. Additionally, production delays could cause a schedule slip of afloat component assembly that have specific windows of opportunities. A missed assembly opportunity could extend the schedule by almost a year or raise the weather risk by assembling components during riskier weather periods. Two main items need to be found to objectively evaluate this alternative. First the length of any schedule delay and second is the cost of an anticipated delay. With this information the total impact to the schedule and other risk areas can be evaluated.

Offering higher prevailing wages would cost more than originally planned but might entice skilled labor from competing projects and industries to work on the MOB project. The cost of this alternative should be relatively simple to estimate but the difficulty with this alternative is estimating the magnitude of labor that will come to work on the MOB.

Increasing labor productivity is an obvious choice for management. In fact, good management practices should be implementing the sub-alternatives shown in Figure 5-40. A review of current work practices may be all that is needed but this effort will most likely require training and additional resources.

Providing alternative work solutions should have been studied in the planning phase but now that more is known about the actual operations of the work environment different solutions may be more efficient. For example, the size and

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weight of the blocks drive the strategy of building large blocks for barge shipment to a common assembly site. Perhaps the size of the blocks could be increased or decreased to make a more efficient system.

Shift work may solve the problem of additional overtime but this alternative has other costs that need to be understood. Shift work is typically not as efficient as straight time work. Oncoming crews need to overlap with off going crews to help a smooth work flow, swing shifts crews are not as productive as regular hours, and the potential of rework from one shift to the next is greater (Oglesby et al. 1989). Adding shift work should also provide the benefit of potentially accelerating the schedule. The total cost of building a MOB should be less than anticipated if it is built in less time.

Lowering the quality of construction may achieve some short term savings but this alternative is not recommended due to the long term cost associated with reduced quality.

5.2.1.10.6.2. Environmental Concerns

The event of increased cost to properly dispose of dredge material from a Gulf of Mexico assembly site has occurred on the MOB project. The objective is to reduce the effect this cost will have on the MOB project. Several alternatives should be investigated to mitigate this cost escalation. Figure 5-41 presents a goal tree of possible solutions to the additional cost occurring in this area.

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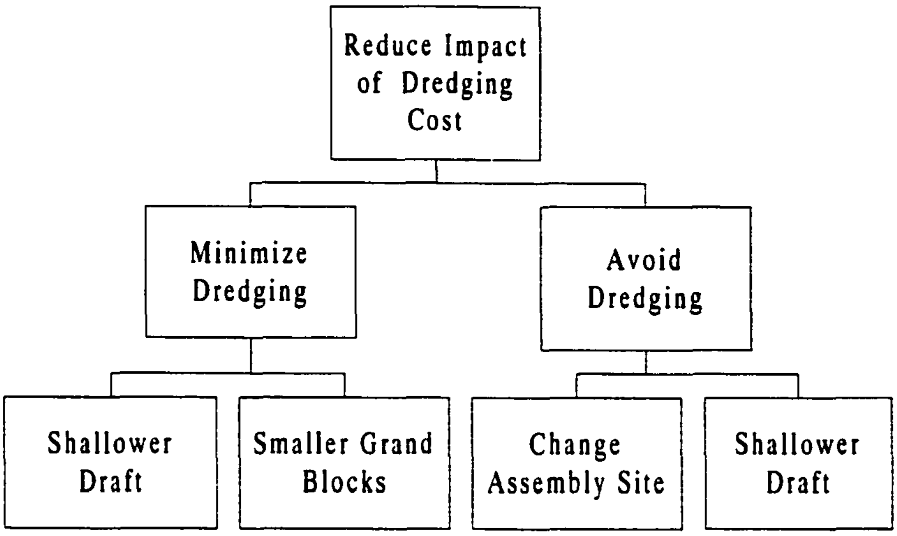

Figure 5-41. Goal Tree to Reduce Impact of Dredging Cost

A review of the risk profile shown in Figure 5-39 indicates that reducing both the likelihood and consequence of this event is required to reduce the risk. The event has occurred, therefore an alternative that seeks to reduce the consequence of this event is required.

The alternative of minimizing the required dredging depth may be achieved by increasing the ballast, thus raising the draft or by reducing the size of the grand blocks. Increasing the ballast is most likely the least expensive alternative. Changing the size of the grand blocks will change the number of grand blocks from five to four. This will have the effect of increasing the cost and schedule associated with at sea assembly operations.

The alternative of avoiding dredging may be possible if another assembly site with a deeper channel is available. The size of the MOB components may have already driven the choice to this location site. If the draft can be raised enough perhaps dredging may be entirely avoided.

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5.2.1.10.7. Specific Action to Correct Variances

Both of the variances that are causing costs to escalate need to be acted on by management. Alternatives have been developed and expressed graphically in a goal tree. To further assist decision-makers the cost of potential alternatives and estimated probabilities can be used to construct decision trees. The alternative with the highest Expected Monetary Value (EMV) is the best alternative.

5.2.1.10.7.1. Labor Shortages

For the cost increase due to labor shortages a decision tree is presented in Figure 5-42. This decision tree was constructed by estimating probabilities and cost to the various alternatives.

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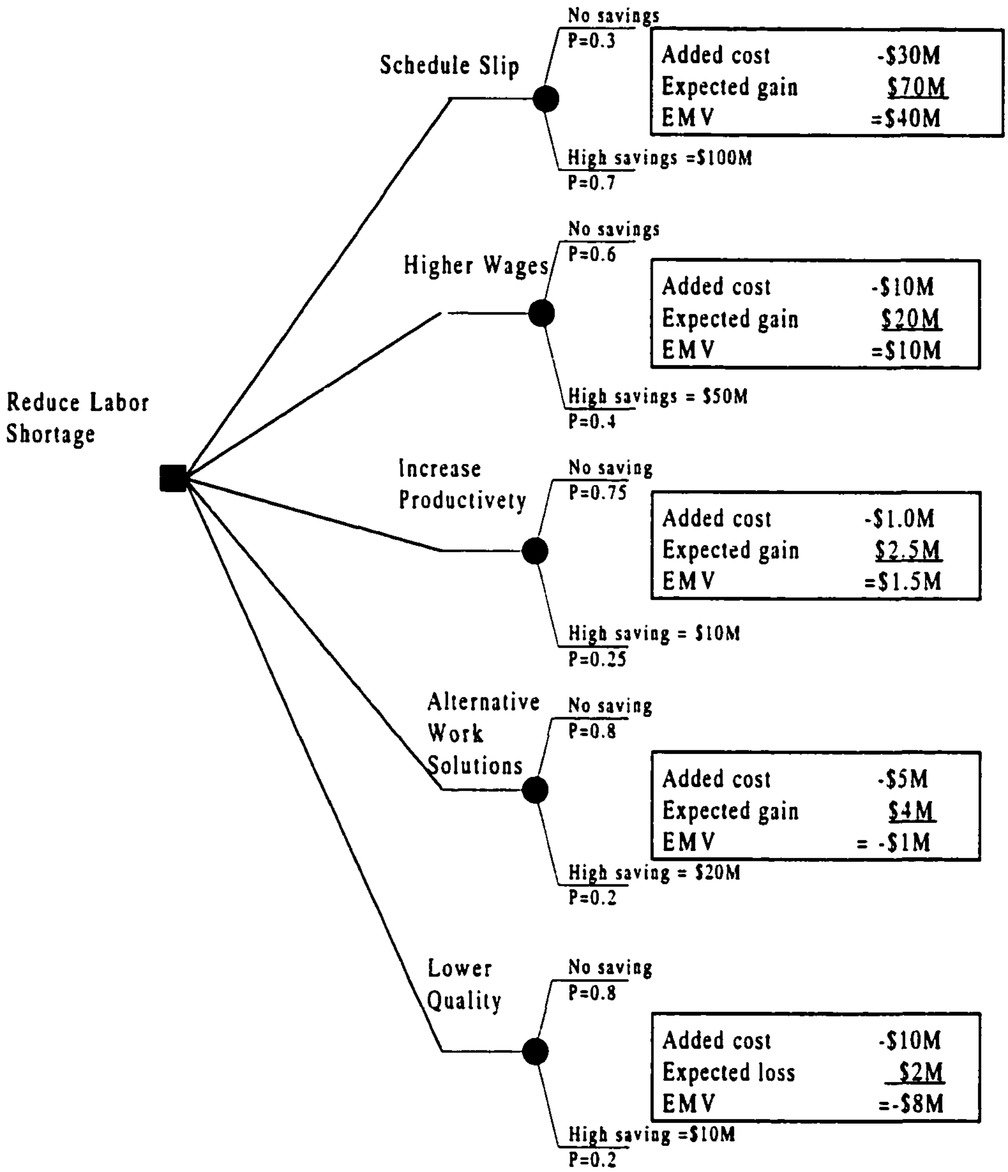

Figure 5-42. Decision Tree to Reduce Labor Shortage

As shown in figure 5-42 the decision to reduce the cost of labor shortages has several alternatives. Using the assigned probabilities and estimated cost the best alternative is to allow the schedule to slip. While this alternative is expected to cost an additional $30 million the expected saving is $70 million resulting in a total saving of $40 million. The total anticipated saving for this decision would not cover the total

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cost of the expected cost overrun. Had this cost variance been acted on earlier in the construction process a greater cost savings may have been achieved.

5.2.1.10.7.2. Environmental Concerns

For the cost increase due to environmental mitigation efforts a decision tree is presented in Figure 5-43. This decision tree was constructed by estimating probabilities and cost of the various alternatives shown in Figure 5-41.

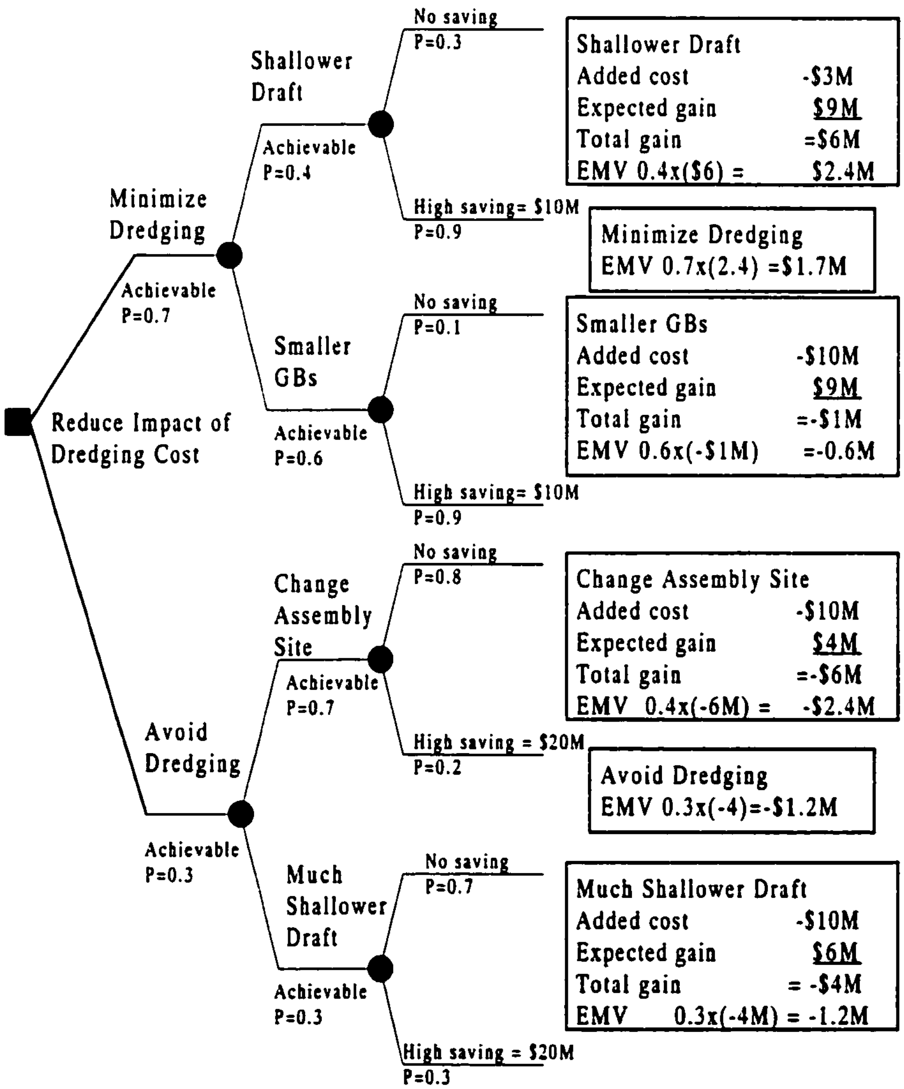

Figure 5-43. Decision Tree to Reduce Dredging Cost impacts

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As shown in Figure 5-43 the best alternative is to minimize dredging through the use of developing a shallower draft for the grand blocks. The alternative of trying to avoid dredging has a negative EMV because of the expense involved in either changing the assembly site or in producing the grand blocks with a much shallower draft.

5.2.1.11. Monitoring Results

The proposed cost control methodology does not stop at rendering decisions for proposed actions to correct observed variances. As shown in Figure 5-16 these actions along with the continuing progress of the MOB project must be monitored until the completion of the project. This monitoring of results is performed on a monthly basis. New or continuing variances are analyzed and decisions are made for corrective actions according to the proposed methodology.

5.3. Case Study Conclusion

The proposed methodology has been exercised through a case study. The planning phase of the risk-based methodology assessed the risk and developed target estimates for cost and schedule to build a MOB module. The execution portion of the proposed methodology was based on a scenario of observing the MOB after ten months of construction. The demonstrated techniques of earned value, risk and decision analysis during the execution phase of the case study show the applicability of the proposed methodology.

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6. VERIFICATION AND VALIDATION

This chapter provides a methodology for verification and validation. Verification and validation are generally thought of as applying to software development (Lewis 1992), but can include a broader range of application to analyze an entire system (Modell 1996). The verification and validation methodology is applied to both the simulation software and the proposed methodology presented in this dissertation.

The verification and validation process is shown in Figure 6-1. The process shows that a conceptual model represents a system. The conceptual model will contain some uncertainty and error. Where uncertainty is " a potential deficiency in any phase or activity of the modeling process that is due to the lack of knowledge" (AIAA 1998). Error is defined as " a recognizable deficiency in any phase or activity of modeling and simulation that is not due to lack of knowledge" (AIAA 1998).

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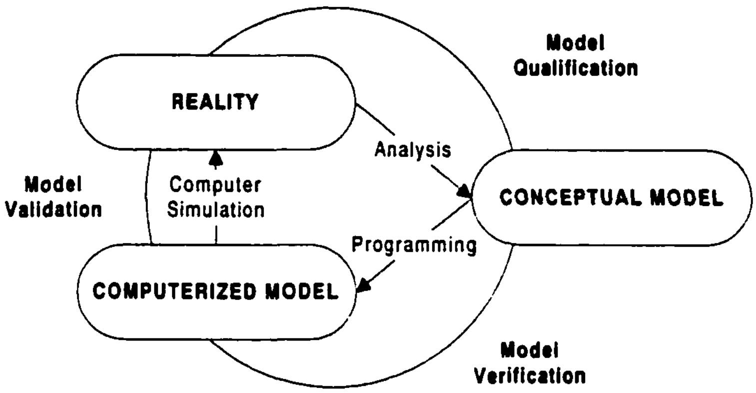

Figure 6-1. Model Verification and Validation (AIAA 1998)

The proposed methodology can be thought as a series of steps as shown in Figure 6-2. The verification and validation methodology will follow these steps to systematically compare the conceptual model or proposed methodology to the computational or computerized model and reality.

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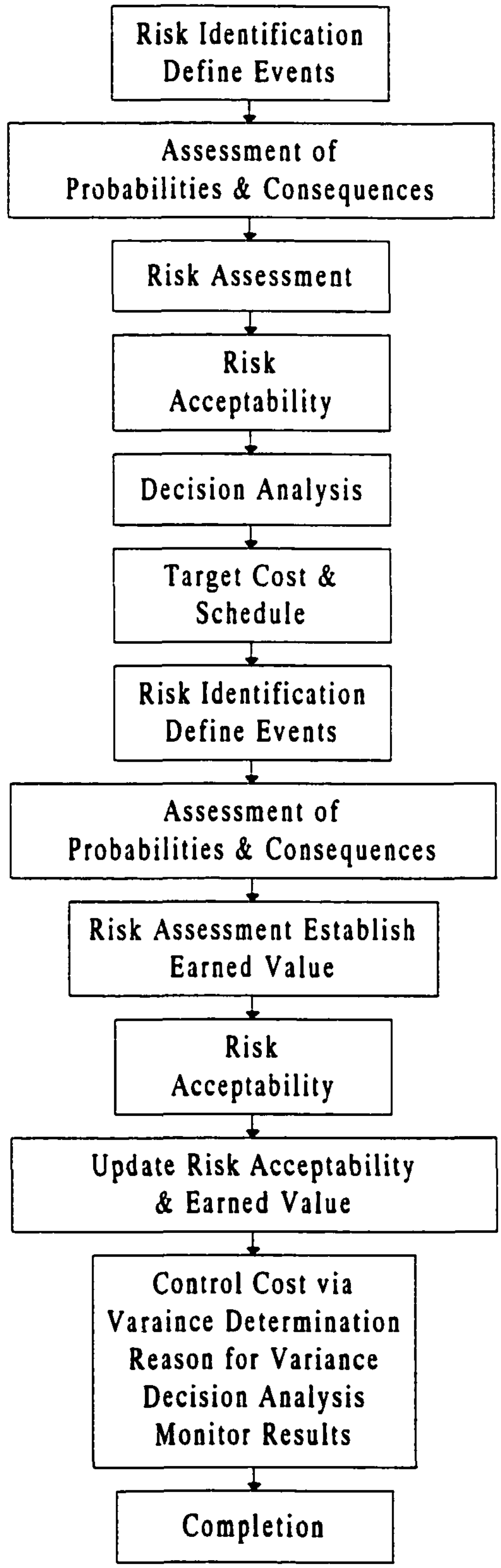

Figure 6-2. Steps in the Proposed Methodology

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6.1. Verification

Verification ensures the methodology is a true representation of the modeled system. It is defined as "the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model" (AIAA 1998). Verification answers the questions; does the model, software, or methodology work right? As shown in Figure 6-3 verification compares the model's computational solution to a highly accurate solution. For example, any software used for a simulation must deliver results achievable through a similar process. The verification step may include making pilot runs of the software or methodology and debugging the system. This process will likely be a summation of small iterative steps to assist in debugging and building the right system.

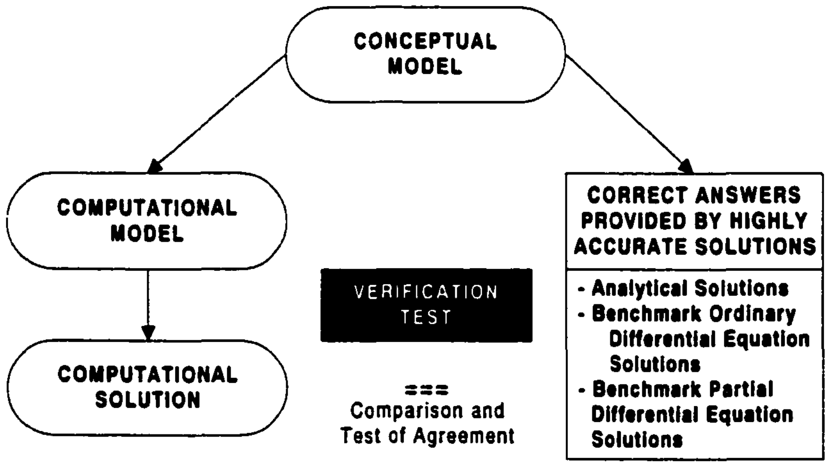

Figure 6-3 Verification Process (AIAA 1998)

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6.1.1. Verification of a Risk-Based Cost Control Methodology

As with the presentation of the proposed methodology the best method to study the verification of the methodology is to divide it into the planning and execution phases. Once these parts are verified a verification of the entire proposed methodology is performed.

6.1.1.1. Verification of the Planning Phase

The objectives during this phase are to assess the risk, develop risk-based cost and schedule targets and decide if a project should progress to the execution phase. The planing phase can be thought of as a series of steps as shown earlier in Figure 6-1. All of these steps are verified by asking the question "does the step work right?" Finally, the entire planning phase process is reviewed to ensure the steps are combined to work correctly together.

6.1.1.1.1. Planning Risk Identification and Event Definition

The objective of this function is to identify the risk and events associated with the project at hand. The process used to identify risk and events is to use a checklist and compare the requirements of a project to the resources available. The project team performs this risk identification function.

This methodology of identifying the risk and events associated with a project is based on certain assumptions. The project needs to be defined well enough by plans and specifications to identify the resource requirements. The capabilities of industry to accomplish the project needs to be understood. Finally, the project team should have a broad, but individually acute knowledge base to be able to identify risks.

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Should any of these assumptions prove invalid the identification of risks and associated events will be sub-par. The basic premise that the project team can make this determination by using only the project documentation and industry resources is difficult to verify. A review of complex projects employing these techniques is required to empirically verify this risk assessment approach.

6.1.1.1.2. Planning Assessment of the Probabilities and Consequences

The assessment of the probabilities and consequences of the identified risk is made by the project team. This assessment is qualitative, for example defined in linguistic terms e.g. unlikely, likely, and highly possible. These expressions of probabilities and consequences are defined but the individual that applies them may subjectively apply their own bias. For example, whether the consequence of the risk event of a labor shortage is critical or marginal may be interpreted differently by individuals.

The assessment process is intended to provide a relatively quick and accurate assessment. The technique is quick but this is done at the expense of accuracy. Therefore the possibility of a different assessment by different people needs to be accounted for in the final assessment. This inexactness is accounted for in the development of risk profiles that show the combined assessment of probabilities and consequences as representing an area versus an exact point. Does this assessment work right? The answer is a qualified yes. The assessments must be used with an understanding that they are imprecise and open to some interpretation.

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6.1.1.1.3. Planning Assessment of Risk

The assessment of risk is qualitative. It is based on the expressions of the probabilities and consequences developed earlier. The actual expression of risk is developed through the use of a risk assessment table. Again this risk is subject to an inexactness that users of this information need to understand. The qualitative expression is not a discrete value but a collective expression open to some interpretation.

Does this assessment work right? Does the risk assessment matrix table produce a risk assessment that reflects the risk on the project? The answer is again a qualified yes. Users of this information need to understand the resulting risk rating is an estimate of the risk.

6.1.1.1.4. Planning Risk Acceptability

Risk acceptability is determined from comparing the risk ratings to established guidelines and calculating the cost effectiveness of risk reduction. Comparing risks with similar consequences assists in determining acceptability. The critical variables in the cost effectiveness calculation are estimating the dollar value of a consequence reduction and the cost of the risk reduction effort. The cost effectiveness calculation should produce accurate results provided information is available to accurately estimate the level of risk reduction and the cost of the consequence reduction effort.

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6.1.1.1.5. Planning Decision Analysis

The decision analysis process is used to decide risk handling, probability distribution characteristics in the simulation of the project's cost and schedule, and assist in the feasibility determination for a project.

Goal trees and where appropriate decision trees are used for risk handling decisions. The methodology of using goal trees is appropriate because it may be difficult or impossible to obtain accurate data to perform a more exacting decision tree analysis. Yet, if accurate data is available a decision tree approach should be employed to produce better results.

The methodology uses tables for determining the appropriate range and parameters of probability distributions to use in the simulation of the target costs and schedule. These tables are developed through the engineering judgement and experience of the project team. The process will work correctly provided the people who use the tables have an understanding of how to apply the appropriate shapes of the probability distributions, their various ranges, and how parameters effect their shape.

The risk assessments is used to assist in the decision making process to determine the feasibility of a project. Although a project's feasibility is typically based on an economic decision the results of the risk assessment will provide a qualitative account of the risks involved in a project.

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6.1.1.1.6. Planning Target Cost and Schedule

The target cost and schedule values are developed through the use of simulation. An important step in developing the simulation is a verification of the code or software used to perform the simulation. The model must accurately represent the conceptual description of the model and solution to the model. The Critical Path Method (CPM) of scheduling is used to conceptually represent the building of a complex project. The CPM derived schedule is modeled by the software to develop risk-based cost and schedule targets.

The verification of the simulation model should be performed through an iterative process. Modelers should begin with a simple model and then introduce complexity as more is understood about the model and confidence in the model grows.

Another important step in model verification is an examination of the model's output reasonableness (Banks et al. 1996). To ensure the model works correctly, results need to approximate the scheduled completion times and cost found in the development of the point estimates. The software model should consistently deliver results that may differ yet are within an acceptable range of accuracy of the point estimate.

The verification process for a complex software project should include some independent verification (Lewis 1992). For the adapted software used to simulate the CPM this independent was achieved by using an iterative process between two researchers.

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6.1.1.1.7. Holistic Verification of the Planning Phase

The objectives during this phase are to assess the risk, develop risk-based cost and schedule targets, and decide if a project should progress to the execution phase. Through the previously discussed steps a combined process that works correctly meets these objectives. Users of the risk assessment and cost information should understand the results of this phase are estimated values and should not be taken as absolute values.

6.1.1.2. Verification of the Execution Phase

To keep the execution phase methodology consistent and simple it is purposely similar to the planning phase. The similarities between the planing and execution phase can be seen in Figure 6-1. The value of information and short reaction time between identifying a variance and correcting it is the major change from the planning phase. In this phase the objective is to identify both cost and risk variances as early as possible and provide solutions to correct these variances. By avoiding or managing cost and risk variances project managers are able to control project costs.

The verification of the execution phase is performed by a review of the individual steps in the proposed methodology during the execution phase. Once this is completed a holistic verification is applied to the proposed methodology during the execution phase.

6.1.1.2.1. Execution Define Risk Events

The objective of this step is to update or define risk events. The project team in this phase will most likely include new members that perform this function. The

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project team reviews the latest information, the previously performed risk analysis work, and makes comparisons between requirements and resources to update or define risk events. This process will collectively account for the major risk events on a project. Accurate results will depend on the strength of the project team, quality of the project documentation, and ability to gauge the industrial capacity to accomplish the project.

6.1.1.2.2. Execution Assessment of Probabilities and Consequences

Once the risk events are identified or reaffirmed the probabilities and consequences of an event are assessed. This assessment should change from the planning phase due to risk reduction efforts in the planning phase and new information in the execution phase. The process outlined will function properly provided the risk assessors collectively have varied backgrounds but individually have expertise in a field related to the project.

6.1.1.2.3. Execution Establish Risk Assessment and Earned Value

Establishing the risk assessment is through the use of risk assessment matrix tables. This process produces a relatively accurate assessment of risk considering the qualitative nature of the assessment.

Developing the value of the work planned performs establishes the baseline for earned value. Matching the cost of the work to when the work is scheduled establishes the planned value of the work. This method will produce accurate results but to make computations and scheduling efficient, dollar values are rounded to appropriate figures. For example, for a $400 million project built over a three year

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period the planned value of the work per month may only be estimated to the nearest $100k.

6.1.1.2.4. Execution Risk Acceptability

Risk acceptability is based on risk assessment profiles, levels of acceptable risk, and the cost of reducing risk to acceptable levels. The methodology uses qualitative risk assessments and their risk profiles to initially determine risk acceptability. For example, all high risks are reduced regardless of the cost effectiveness and low risks are only monitored. Medium risks are reduced if it is cost effective. There is a potential for an error if a high risk event is incorrectly assessed as a medium risk and it is not mitigated because it is too expensive. Should this happen the next step of updating risk assessment should alleviate the problem.

6.1.1.2.5. Execution Update Risk Assessment and Earned Value

Once a project is in the execution phase the project is under construction and costs are being expended. The proposed methodology requires for monthly updates to the risk assessment and earned value analysis. A methodology could require more frequent updates but the level of effort and costs required to generate this data needs to be considered. Are monthly updates the correct method to receive periodic updates? Another method to provide updates is through the use of milestone accomplishment tracking. This method was not used because of the varied sub-milestones and completion dates that are used for the various sub-components of a complex project. Monthly updating is about right on large complex projects given the volume of data

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available and the cost to collect it. The use of monthly updates for similar data by the construction industry provides favorable results (Gould 1997).

6.1.1.2.6. Execution Cost Control

The objective of this step is to control cost through decision analysis and action. Once the reason for a variance is understood an objective is defined and goal trees can be used to graphically display alternatives to achieve the objective. Decision trees can also be used if accurate data can be readily obtained. The circumstances of the situation will determine if a correct decision has been made. What's important in the execution phase is that the decisions made to control costs are monitored to ensure the actions taken are working.

6.1.1.2.7. Holistic Verification of the Execution Phase

Do all the steps in the execution phase combine to give the correct answer? The answer to this question is that they *can* combine to give the correct answer. A strict recipe can not be applied in the field of project management. The execution methodology provides the basic framework to identify problems, control cost through identifying solutions, and taking action to mitigate these problems. The outcomes of the actions should produce correct results but they need to be monitored due to the uncertain nature of a project's direction.

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6.1.1.3. Verification of the Proposed Methodology

The individual steps in the proposed methodology provide a sequenced structure to analyze and control project costs. These individual steps combine to develop a proposed methodology that is risk-based and anticipatory of cost problems.

The major verification effort for the proposed methodology involves the verification of the simulation software. Provided the simulation is built through an iterative process, is reviewed, and the results are checked for reasonableness the author is highly confident the simulation will produces correct results.

The proposed methodology was built in an iterative and top down approach. High level objectives and processes were proposed and refined. These were then broken down into lower level objectives and processes. These lower level objectives and processes (the steps in the methodology) were proposed and refined. Through this iterative process the author has a high degree of confidence the proposed methodology is capable of producing acceptable results.

6.2. Validation

An important step in the methodology building process is validation. Validation is defined as "the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model" (AIAA 1998). Validation is needed to answer the question; does the model or methodology truly represents reality? As shown in Figure 6-4 the validation process compares the computational solution to real world observations.

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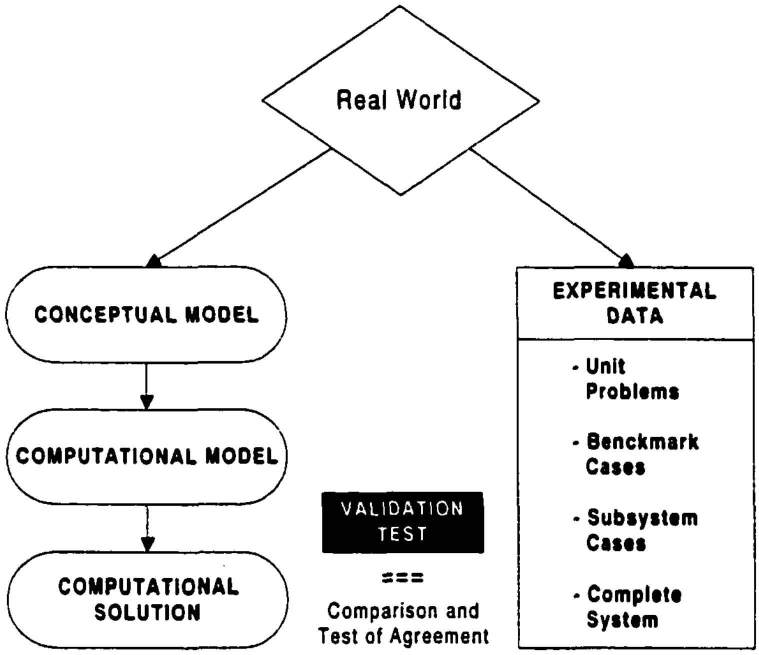

Figure 6-4 Validation Process (AIAA 1998)

6.2.1. Validation of a Risk-Based Cost Control Methodology

This section will validate the proposed methodology to ensure it represents a system that can be employed in the project management field. The validation process will review each individual step in each phase and provide a holistic validation of the entire process.

The project management field, specifically construction management, typically performs risk management and cost control in a reactionary mode (Hastak et al. 1994), intuitively or through the use of rules-of -thumb (Al-Bahar and Crandall 1991). The proposed methodology provides an anticipative perspective and structure to provide a risk-based cost control system that attempts to account for and formalize the use of the project team's experience and judgement.

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6.2.1.1. Validation of the Planning Phase

The planning phase of the methodology closely represents reality in that its main objective is to identify the costs and schedule of the project. Where the proposed methodology differs from standard practice is in the systematic and combined use of risk analysis, simulated cost, and scheduling to develop target values. The proposed planning methodology represents a very good approximation of the anticipated risks through a qualitative risk technique. The actual construction processes are accurately represented through the use of CPM and simulation.

6.2.1.1.1. Planning Risk Identification and Event Definition

How a project's risks are identified may be performed by several techniques. The process can be through a series of formal meetings e.g. the working group concept, based on past experience, or in a worst case scenario not identified in advance but encountered during the construction process. The proposed methodology uses a checklist to assist the project team in identifying project risks. The checklist is used by the project team in conjunction with the knowledge of the requirements of a project verses the capabilities of the specific industry. This methodology formalizes and provides structure to similar processes that occur in the construction industry.

6.2.1.1.2. Planning Assessment of the Probabilities and Consequences

The assessment of probabilities and consequences is performed by the project team and provides a qualitative assessment of these items. Practitioners can easily implement the proposed methodology provided the time and resources are allocated to perform this function.

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6.2.1.1.3. Planning Assessment of Risk

The proposed methodology combines the assessment of probabilities and consequences in a risk assessment matrix table to develop an assessment for risk. The assessment of risk through the use of risk assessment matrix tables is a valid concept (Defense Acquisition University 1998) and (Wiggins 1985).

6.2.1.1.4. Planning Risk Acceptability

The proposed methodology determines risk acceptability through guidelines and the cost effectiveness of risk reduction. In reality business decisions are based on economics or the cost effectiveness of the decision. The proposed methodology varies slightly from reality and uses some subjective judgements to reduce high risks. Medium and lower rated risks are reduced only if economical. This process is valid because it seeks to apply economics to risk acceptability decisions.

6.2.1.1.5. Planning Decision Analysis

In the planning phase decisions are required to reduce risk. The proposed model uses goal trees and when data is available decision trees to support decision-making. In reality the method of decision-making can range from using a comprehensive decision analysis technique to making arbitrary and capricious decisions. The proposed methodology offers a choice of techniques that are appropriate for the level of information available.

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6.2.1.1.6. Planning Target Cost and Schedule

The development of the target cost and schedule is performed through simulation. Validation of the model building and simulation are an important process to ensure they reflect reality.

The Critical Path Method (CPM) is employed to model a construction scenario. Since the 1950's CPM has been used to model a construction system and has been validated as a viable method by numerous authors (Gould 1997) and (Minks and Johnson 1998). CPM does have one major shortcoming, the duration of activities may not reflect reality (Jaffari 1984). To better represent the reality CPM is simulated by probability distributions to reflect the uncertainty in an activity's duration.

Based on a project's critical path, a model is built by using commercially adapted discrete event simulation software. A colleague or independent entity should then critique the model and make necessary changes to the model. From this iterative process between builder and reviewer more will be understood about the model and compared to the CPM to ensure an accurate representation is developed. This iterative process may take several cycles for completion.

By following the steps provided in the previous two paragraphs the proposed methodology of simulating cost and schedule is validated.

6.2.1.1.7. Holistic Validation of the Planning Phase

Does the proposed methodology of the planning phase represent reality? Yes, all of the steps described collectively represent a systematic process that is seen in varying degrees and forms throughout the construction project management field

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(Humphreys 1991). The proposed methodology seeks to add a systematic and risk-based structure to practiced activities. The methodology proposed in the planning phase *can* be implemented to decrease the level of uncertainty that is often experienced in the planning phase of a project.

6.2.1.2. Validation of the Execution Phase

During the execution phase cost control is achieved through anticipating risky cost issues, collecting data to make decisions and monitoring results. This process employs sequential steps that will be validated individually. Finally the entire phase is validated.

6.2.1.2.1. Execution Define Risk Events

The risk assessment work performed in the planning phase should carry over to the execution phase but will require updating because of new project team members and information. If an update is not possible risk identification and the definition of events will need to be established again. The weak link in transitioning from planning to execution is the transfer of information from planners and designers to constructors. The process of updating an existing risk analysis will work only if the project team makes a concerted effort.

6.2.1.2.2. Execution Assessment of Probabilities and Consequences

The proposed methodology establishes a realistic method to reassess the probabilities and consequences. This method uses a qualitative approach to express the probabilities and consequences. It is realistic because project team members

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currently perform this function but not in a structured and systematic process (Al-Bahar and Crandel 1991) as the proposed methodology does.

6.2.1.2.3. Execution Establish Risk Assessment and Earned Value

The establishment of risk assessment and earned value is valid because independent of each other the steps for establishing a risk assessment and an earned value analysis is be performed on construction projects (Bent and Humphreys 1996) and (Fleming and Hoppelman 1996). The proposed methodology performs these methods concurrently to create a system for classic risk assessment and earned value to enhance each other.

6.2.1.2.4. Execution Risk Acceptability

Risk acceptability is determined by reference to guidelines and the cost effectiveness of a risk reduction effort. Both of these approaches to risk acceptance are valid techniques (Kumamoto and Henley 1996) and (Ayyub and Wilcox 2000). The unique aspect of the proposed methodology is that the combined and systematic application of risk acceptability when combined with other steps should produce results that resemble reality.

6.2.1.2.5. Execution Update Risk Assessment and Earned Value

The methodology proposes that updates to the risk assessment and earned value analysis occur monthly. On a very short project this would not reflect the appropriate level of updating. However, since the proposed methodology is applied to complex projects that are almost always lengthy, monthly updating is appropriate.

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6.2.1.2.6. Execution Cost Control

The actual control of cost is through observing variances in risk and earned value, using decision analysis, taking action, and monitoring results. The success of any proposed solutions to cost problems is reflected in the actual cost improvements that result. This final step is difficult to validate because each cost problem is sensitive to issues surrounding each specific case. Yet, the proposed methodology does represent reality in a generic sense, its objectives are similar to cost control methods used in practice (Humphreys 1991).

6.2.1.2.7. Holistic Validation of the Execution Phase

Does the proposed methodology in the execution phase represent reality? Yes, but it attempts to address the "chaos" that typically confronts busy project managers. Where chaos is defined as the uncertainty of a project's direction combined with the scarcity of time devoted to solve potential problems until they become a crisis (Laufer 1996). The proposed methodology brings to the field of project management a structured sequence of events designed minimize the practice of management constantly jumping from one problem to another in the execution phase.

6.2.1.3. Validation of the Proposed Methodology

Analyzing the entire proposed methodology reveals a common theme among the various steps in the process. Portions of the proposed methodology and to varying degrees of application the proposed methodology is currently used, although disjointedly, by the project management field. The proposed methodology is valid more because it *can* be implemented versus it is an accurate reflection of project

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management in the uncertain planning phase and the chaotic nature of the execution phase.

6.3. Verification and Validation for the MOB Case Study

This section describes how the methodology for verification and validation can be applied to the construction of the MOB.

6.3.1. Verification of the MOB Case Study

Verification of the proposed methodology as applied to the MOB case study will review the case study to determine if the proposed methodology produces correct results. The verification process will review the steps of the proposed methodology and conclude with considering all of the steps combined. This process is shown in Figure 6-5. On the left side of Figure 6-5, the proposed methodology requires computations to develop target costs and schedule, risk assessment, and other results. On the right side of Figure 6-5 the case study verifies that correct results can be obtained by comparing the simulation results to earlier developed deterministic results and verifying the reasonableness of other steps such as risk assessment and decision analysis.

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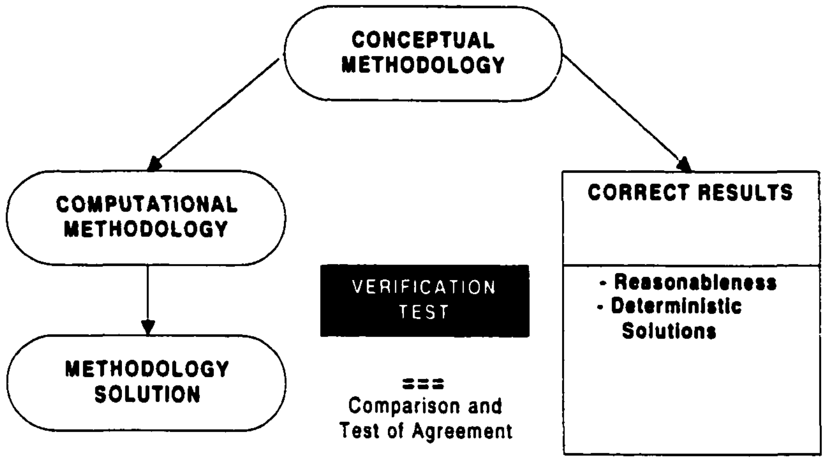

Figure 6-5 Verification Process Using Case Study
Adapted from AIAA (1998)

6.3.1.1. Verification of the Planning Phase of the Case Study

6.3.1.1.1. Planning Risk Identification and Event Definition for the MOB

The risks for building the MOB were identified by using a checklist and comparing the resource requirements to build a MOB with the existing MOB documentation. The methodology was broadly applied and the identified risks and events defined are the major ones acknowledged by the author. This assessment did not detail the risk events to a fine degree. For example, safety risks were broadly defined as accidents that could cause various levels of consequences. These were not refined to the detail of individual events such as a worker being crushed while performing rigging operations.

6.3.1.1.2. Planning Assessment of the Probabilities and Consequences for the MOB

The author developed the assessment of probabilities and consequences for building the MOB. The results are based on documentation presented in the

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referenced literature and the personal experiences of studying the MOB construction for over two years. Considering the experience base of the author and unique construction aspects of a MOB the results should be fairly accurate.

6.3.1.1.3. Planning Assessment of the Risk for the MOB

The risk assessments are correctly rated according to the risk assessment matrix tables provided by the proposed methodology.

6.3.1.1.4. Planning Risk Acceptability for the MOB

In the case study risk events were categorized as unacceptable, mitigated if cost effective, or monitored in the execution phase. Additionally, to assist in a risk acceptance determination, risk profiles were displayed by their consequence category. This determination was made according to the guidelines outlined in the proposed methodology and a particular event's risk profile.

6.3.1.1.5. Planning Decision Analysis for the MOB

Based on their risk acceptability category, risk events were handled in the planning phase according to suggested alternatives documented in referenced literature or in the case study chapter. It was assumed the correct and necessary actions to reduce risk were accomplished in this phase.

6.3.1.1.6. Planning Target Cost and Schedule for the MOB

The most important verification process in applying the proposed methodology to the case study is the verification of the simulation software. This was performed through an iterative process. Initially the model was built as simply as possible, then

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complexity was introduced as more was understood about the model and confidence in the model grew. Additionally, after each step in the modeled construction process histograms were displayed to ensure the software accounted for an activity's duration and after each activity a display would indicate whether an attribute for duration was logically increasing. For example, if the lower hulls required about six months to complete and transportation required about a month, after these activities a histogram display should indicate the a duration of approximately seven months. A continuous display of output during model building ensured the model was following the critical path and was a true representation of the construction process.

Another important step in model verification is an examination of the model's output reasonableness (Banks et al 1996). To ensure the model worked correctly, results had to approximate the schedule completion times and cost found in the development of the point estimates. The software model consistently delivered results that were different yet within an acceptable range of accuracy of the point estimate.

The verification process of a software model should also include some independent verification (Lewis 1992). A colleague through an iterative process verified the software used for the simulation (Ayyub et al. 1999c). This process involved the author building a model and simulation. A colleague then reviewed the model and changes were proposed. This iterative process took several cycles for the modeling and simulation process to be completed.

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6.3.1.1.7. Holistic Verification of the Planning Phase of the Case Study

The planning phase of the case study is an accurate representation of the risks, cost, and schedule of building a hinged MOB. The systematic and structured thought processes to achieve the presented risk assessment results are only the efforts of one experienced person. If the case study using the proposed methodology was subjected to input from more people the results may have slightly changed. This would not be due to a methodology flaw but because of a broader experience base.

6.3.1.2. Verification of the Execution Phase of the Case Study

6.3.1.2.1. Execution Define Risk Events for the MOB

The definition of risk events in the execution phase is based on the assumption that most risk events identified in the planning phase are still present, although reduced, in the execution phase. This is a reasonable assumption considering risk events are broadly defined and one of the objectives of the planning phase is to reduce risk. However, the total elimination of risk is not cost effective or feasible unless a MOB is not built.

6.3.1.2.2. Execution Assessment of Probabilities and Consequences for the MOB

The determination of the probabilities and consequences of risk events for building the MOB were determined by the author. This approach lacks input from other professionals but due to the author's experience in marine construction and studying the MOB, the results achieved should be representative of those expected from a broader group.

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6.3.1.2.3. Execution Establish Risk Assessment and Earned Value for the MOB

Using the risk assessment matrix tables from the proposed methodology the risk assessment ratings were developed. The mechanics of using these tables is straightforward and correct results were achieved.

The earned value analysis data was established by breaking down the target cost to each individual major MOB component and spreading this cost over a component's time duration for construction. This developed a monthly cost per component. The monthly cost per component was then put into a spreadsheet. These costs are accurate estimates based on the target cost achieved in the simulation.

6.3.1.2.4. Execution Risk Acceptability for the MOB

Identified risks in the execution phase need a determination of risk acceptability. This determination is based on the level of risk and the cost to mitigate the risk. All events with high risk ratings are mitigated and goal trees are presented that offer proposed solution to mitigate the risk. The selection of which alternative to choose will be based on the cost of the alternatives and level of risk reduction provided. Specific alternatives were not selected but their ability to change the likelihood of occurrence and consequences of a risk event were discussed.

6.3.1.2.5. Execution Update Risk Assessment and Earned Value for the MOB

To obtain data for a MOB that has not been built the case study presents a hypothetical scenario for ten months of construction. The scenario develops the MOB as being built about on schedule but overrunning costs. Simulated monthly cost and risk assessment data was presented. The updated risk assessment and earned value

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data provided the clues to the potential problem areas. The use and application of the earned value equations produced correct results based on the data given. Solutions to cost problems were developed through the use of goal and decision trees. The correct responses to the scenario were developed but readers should understand this was an academic exercise. In practice, if the correct responses were not chosen the proposed methodology would account for this through continuous monitoring.

6.3.1.2.6. Execution Cost Control for the MOB

Identifying variances, identifying solutions to the variances, and then implementing the selected solutions performs cost control. In the MOB case study the variances were exposed through monthly data displayed graphically as risk profiles or earned value curves. The reasons for the cost variances were investigated through a series of questions provided in the proposed methodology. Using decision trees recommended actions were identified by finding the Expected Monetary Value (EMV) for alternatives. The actual recommended solutions were not implemented but the proposed methodology was demonstrated. The case study shows that correct solutions can be obtained.

6.3.1.2.7. Holistic Verification of the Execution Phase of the Case Study

A postulated MOB construction scenario was developed to demonstrate the proposed methodology. Do all the steps individually combine to produce the appropriate answer? Yes, the case study shows appropriate results can be achieved by applying the proposed methodology.

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6.3.1.2.8. Holistic Verification of the Proposed Methodology for the MOB

The MOB construction case study demonstrates the proposed methodology in its entirety. Does an application of the proposed methodology provide the correct results when applied to the MOB? Yes, for three reasons: 1) the target cost and schedule estimates for the MOB are generated with a high level of confidence, 2) cost control problems of building a MOB can be anticipated and avoided, and 3) if cost problems do arise, the methodology provides a systematic method for selecting appropriate control measures.

6.3.2. Validation of MOB Case Study

Validation of the proposed methodology as applied to the MOB case study will review the case study to determine if proposed methodology was correctly applied. The validation process will review the steps of the proposed methodology and conclude with considering all of the steps combined.

As shown in Figure 6-6 the validation of the proposed methodology using a case study is designed to show how the proposed methodology can be used and determine if it was correctly applied. The proposed methodology models a possible real world process through a series of steps and the case study demonstrates the proposed methodology. On the bottom left of Figure 6-6 the proposed methodology is shown as the conceptual methodology used to develop a solution. This is compared to how the case study uses the proposed methodology to develop a solution as shown on the lower right side of Figure 6-6.

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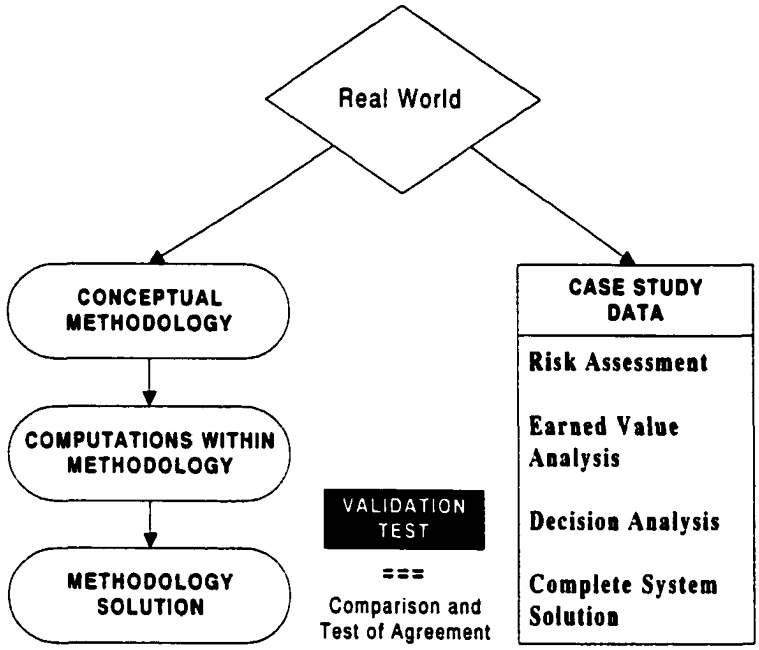

Figure 6-6 Validation Process Using Case Study
Adapted from AAIA (1998)

6.3.2.1. Validation of the Planning Phase for the Case Study

6.3.2.1.1. Planning Risk Identification and Event Definition for the MOB

Using a checklist and comparing the resource requirements to build a MOB with the existing MOB documentation identified risks for building the MOB. Except for the actual risk identification being performed by the author this is how the proposed methodology should be applied.

6.3.2.1.2. Planning Assessment of the Probabilities and Consequences for the MOB

The author developed the assessment of probabilities and consequences for building the hinged MOB. In the proposed methodology the project team performs this function but for practicality reasons this was performed by the author.

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6.3.2.1.3. Planning Assessment of the Risk for the MOB

The risk assessment matrix tables from the proposed methodology were use to develop a risk rating. This is a correct application of the proposed methodology.

6.3.2.1.4. Planning Risk Acceptability for the MOB

The case study correctly exercised the proposed methodology's method for determining risk acceptability. This was performed by establishing risk profiles of events by consequence category and ranking risks. This allowed for a graphical and tabular method to help establish risk acceptability.

6.3.2.1.5. Planning Decision Analysis for the MOB

The planning decision analysis for the case study was applied to mitigate the level of risk for the identified events. The level of risk also helped to establish the shapes and ranges of the probability distributions used in determining the MOB's target cost and schedule through simulation. The correct use of a particular distribution was validated in Chapter five. Finally, the risk ratings helped to establish the feasibility of the MOB project. These steps are a correct application of the proposed methodology.

6.3.2.1.6. Planning Target Cost and Schedule for the MOB

The most important validation step in the planning phase is the validation of the simulation software to develop target estimates for the cost and schedule of building a MOB.

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The critical path method was employed to schedule the construction scenario. Based on this critical path, a model was built by the author and critiqued by a colleague. Then necessary changes were made to the model. This iterative and collaborative approach to model building helped to ensure the right model was built. From this iterative process more could be understood about the model and compared to the proposed MOB construction scenario to ensure an accurate representation was developed. This iterative process generally took several cycles for completion.

6.3.2.1.7. Holistic Validation of the Planning Phase of the Case Study

The author is confident the proposed methodology was correctly applied to the case study. The only significant deviation from the proposed methodology is that the author, instead of a project team, performed certain steps.

6.3.2.2. Validation of the Execution Phase of the Case Study

The case study provided a form to demonstrate the proposed methodology. The hinged MOB has not been built. Therefore, certain assumptions and hypothetical data have been developed for this portion of the case study to allow a demonstration of the proposed methodology.

6.3.2.2.1. Execution Define Risk Events for the MOB

In accordance with the proposed methodology risk events were defined by updating the previous risk analysis work from the planning phase. This was performed by the author and not by a project team as specified in the proposed methodology.

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6.3.2.2.2. Execution Assessment of Probabilities and Consequences for the MOB

The assessment of probabilities and consequences of building a MOB was performed by the author instead of by a project team. This was not performed as prescribed by the proposed methodology due to the limited resources available to the author.

6.3.2.2.3. Execution Establish Risk Assessment and Earned Value for the MOB

The risk assessment was established based on using the risk assessment matrix tables as provided in proposed methodology. Breaking down the target cost of a MOB module into the estimated cost of the components established the earned value data. The component's estimated cost was spread over a component's scheduled length of time for construction to develop a planned monthly value of the work. The planned value of the work was then graphed as cumulative costs versus time. The steps within the proposed methodology were correctly applied for building a MOB.

6.3.2.2.4. Execution Risk Acceptability for the MOB

Risk profiles for the identified risk events were developed per consequence category. Using the proposed methodology risk acceptance was based on a qualitative assessment and the cost benefit of risk reduction. Risk acceptability determinations for building the MOB were correctly applied by assigning high risk to be mitigated, medium risks to be mitigated if cost effective and low risks were monitored.

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6.3.2.2.5. Execution Update Risk Assessment and Earned Value for the MOB

The proposed methodology was correctly applied to the MOB case study. Risk profiles changed due to new information and the simulated earned value data was processed according to the proposed methodology.

6.3.2.2.6. Execution Cost Control for the MOB

Given the changed risk profiles and calculating the estimates at completion it was apparent that variances were occurring in certain risk areas and the cost of building a MOB was escalating. Based on a series of questions taken from the proposed methodology alternatives were developed to reduce the cost impacts that the labor shortages and an environmental issue were causing. A goal tree and decision tree approach to decision analysis was applied to select the best alternative. The proposed methodology was correctly applied to the problems in the scenario.

6.3.2.2.7. Holistic Validation of the Execution Phase of the Case Study

Is the proposed methodology correctly applied to the case study in the execution phase? Yes, provided readers understand that the author performed the functions of the project team. Additionally, the executed scenario is a hypothetical case designed to demonstrate the proposed methodology.

6.3.2.2.8. Holistic Validation of the Proposed Methodology for the Case Study

The proposed methodology has been correctly applied to the case study from the first identification of risk events to selecting alternatives that control cost. The

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proposed methodology's sequential application and repetitive theme make it a relatively straightforward system to validate.

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7. CONCLUSIONS AND RECOMMENDATIONS

A summary, original contributions, conclusions, and recommendations are presented in this chapter. The documented conclusions summarize the findings, completion of objectives, and results of the proposed methodology applied to the case study. The recommendations present areas of future research.

7.1. Summary

Cost control is needed in the construction project management field because of the high level of uncertainty associated with the cost of building complex structures. Although there is a potential for projects to be completed under budget the literature suggest otherwise (Bent and Humphreys 1996). To be the most effective over the lifecycle of a project a cost control system should be applicable to both the planning and execution phases. The system needs to be simple enough that it is applicable and generic enough to apply to a wide cross section of projects. This research provides an in-depth study into the current methods of project cost control.

Risk is represented by an event with a probability of occurrence and a consequence that can have a negative or favorable outcome. Risk is inherent in the construction of complex structures. Risk analysis is a systematic process that can be applied to help solve the construction challenges associated with complex structures. This analysis should include a process that begins by identifying risks to finally

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making decisions on how to handle the risks. Risk analysis alone will not control cost, it provides clues to cost issues, but does not track costs associated with risky items. This research presents current risk analysis techniques, particularly as they are suited for use within the construction industry.

A proposed risk-based cost control methodology is provided that combines simulation, earned value, and risk analysis techniques in a novel approach to cost control. The proposed methodology provides construction project managers with a structured framework to make cost control decisions during the planning and execution phases of construction. During the planning phase risk is identified, assessed, deemed acceptable or unacceptable, decision analysis is performed, and risk-based cost and schedule targets using a simulation technique are developed. During the execution phase a similar process is followed with the addition of the cost control technique of earned value that is intertwined with risk assessment updates and decision analysis to provide cost control.

The construction industry is unique in that it rarely builds something the same way, at the same place, or with the same set of people. Additionally, construction professionals tend to describe risk in linguistic terms based on their experience and judgement. Therefore, data to perform a classic quantitative risk assessment may be lacking. The proposed methodology recognizes this and develops a qualitative risk assessment that uses qualitative expressions to develop a risk assessment. Additionally, the proposed methodology uses goal and decision trees, where appropriate, to develop the most cost-effective solution to cost issues.

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A salient feature of the proposed methodology is the structured format, graphical expression of risk, and proposed solutions to mitigate the risk. The structured format allows project team members to systematically identify, quantify, discuss, and pose solutions to potential cost issues. Risk profiles of risk events are displayed by consequence category and the cost effectiveness of risk reduction is used to assist in making risk acceptability decisions. The graphical expressions of risk also helps to determine whether lowering a consequence or likelihood of an event will have the greatest impact on lowering the risk.

An important part of the proposed methodology is monitoring risks over time. The proposed methodology does this by reassessing risk once the project transitions from the planning phase to the execution phase. Risk assessment and earned value data are continually monitored in the execution phase. This provides project managers with an early warning of potential cost problems on the project.

The primary objective of the proposed methodology is to control costs when building complex structures. This is achieved through a succession of steps culminating in a decision analysis process. The decisions made must be followed by actions designed to rectify a problem or take advantage of a situation. The results of these actions are also monitored to ensure a correct alternative was chosen. The cycle of reassessment, analyzing earned value data, decision making and monitoring continues until a project is completed.

The presented case study demonstrates how the proposed methodology can be applied to the construction of the MOB. This structure is appropriately complex and aptly demonstrates the applicability of the proposed methodology.

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7.2. Original Contributions

This dissertation has advanced the field of cost control as applied to the construction of complex structures. The presented research uses simulation, cost control, and risk analysis techniques as a foundation to present a proposed methodology for cost control that is risk-based. Specifically this dissertation has:

- Combined cost control and risk analysis techniques to develop a novel methodology for controlling costs when building complex structures.
- Furthered the application of risk techniques in the fields of cost engineering and project management.
- Provided an encompassing methodology that supports project management throughout the planning and execution phases of a project.
- Presented a unique methodology that is relatively straightforward, has a practical application, and is suited for use by the construction industry.

The proposed methodology has brought together recognized areas of project management that are typically performed independently. The application of risk analysis to help identify cost issues is not new but the proposed methodology's specific application of using risk techniques to control costs is an original contribution.

Most applications of risk techniques in the fields of cost engineering and project management concentrate on accounting for uncertainty when developing cost and schedule estimates. This may include techniques such as a Monte Carlo application or an application of fuzzy set theory to modify deterministic values. The proposed methodology also accounts for uncertainty in developing target costs and schedule, but

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is performed in a more comprehensive manner than currently exists. The proposed methodology advances cost engineering and project management by requiring the additional formal steps of risk acceptability and decision analysis.

Risk analysis is generally applied in the planning phase and cost control in the execution phase. The proposed methodology presents a system to span both phases of the planning and execution portion of the project lifecycle. Risk analysis and cost work performed in the planning phase carries over to the execution phase in the form of a risk assessment update and earned value data. Throughout both phases of a project the intertwining of risk analysis and cost control techniques combine to form a methodology that is better than performing them independently.

The construction industry is in need of project management tools that are straightforward and take advantage of the industry's tendency to use engineering judgement to solve problems. The proposed methodology uses a qualitative risk assessment technique that capitalizes on providing a structured format to develop experience and judgement into a formal risk assessment process. This process of providing structure to allow the project team to use their experience is a central theme of the proposed methodology. However, numerical values are used where appropriate such as a determination of risk acceptability is based on the cost effectiveness of risk reduction. The decision analysis technique of using decision trees is also based on cost values and numerical expressions for probability.

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7.3. Conclusions

Chapter one established the primary objective of this dissertation, develop a proposed methodology to control costs when constructing complex structures. This objective was met by developing a proposed methodology that includes a compatible and symbiotic combination of risk analysis, simulation and cost control techniques. In addition, the following sub-objectives have been achieved:

- This research establishes the state of the art of cost control and risk analysis as applied to the construction of complex structures.
- Suitable methods of cost control and risk analysis have been defined and employed in a proposed risk-based methodology to control cost.
- A proposed methodology to control cost when constructing complex structures has been developed and presented.
- An example of how the proposed methodology is applied was demonstrated by planning and hypothetically executing the construction of a MOB.
- The proposed methodology was verified and validated.
- This chapter documents the final conclusions and recommendations of this study.

Complex structures are challenging to deliver under budget due to the uncertainty associated with the risks involved in their construction. This study has proposed a methodology to help quantify this uncertainty by applying a structured approach to assess risk and control costs.

Case study results show how the proposed methodology can be applied to a complex project such as the MOB. The risk analysis combined with simulation

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developed cost and schedule targets that account for uncertainties when building this structure. A hypothetical construction scenario successfully demonstrated the combined use of risk analysis and cost control to identify and solve cost problems.

7.4. Recommendations

The proposed methodology relies on the experience and judgment of the project team to quantify the risks associated with a complex project. This reliance should provide satisfactory results provided the team is well balanced, has sufficient knowledge, and experience with the project under consideration. The size and definition of the project team needs further study to better quantify the appropriate number and mix of personnel.

The proposed methodology uses tables based on the outcome of the risk assessment to establish shape parameters and ranges of probability distributions used in the simulation to establish cost and schedule targets. The linkage between the risk assessment and determining the appropriate probability distributions should be researched for a more analytical connection. Perhaps an Analytical Hierarchy Process (AHP) or another decision technique could be used. The level of effort required to produce this tighter linkage needs to be balanced against the potential increase in accuracy of the results.

The proposed methodology is readily adaptable to fuzzy set theory. The risk assessment is preformed in linguistic terms and could be reduced to mathematical expressions. This may provide a convenient linkage between risk analysis and a numerical cost control technique.

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The decision analysis techniques employed by the proposed methodology are goal or decision trees. Decision trees are preferred because they produce more discerning results provided the data is available to populate the expected probabilities. Applying a fuzzy technique can also develop the required probability data.

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APPENDIX A EARNED VALUE CHART FOR HINGED MOB

The earned value data for the case study is shown in Table A-1. This table shows the planed value of the work for one hinged MOB module. The data was developed using the estimated cost for MOB components, spread out over a component's construction duration. Figure A-1 is the planned value chart for the one hinged MOB module.

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Table A-1. Earned Value Data for the Hinged MOB Module

WBS	Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
11011	P L Hull	2	4	8	10	10	12	14	12	8									
11012	S I Hull			2	4	8	10	10	12	14	12	8							
11510	S Columns					1	1	1	1	2	2	2	2	2	2	2	3	3	3
11520	P Columns									1	1	1	1	2	2	2	2	2	2
11410	Braces set 1				1	1	2	2											
11420	Braces set 2							1	1	2	2								
11430	Braces set 3										1	1	2	2					
11440	Braces set 4													1	1	2	2		
13610	U Hull 01 deck	3	6	9	10	10	12	13	12	12	10	8	8						
13620	U Hull 02 deck							3	6	9	9	10	11	12	12	12	10	8	8
13630	U Hull 03 deck													3	6	9	9	10	11
13640	U Hull 04 deck																		
13650	U Hull 05 deck																		
15000	Assembly													2	5	3			2
	Column Sum	5	10	19	25	30	37	44	44	48	36	30	24	24	28	30	26	23	26
	Cumulative	5	15	34	59	89	126	170	214	262	298	328	352	376	404	434	460	483	509

WBS	Item	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
11011	P L Hull																		
11012	S I Hull																		
11510	S Columns	2	2	1	1														
11520	P Columns	2	3	3	3	2	2	1	1										
11410	Braces set 1																		
11420	Braces set 2																		
11430	Braces set 3																		
11440	Braces set 4																		
13610	U Hull 01 deck																		
13620	U Hull 02 deck																		
13630	U Hull 03 deck	12	12	12	10	8	8												
13640	U Hull 04 deck	3	6	9	9	10	11	12	12	12	10	8	8						
13650	U Hull 05 deck							3	6	9	9	10	11	12	12	12	10	8	8
15000	Assembly	5	3					2	5	3						2	5	3	
	Column Sum	24	26	25	23	20	21	18	24	24	19	18	19	12	12	14	15	11	8
	Cumulative	533	559	584	607	627	648	666	690	714	733	751	770	782	794	808	823	834	842

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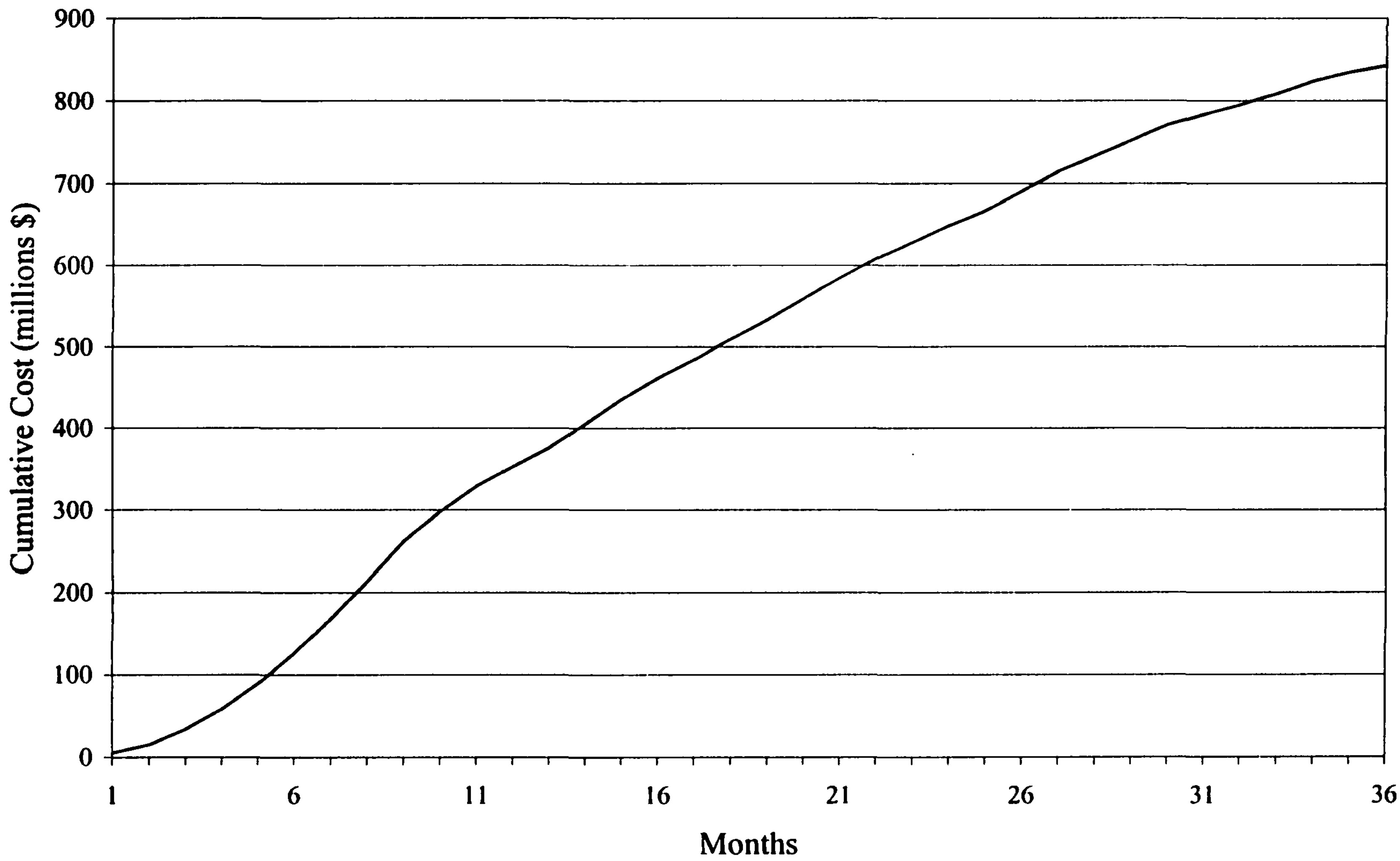

Figure A-1. Planned Value of the Hinged MOB Module

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REFERENCES

1. AACE (2000). "AACE International's Risk Management Dictionary." *Cost Engineering,* Volume 42/No 4 April 2000, Association for the Advancement of Cost Engineering, Morgantown, WV.

2. AIAA (1998). "*Guide for the Verification and Validation of Computational Fluid Dynamics Simulation*". American Institute of Aeronautics and Astronautics, Report G-077-1998, Reston, VA.

3. Aaron, A.L. (1997). "The Estimating Process." *The Engineer's Cost Handbook,* Edited by Richard E. Westney, Marcel Dekker, New York, NY.

4. Abba, W.F. (1997). "Earned Value Management Reconciling Government and Commercial Practices." *Program Manager Magazine*, JAN-FEB Issue, Defense Systems Management College Press, Fort Belvoir, VA.

5. AbouRizk, S.M., and Halpin D. (1992). "Statistical Properties of Construction Duration Data." *Journal of Construction Engineering and Management*, Vol. 118, (3). American Society of Civil Engineers (ASCE), Reston, VA.

6. Abu-Hijleh, S.F. and Ibbs, C.W. (1993). "Systematic Automated Management Exception Reporting." *Journal of Construction Engineering and Management*, Vol.119(1), ASCE, Reston, VA.

7. Adrian, J.J. (2000). "Construction Productivity." Construction Productivity Seminar Notebook prepared of the Association of General Contractors of Washington, Seattle, WA.

8. Aker Maritime Inc. (1997). "ARCOMS Concept Study." a report prepared for NSWC Division USN, Bethesda, MD.

9. Al-Bahar, J.F. and Crandall, K. C. (1990). "Systematic Risk Management Approach for Construction Projects." *Journal of Construction Engineering and Management*, Vol.116(3), ASCE, Reston, VA.

10. American Society of Civil Engineers (ASCE). (1985). *Construction Cost Control,* ASCE Manuals and Reports of Engineering Practice No. 65, ASCE, Reston, VA.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

11. Ang, Alfredo H-S., and Tang, Wilson H. (1984). *Probability Concepts in Engineering Planning and Design, Volume II Decision, Risk and Reliability*, John Wiley and Sons, New York, NY.

12. Ayyub, B.M. and Bender, W. J. (1999). "Assessment of the Construction Feasibility of the Mobile Offshore Base Part IV- Preliminary Construction Guidelines." a report for the Office of Naval Research and the Naval Facilities Engineering Service Center, Port Hueneme, CA

13. Ayyub, B.M. and Bender, W. J. and Blair, A.N. (1999a). "Assessment of the Construction Feasibility of the Mobile Offshore Base Part I- Risk Informed Assessment Methodology." a report for the Office of Naval Research and the Naval Facilities Engineering Service Center, Port Hueneme, CA

14. Ayyub, B.M., Bender, W.J. and Blair, A.N. (1999b). "Assessment of the Construction Feasibility of the Mobile Offshore Base Part II- Construction Systems Definition." a report for the Office of Naval Research and the Naval Facilities Engineering Service Center, Port Hueneme, CA.

15. Ayyub, B.M., Bender, W.J. and Blair, A.N. (1999c). "Assessment of the Construction Feasibility of the Mobile Offshore Base Part III- Construction Risk Analysis." a report for the Office of Naval Research and the Naval Facilities Engineering Service Center, Port Hueneme, CA.

16. Ayyub, B.M., Bender, W.J. and Blair, A.N. (2000). "Assessment of the Construction Feasibility of the Mobile Offshore Base Part V- Special Topics: Terrestrial Construction and Weather Risk Analysis." a report for the Office of Naval Research and the Naval Facilities Engineering Service Center, Port Hueneme, CA.

17. Ayyub, B.M. and Haldar, A. (1984). "Project Scheduling Using Fuzzy Set Concepts." *Journal of Construction Engineering and Management*, Vol. 110(2). ASCE Reston, VA.

18. Ayyub, B.M. and Haldar, A. (1985). "Decisions in Construction Operations." *Journal of Construction Engineering and Management*, Vol. 111(4). ASCE Reston, VA.

19. Ayyub, B. M. and McCuen, R.H. (1997). *Probability, Statistics and Reliability for Engineers*, CRC Press, Boca Raton, FL.

20. Ayyub, B.M. and Wilcox, R. (2000). "A Risk-based Compliance Approval Process for Personal Flotation Devices." a report for US Coast Guard, BMA Engineering, Potomac, MD.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

21. Baker, M. J., Graves, R.J. and Kearney, M. (1995). " A Methodology for Risk Management in Civil, Mechanical and Structural Engineering." *Risk Management in Civil, Mechanical and Structural Engineering,* conference proceedings edited by M. James, Thomas Telford Publishers London, England.

22. Banks, J., Carson, J.S., and Nelson, B.L. (1996). *Discrete – Event System Simulation* 2nd edition, Simon and Schuster, Upper Saddle River, NJ.

23. Barrie, D.S. and Paulson, B.C. (1984). *Professional Construction Management* 2nd edition, McGraw-Hill, New York, NY.

24. Bechtel National Inc. (1997). "Independent Module MOB Concept Development." a report prepared for NSWC Division USN, Bethesda MD.

25. Bender, W.J. (1998). "Risk Analysis of a Small Construction Project." a graduate course report for Risk for Engineers ENRE 670, University of Maryland, College Park, MD.

26. Blair, A.N. (1999). "Risk Analysis of Cost and Schedule of Complex Engineering Systems. " Doctoral Dissertation, University of Maryland, College Park, MD.

27. Blair, A. N., Ayyub, B.M., Bender, W.J. (2000). "Fuzzy Stochastic Risk-Based Decision Analysis: MOB Case Study." *Marine Structures Journal,* Society of Naval and Marine Engineers, expected publication date fall 2000, Jersey City, NJ.

28. Bledsoe, J.D. (1992). *Successful Estimating Methods*, RS Means, Kingston, MA.

29. Brown & Root. (1994). "MOB Report No. HE 94-001." a report prepared for NSWC Division USN, Bethesda MD.

30. Bureau of Labor Statistics (BLS) (1998). *National Industry-Occupation Employment Matrix*, BLS, Washington D.C.

31. Carr, R.I. (1993). "Cost, Schedule, and Time Variances and Integration." *Journal of Construction Engineering and Management*, Vol. 119(2). ASCE Reston, VA.

32. Carr, R.I. (1990). "Cost Estimating Principles." *Journal of Construction Engineering and Management*, Vol. 116(1). ASCE Reston, VA.

33. Christensen, D.I. (1993). "The Estimate At Completion Problem: A Review of Three Studies." *Project Management Journal*, Project Management Institute Upper Darby, PA.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

34. Clemen, R.T. (1996). *Making Hard Decisions An Introduction to Decision Analysis*, Duxbury Press, Pacific Grove, CA.

35. Code of Federal Regulations (CFR). (1969). "*40 CFR 6, EPA Regulations on Implementation of the National Environmental Policy Act Procedures.*" Washington, DC.

36. Construction Industry Institute (CII). (1987). "Guidelines for Implementing a Constructability Program." *Publication 3-2*, Construction Industry Institute, Austin, TX.

37. Construction Industry Institute (CII). (1989). "Management of Project Risk and Uncertainties." *Publication 6-8*, Construction Industry Institute, Austin, TX.

38. Covello, V.T. (1996). "Communicating Risk in Crisis and Noncrisis Situation." *Risk assessment and Management Handbook*, McGraw Hill Inc, New York, NY.

39. Curan, M.W., and Curran, K.M. (1995). "Range Estimating." *Effective Project Management Through Applied Cost and Schedule Control*, K.K. Humphreys editor, Marcel Deckker, New York, N.Y.

40. Curole, M.A. (1995). "Mars Risk Management Program." *Offshore Technology Conference 1995 Proceedings*, Houston, TX.

41. Cybulsky, M.K., Currie, R.L., Blair, A.N., Ayyub, B.M., Bender, W. (2000). *Simulation and Modeling of the Construction of a Mobile Offshore Base*, 23rd Meeting of the US-Japan Marine Facilities Panel of the United States - Japan Cooperative Program on Natural Resources (UJNR)," Tokyo, May 2000. US Navy, Carderock Division, Naval Surface Warfare Center, Bethesda. MD.

42. Dagostino, F.R. and Feigenbaum, L. (1999). *Estimating in Building Construction*, Prentice-Hall, Upper Saddle River, NJ.

43. Defense Acquisition University (1998). *Risk Management Guide*, Defense Systems Management College Press, Fort Belvoir, VA.

44. Diekmann, J.E. (1997). "Risk Analysis for Environmental Remediation Projects: A Comprehensive Approach." *Cost Engineering* Vol. 39 No. 8. Association for the Advancement of Cost Engineering, Morgantown, WV.

45. Edwards, L. (1995). *Practical Risk Management in the Construction Industry*, Thomas Telford Publications, London, England.

46. Farmer, F. R. (1967). "Reactor Safety and Siting: A Proposed Risk Criterion." *Nuclear Safety*, 8(6), 539-548.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

47. Fleming, Q.W. and Hoppelman, J.M. (1996). *Earned Value Project Management*, Project Management Institute, Upper Darby, PA.

48. Fuente, R. and Manzanares, E. (1996). "A Production Control System Based on Earned Value Concepts." *Journal of Ship Production*, Vol 12(7), Society of Naval and Marine Engineers, Jersey City, NJ.

49. Gould, F.E. (1997). *Managing the Construction Process,* Prentice Hall, Upper Saddle River, NJ.

50. Grose, V.L. (1987). *Managing Risk,* Prentice Hall Inc, Englewood Cliffs, NJ.

51. Halpin, D.W. (1985). *Financial and Cost Concepts for Construction Management*, John Wiley and Sons, New York, N.Y.

52. Hastack, M., Halpin, D.W., Vaneges, J. (1997). "COMPASS-New paradigm for Project Cost Control Strategy and Planning." *Journal of Construction Engineering and Management*, Vol. 122(3), ASCE, Reston, VA.

53. Heinze, K. and Westney, R.E. (1997). "Cost Control Systems." *The Engineers Cost Handbook,* Marcel Dekker, New York, NY.

54. Hendrickson, C. and Au, T. (1989). *Project Management for Construction,* Prentice Hall, Edgewood Cliffs, NJ.

55. Hess, P., III, and Ayyub, B.M. (1997). "Failure Definition for Structural Reliability Analysis." SR-1383, SSC, USCG, Washington, D.C.

56. Hulett, D.T. (1995). "Project Schedule Risk Assessment." *Project Management Journal*, Project Management Institute, Upper Darby, PA.

57. Humphreys, K.K. (1991). *Jelen's Cost and Optimization Engineering* 3rd edition, McGraw-Hill, New York, NY

58. Ibbs, C.W., Ashely, D.B., Neil,J.M. and Feiler,F.W. (1987). "An Implementation Strategy for Improving Project Control Systems." *Project Controls: Needs and Solutions*, edited by C. William Ibbs and David Ashley, ASCE, Reston, VA.

59. Jaafari, A. (1984). "Criticism of CPM for Project Planning Analysis." *Journal of Construction Engineering and Management* Vol 110(2), ASCE, Reston, VA.

60. Jeljeli, M.N. and Russell, J.S. (1995). "Coping with Uncertainty in Environmental Construction: Decision-Analysis Approach." *Journal of Construction Engineering and Management* Vol 121(4), ASCE, Reston, VA.

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61. Kangari, R. (1995). "Risk Management Perceptions and Trends of U.S. Construction." *Journal of Construction Engineering and Management Vol 121(4),* ASCE, Reston, VA.

62. Kaplan, S. (1991). "The General Theory of Quantitative Risk Assessment." *Risk-Based Decision making in Water Resources V,* Proceeding of the fifth conference, Edited by Y. Haimes, D. Moser, E. and Stakhiv, ASCE, Reston VA.

63. Karaszewski, Z. (1998). "Risk Analysis of Constructed Systems." ENCE 688 course notes. University of Maryland at College Park, MD.

64. Kartam, N.A. (1996). "Making Use of Construction Lessons Learned in Project Life Cycle." *Journal of Construction Engineering and Management* Vol. 122(1), ASCE, Reston, VA.

65. Kazi, A.S. and Charoenngam, C. (1999). "A Cost Analysis Information System for Developing and Underdevelopied Counties." *Cost Engineering,* Volume 41/No8 August 1999, Association for the Advancement of Cost Engineering, Morgantown, WV.

66. Kerzner, H. (1992). *Project Management* 4th edition, Van Nostrand Reinhold, New York, NY.

67. Kim, S. and Bajaj, D. (2000). "Risk Management in Construction: An Approach for Contractors in South Korea." *Cost Engineering,* Volume 42/No1 January 2000, Association for the Advancement of Cost Engineering, Morgantown, WV.

68. Koskela, L. (1992). "Application of the New Production Philosophy to Construction." *Technical report No. 72*, Center for Integrated Facility Engineering. Department of Civil Engineering. Stanford University, CA. Available at www.leanconstruction.org/papers.htm

69. Kumamoto, H., and Henley, E.J. (1996). *Probabilistic Risk Assessment and Management for Engineers and Scientists*, 2nd *Edition*, IEEE Press, New York, NY.

70. Kvaerner Maritime (1999). "Seabase, The Flexible Bridge Concept." MOB Technical Exchange Conference, March 1999, Arlington, VA.

71. Laufer, A. (1996). *Simultaneous Management: Managing Projects in a Dynamic Environment*, American Management Association, New York, NY.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

72. Laufer, A., and Howell, G.A. (1993). "Construction Planning: Revising the Paradigm." *Project Management Journal*, Project Management Institute, Upper Darby, PA.

73. Law, A. and Kelton, W. D. (1991). *Simulation Modeling and Analysis* 2nd edition, McGraw-Hill, Inc, New York, NY.

74. Lewis, R.O. (1992). *Independent Verification and Validation,* John Wiley and Sons, New York, NY.

75. Linstone, H.A. and Turoff, M. (1975). *The Delphi Method Techniques and Applications*, Addison-Wesley, Reading, MA.

76. Maritime Administration (MARAD). (1997). "Report on Survey of US Shipbuilding and Repair Facilities." prepared by, Division of Cost Analysis and Production, Office of Ship Construction, Maritime Administration, US Department of Transportation, Washington DC.

77. McDermott Shipbuilding Inc. (1996). "Mobile Offshore Base Preliminary Design Drawing." Prepared for NSWC Carderock Division USN, Bethesda, MD.

78. McDermott Shipbuilding Inc and McDermott Technology Inc. (1997). "Mobile Offshore Base (MOB) Build Strategy." a report prepared for NSWC Carderock Division USN, Bethesda, MD.

79. McKim, R.A. (1992). "Risk Management Back to Basics." *Cost Engineering* Vol. 34(12), Association for the Advancement of Cost Engineering, Morgantown, WV.

80. Microsoft Corporation. (2000). www.microsoft.com

81. Mincks, W.R. and Johnson, H. (1997). *Construction Jobsite Management*, Delmar Publishers, Albany, NY.

82. Mitten, D.N. (1997). "Applying the Principles of Value Engineering." *The Engineer's Cost Handbook*, Edited by Richard E. Westney, Marcel Dekker, New York, NY.

83. Modell, M.E. (1996). *A Professional's Guide to Systems Analysis,* McGraw Hill, New York, NY.

84. Mullholland, B. and Christian, J. (1999). "Risk Assessment in Construction Schedules." *Journal of Construction Engineering and Management*, Vol. 125(1), ASCE, Reston, VA.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

85. Mustafa, M.A. and Al-Bahar, J.F. (1991). "Project Risk Assessment Using the Analytic Hierarchy Process." *IEEE Transactions on Engineering Management,* Vol 38(1) IEEE, Piscataway, NJ.

86. National Research Council. (1989). *Improving Risk Communication,* National Academy Press, Washington, DC.

87. National Research Council. (1983). *Risk Assessment in the Federal Government: Managing the Process,* National Academy Press, Washington, DC.

88. NAVSEA Naval Sea Systems Command. (1999). "Quarterly Ship Production Reports." Cost, Engineering and Industrial Analysis Division, NAVSEA, Washington, DC.

89. Newnan, D.G., Lavelle, J.P., and Eschenbach, T.G. (2000). *Engineering Economic Analysis,* Engineering Press, Austin, TX.

90. Ock, J.H. (1996). "Activity Duration Quantification Under Uncertainty: Fuzzy Set Theory Application." *Cost Engineering* Vol. 38/ No. 1. Association for the Advancement of Cost Engineering, Morgantown, WV.

91. Oglesby, C.H., Parker, H.W., and Howell, G.A. (1989). *Productivity Improvement in Construction,* McGraw-Hill, New York, NY.

92. Orczyk, J.J. (1997). "Controlling the Cost of Construction Labor." *The Engineer's Cost Handbook,* Edited by Richard E. Westney, Marcel Dekker, New York, NY.

93. Ostwald, P.E. (2000). *Construction Cost Analysis and Estimating,* Prentice Hall, Upper Saddle River, NJ.

94. Paek, J.H., Lee, Y.W. and Ock, J.H. (1993). "Pricing Construction Risk: Fuzzy Set Application." *Journal of Construction Engineering and Management,* Vol. 117(3), ASCE, Reston, VA.

95. Primavera Systems INC. (2000). www.primavera.com

96. Project Management Institute (PMI). (1996). *A Guide to the Project Management Body of Knowledge,* Project Management Institute, Upper Darby, PA.

97. Rasdorf, W.J. and Abudayyeh, O.Y. (1992). "Cost and Schedule-Control Integration Issues and Needs." *Journal of Construction Engineering and Management,* Vol. 117(3), ASCE, Reston, VA.

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98. Rayburn, L.G. (1996). *Cost Accounting* 6th edition, Times Mirror Irwin Book Team, Chicago, IL.

99. Riggs, L. (1986). "Project Controls and Techniques." *Proceedings of the Specialty Conference on Project Controls Needs and Solutions,* Edited by C.W. Ibbs and D.B Ashley, ASCE, Reston, VA.

100. Russell, J.S. and Gugel, J. G. (1993). "Comparison of Two Corporate Constructability Programs." *Journal of Construction Engineering and Management*, Vol. 119(4), ASCE, Reston, VA.

101. Reuters (2000). "Big Dig Final Cost Put at $13.5 Billion" 16 June 2000, available at http://news.excite.com

102. R. S. Means (1999). *Building Construction Cost Data 58th Annual Edition*, R.S. Means, Kingston, MA.

103. Sackman, H. (1972). *Delphi Critique: Expert Opinion, Forecasting and Group Process,* Lexington Books, Lexington, MA.

104. Seattle Post Intelligencer (2000a) 13 October, 2000

105. Seattle Post Intelligencer (2000b) 10 July, 2000

106. Seattle Post Intelligencer (2000c) 20 September, 2000

107. Singh, A. (1991). "Knowledge Base for C/SCSC" *Cost Engineering* Vol. 33(6). Association for the Advancement of Cost Engineering, Morgantown, WV.

108. Smith, N.J. (1999). *Managing risk in Construction Projects*, Blackwell Science Ltd, Malden, MA.

109. Smith, G.R. and Bohn, C.M. (1999). "Small to Medium Contractor Contingency and Assumption of Risk." *Journal of Construction Engineering and Management*, Vol. 125(2), ASCE, Reston, VA.

110. Spinner, M. (1997). *Project Management Principles and Practices*, Prentice Hall Upper Saddle, NJ.

111. Snel, A. (1999). Safco Field Cost $100 Million More than Expected." *Seattle Post Intelligencer*, 9 July 1999, Seattle, WA.

112. Stewart, R.D., Wyskida, R.M., and Johannes, J.D. (1995). *Cost Estimators Reference Manual,* John Wiley and Sons, New York, N.Y.

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113. Storch, R.L., Hammon, C.P., Bunch, H.M., Moore, R.C. (1995) *Ship Production 2nd Edition*, Cornell Maritime Press, Centreville, MD.

114. Wang, J.X. and Roush, M.L. (2000). *What Every Engineer Should Know About Risk Engineering and Risk Management,* Marcel Dekker, New York, NY.

115. Ward, S. (1999). "Requirements for an Effective Project Risk Management Process." *Project management Journal* Vol. 30(3), Project Management Institute, Upper Darby, PA.

116. Wendling, R.V., and Lorance, R.B. (2000). "Integration of Cost and Schedule Risk Models." *Cost Engineering* Vol. 42/ No. 4. Association for the Advancement of Cost Engineering, Morgantown, WV.

117. Woodward, R.W. (1992). "A Case Study." *Lean Construction*, Edited by Luis Alarcon, A.A. Balkema, Rotterdam, Netherlands.

118. Wiggins, J., "ESA Safety Optimization Study." Hernandez Engineering, HEI-685/1026, Houston, TX, 1985.

119. Wilcox, R.C., Karaszewski, Z.I., and Ayyub, B.M., 1996, "Methodology for Risk-based Technology Applications to Marine System Safety." *Proceedings of the Ship Structures Symposium*, SSC and SNAME, Arlington, VA, D1-D15

120. WSDOT (Washington State Department Of Transportation) (2000). www.wsdot.wa.gov

121. Zack, J.G. (1996). "Risk Sharing" Good Concept, Bad Name." *Cost Engineering* Vol. 38/ No. 7. Association for the Advancement of Cost Engineering, Morgantown, WV.

122. Zhan, J.G. (1998). "A Project Cost Model." *Cost Engineering* Vol. 40/ No. 12. Association for the Advancement of Cost Engineering, Morgantown, WV.

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Position

Assistant Professor of Construction Management, Industrial Engineering Technology Department, College of Professional and Education Studies, Central Washington University, Ellensburg, WA.

Education

BSCE 1981 Washington State University
MSCE 1989 Oregon State University
PhD Candidate University of Maryland, College Park

Professional Experience

Builder & construction manager for US Navy, instructor Naval Academy 1981-1998.
Assistant Professor of Construction Management 1998-Present.
Consultant to construction industry in cost control, project management, and contract dispute resolution.

Courses Taught

Fall '00		Winter '00		Spring '00	
Statics	4	Estimating I	4	Estimating II	4
Contract Law	4	Statics	4	Project Management	4
Competition Prep	1	Blueprint Reading	4	Mechanical Systems	3
Taught Engineering Economics, Ocean/ Civil Engineering Design, and Naval Architecture					

Refereed Publications

"*Mobile Offshore Base Construction Feasibility*" W.J. Bender and B.M. Ayyub, **Journal of Offshore and Petroleum Engineers**. Paper is published in the proceedings and was presented at the International Society of Offshore and Petroleum Engineers conference in Seattle, May 2000.

"*Fuzzy Stochastic Risk-Based Decision Analysis: MOB Case Study*" A. N. Blair, B.M. Ayyub, and W.J. Bender, **Marine Structures Journal**, by the Society of Naval and Marine Engineers, to appear in Fall 2000.

"Risk-Based Cost Control For Construction of Complex Systems" W. J. Bender and B.M. Ayyub, to appear in **2001 Association for the Advancement of Cost Engineering International Transactions**, May 2001.

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"Risk-based Simulation Models for the Construction of the Mobile Offshore Base" W.J. Bender, B.M. Ayyub, and A. N. Blair, currently being reviewed for **The Journal of Ship Production,** by the Society of Naval and Marine Engineers.

Published Works That Contribute to the Profession

"*Assessment of the Construction Feasibility of the Mobile Offshore Base, Part I* **Risk Informed Assessment Methodology**" January 1999 with Bilal M. Ayyub and Andrew N. Blair, University of Maryland. This 35-page report is a contract deliverable for the Office of Naval Research (ONR). It introduces the topic of risk analysis and describes the methodology that will be applied to assess the construction feasibility of the MOB.

"*Assessment of the Construction Feasibility of the Mobile Offshore Base, Part II* **Construction Systems**" May 1999 with Bilal M. Ayyub and Andrew N. Blair, University of Maryland. This 72-page report for ONR estimated and scheduled five potential MOB concepts. Additionally the US capacity to build a MOB was documented and potential risk areas were identified.

"*Assessment of the Construction Feasibility of the Mobile Offshore Base, Part III* **Risk Analysis**" July 1999 with Bilal M. Ayyub and Andrew N. Blair, University of Maryland. This 119-page report for ONR performed a construction risk analysis using simulation, decision tree analysis and fuzzy techniques.

"*Assessment of the Construction Feasibility of the Mobile Offshore Base, Part IV* **Constructability Guidelines**" September 1999 with Bilal M. Ayyub, University of Maryland. This 55-page report for ONR developed construction guidelines to efficiently build a MOB.

"*Assessment of the Construction Feasibility of the Mobile Offshore Base, Part V* **Special Construction Methods and Weather Risk Analysis**" July 2000 with Bilal M. Ayyub and Andrew N. Blair, University of Maryland. This 95-page report for ONR developed a novel construction method to build a MOB and used risk methods to assess weather impacts to the long term construction window.

Articles in Non-refereed Journals

"*Mobile Offshore Base Construction Feasibility Assessment*", W. J. Bender and B. M. Ayyub, Proceedings of the Very Large Ocean Structures Conference, September 1999.

"*Fuzzy Stochastic Risk Assessment for Mobile Offshore Base Construction*", W. J. Bender, B. M. Ayyub and A. N. Blair, Proceedings of the Very Large Ocean Structures Conference, September 1999.

"*Simulation and Modeling of the Construction of a Mobile Offshore Base*" M. K. Cybulsky, R. L. Currie, W.J. Bender, A. N. Blair, and B.M. Ayyub, Proceedings of the United States and Japan Cooperative Program for Natural Resources, May 2000.

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Presentations:
"Mobile Offshore Base Construction Simulation" Mobile Offshore Base technology conference, presented 9/21/98 in Rosslyn, VA

"Lake Keechelus Dam Assessment and Contingency Profile", A. Kaiyala and W. Bender research project presented at Symposium on Undergraduate Research and Creative Expression, Central Washington University, May 8 1999.

"Mobile Offshore Base Construction Feasibility" given at the Very Large Floating Structures Conference, Honolulu, HI, September 22-23 1999.

"Fuzzy Stochastic Risk Assessment for Mobile Offshore Base Construction" given at the Very Large Floating Structures Conference, Honolulu, HI, September 22-23 1999.

"Construction and Maintenance of Large Floating Structures" Panel Member Very Large Floating Structures Conference, Honolulu, HI, September 22-23 1999.

"Timberline Estimating Lab Take Home Exam" Panel member and delivered working paper to the Timberline educators conference Portland, OR, June 2000.

Other Scholarly Work
Developed and presented an all day professional development seminar "Construction Cost Control" for American Society of Civil Engineers (ASCE) San Francisco, CA. September 2000.

Three hour seminar developer and presenter for the ASCE national convention in Seattle titled "Construction Cost Control". October 2000.

Leadership seminars for the Association of General Contractor to be given in Yakima and Wenatchee, WA January 2001.

"Cost Control Seminar" Accepted as a trainer to develop and deliver a two day seminar to be presented at the Association for the Advancement of Cost Engineering International, Pittsburgh, PA, May 2001.

Credentials
Professional Engineer, Civil, Washington State
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