TRENDING AND FORECASTING IN CONSTRUCTION OPERATIONS

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ABSTRACT

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This research aims to understand the process of progress reporting and forecasting project status of different future targeted dates. The study focuses mainly on trending and time/Cost control of engineering, procurement and construction (EPC) project. A field study of the practices of the industrial collaborator (SNC-Lavalin), along with related materials from the literature, is conducted and documented.

This research presents a model for improving trending and forecasting of time and cost in construction operations. The proposed model has 3 main functions: 1) trend estimate accuracy, 2) project progress integrated control and forecasting, and 3) progress visualization database. @Risk 5.0 for excel, Windows SharePoint Server and visual basic for application (VBA) are used to develop 3 add on tools implementing the above 3 functions. This model, with 3 developed add on tools, is designed to work together with industrial collaborator's project management system, PM+. The 1st add on tool applies probabilistic forecasting to provide trend estimate results utilizing estimate range. Engineering completion percentage and self adjustment algorithm are both utilized to provide accuracy range reference. The 2nd add on tool implements earned value method in project

progress monitoring and forecasting. Numerous progress measurement templates for engineering, procurement and construction work are utilized for plan definition and earned measurement. The 3rd add on tool provides a multimedia capability and an integration of scheduling tools and progress reports via relational database. Numerical examples based on a set of data from a training project provided by SNC are presented to illustrate and validate the essential features of the developed methodology and model.

Acknowledgements

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NOMENCLATURE

AACEI	Association for the advancement of cost engineering international
AC	Actual cost
ACWP	Actual cost of work performed
AFSC	Air force system command
ANSI	American national standard institute
BAC	Budget at completion
BCWP	Budgeted cost for work performed
BCWS	Budgeted cost for work scheduled
BO	Black out
C/SCSC	Cost/schedule control system criteria
CAP	Control account plan
CCM	Cost center method
CD	Compact disk
CP	Commitment package
CPI	Cost performance index
CRC	Commodity and resource code
CTARN	Cumulative trend accuracy range (Negative variance)
CTARP	Cumulative trend accuracy range (Positive variance)
CV	Cost variance
CWBS	Contract work breakdown structure
DoD	Department of defense

DoE	Department of engergy
EAC	Estimate at completion
EAC_t	Time Estimate at Completion
EA_m	Most likely estimate amount
EA_o	Optimistic estimate amount
EA_p	Pessimistic estimate amount
EIA	Electronic industrial association
EPC	Engineering, procurement, and construction
EPCM	Engineering, procurement, and construction management
ETC	Estimate to completion
EV	Earned value
EVM	Earned value method
FEAi:	Final evolution amount I
FFC	Forecast final cost
ISBL	Inside battery limit
IW	Initial Weight
W_{lri}	The weight of trend variance which is outside default
LR_{sa}	Self-adjustment lower range of estimate accuracy
LR	Default lower range of estimate accuracy
NASA	National aeronautics and space agency
OBS	Organization breakdown structure
OC	Outstanding change
OSBL	Outside battery limit

PBS	Project breakdown structure
PC	Personal computer
PDF	Portable document format
PERT	Program evaluation and review technique
PMB	Performance measurement baseline
PMI	Project management institute
PPI	Project performance index
PPICF	Project progress integrated control and forecasting
PV	Planned value
PVD	Project visualized database
RNG	pseudo-Random number generator (RNG)
SAR	Subjective Accuracy Range
SNC	SNC-Lavalin Group
SPI	Schedule performance index
SQL	Structure query language
SV	Schedule variance
TA	Trend amount
TAPP	Trend accurate probability program
TC	Total commitment
TCNV	Total cost amount with negative variance
TCPV	Total cost amount with positive variance
TCPI	To-complete performance index
TE	Trend estimate

TEA	Total estimated amount
TR	Trend
Twi	Weight of trend i in total occurred trends
UB	Unallocated budget
UR%	The default upper range of estimate accuracy
UR_{sa}%	The self-adjustment upper range of estimate accuracy
V_{lri}%	The trend variance percentage which is outside default lower range
V_{urj}%	The trend variance percentage which is outside default upper range
VAC	Variance at completion
VWP%	Variance weight percentage with variance
W_{lri}%	The weight of trend variance which is outside default lower range
W_{uri}%	The weight of trend variance which is outside default upper range
WBS	Work breakdown structure
WP%	Weight percentage with variance

1 Chapter one: INTRODUCTION

1.1 The Background

Time and cost control are essential management functions for achieving successful delivery of engineering, procurement and construction (EPC) projects. The primary objective of project management is to deliver the required scope of work to the client on time and within budget while meeting specified quality requirements. Tracking project progress through trending is crucial to time and cost control. A number of methods have been proposed to improve effectiveness of cost and schedule trending and control. Considerable research efforts have been made in this field, such as Cost/Schedule Control System Criteria (C/SCSC) (DoD, 1967), web-based integrated project control system (Moselhi et all, 2004). Various methods have been proposed to increase the tracking and control accuracy of cost elements of labor, material and equipments, such as computerized cost and schedule control system for construction projects (Alshibani, 1999), and for automated labor monitoring (Sacks, 2003). [1]

For EPC projects, typically, the portions of subcontract cost range from 50 to 70%. Material, labor, equipment, and indirect cost vary from 25 to 35%, 5 to 15%, 10 to 25%, and 5 to 15%, respectively (Oberlender, 2000). Successful trending and control of subcontracted work will be critical to successful project delivery.

Many EPC companies have developed their own trending methodology and internal progress report system. SNC-Lavalin Inc. one leading engineering, procurement, and construction company in Canada, has developed a project management system, which is called PM+, with a good function of trending and control subcontracted work using what is referred to as Cost Center Method (CCM).

1.2 Research Scope and Objectives

The purpose of this research is to understand the process of progress reporting and forecasting project status of different future targeted dates. The study focuses mainly on trending and time/Cost control of engineering, procurement and construction (EPC) project. The research conducted in this thesis is for the use of a field study of the practices of the industrial collaborator (SNC-Lavalin, a large EPC company in Canada), along with related materials from the literature.

The main objectives of this research are to: 1) study current trending and control methods in construction, including methods used in current practice, 2) develop an integrated method that improves the trending and forecast functions, 3) study multimedia utilization & progress reporting to visualize the reported information, 4) develop prototype add-on computer applications for the implementation of the proposed methodology, and 5) use a case study to demonstrate and validate of the proposed methodology and add-on programs.

Essentially the scope of this research is limited in: 1) the construction phase of EPC projects, 2) placing special emphasis on subcontracted work and purchase orders from the perspective of general contractor, 3) considering only time and cost, i.e. it excludes quality and safety control.

1.3 Thesis Organization

Chapter 2 provides a literature review on project planning and scheduling method, performance evaluation methods, trending and forecasting techniques, and reporting methods, including a review of the Cost Center Method (CCM) used by the industrial collaborator, SNC.

Chapter 3 documents a field study provided by SNC based on a training project. Practical processes from project definition to execution reporting are presented.

Chapter 4 describes improved methods for better trending and forecasting for subcontracted work, including trend accuracy improvement, integrated progress reporting, and visualized project reporting for better control.

Chapter 5 presents the development of 3 proposed add-on tools for implementation. It includes the programs' components, architecture and interface design.

Chapter 6 presents a case study for the validations of the proposed methodology and add-on tools.

Chapter 7 describes the conclusions of this research, highlighting its limitations, and contributions as well as suggestions for future work.

2 Chapter two: Literature review

2.1 Planning Methods

2.1.1 Scope of Work and Work Breakdown Structure (WBS)

Planning is the most crucial, knowledge intensive and challenging phase in the project development cycle, while scheduling is planning plus time (Moselhi, 1993). There likely is no factor that would contribute more to the success of any project than having a good and complete definition of the project's scope of work. Project Scope Management includes the processes required to ensure that the project includes all the work required, and only the work required, to complete the project successfully. It is primarily concerned with defining and controlling what is or is not included in the project (PMI Standards Committee 2000, 51).

Good project management relies on the Work Breakdown Structure (WBS) to define the project scope. Sometime in the early 1960s came this concept. One of the best definitions of the WBS was published in 1976 in which the author was describing what he called at the time a Project Breakdown Structure (PBS). In retrospect, the term "WBS" stuck, and PBS did not: The PBS is a graphic portrayal of the project, exploding it in a level-by-level fashion, down to the degree of detail needed for effective planning and control. It must include all deliverable end items...and include the major functional tasks that must be performed (Archibald, 1976).

The PMBOK Guide defines a WBS as a deliverable-oriented grouping of project elements that organizes and defines the total scope of the project: work not in the WBS is outside the scope of the project. (PMI Standards Committee 2000, 59)

There are many ways to develop a WBS for a project and it always reflects the way a project has been planned, cost estimated and will be managed. Figure 2.1 is a WBS example for an energy project. Some other WBS examples for different construction projects were summarized in appendix A as references, which were contributed from U.S.A Department of Defense (DoD), Department of Energy (DoE), National Aeronautics and Space Agency (NASA), Primavera P3 Manual, and Fleming Q.W. 2000, and PMI 2001.

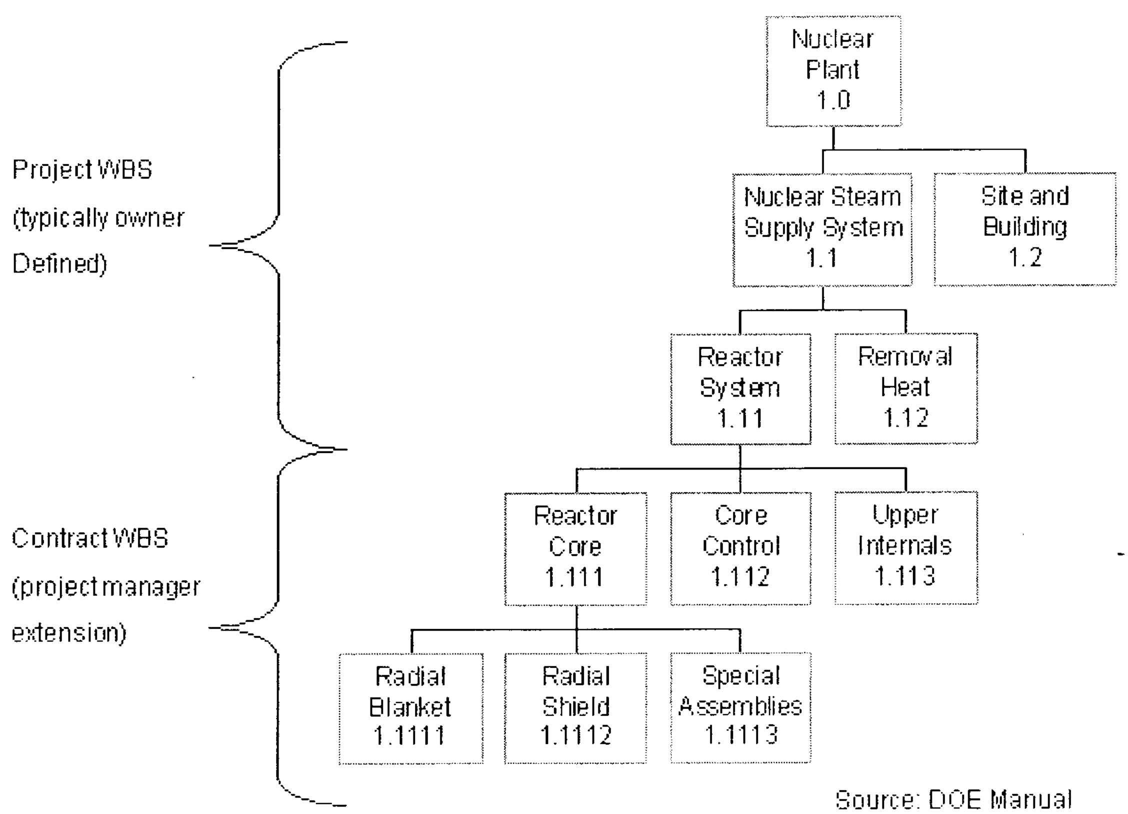


Figure 2-1 WBS Example for an Energy Project

2.1.2 Control Account, Commitment Package and Work Package

At the lowest level of each WBS element, the project will define a management-control point, which initially went by the term "cost account", but more recently is called a "control account." Cost account is a management control point at which actual costs may be accumulated and compared to the budgeted cost of work performed. A cost account is a natural control point for cost/schedule planning and control, since it represents the work assigned to one responsible organizational element on one contract work breakdown structure (CWBS) element (DoD 1967).

Initially the cost/control account was defined as the intersection point of a single organizational unit. More recently, with the increasing popularity of integrated multifunctional project teams, the requirement for one organizational unit has been expanded to constitute one multifunctional team. Additionally, while the scheduling of activities may continue to take place deeply within detailed WBS elements, the use of multifunctional project teams has resulted in larger segments of defined work being done within control accounts at higher levels of the project WBS.

Thus, under the multifunctional project team approach, management will monitor the performance of less management control points-a more logical approach and one that has led to a reduction of some 90 percent in the total number of management points (Fleming and Koppelman, 2005).

SNC-Lavalin, one of the world's leading groups of engineering and construction companies located in Montreal, uses the term Commitment Package (CP) to regroup the broken down project scope for execution planning strategy purpose. The CP is the project execution strategy expressed in terms of future Purchase Orders and Contracts (CCM user guide, 2006). Each CP contains a certain scope of work, budget, and duration. The regrouped broken scope of work can cover multiple areas and systems, or only one specific area and single system. Figure 2-2 is an example of Work Breakdown Structure from SNC-Lavalin in a Poly training project used by the Project Management System group.

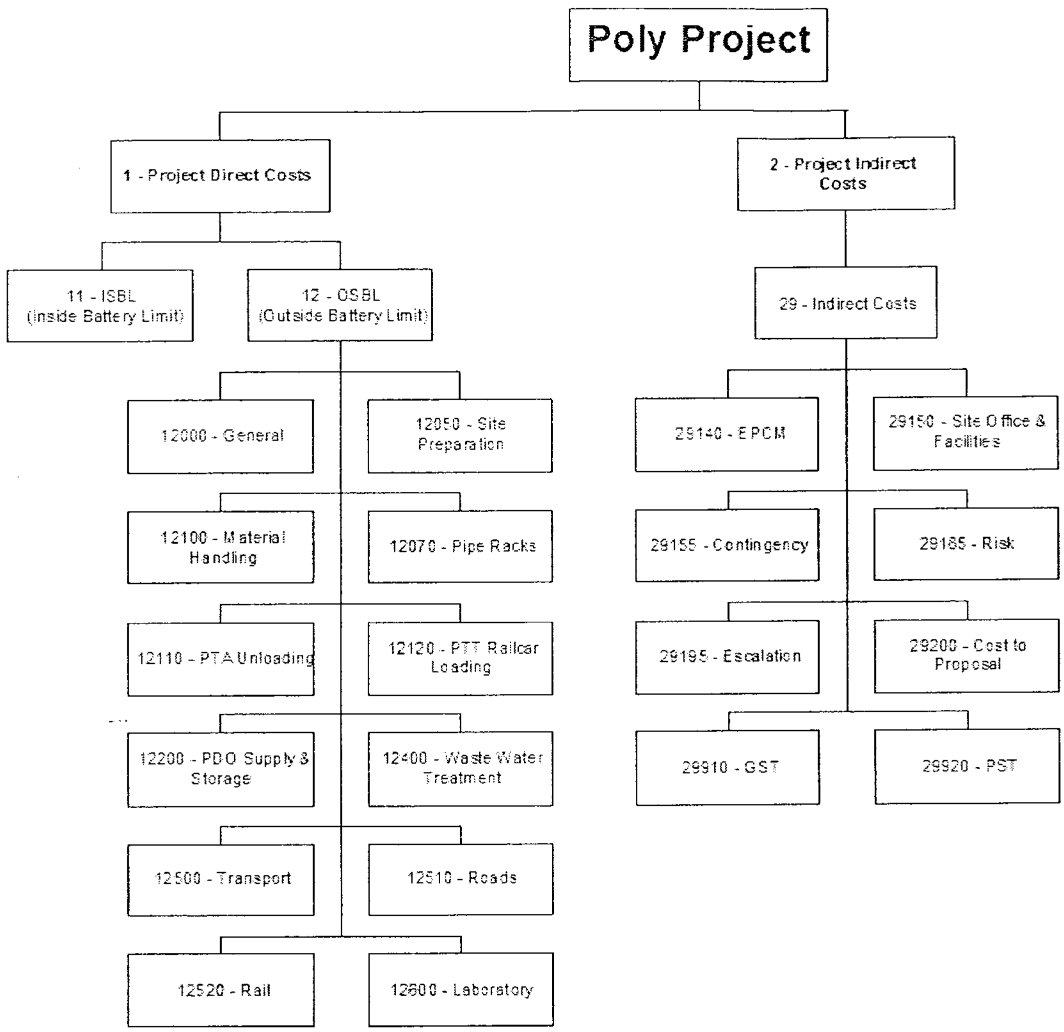


Figure 2-2 WBS Example Poly Training Project (SNC 2007)

Two CP examples in this project are extracted in table 2-1. One CP will be executed by one or multiple Purchase Orders (PO) or subcontracts, which is called PO/Contract. It is also called one to one, or one to many relationships. These relations depend on the size of the CP and market situation.

Table 2-1 CP Examples (SNC 2007)

Items	CP 2-902	CP 4-002
Code	2-902	4-002
Title	OSBL Founds- Utility, Lab, EL & Material Handling	Laboratory furniture
Type	Construction	Purchase
Scope of work	Excavation, rebar preparation and installation, formwork install and concrete casting.	Provide furniture to Laboratory building
Area	12 –OSBL	In sub area 12600 – Laboratory
Discipline	2 – Concrete work	4 – Architecture

Control account, commitment package, and work package have some similar attributes, which include certain scope of work, budget and duration. Control account groups scope of work from the view point of cost breakdown, an example being the formwork for 10 inches concrete wall; Work package groups scope of work from the view point of WBS, such as formwork in area A; Commitment package groups the scope of work from the view point of execution strategy plan, which may group certain scope of work that will be executed by multiple purchase orders or construction contracts.

The term Control Account Plan (CAP) has similar function as a CP. Figure 2-3 is an example to display this integration:

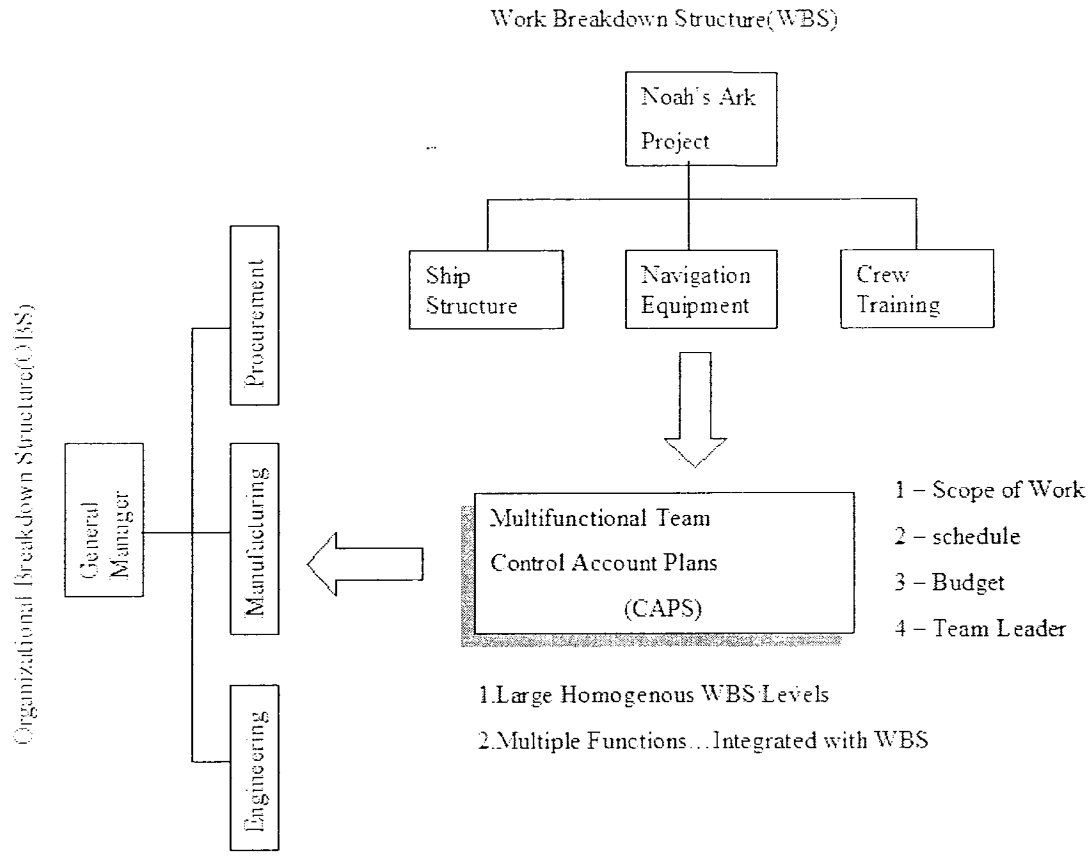


Figure 2-3 CAP and WBS

2.1.3 C/SCSC and Earned Value Method

The earned value concept was conceived more than a hundred years ago sometime in the latter part of the nineteenth century. It has experiences 4 phases of evolution (Fleming and Koppelman 2005). They are summarized in Figure 2-4.

- Phase 0 - Late 1800s. Industrial engineers in the early American factory. They used "Three dimensional" approach to assess the cost performance.
- Phase 1 – 1962-1965. U.S. Navy (Special Project Office 1958) introduced the "Program Evaluation Review Technique" (PERT) as a network-scheduling device. And in 1962, the Office of the Secretary of Defense and

National Aeronautics and Space Administration introduced the term of PERT/cost, which includes term "cost of work report"

- Phase 2 – 1976-1996. Department of Defense (DoD) formally issued its Cost/Schedule Control Systems Criteria (C/SCSC), which includes terms "Budgeted Cost of Work Performed (BCWP)," Budgeted Cost for Work Scheduled (BCWS), and Actual Cost of Work Performed (ACWP).
- Phase 3 – 1996 to Present. American National Standard Institute/Electronic Industrial Association (ANSI/EIA) 748 Guide was officially issued. Gone were the vague terms of BCWS and BCWP, and in their place were put "Planned Value" and "Earned Value." The 35 criteria were reduced into 32 criteria.

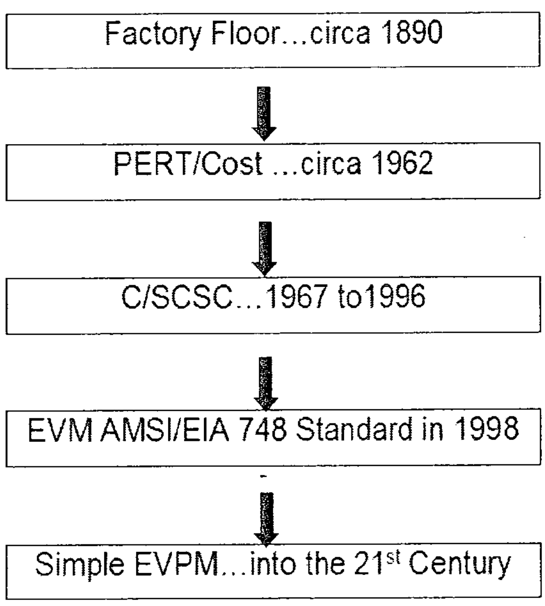


Figure 2-4 Evolution of Earned Value (Fleming and Koppelman 2005)

2.1.4 Performance Measurement Baseline

The performance measurement baseline (PMB) is an essential component of earned value project management. According to the unofficial findings of Fleming and Koppelman: the responsibilities of project managers for cost management vary considerably from one company to another, and even from project to project within the same company (Fleming and Koppelman 2005). They attempted to define a spectrum of cost responsibilities for project managers, as shown in figure 2-5. This figure begins with the more limited responsibilities as with item 1. With each additional step, the responsibilities of the project managers are broadened, and they are held accountable for managing additional categories of costs – as with overheads, materials, other direct cost, even profits.

1. Direct Labor Hours (only)
2. Direct Labor Hours (within specific labor categories)
3. Direct Labor Costs (both hours and dollars)
4. Direct Labor in Total (through overhead applications)
5. Materials and Subcontract Costs
6. Other Direct Costs-ODC (e.g., travel)
7. All Project Costs (through general and administrative)
8. All Project Costs (including profit) = Contract Price

Figure 2-5 Composition of a PMB

Figure 2-6 conceptually displays the process of taking three initial steps to form an earned value project baseline (step four in Figure 2-6). The project baseline must be established, typically done in the sequence as shown in Figure 2-6. Step one is that the project's scope of work must be defined, often with use of a work breakdown structure (WBS), leading to a statement of work, which is then assigned to a functional organization for a performance. Step two, the defined scope must be planned next and scheduled down to the detailed work package or task level. Finally, in step three, the required resources must be estimated and subsequently authorized in the form of official project budgets (Fleming and Koppelman 2005).

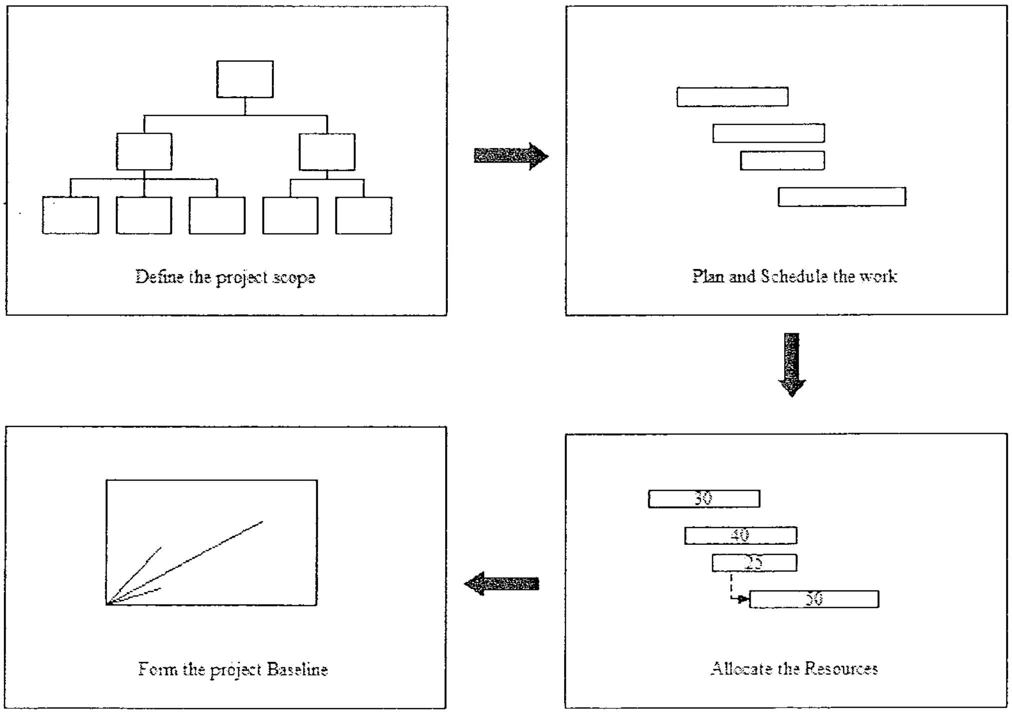
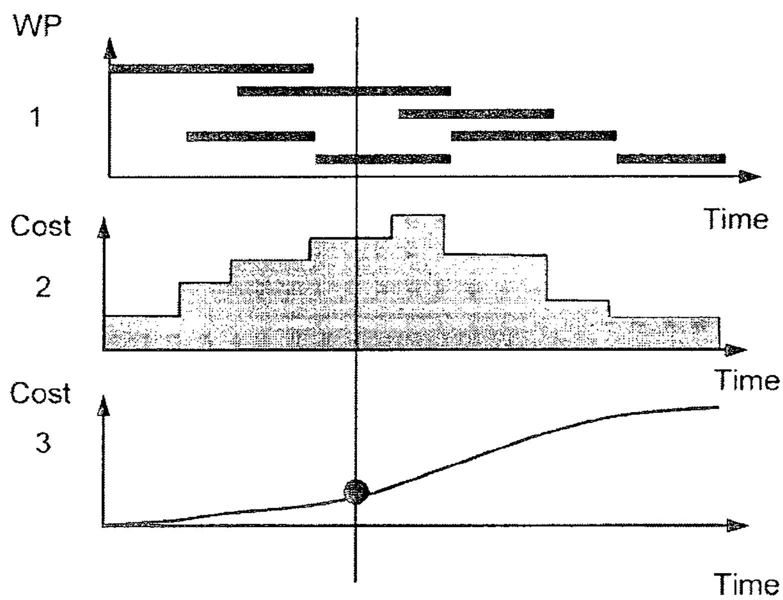


Figure 2-6 Steps to Forming the Project Baseline (Fleming and Koppelman 2005)

The control baseline is also known as a "S" curve that can be developed by allocating a cost to the individual activities, on a time-phased schedule, aggregating the cost on a period-by-period basis from start to completion, and plotting the cumulative cost as shown in figure 2-7 (Moselhi, 1993).



1. Project bar chart schedule
2. Activity resource allocation
3. Baseline S curve

Figure 2-7 Baseline Derivation Process (Moselhi 1993)

Figure 2-8 shows a comparison of WBS and OBS. On the left side is the more traditional functional matrix approach, which most projects have employed. By contrast, on the right side is an integrated management approach, required in order to employ earned value method (EVM). Each function must work in concert with all other functions on the same defied work, all within the project's WBS

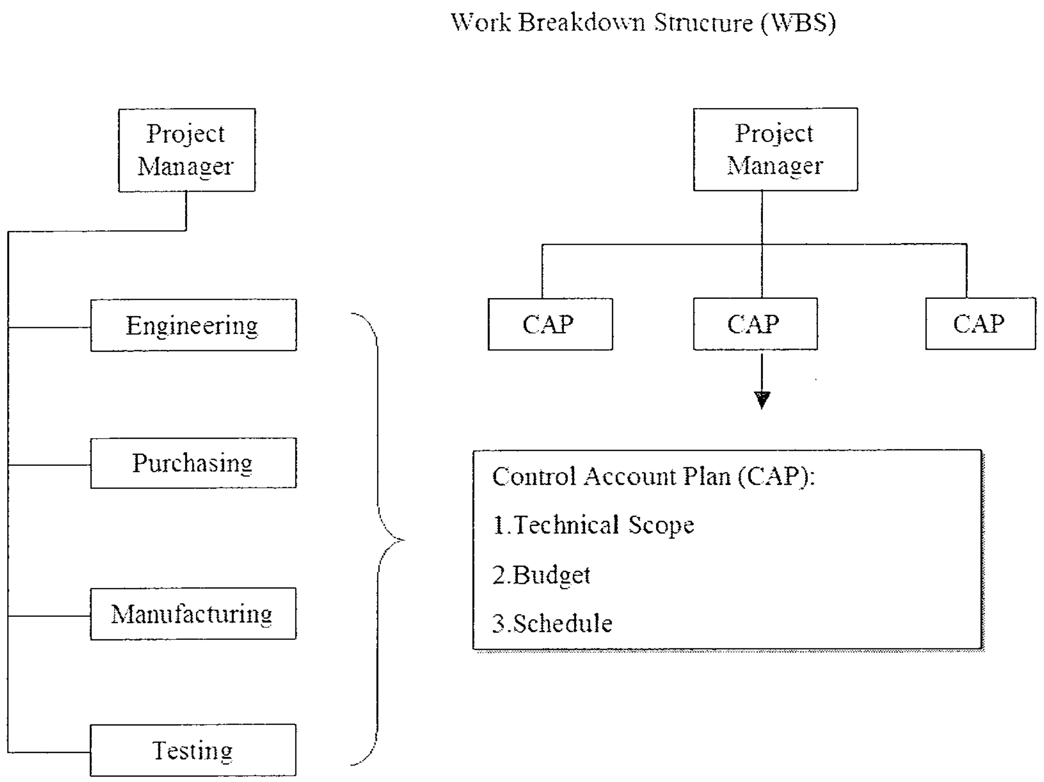


Figure 2-8 Earned Value Requires an Integrated Project Baseline

2.2 Performance Evaluation Methods

The performance evaluation method is used to track and control of time and cost from its baseline and assesses the value of the deviation. Over years, a number of methods have been developed to facilitate overall project control. Some of these methods separate schedule and cost control, while others integrate them (Moselhi 1993). Follows will discuss the individual and integrated methods.

A project scheduling system will, by definition, reflect the project's scope of work, and then place all the defined work into a specific time frame for execution. When one adds resources to the scheduling system, and the metrics to plan and consume such resources, the earned value performance plan is in place. The determination as to which metrics should be used to measure a particular application is a personal, judgmental issue and will vary by project. But the project team and the various work packages and control-account managers must ultimately select those measurement metrics that best support their particular needs (Fleming and Koppelman 2005)

The progress measurement template divides a control object into control points; based on its time and cost characteristics. For example, a control object of 'piling', representing driving a set of piles into soil is divided into four control points: 1) rig in position, PCa=40%; 2) drive and inspect, PCa= 80%; 3) trim and finish, PCa=95%; 4) hand over, PCa=100%, where PCa is planned to-date percentage completion (Ji li, 2004). Such templates serve as a default option. The users, however, have the right to modify the performance complete percentage according to individual contract agreement.

2.2.1 Traditional Tracking and Control Methods

Traditionally, time is tracked and controlled through some forms of schedules, tied to some measure of physical progress templates, while cost is controlled through the use of S-curve, including standard S-curve, single S-curve, Double S-curve, Superimposed Cost and percentage complete S-curve method. The basic variations of S-curve include:

1) The Standard S-Curve, as shown in Figure 2-9, contains three project progress stages, where starts slowly up to 25% of the project duration, accelerates from 25% to 75% of the project duration, and then slows again to completion.

2) The Single S-Curve is project dependent. The baseline may or may not be schedule-based. Those that are not schedule-based utilize some form of curve fitting models using cost and progress data collected from previously constructed projects.

3) Double S-Curve and Superimposed cost and percent complete S-Curves are as shown in Figure 2-10. They are employed as a basis for comparison with the project's actual progress. They may or may not be schedule-based with either an arbitrary specified range of variations.

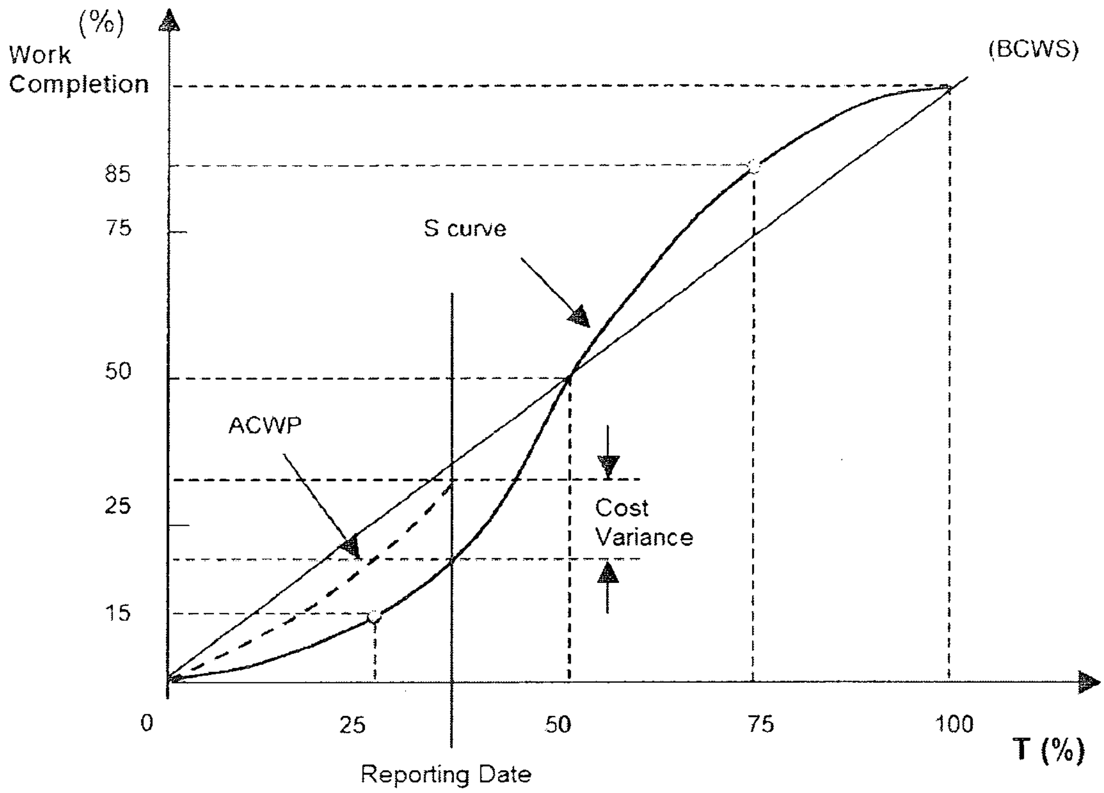


Figure 2-9 Standard S Curve for Project Control

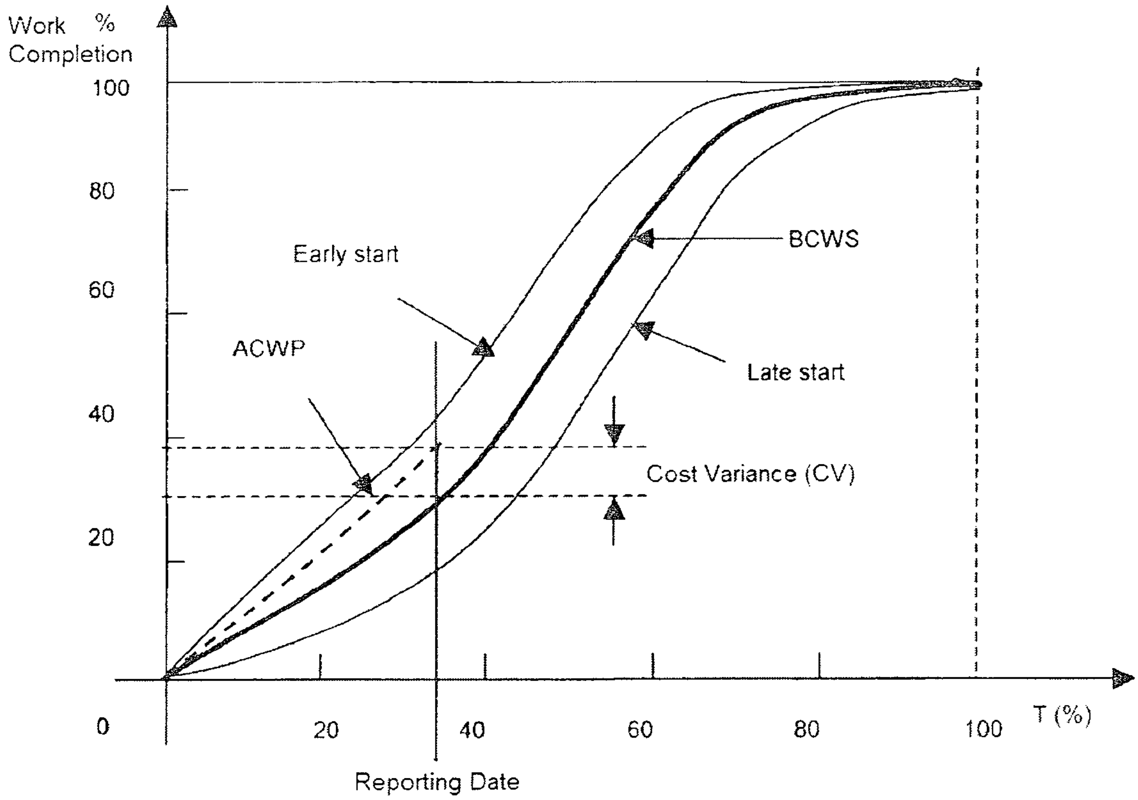


Figure 2-10 Double S-Curve for Project Control

Program Evaluation and Review Technique (PERT) is a method that tries to improve the project control function using simulation and statistical probability methods, which was first introduced to industry as a network-scheduling device by the U.S. Navy in 1958. But neither computers nor software programs were available to support the concepts of PERT or PERT/Cost at that time. The concepts were too complex and burdensome for such a large project. But it did leave an important legacy: the use of earn-value data to monitor the true cost performance during the life of a project (Fleming and Koppelman 2005).

The PERT method, technically, is a special case of a scaled Beta distribution. It can generally be considered as superior to the triangle distribution when parameters result in a skewed distribution, as the smooth shape of the curve places less emphasis in the direction of skew (@Risk 2008). The PERT approximations are exact to Beta distribution only when the shape factors of beta distribution $\alpha = 3 - \sqrt{2}$ and $\beta = 3 + \sqrt{2}$.

Cliff S. F. et al. (2005) proposed a formulation for developing a Beta probability density function (PDF) for use in construction simulation modeling. Subjectively estimated Beta PDF parameters and simulation with Beta PDF defined by project data were implemented and compared. The results vary slightly of 4% variation.

2.2.2 Integrated Tracking and Control Methods

Recently, the adoption of earned value method (EVM) has been gaining popularity, and more and more standards bodies have started developing EVM standards. EVM can help to illuminate where a project is and where it is going as compared to where it was supposed to be and to be going. It provides organizations with the methodology needed to integrate the management of project scope, schedule, and cost. This method relies on three key data points that are shown in figure 2-11, while figure 2-12 indicating these terms in a simplified way.

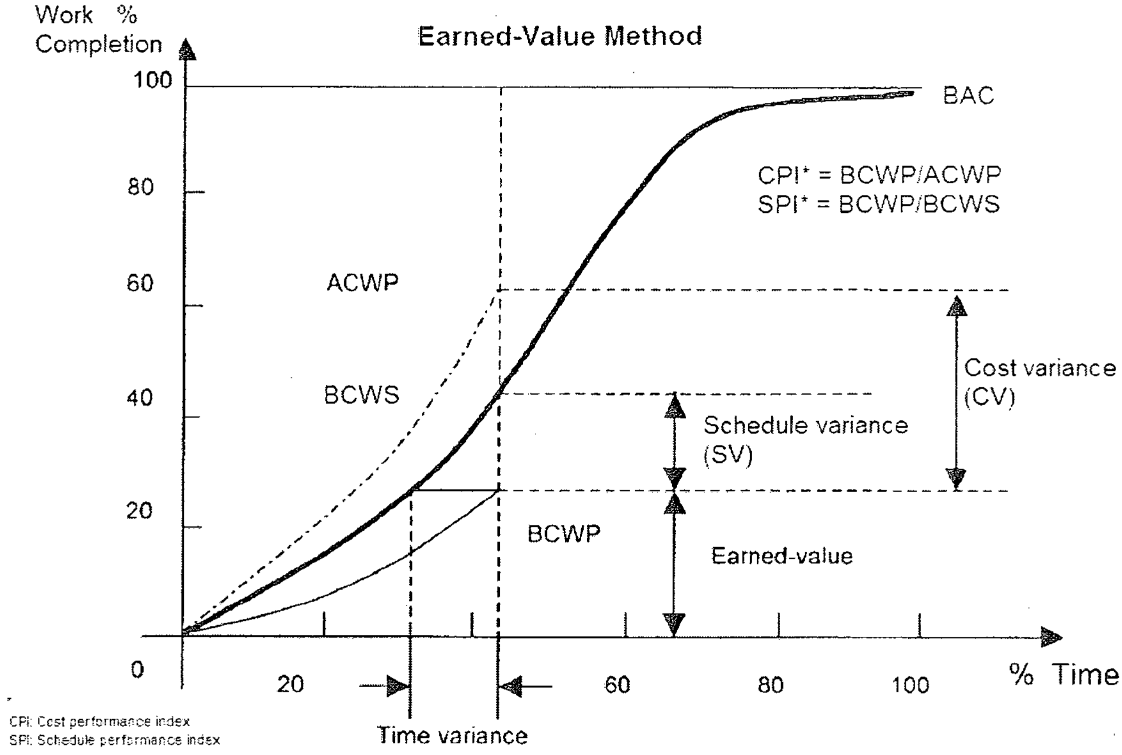


Figure 2-11 Earned Value Method

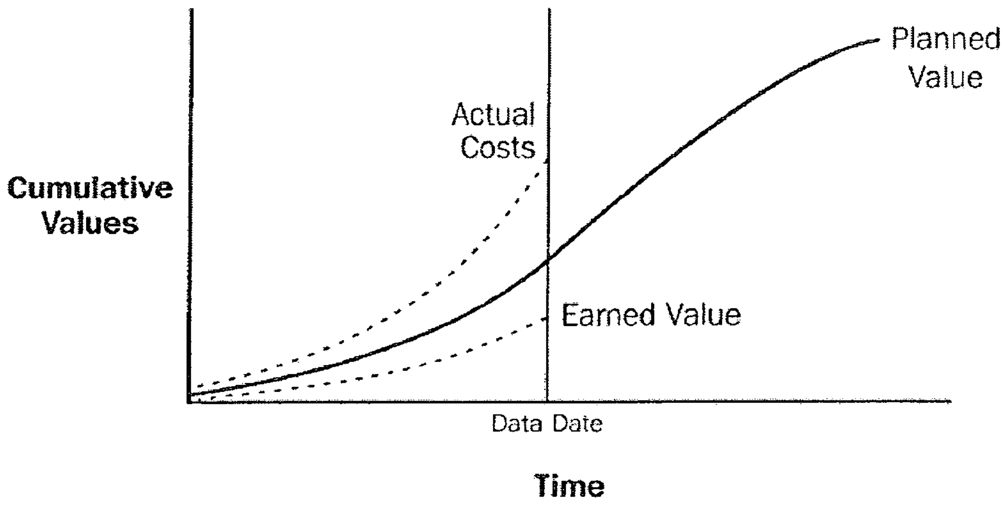


Figure 2-12 Earned Value Method (PMI 2000)

1) Planned Value (PV) describes how far along project work is supposed to be at any given time in the project schedule, also known as the Budgeted Cost of Work Scheduled (BCWS). It is the established baseline against which the actual progress of the project is measured. Once established, this baseline may only change to reflect cost and schedule changes necessitated by changes in the scope of work. PV is also referred as the performance measurement baseline.

2) Earned Value (EV) is a snapshot of work progress at a given point in time, also known as the Budgeted Cost of Work Performed (BCWP). It reflects the amount of work that has actually been accomplished to date (or in a given time period), expressed as the planned value for that work.

3) Actual Cost (AC) is an indication of the level of resources that have been expended to achieve the actual work performed to date (or in a given time period). It is also known as the Actual Cost of Work Performed (ACWP)

According to this method, three S-Curves representing the PV, EV and AC are shown in figure 2-12. The combination scenarios of these three curves can be summarized into six cases as shown in figure 2-13 (Ji li, 2004), where the Case 1 is the worst and Case 2 is the best, and the others are in between.

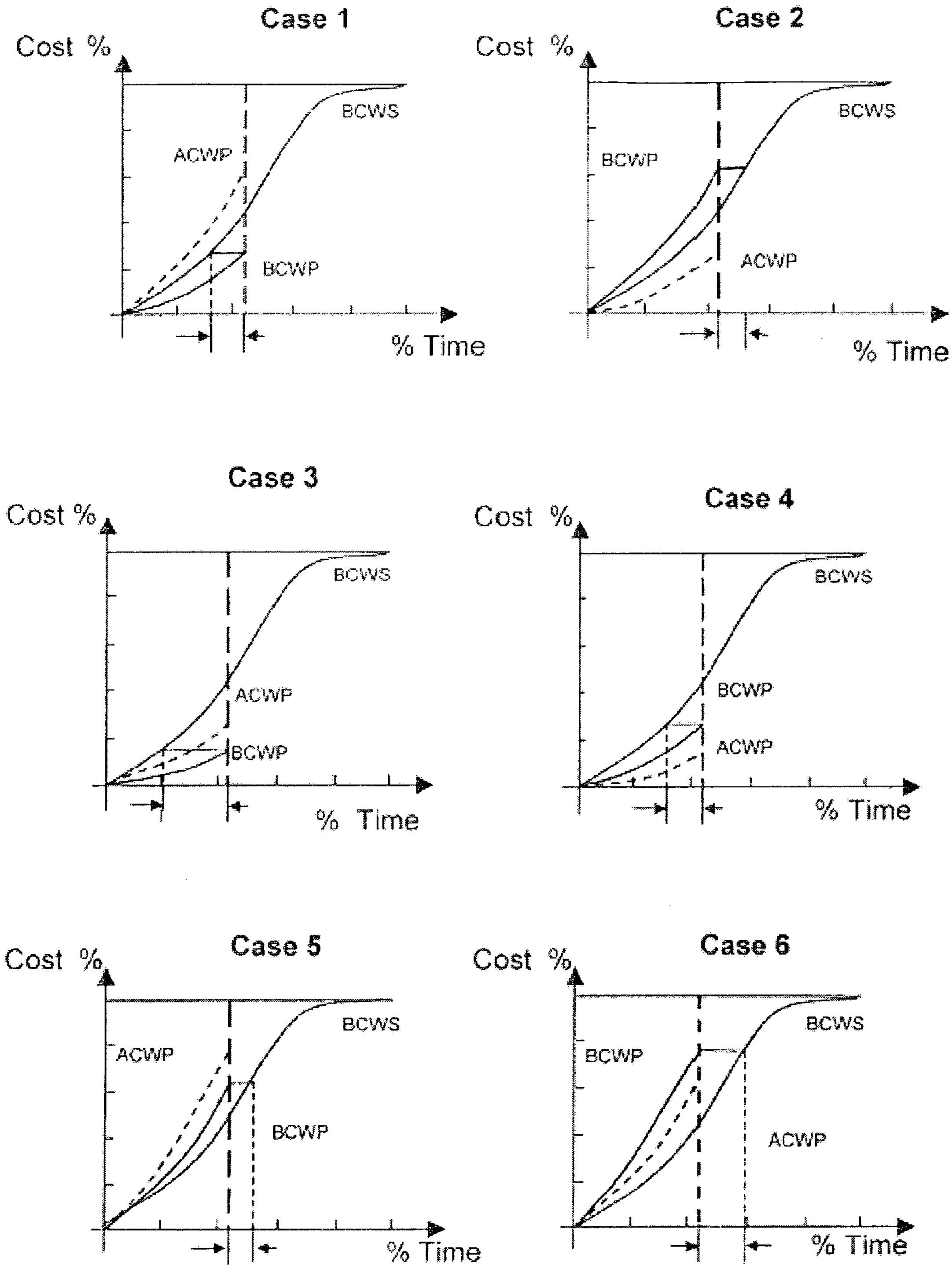


Figure 2-13 Performance Evaluation Scenarios (Ji li 2004)

2.3 *Forecasting and Trending Methods*

2.3.1 Earned-value Based and Its Extension Methods

Christensen (1992) and Christensen et al. (1995) describe a generic index-based formula to calculate estimate at completion (EAC) (Equation 2-1). It is assumed that the contractor's past performance will continue to the end of the contract.

$$EAC = ACWP_{to-date} + \left(\frac{BAC - BCWP_{to-date}}{index}\right) \qquad \text{Equation 2-1}$$

Based on a comprehensive research finding, Ji, Li (2004) pointed out that the performance indexes used in this model can be classified into seven groups:

1) Index=1; this means the remaining job of the project will be executed precisely at the full budgeted rate. It is not widely accepted in government quarters.

2) Index=CPI;

3) Index=SPI;

4) Index=CPI×SPI;

5) Index=α% + CPI;

6) Index=(α% + CPI) ×(α% + SPI);

7) Index=W1×CPI + W2×SPI.

Christensen (1992) compares the forecasting results for the indexes in groups 2, 3, 4, and 7 by using 12 development and 18 production contracts (Navy). The results found that the three-month average CPI was accurate, irrespective of the stage of the completion. Christensen (1996, 1999) confirmed that CPI-based estimate at completion is a reasonable lower boundary of a final cost of a contract. This rule is valid in early and middle stages of a project, but it is not valid in later stages of a project (Christensen and Rees 2002). However, the group 4 index is one of the most widely used and accepted indexes to statistically forecast the high-end cost requirements for any project (Fleming and Koppelman 2005). Air Force System Command (AFSC) used group 7 index with w1=0.8 and w2=0.2 as a formula in all stages of the life of a contract (Abu-Hijleh 1991).

The indexes in groups 5 and 6 are proposed by Alshibani (1999). He adds the coefficient "management and job conditions factor" to forecast the final cost and completion time. Even though he mentioned that if the condition was better than as planned, the α would be positive. If the condition was worse than as planned, the sign would be negative. He could not provide guide to determine the value of α.

Beside the two indexes SPI and CPI, and two forecasts EAC and ETC, PMI (2005) introduces the To-Complete Performance Index (TCPI) and the Time Estimate at Completion (EAC_t). The following three variances, three indices and three forecasts can be calculated as shown in figure 2-14.

They are:

Variances: Schedule Variance (SV); Cost Variance (CV); and Variance at Completion (VAC). Indices: Schedule Performance Index (SPI); Cost Performance Index (CPI); and To-Complete Performance Index (TCPI)

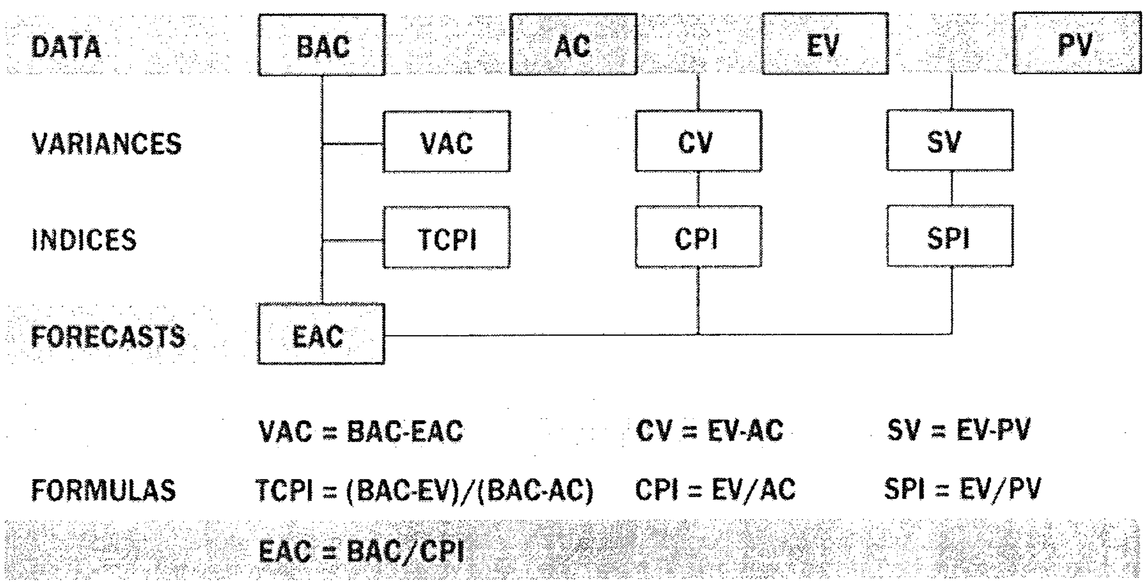


Figure 2-14 EVM Performance Measures (PMI 2005)

2.3.2 Cost Center Method (CCM) Forecasting Method

SNC uses PM+ (its in-house system) to perform the plan, control and forecasting of projects. There are 13 modules in this system and 4 of them perform the key control functions of engineering, procurement and construction management. The integration mechanism is described in figure 2-15 and the details are:

1) Internal Mandate module applies the EVM to perform the plan, control and forecasting of engineering and management scope of work using the work hours as the measurement unit. CPI and completion ratio can be reported at different levels, such as by project, by department, by discipline or by internal work package (IWP).

2) Procurement module mainly performs the 2 functions: the first is the material control, including, expediting, logistic, and site warehouse management; the second is to provide procurement cost information to cost controllers.

3) Construction Module also applies the EVM to perform the plan, control and forecasting of construction scope of work using labor hours as the measurement units. Detail construction quantities can be tracked at contract pay item levels. These actual progresses are integrated to incurred cost calculation and accounting automatically. Tied-in and commission are registered and tracking in this module as well.

4) Cost Center Method (CCM) Module is designed to integrate all the cost information from the above 3 modules to plan the budget, monitor the commitments, progress and changes. The project overall forecast final cost report is generated in this module.

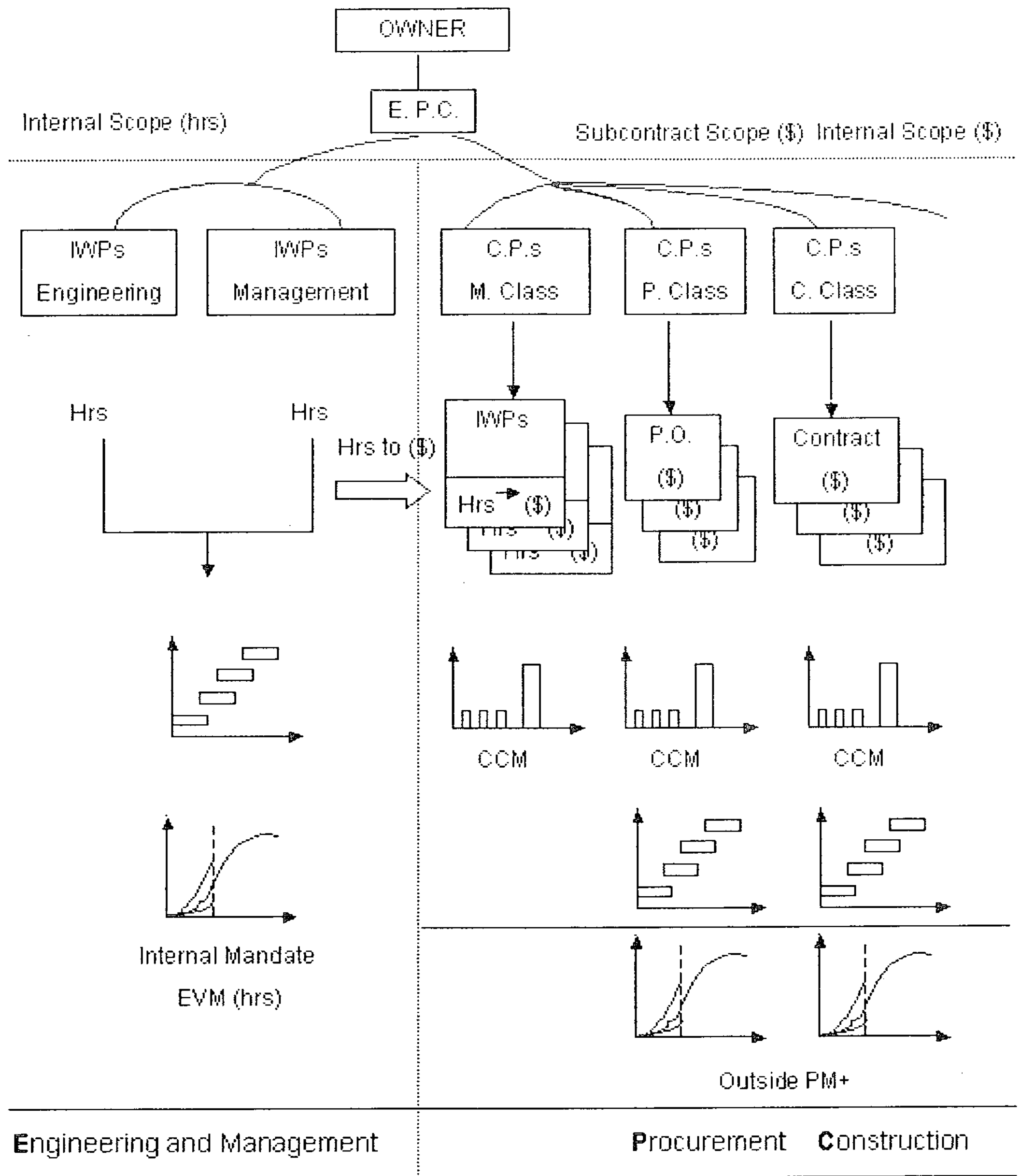


Figure 2-15 Cost Integration Forecasting Mechanism in PM+ in SNC

In figure 2-15, P class refers to purchase order work packages; C class refers to construction contract work packages and M Class refers to miscellaneous work package

The CCM method experiences 2 phases of evolution in forecasting:

Phase 1: In year 1995-2002, it was called Standard Cost Method. Equation 2-2 shows the calculation mechanism. And figure 2-16 shows the header of project cost report, which applied the Standard Cost method to perform FFC calculation.

$$FFC = TC + RTC \qquad \text{Equation 2-2}$$

- *FFC: forecast final cost*
- *TC: Total committed amount, which includes the awarded PO/Contracts amount and approved change orders*
- *RTC: Remaining to commit. It sums up all pending change orders and manual entry of foreseen changes.*

Costs				
	Incurred			
Committed Amount	This Period	To-Date	Remaining To Commit	Forecast Final
(C)	(D)	(E)	(F)	(G=C+F)

Figure 2-16 Header of Project Cost Report in Standard Cost (PM+ 2007)

This method can provide the project forecast final cost but can not provide detail tracking of the foreseen changes.

Phase 2: From year 2003 to present. The Standard Cost method was replaced by Cost Center Method (CCM). Equation 2-3 shows the calculation. And figure 2-17 shows the header of project cost report, which applied the Cost Center Method to perform FFC calculation.

$\sum FFC_i = \sum \text{Total Commitment}_i + \sum \text{Outstanding Change}_i + \sum \text{Trend}_i + \sum \text{unallocated budget}_i$. Equation 2-3

- $\sum$Total Commitment$_i$: Awarded PO contract$_i$ + Approved Change order + signed Amendments.
- $\sum$Outstanding Changes: Pending change order or change notice
- $\sum$Trends: A tool meant to analyze the impact of a change before processing the change.
- $\sum$Unallocated budget: Portion of the budget for future commitments.

Budget						Forecast	
Original	Revised	Total Commitment*	Outstanding Changes	Trends	Unawarded Scope (Unalloc. Budget)	Current	
(1)	(2)	(3)	(4)	(5)	(6)	(7=3+4+5+6)	(8=(

Figure 2-17 Header of Project Cost Report in Cost Center Method (PM+ 2007)

The detail workflow of CCM is displayed in figure 2-18. The left column is budgets, which can be transferred or manually input into CCM module. The budgets come from the approved estimates, and are regrouped by commitment packages for future execution purpose. All the changes to frozen budgets have to go through the procedure of scope change. The right column is commitments. All the changes to award purchase orders or construction contracts have to go through the procedure of change orders / change notices and amendments. The

CCM method provides variable reports on FFC, incurred cost, and paid amount.

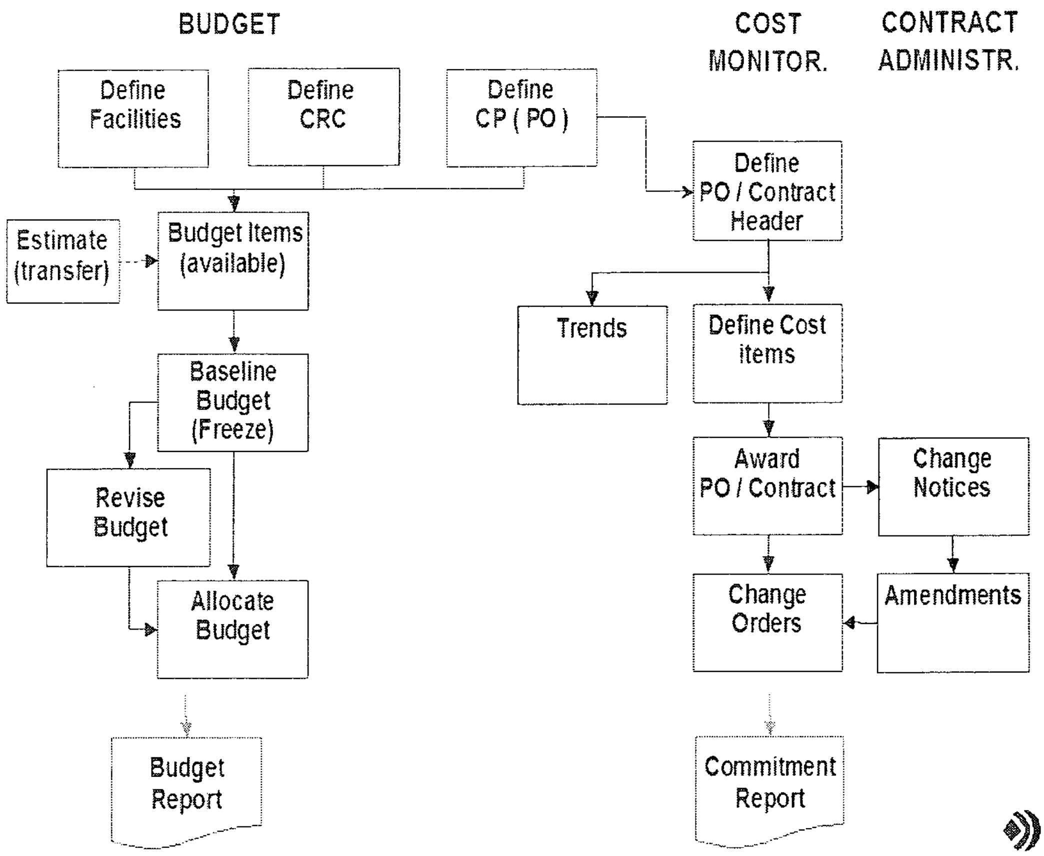


Figure 2-18 CCM Workflow (Bebawi 2006)

One of the improvements in CCM is to integrate the outstanding changes and trend into FFC. Recently, a new function of integrating procurement and construction to CCM module was developed. It enables automatic cost information flow between these 3 departments. But still, one of the limitations is that there is no specific method to calculate the trend amount and the probability.

Both of these two methods were originally designed to manage subcontract works or to perform a procurement and construction management function in EPCM projects. According to figure 2-15, for the internal scope of work, the users can translate the work hours' amount to dollar amount and group them in miscellaneous type of commitment packages, so that overall project cost can be reported.

2.3.3 Other Forecasting Methods

The Stochastic forecasting models are exponentially moving weighted average methods (Al-Jibouri 1985). He proposed two models called independence and dependence cost models to predict cost at completion for control purpose. The study reveals that the reliability of the two models, however, depends fully on the measurement of the cost of unit of earning at each reporting period

Social Judgment Theory was proposed by Diekmann and Al-Tabtabai (1992). This method provides a way to predict the future based on a set of cues, which comes from human judgment rather than mathematical algorithms. Equation 2-4 describes such model.

$$J = W_1X_1 + W_2X_2 + W_kX_k + c + e' \qquad \text{Equation 2-4}$$

Where,

J = judgment of an individual;

X_k = cues used to make the judgments;

W_k = weights for the cue variables;

C = constant for individual

e'=error term.

This method improved the previous forecasting technique by considering not only current variance, but also the other impact factors. However, the method based on such judgment requires expert project managers to get satisfactory results (Ji, Li 2004).

The Fuzzy Modeling Methods can be classified into two categories: subjective modeling and objective modeling. The subjective modeling was first introduced by Mamdani and Assilian (1975). The objective modeling was initially proposed by Sugeno (1985) and Takagi and Sugeno (1985). In either model, a set of fuzzy if-then rules form the fuzzy knowledge-based model of the system. The difference between these two models lies in the consequence of their fuzzy rules. The subjective modeling is a qualitative expression of using natural language, for example, Large, Medium, and Small. An example can be written as: IF Productivity is Increase THEN Actual Cost is Decreased. The objective modeling is a quantitative expression of the system and has been used in industrial control process. An example of it can be written as: IF X(t) is 25 AND Y(t) is 30 Then z (t+1)=5X(t) +8Y(t).

Hassanein A. and O. Moselhi (2003) proposed an alternate methodology to forecast linear infrastructure project time and cost at completion, enabling the assignment of a higher weight to recent performance of crews. Unlike earlier models, which evaluate progress at the activity level, the proposed model evaluates productivity at the crew level. The model also enables blacking out certain time periods during which exceptional conditions are known to have prevailed, and not likely to be repeated beyond the reporting date (by setting their weight to zero). This model forecasts future crew productivity as either equal to that planned, or equal to the average actual productivity experienced so far. The default weight assigned to each period is dependent on the duration of that period. The user can modify the default values by assigning higher weights to periods when actual crews were progressing normally, and lower weights to periods when it is known that crew productivity was impacted by external factors that are not likely to be repeated beyond the reporting date. Future crew productivity can be estimated from equation 2-5:

$$\mathrm{Pr}od_f = A \times \mathrm{Pr}od_p + (1-A) \times \sum_{i=1}^{i=n} W_i \times \mathrm{Pr}od_{aj} \qquad \text{Equation 2-5}$$

Where,

$Prod_f$ is the forecast crew productivity

A is the weight given to planned productivity (default = 0.5)

$Prod_p$ is the planned productivity

W_i is the weight given to productivity during period I ($\sum W_i = 0.5$)

$Prod_{ai}$ is the actual productivity during period i and n is the total number of periods being considered.

Ji li (2004) proposed "Self-Learning Adjustment" method. In this method, the differences between predicted results and actual occurred values are used to improve the accuracy of the forecasted results. Equation 2-6 are developed by him to adjust the forecast cost and duration at completion and at interim future horizons based on the dynamically captured difference during construction process, respectively.

$$C_k' = C_k + (1+\alpha_k)\times(ACWP_i - C_i)$$ Equation 2-6

Where,

C_k' = adjusted cost at the Kth future horizon,

C_k = as in C_k', but based on data up to the previous reporting period,

C_i= predicted cost using performance data from the previous reporting period

i = the ith percentage completion at reporting date

K = at future horizons, K= 1 to 10,

α_k = 10 % increments for K^{th} future horizons measured moving for from the reporting date, e.g. for i at 30% completion, K=5 (50% completion)

$ACWP_i$ = actual cost of work performed at the ith percent complete.

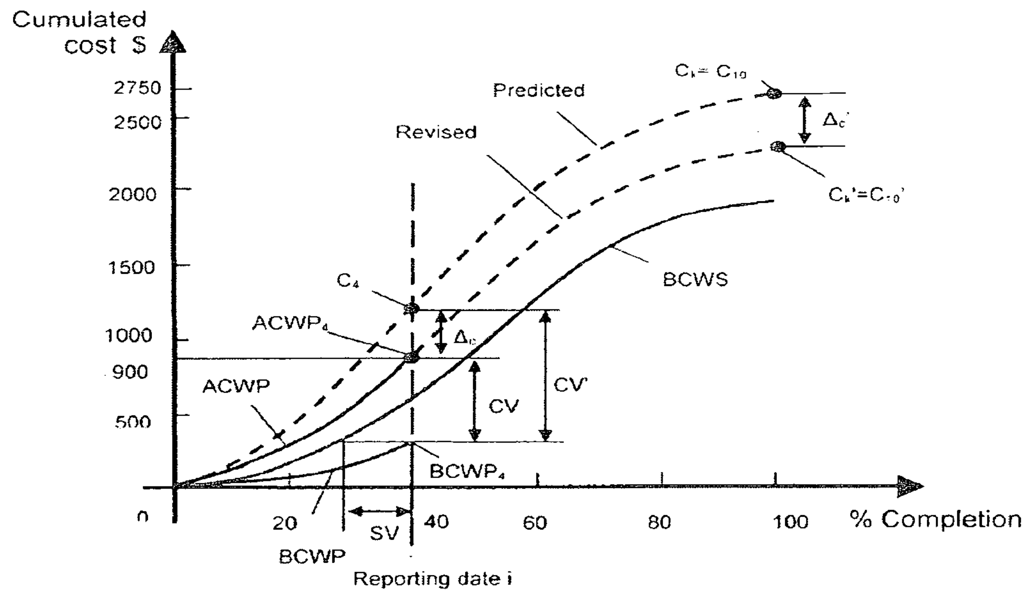


Figure 2-19 Self-Adjustment Method (Ji Li 2004)

Adel Alshibani (2008) presents a new model for tracking and control of earth moving operations. The proposed model uses spatial technologies, which includes Global Positioning Systems (GPS) and Geographic Information Systems (GIS) to facilitate its method. The proposed system is designed for highway construction projects, by using GPS to automate site data collection and using GIS to automate data acquisition and analyze collected spatial data.

His proposed model adopts the earned value method to report project progress. The EV is equal to installed (filled) quantity over budgeted quantity at the same reporting time. The proposed forecasts project time and using 2 assumptions: 1) the established performance at the report date will continue until completion, and 2) the remaining work will be performed as planned. The proposed model can deterministically calculates two values (lower and upper) of project cost and time at any set future date. The most likely value, assuming a symmetric probability distribution, is taken as the average value. The lower value is called Min Cost at completion (CAC), and Max CAC. Figure 2-20 demonstrates this idea.

Further more, the proposed model uses adaptive, self learning adjustment factors to improve the accuracy of forecasted time and cost. The adaptive factors are generated at each reporting period as the ratio of actual versus forecasted and these factors are used to systematically reduce the gap between the forecasted and actual value.

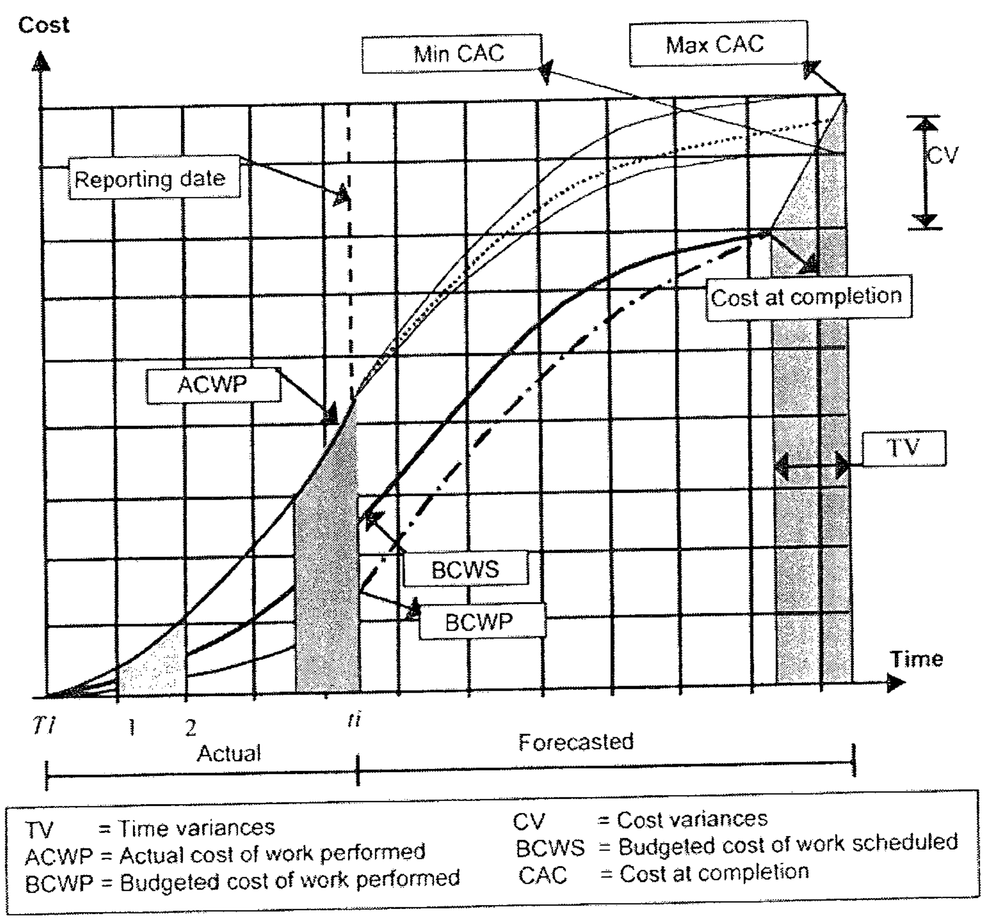


Figure 2-20 Cost and Time Forecasting (Alshibani, A. and Moselhi, O. 2008)

2.4 *Program Reporting*

2.4.1 Reporting Functions and Periods

The purpose of reporting is to generate tabular, graphical, or visualized reports to facilitate project tracking, control and forecasting time and cost at completion. A project level management requires an overview of project progress and milestones, while the work package level may require a detail report on activities.

Functions can be productivity of crew rate, cost report by WBS, by control account, by package, or other reporting criteria by users. Cost and progress reporting period can be weekly, bi-weeks, or monthly, which depends on the contract term. Normally, it is monthly based.

2.4.2 Reporting Styles and Types

There are 4 main types of reports; textual, tabular, graphical, and visual. Hassanein (2002) proposed a reporting module that can generate reports at varying degrees of detail, to suit the needs of all project participants in three formats; tabular, graphical, and exception reporting.

SAAD (1999) proposed a method to illustrate one effort to convert the text-oriented paper-printed static report into an audio-visual, interactive multimedia report that can be stored and distributed on a compact disk (CD) or on the

Internet. The report was structured to mimic the traditional text-based report in its main components (SAAD, 1999):

• Progress information including:

   - A summary of the current status of the schedule, budget, and expected completion date
   - Report on the current progress this period (since last update to date)
   - Report on the cumulative progress to date (Since the start of the project)
   - Report on the end forecast (Expected time and cost at completion)

• Technical details related to:

   - Constructability issues
   - Design modifications
   - Unexpected site conditions
   - Quality measures
   - Contractual measures including change orders and contract modifications

The project reporter's navigation pattern is described in figure 2-21.

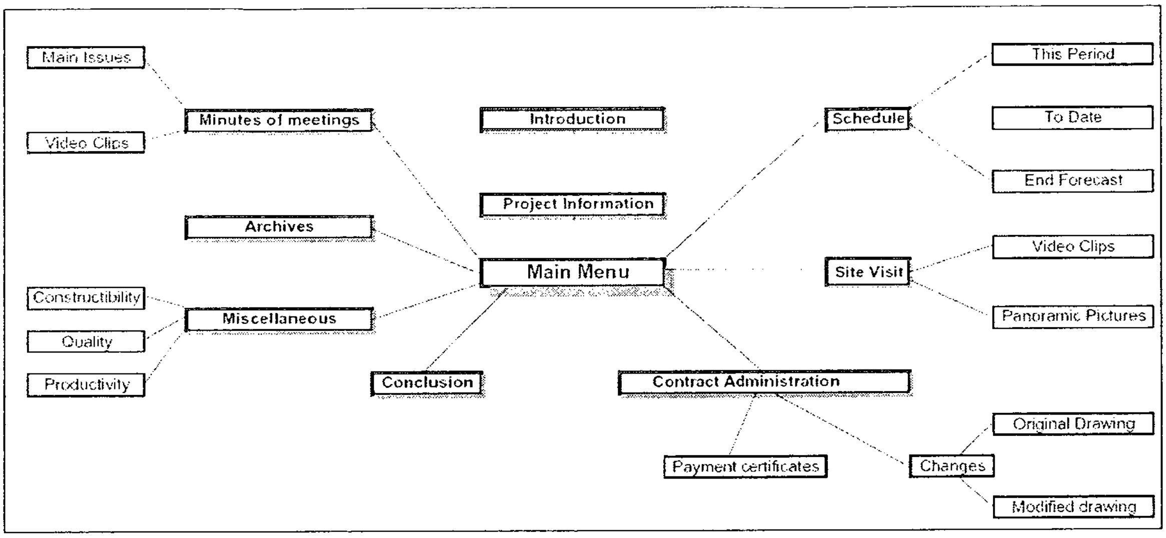


Figure 2-21 Project Reporter's Navigation Pattern (SAAD 1999)

PM+ system provides comprehensive reporting function in tabular and graphic types. Most of the project data are registered and stored at lowest detail level. For example, in Internal Mandate Module, 22 standard tabular reports can be generated for work hour analysis purpose, and the ad-hoc customized report can be created according to the requirements of different kind of projects. One example of these reports, which named "work hour analysis report", is presented in figure 2-22. This report integrated the earned value methodology.

PM +

IM001

DETAIL WORK HOUR ANALYSIS BY DEPARTMENT/DISCIPLINE/IWP/TASK
Project: CM005 - Poly Plant - Training : CCM Phase 2 (c2)
Client: POLY - POLY TECHNOLOGY CANADA
Scope of report for IWP: All IWP and Task: All Tasks

SNC · LAVALIN
Report date: 2007-01-12
Time: 11:33:12
Period Start: 1999-11-01
Period End: 1999-11-30

Department / Discipline / Internal Work Package (IWP) / Task Code - Description	Control Budget Disc.	Control Budget IWP	Allocated Budget (wkhrs) Original (A)	Approved (B)	Transfer (C)	Revised (D=A+B+C)	Pending (E)	Earned(wkhrs) Revised (F)	Pending (G)	Total (H=F+G)	Actual (wkhrs) Period (I)	To-Date (J)	Forecast FTC (K)	Final (L=J+K)	CPI (M=H/J)	Earned (%) (N=H/(D+E))	Compl. (%) (O=J/L)	Budget Var. (P=D-L)
3 PROJECT MANAGEMENT																		
3-1 PROJECT MANAGEMENT																		
31-01 Project Manager																		
31-01-001 Project Manager			1,560	0	0	1,560	0	0	0	0			1,560			0		
31-01-002 Deputy Project Manager			1,430	0	0	1,430	0	0	0	0			1,430			0		
31-01-003 Head Office Support			520	0	0	520	0	0	0	0			520			0		
Subtotal IWP: 31-01		3,510	3,510	0	0	3,510	0	0	0	0	0	0	3,510	3,510	0.00	0	0	0

Figure 2-22 Work Hour Analysis Report (PM+ 2007)

The tabular reports generated from PM+ can be grouped by different kinds of criteria and at different levels. Figure 2-23 is an example for project cost report in Cost Center Method Module. Graphic reports can also be generated from PM+, figure 2-24 demonstrates this function.

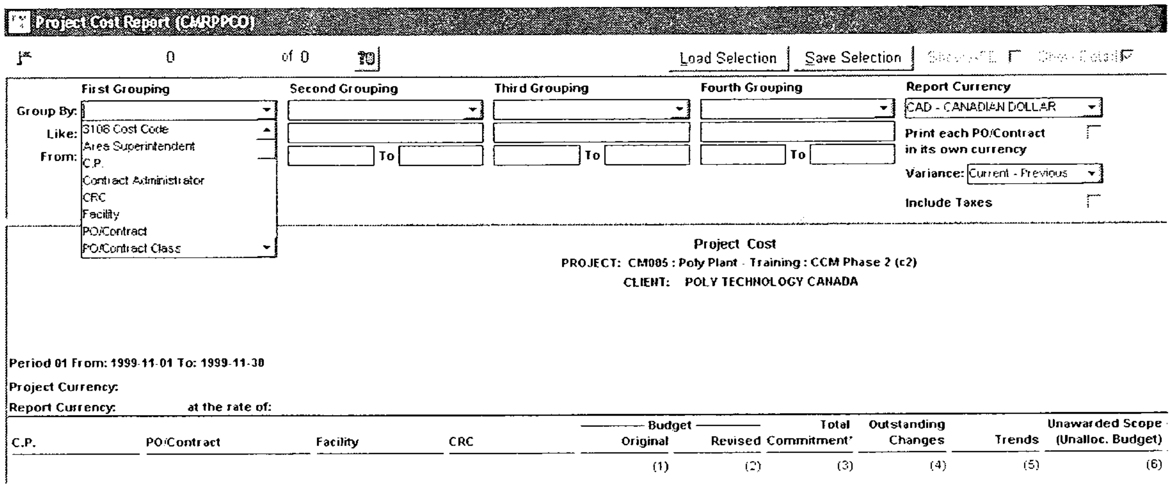


Figure 2-23Project Cost Report Selection Criteria (PM+ 2007)

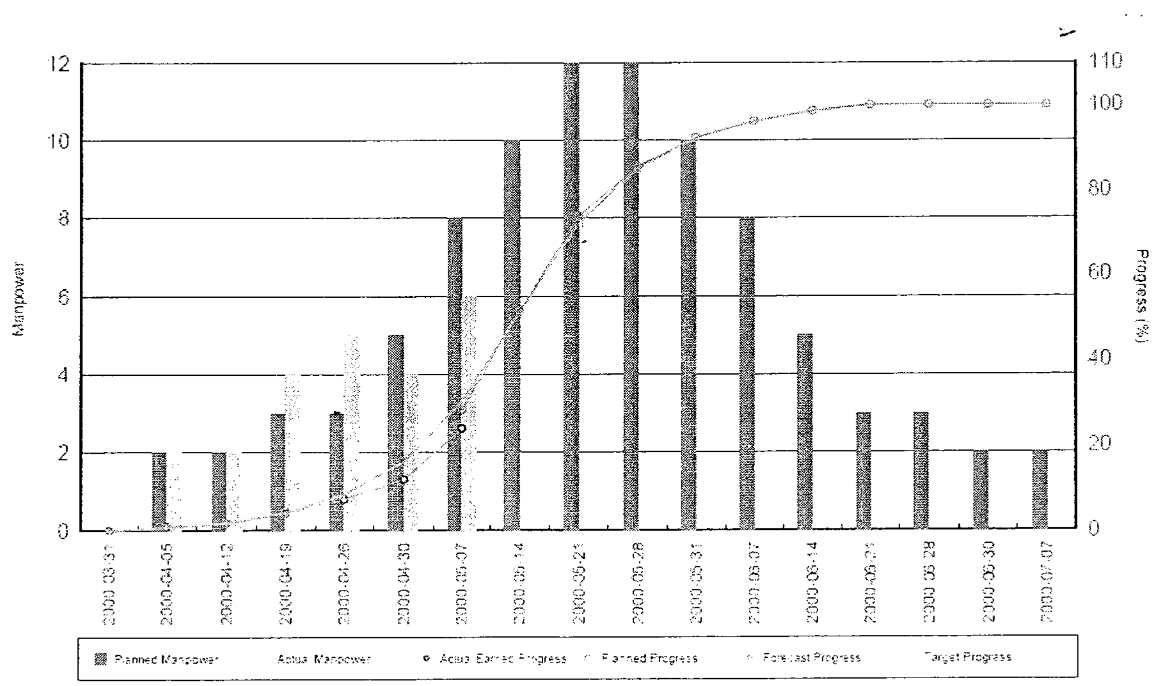


Figure 2-24 Construction Progress Report (PM+ 2007)

2.4.3 Reporting Visualization

In the construction management domain, the lack of adequate visual representation causes construction managers to struggle with huge amounts of data, which may cause costly errors or lead to project failure. It is important to use visual representations to clarify the complicated structure of data, eliminate confusing factors, and identify key elements. (Eddy M. R., 2007)

John Hildreth (2005) developed a methodology for making equivalent decisions based on GPS data and presents the procedures developed to identify the key records necessary to calculate activity durations. The data captured by the developed system are position and velocity data and are autonomously recorded. Mani G. F. (2007) proposed several semi-automated vision-based approaches to further improve and facilitate the communication of progress information and decision making on corrective actions. Figure 2-25 illustrates how to quantify easily the progress deviation between as-planned and as-built. Other information related to the activity such as resource and budget information can be generated in this figure.

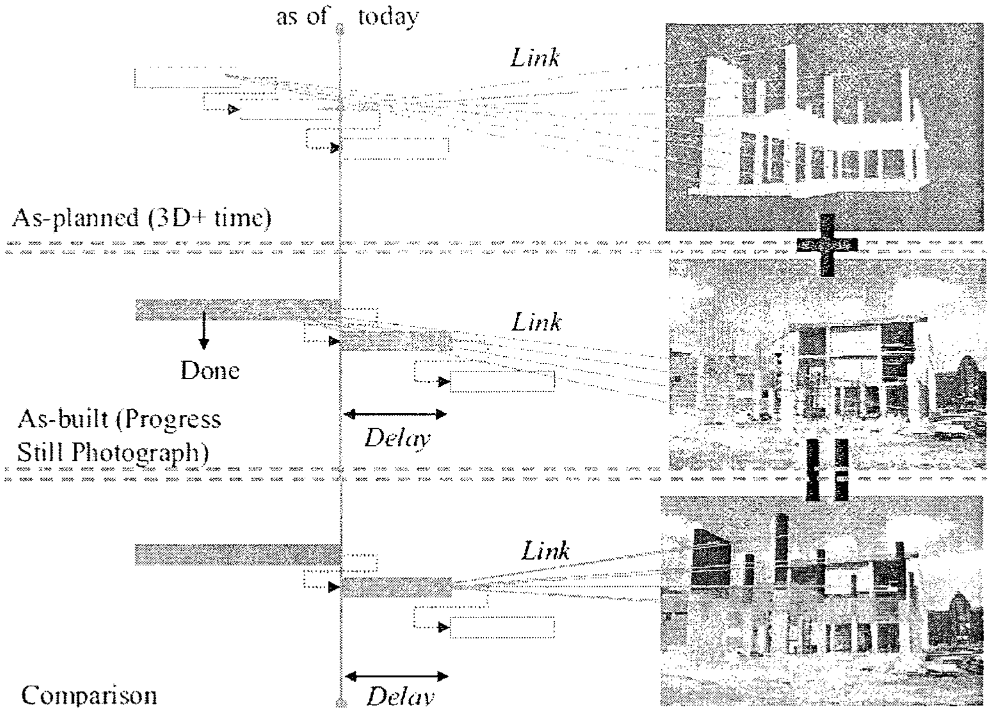


Figure 2-25 Augmented Reality-based Progress Monitoring (Mani G. F., 2007)

However, most of these efforts have focused on visualizing either spatial building structures or sequences of construction activities. There has been little research efforts focused on information visualization in construction management at area or work package level.

3 CHAPTER THREE: FIELD STUDY

3.1 General

The purpose of this field study is to understand the management practice of the industrial project. All the studied data are from the training project provided by SNC Project Management System group. The training project was elaborated using adjusted information from a real project. Numerical examples based on a set of data from a training project will be used to illustrate and validate the essential features of the developed methodology and model. The efforts that have been spent on and the material studied are listed in table 3-1.

Table 3-1 Efforts and Document List for Field Study

Item	Description
1	Site visit to appreciate the essential components of the training project
2	14 drawings (Plot plan and OSBL architecture drawings) were studied.
3	The training project master schedule was studied
4	Change notice distribution report of CP 1-902 was studied
5	Amendment justification report of CP 1-902 was studied
6	10 monthly progress reports from Feb/2002 to December/2002 were studied.
7	6 meetings were held between Concordia University research team and SNC PM+ team (in SNC office)
8	Part of the budget and cost data of this training project in PM+ system were studied.

3.2 Project Background and Description

Sponsored by SNC-Lavalin, a field study is conducted to investigate the current project management practice as a part of this research. The field study of the training project named PTT Poly Canada. The data for this training project were elaborated using a real project created by SNC. The scope of the training project is a fracture of the same project and the financial values were modified to respect confidentiality.

The real project is a new plant located in the industrial zone of Montreal east, Quebec, Canada, with capacity of 95,000t/yr of polymer. PTT is an innovative polyester polymer that is used for the production of fibers and yarns providing enhanced properties in carpeting, textiles, clothing and other applications. It is claimed that the production plant is the largest of its kind in the world.

Figure 3-1 is the plan of this project. SNC's mandate is to provide the following services up to mechanical completion:

- Overall project management,
- Detailed engineering for Outside Battery Limit (OSBL),
- Supply of OSBL equipment and material, and
- Construction management.

A partner engineering company, acting as the main subcontractor to SNC-Lavalin, provided: 1) revising to Inside Battery Limit (ISBL) engineering, 2) ISBL equipment/material, and 3) technical assistance during construction.

PM+, developed by SNC-Lavalin, is used as a project management system in this project. It is an integrated project management system contained 13 modules to perform different kinds of project management functions, such as estimating, document control, cost control, procurement, and construction management. PM+ is designed for use by project team members including clients, suppliers, sub-contractors and consultants. This allows users to access critical information rapidly and efficiently, resulting in a highly responsive and practical management and reporting tool. The system is programmed with power builder, and the data are stored in structure query language (SQL) database.

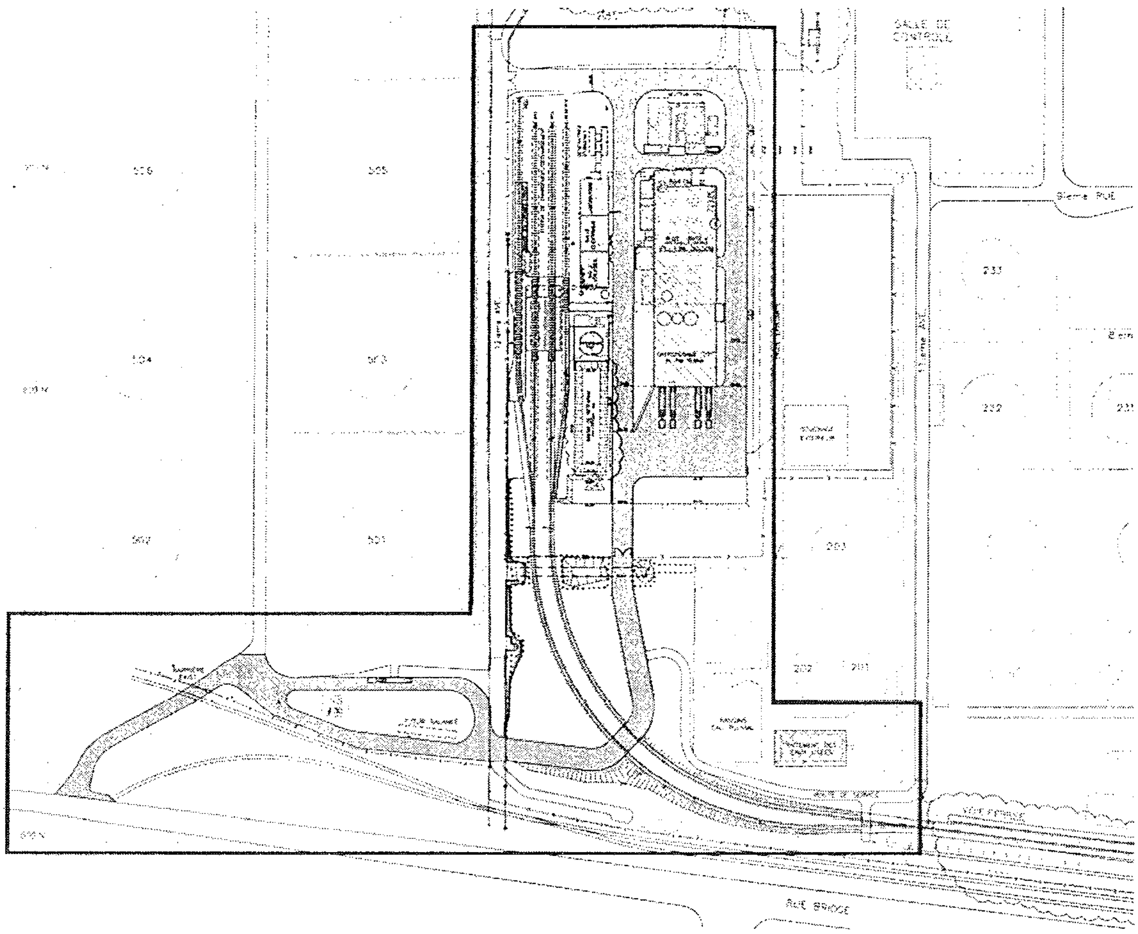


Figure 3-1Plot Plan of Field Study Training Project (SNC 2007)

The main process area, called inside battery limit (ISBL) is housed in a four-storey building and comprises: 1) paste preparation, 2) etherification, 3) pre–poly condensation, 4) poly condensation, 5) Chips Production and Crystallization. The remaining areas, called outside battery limit (OSBL) includes: 1) PTA unloading, 2) PDO unloading and storages, 3) PTT loading, 4) waste water treatment, 5) infrastructure and utilities.

3.3 Planning of Project Baseline

The planning of this project includes the work breakdown, definition of commitment packages dictionary, budgeting, and the work sequencing.

The WBS (figure 3-2) has a structure of 4 levels. The coding of each level inherits the starting coding from superior level. For example, 12000- General is at 4^{th} level. The first digit "1" means the project direct cost, the second digit "2" means the OSBL, and the last 3 digits "000" means general. So, 12000-General means the General direct cost in OSBL. Beneath level 4, each element will be divided by disciplines, such as civil, steel structure and mechanical.

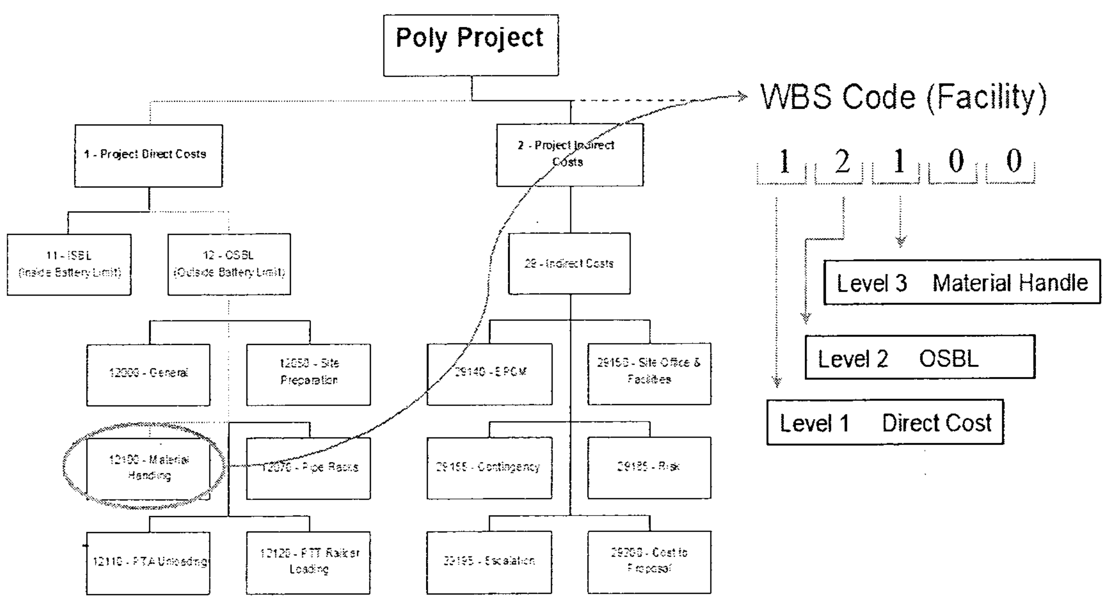


Figure 3-2 WBS and Coding Structure (SNC 2007)

After the breakdown of the scope of work, SNC uses commitment packages to regroup it for execution strategy purpose. The coding structure of CPs in this project contains 4 digits. Figure 3-3, 3-4 and 3-5 are examples to explain CP dictionary, the coding structure of CP and disciplines. In this training project, totally 189 commitment packages are used to regroup the project scope for execution purposes.

SNC·LAVALIN	Project # and Name "Poly Canada PTT"	CP #: C1-902		
	Package Dictionary	Rev.	Date	Page
		00	99/12/01	1/1
CP Description : Site preparation and Underground services				
Scope:				
Included	Install permanent and temporary fencing			
	Prepare site for Utility bldg, Mat'l Handling, WWT , PDO			
	Excavate / Backfill / level – Site contractors area			
	Fences			
Excluded	Site Preparation for Poly Building done by others			
	Roads construction done by C1-904			
	Rail Road Site Preparation by C1-903			

Figure 3-3 Example of Commitment Package Dictionary (SNC 2007)

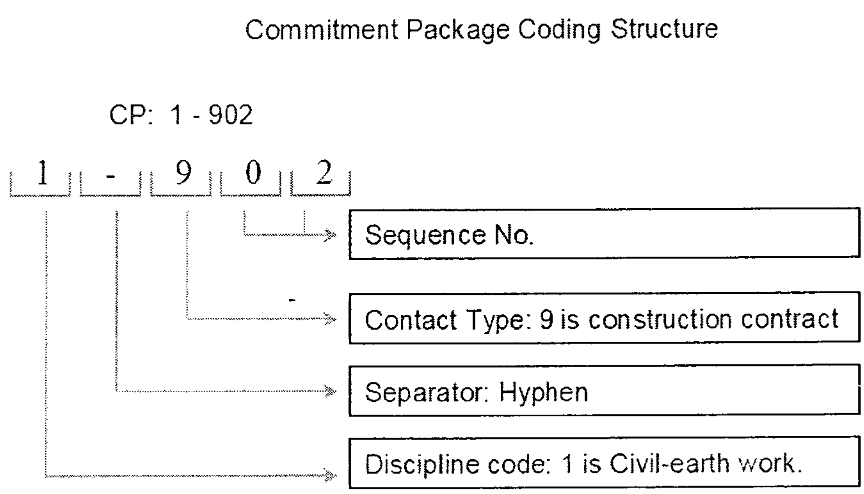


Figure 3-4 Commitment Package Coding Structure (SNC 2007)

Disciplines Coding Structure

1- Civil – Earthwork
2- Civil – Concrete
3- Structural Steel
4- Architecture
5- Mechanical
6- Piping
7- Electrical
8- Instrumentation

Figure 3-5 Discipline Coding Structure (SNC 2007)

After the definition of CPs, the baseline estimates approved by the client will be recast to CPs and transferred to budget line items. Each budget line item code must have a combination of five attributes: 1) CP, 2) PO/Contract (virtual), 3) WBS (facility), 4) Commodity and Resource Code (CRC), and 5) Sequence No. The CRC is the goods and services that the project will deliver to the client. It is a standard coding of SNC at corporate level. The first digit is in consistence with disciplines coding, except number 9, which is process in engineering discipline but is indirect cost in CRC. Figure 3-6 is an example of CRC.

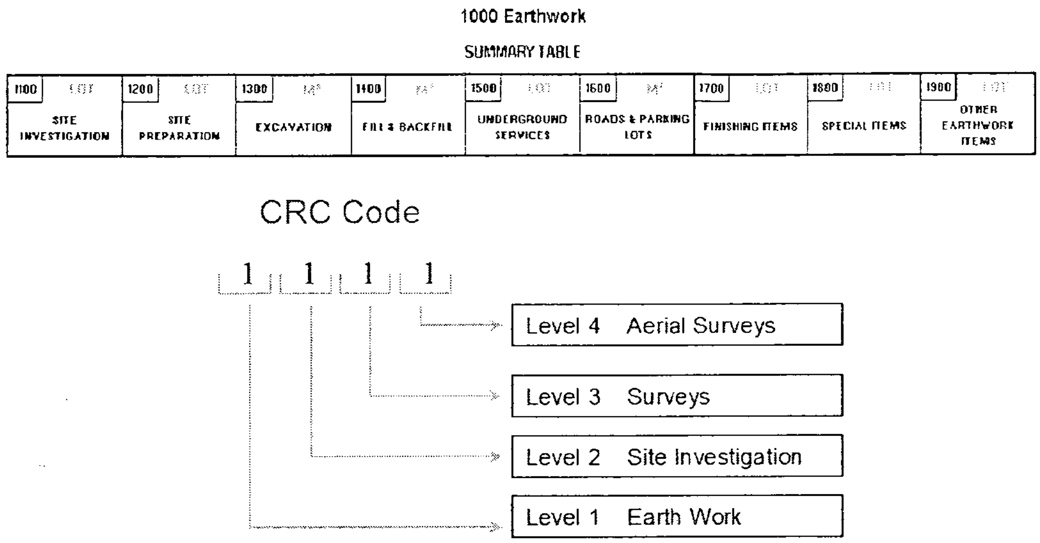


Figure 3-6 CRC Example and Coding Structure (SNC 2007)

After the definition of WBS, CP, and Budgets, the schedule of the project is prepared in Primavera software. Figure 3-7 is an example of the master schedule at level of CP prepared in Primavera. It covers the whole life cycle of each CP, including engineering work schedule, procurement schedule, and construction schedule. But in PM+, the same CP covers only the procurement or construction scope of work with related budgets. If the general contractor performs the engineering work by itself, the engineering work related to the scope of work of this CP will be executed and controlled by Internal Work Package(s) (IWP) and will be associated to this CP.

PM+ provides interface to import the scheduling information from Primavera, or other scheduling tools. Then the scheduling information can be spread out at the system for high level of milestone information purpose. Figure 3-8 is an example of commitment package schedule report providing the baseline information about time. In this report, the milestone information, such as the date of engineers to issue the request for information (RFI) and for procurement to award a PO is listed. The detail construction and fabrication are not maintained in PM+ due to the impractical data handling burden, but they are planned and tracked in scheduling tools.

This milestone schedule information is not integrated with the budget of each CP, purchase order or contract and the cash flow is not generated inside PM+. Figure 3-9 is an example of budget grouping report by facility at level 3, providing the cost baseline information.

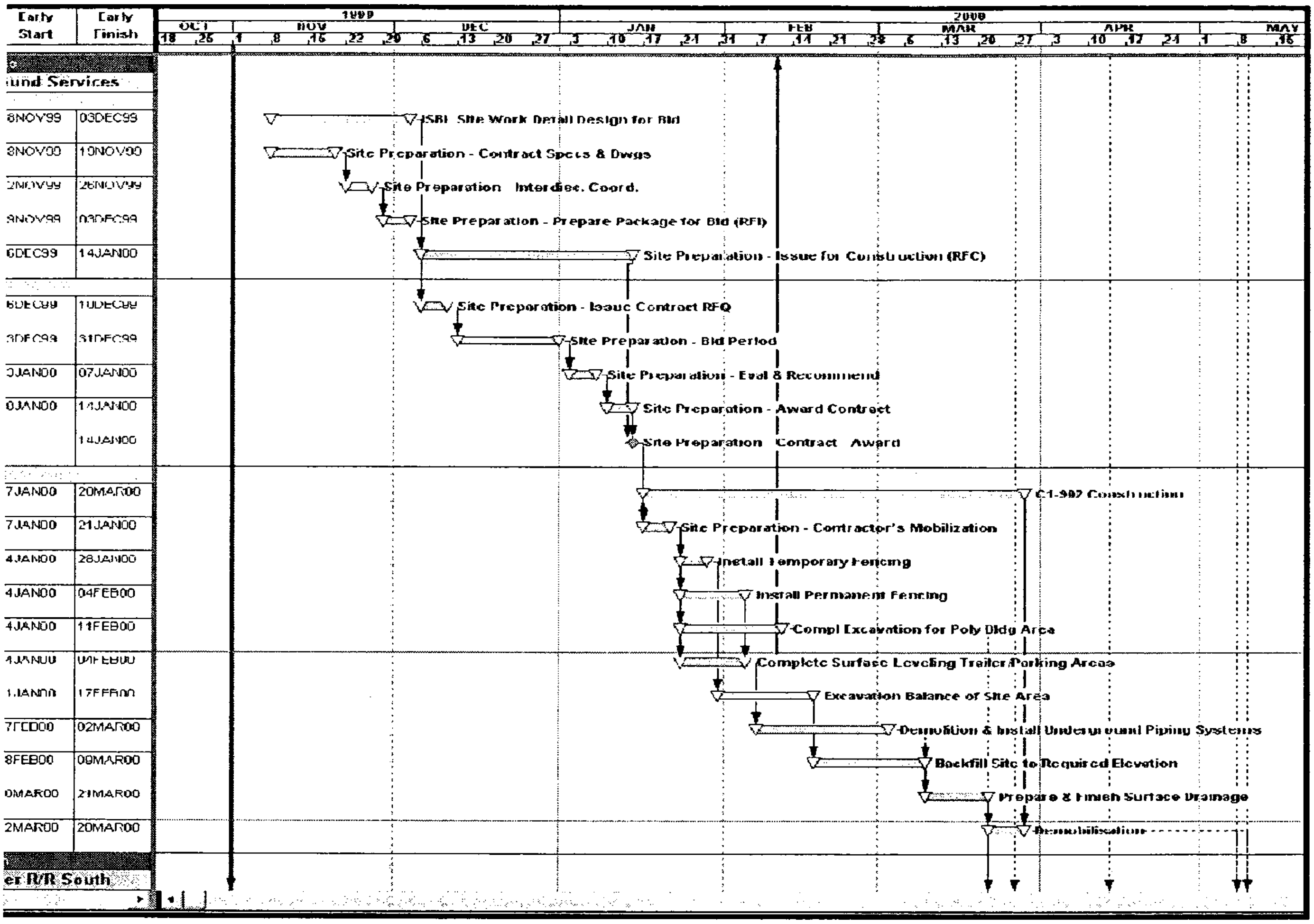


Figure 3-7 Master Schedule at CP Level (SNC 2007)

COMMITMENT PACKAGE SCHEDULE STATUS REPORT
Project: IM001 : Poly Plant - Training:Internal Mandate 1
Client: POLY TECHNOLOGY CANADA
Scope of Report: Type: All - Discipline: All

SNC·LAVALIN
Page 1 of 1
Report Date: 2006-08-09
Time: 14:37:06

Template: CPN-C – Contract Schedule

Di. FAC		Start Engineering	Interdiscipline Coordination	Prepare for Bid (RFI)	Issue for Construction	Issue Contract RFQ	Bid period	Bid Eval & Recommend	Technical evaluation	Orange Folder	Award	Construction start	Construction complete
)	S	1999-11-08	1999-11-22	1999-12-03	2000-01-14	1999-12-10	2000-01-06	2000-01-19	2000-01-26	2000-01-28	2000-02-02	2000-02-03	2000-02-24
	F				2000-01-25	1999-12-21	2000-01-17	2000-01-28	2000-02-04	2000-02-08	2000-02-11	2000-02-14	2000-04-03
ırd, Robert	A	1999-11-15	1999-11-26	1999-12-15									
	Variance:	-5	-4	-8	-7	-7	-7	-7	-7	-7	-7	-7	-27
	Remarks:												
CHNOLOGY													
41													
;outh	S	2000-01-17	2000-02-14	2000-03-03	2000-04-28	2000-03-10	2000-04-07	2000-04-21	2000-04-21	2000-04-28	2000-05-05	2000-05-08	2000-07-07
	F	2000-01-17	2000-02-14	2000-03-03	2000-04-28	2000-03-10	2000-04-07	2000-04-21	2000-04-21	2000-04-28	2000-05-05	2000-05-08	2000-07-07
ıe, Richard	A												
	Variance:	0	0	0	0	0	0	0	0	0	0	0	0
	Remarks:												
CHNOLOGY													

Figure 3-8 Commitment Package Scheduling Report (PM+ 2007)

Budget Grouping Report
PROJECT: CM006 : Poly Plant - Training : CCM Phase 2 (c3)
CLIENT: POLY TECHNOLOGY CANADA

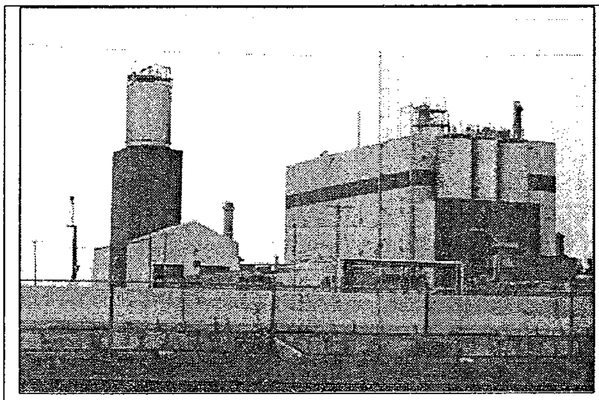
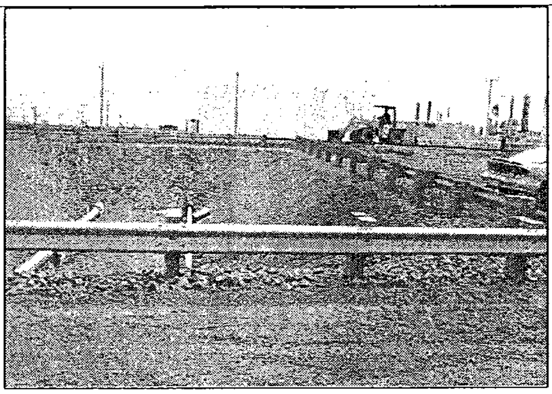
SNC·LAVALIN
CMRPBGRP

1.)0000000

	Hours	Equipment	Materials	Installation	Total
	1,471.89	0	1,026,902	729,008	1,755,910
	6,760.20	0	280,931	671,921	952,851
	3,132.40	853,551	240,984	1,405,197	2,499,730
	4,758.44	502,013	1,324,902	887,465	2,714,380
	4,526.91	365,980	580,492	922,021	1,868,492
	5,716.77	1,315,865	347,770	766,023	2,429,658
	25.94	0	405,695	214,275	619,970
	1,047.97	194,395	274,998	262,088	731,481
	402.57	285,500	208,088	212,857	706,445
	0.00	0	3,837,000	136,000	3,973,000
	42.00	0	2,630,675	2,484	2,633,159
	0.00	0	1,473,000	0	1,473,000
	0.00	0	500,000	0	500,000
	0.00	0	700,000	0	700,000
	0.00	0	156,394	0	156,394
Total:	28,505.09	3,517,304	14,187,828	6,209,337	23,914,469

Figure 3-9 Budget Baseline in PM+, by Facility at Level 3 (PM+ 2007)

Site visit is conducted to appreciate the essential components of the project and some photos are taken for visualization study purpose. 2 of them are listed bellows: 1) Training project south elevation view, 2) Site preparation in south area.

	
Training project south elevation view	Site preparation in south area

3.4 Monitoring, Trending and Forecasting in Project Execution

The 189 CPs, execution strategy of this training project, were executed by 356 PO/contracts, which means that each CP was executed by about 2 PO/Contracts. To simplify the research work, 9 typical commitment packages were selected for study purpose. They include 8 construction type of CPs and 1 purchasing type of CP. The detail information of them is listed in table 3-2. According to the site visit and available drawings, general layout of 9 selected CPs in training project is indicated in figure 3-10. One 3D model of the field study project has been developed for visualization purpose and area breakdown related with 9 selected CPs are displayed on it as shown in figure 3-11.

Table 3-2 Detail Information of 9 Selected CPs

Item	CP No	Title	Discipline	Type	Currency	Budget
1	1-901	Install Temporary Facilities(Electrical)	41	C - Construction Contract	CAD	138 750.00
2	1-902	Site Preparation & Underground Services	41	C - Construction Contract	CAD	1 334 291.00
3	1-903	Site Preparation Work Under R/R & South	41	C - Construction Contract	CAD	774 282.00
4	2-902	OSBL FoundsiUtility, Lab,El & Matl Han	42	C - Construction Contract	CAD	589 491.00
5	2-903	New Piperack & HTM Foundations	42	C - Construction Contract	CAD	304 202.00
6	3-902	Utility Blds & Lab Structural Steel	43	C - Construction Contract	CAD	600 368.00
7	4-902	Arch Siding Util/Elec,Lab,MatlHan& Store	44	C - Construction Contract	CAD	236 724.00
8	6-903	OSBL Piping Installation	46	C - Construction Contract	CAD	1 730 869.00
9	5-006	Waste water treatment package	45	P - Purchase Order	CAD	1 210 000.00
						6 918 977.00

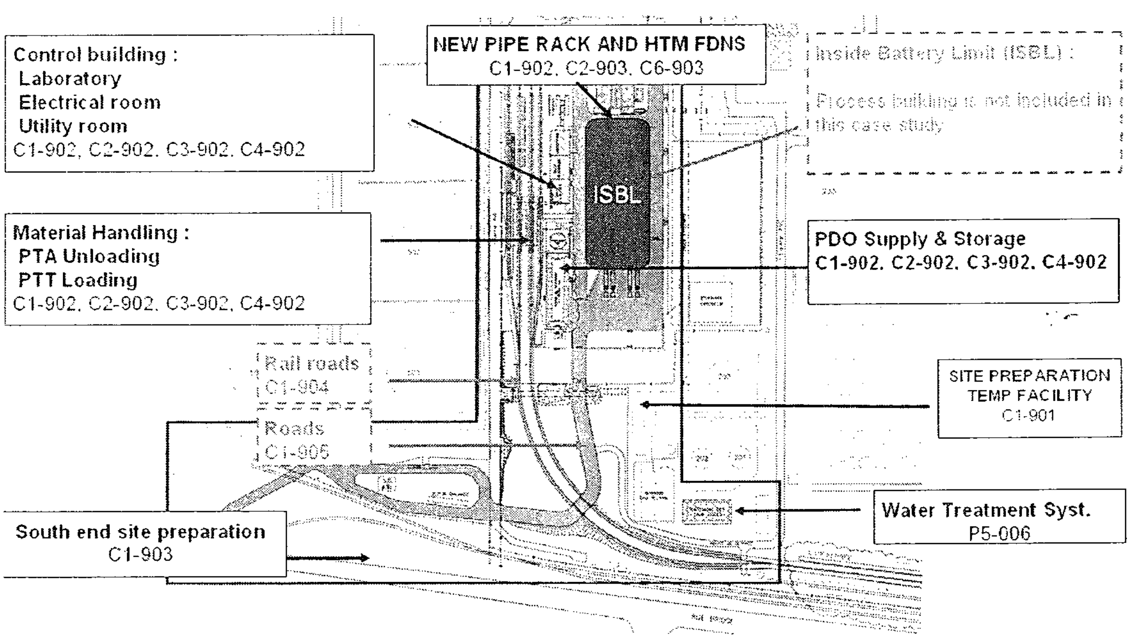


Figure 3-10 General Layout of 9 Selected Commitment Packages in Training Project Plot Plan (SNC 2007)

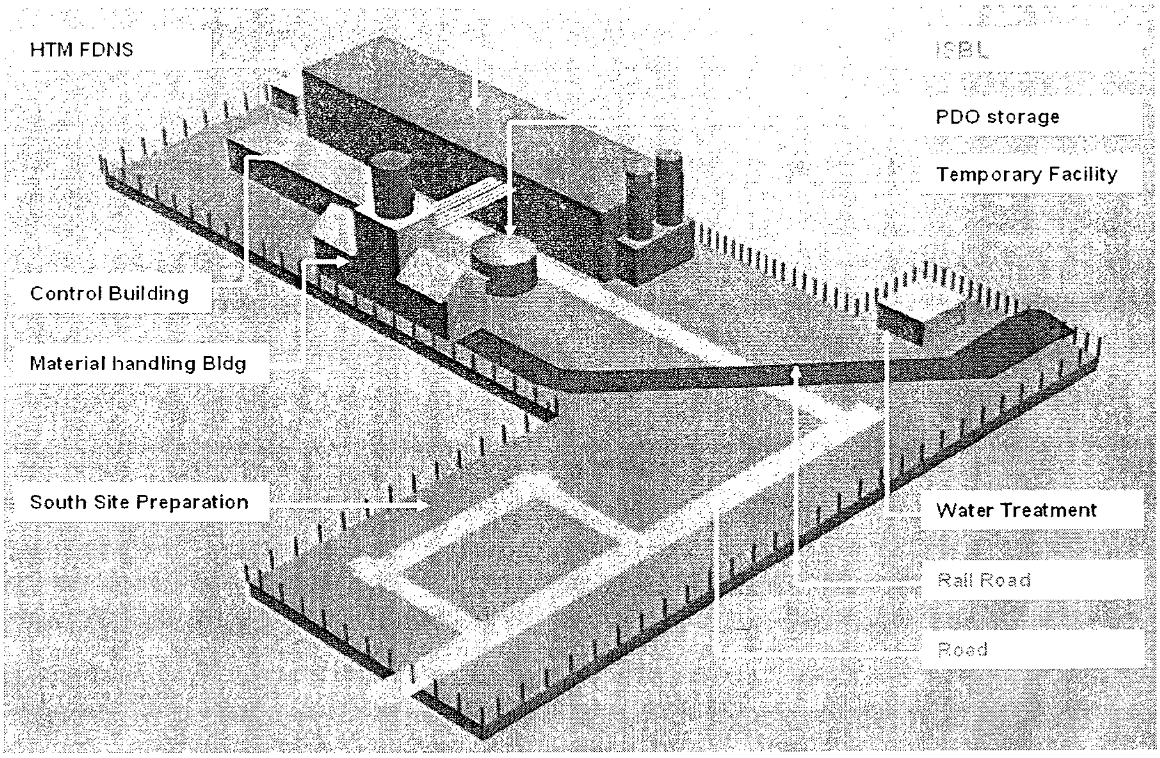


Figure 3-11 Plot Plan Visualization with Listed Facilities

10 monthly progress reports of the training project were studies, from February 2002 to November 2002. The procurement and construction schedule were partially extracted and displayed in table 3-3, but the engineering schedule was excluded.

-

Table 3-3 Actual Schedule of the 7 CPs

The Procurement and Construction schedule of 7 selected CPs (Actual)

2002

CP	PO/Contract	Duration	February	March	April	May	June	July	August	September	October	November
1-901	1-901 01	19d										
	1-901 02	10d										
1-902	1-902	52d										
2-902	2-902	40d										
3-902	3-902	50d										
5-903	5-903	128d										
5-002	5-002	125d										
5-006	5-006	245d										

According to the available information, one training commitment package, CP 1-902 (Site Preparation & Underground Services), was selected for detail cost planning, monitoring, trending and forecasting study. It is construction type of contract. Some fundamental cost information was extracted from PM+ system. This information includes original budget, scope changes, commitments, amendments, outstanding changes, trends and forecast final cost.

The following screens have been investigated in Cost Center Method Module in PM+:

- Budget registration screen (BUDGET-CM)
- Commitment Package registration screen (CMCPACK)
- Scope Change registration screen (SCHGTR-CM)
- Trend registration screen (SCTREND-CM)
- Change Notice registration screen (CNCN-CM)
- Amendment registration screen (CNAMD-CM)
- Budget report (BUDGETR-CM)

- Commitment List (COMML-CM)
- Scope Change List (PCN-CM)
- Trend Summary Report (TRENDS-CM)
- Contract Summary (CSU)

In the training project, CP 1-902 originally has 1,334,291.36 $(CAD) budget. These budgets are registered in PM+ as 14 separated budget lines and distributed to 2 different facilities or 8 CRC codes. The details are listed in table 3-4.

Table 3-4 Budget Details of CP 1-902

C P 1-902 (Site Preparation and Underground Services)

Budget Item	Description	CRC	Facility	UoM	Quantity	Total*
1	PREPARE AREA FOR CONTRACTOR TRAILERS BASE (COASTAL REMOVES ABOVE GROUND STRUCTUR	9410	29150	LOT	1	35 100.00$
2	ROCK EXCAVATION - PLATFORM	1322	12050	M3	2300	68 914.90$
3	MASS BACKFILL GRANULAR MATERIAL FOR PLATFORM - BUILDINGS, RAIL SIDING AREA...	1422	12050	M3	23489	578 146.50$
4	REMOVAL OF EXISTING BURIED FOUNDATIONS & SERVICES	1231	12050	EACH	1	54 050.00$
5	FENCING ALL AROUND SITE AREA - PERMANENT	1730	12050	M	965	104 277.90$
6	PEDESTRIAN GATES - PERMANENT	1730	12050	M	4	3 402.00$
7	VEHICULAR GATES - PERMANENT	1733	12050	EACH	4	10 007.00$
8	LAYDOWN AREA FOR MATERIALS	9410	29150	LOT	1	40 950.00$
9	SITE FENCE	9410	29150	LOT	1	36 000.00$
10	ACCESS ROADS (SUBASE IN DIRECTS)	9410	29150	LOT	1	42 578.00$
11	MASS BACKFILL GRANULAR MATERIAL MG20 - GENERAL	1422	12050	M3	8686	206 196.95$
12	PROTECTION OF EXISTING STRUCTURES	1100	12050	EACH	1	38 325.00$
13	MACHINE EXCAVATION MASS - PLATFORM	1312	12050	M3	13086	93 139.61$
14	MACHINE EXCAVATION MASS - 150 MM STRIPPING AND CLEARING	1312	12050	M3	3260	23 203.50$
	Total					**1 334 291.36$**

Note: This value was modified from real data to respect confidentiality

In definition phase, CP 1-902 has zero commitment. No budget has been allocated, so the un-allocated budget is equal to the original one. According to the equation 2.3, the FFC_0 = unallocated budget = 1,334,291.36 $(CAD)

In execution phase, the period 1 of this CP, one contract, named PO/contract 1-902 (Site Preparation & Underground Services), was signed between SNC and contractor. This contract executed the entire original scope of work included in CP 1-902. This contract had 20 pay items with original commitment amount of 1,138,000.00$(CAD). The details are listed in table 3-5. After the contract was awarded, the relevant budget for the same scope of work was allocated manually. In this same period, a change notice was submitted in an estimate price of 100,000.00$ from contractor to SNC due to site condition variance. This change notice was under discussion in this period. End of period 1, the FFC_1 =Total Commitment (TC) + Outstanding Change (OC) =1,138,000.00 + 100,000.00 = 1,238,000.00$(CAD).

Table 3-5 Commitment Details of Contract 1-902

PO/Contract: 1-902 - Site Preparation & Underground Services
Vendor/Contractor: Les Excavations Chandmar - Victoriaville, Qc Currency CAD

Items	Pay Item Description	Pricing Mode	Facility	CRC	UoM	Commitment ($)
1	Roulottes et services connexes	LS	29150	9410	EACH	45 000.00$
2	Clotures Temporaires	LS	29150	9410	M	40 000.00$
3	Clotures Permanentes et MALT	LS	12050	1730	M	110 000.00$
4	Demol. des Reseaux Souterrains Existants	LS	12050	1231	UNIT	50 000.00$
5	Remblai MG 20	LS	12050	1422	M3	190 000.00$
6	Remblai Sable	LS	12050	1422	M3	75 000.00$
7	Tout Autre Remblai	LS	12050	1422	M3	480 000.00$
8	Glissieres en Beton	LS	12050	1422	M	10 000.00$
9	Mur de Soutenement	LS	12050	1422	M	15 000.00$
10	Programme Particulier de Prevention	LS	12050	1100	EACH	1 500.00$
11	Programme de Controle de Qualite	LS	12050	1100	EACH	3 500.00$
12	Demolition des ouvrages en beton	UP	29150	9410	LOT	72 000.00$
13	Demolition des tuyaux	UP	29150	1231	EACH	15 000.00$
14	Transport - Beton demoli	UP	29150	1231	EACH	12 000.00$
15	Transport - Tuyaux	UP	29150	1231	T	7 000.00$
16	Sols contamines - prix supplementaire	UP	29150	1231	EACH	5 000.00$
17	Sols contamines - Surexcavation	UP	29150	9410	LOT	7 000.00$
18	Holdback	LS	29150	1100	EACH	0.00$
19	Federal Sales Tax	LS	29910	9960	LOT	0.00$
20	Provincial Sales Tax	LS	29920	9960	LOT	0.00$
		TOTAL				**1 138 000.00$**

Note: This value was modified from real data to respect confidentiality

In period 2, the outstanding change notice was approved and became a part of contract amendment. End of period 2, the FFC_2 =Total Commitment (TC) + Outstanding Change (OC) =1,238,000.00+ 0 =1,238,000.00$(CAD). The FFC of period 1 and 2 are the same, but the value in period 2 is more certain than that in period 1, since outstanding change notice has become a part of total commitment in period 2.

In period 3, SNC submitted a Design Change Notice (DCN) to client and it was approved as new scope. New budget was registered in PM+ to reflect this approved scope change. SNC also received another quotation for potential change from contractor. Both the change notice and new budget were registered in the system. End of this period, the FFC =Total Commitment (TC) + Outstanding Changes (OC) + Unallocated Budgets (UB) =1,238,000.00 + 150,000.00 + 150,000.00 = 1,538,000.00$(CAD).

In period 4, the outstanding change was approved and considered as commitment but in an amount of 140,000.00$ CAD. The new budget was completely allocated to cover the commitment changes. End of this period, the FFC_4 =Total Commitment (TC) = 1,378,000.00$(CAD). Table 3-6 lists the above investigation.

Table 3-6 Project Cost Status by Period of Contract 1-902

Items	Budgets		Total Commitment	Outstanding Changes	Trends	Unallocated Budgets	FFC=(3)+(4)+(5)+(6) (Forecast Final Cost)	Varaince
Period	(1). Original	(2). Revised	(3)	(4)	(5)	(6)	(7)	(8) = (2)-(7)
Period 0	1 334 291$	1 334 291$	- $	- $	- $	1 334 291$	1 334 291$	- $
Period 1	1 334 291$	1 334 291$	1 138 000$	100 000$	- $	- $	1 238 000$	96 291$
Period 2	1 334 291$	1 484 291$	1 238 000$	- $	- $	150 000$	1 388 000$	96 291$
Period 3	1 334 291$	1 484 291$	1 238 000$	150 000$	- $	- $	1 388 000$	96 291$
Period 4	1 334 291$	1 484 291$	1 378 000$	- $	- $	- $	1 378 000$	106 291$

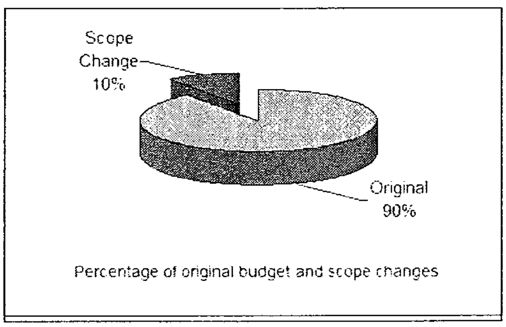


Figure 3-12 Percentage of Original Budget and Scope Changes

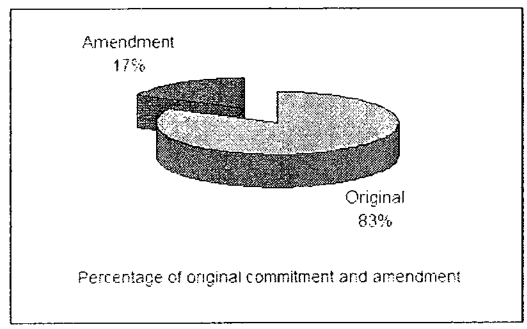


Figure 3-13 Percentage of Original Commitment and Amendments

From above analysis, the CCM forecasting method can easily integrate the scope change and commitment changes into the forecast final cost. Also the 10% of increased scope of work and 18% increase in commitment changes indicate that integration of changes management into forecasting is crucial to successful project control and forecasting. There is no detail trend information in this case study.

3.5 Progress Reports

10 monthly progress reports of the training project were studies. The table of content of the progress reports is:

- Executive summary
- Project status summary
- Project controls
- Activities this month
- Activities plan for next period
- ISBL activities
- Exhibits
  - Health and safety summary and statistics
  - Key milestone
  - Project master schedule
  - Progress curves
  - Milestone payment table
  - Project change notice register
  - Partner's engineering schedule
  - Partner's procurement schedule
  - Photographs

The cash flow is not included in these monthly progress reports and is prepared separately at company level. The progress visualization is poorly presented in these monthly reports. Figure 3-14 is an example from the training project monthly progress photo report. In this report, the construction progress photos are manual extracted from folders in construction site PC and put into a word process document. It cannot generate photos or video reports by area or contract, which are often requested by clients and management. Figure 3-15 and 3-16 report the progress of engineering services and the construction services.

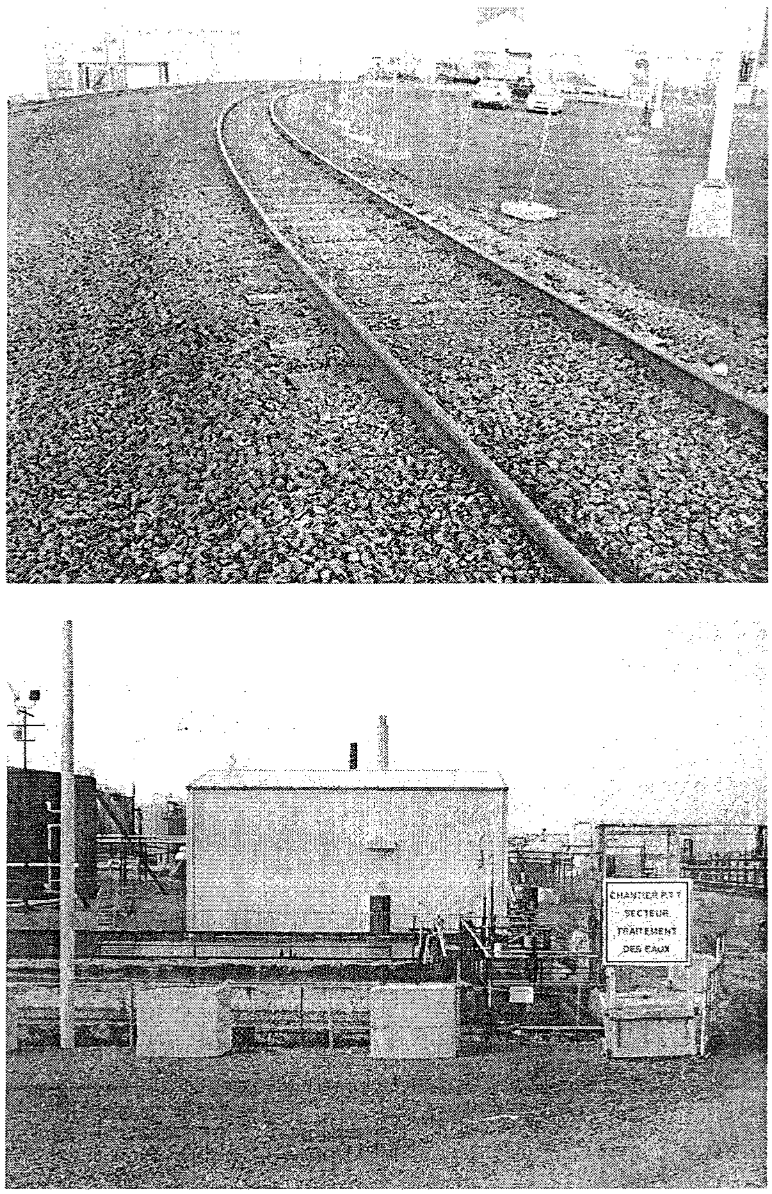
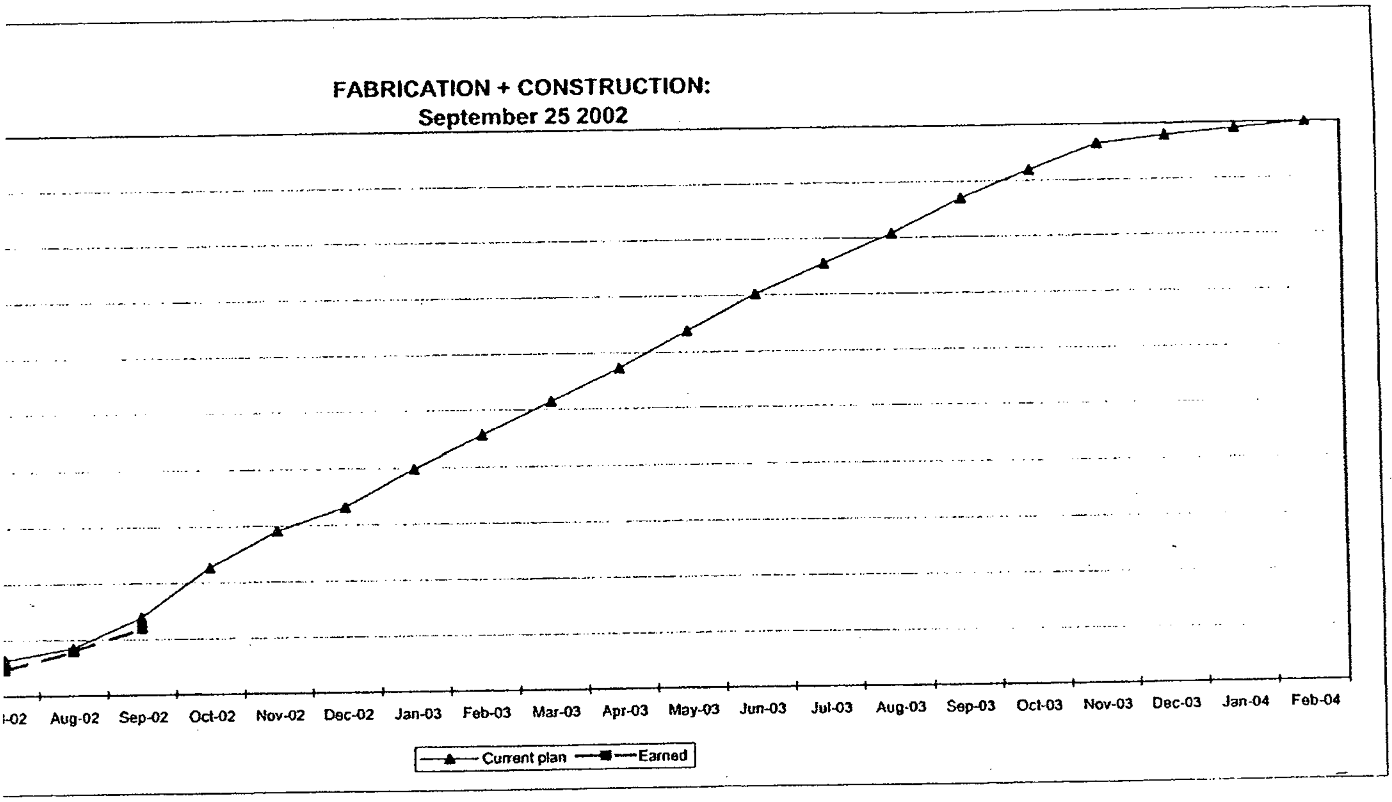
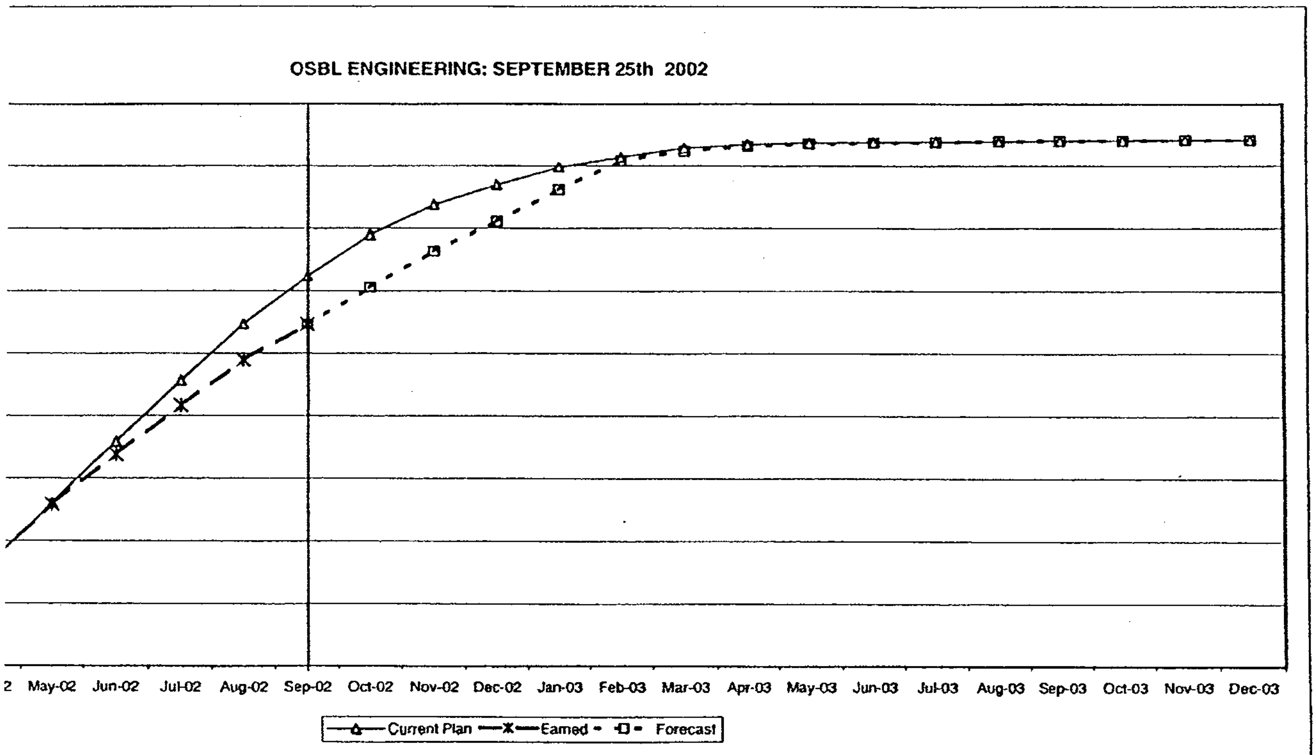


Figure 3-14 Progress Photo Report from Training Project



	Jul-02	Aug-02	Sep-02	Oct-02	Nov-02	Dec-02	Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03	Jan-04	Feb-04
%	6.3%	8.5%	13.8%	22.6%	29.0%	33.1%	39.8%	45.5%	51.4%	57.2%	63.7%	70.1%	75.5%	80.7%	86.9%	91.9%	96.5%	97.8%	98.9%	100.0%
%	4.6%	7.9%	11.9%																	
%	-1.7%	-0.6%	-1.9%																	
7	0.7	0.9	0.9																	

Figure 3-15 Engineering Services Progress from Training Project



ar-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02	Sep-02	Oct-02	Nov-02	Dec-02
9.9%	19.4%	31.2%	42.6%	54.2%	65.0%	74.2%	82.0%	87.6%	91.4%
9.0%	19.6%	30.8%	40.1%	49.5%	58.2%	65.0%			
-0.9%	0.4%	-0.4%	-2.4%	-4.7%	-6.8%	-9.2%			
							72.0%	79.0%	84.5%
0.90	1.02	0.99	0.94	0.91	0.90	0.88			

Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03
94.8%	96.7%	98.5%	99.2%	99.5%	99.6%	99.7%	99.8%	99.8%	99.9%	100.0%	100.0%
90.5%	96.0%	97.9%	98.9%	99.3%	99.5%	99.6%	99.8%	99.9%	99.9%	100.0%	100.0%

ure 3-16 Fabrication and Construction Services Progress from Training Project

4 CHAPTER FOUR: METHODOLOGY

4.1 Statement of the Problems

4.1.1 Forecasting Accuracy

When submitting a trending analysis or project cost report for a project, three key questions are often asked by the clients or management:

- How accurate is the estimate or forecasting?
- What is the probability that the project will be delivered within this estimate and forecasting actually?
- How much extra budget should be included in order to deliver this project with a certain degree of confidence?

In EVM, the calculation of estimate at completion (EAC) can provide forecast final cost, but it does not tell the confidence level of the forecasting amount. Neither the PM+ system nor the monthly cost report answers these three questions.

4.1.2 Progress Curves and Performance Index

There are some concerns from project controls people about the progress curves and 3 limitations were identified. They are as follows:

- In monthly report, the engineering, fabrication and construction progress curves were provided, but the earned value method was not applied. In PM+, the earned value method is partially applied to control the EPCM work hours and construction work hours and only the CPI index is reported.

- Project team has some difficulties to generate overall project progress curve, due to different control criteria between engineering services, procurement services and construction services. For example, engineering services will be reported in the unit of measure in work hour, yet the procurement works will be reported in the unit of measure in dollar value. In such a case, accurate CPI or SPI index at a project level is hard to achieve.
- The forecast final budget (hours and dollars) is not distributed according to time, due to discrepancy between scheduling activities and cost control account.

4.1.3 Progress Visualization

3 limitations were identified:

- Only pictures were attached in the monthly reports in hardcopy format. Other media were not integrated to progress reporting.
- Project control staffs have difficulties to search and group multimedia information for progress visualization reporting purpose, due to lacking proper multi-media coding structure
- Project management or clients have difficulties to access construction progress media files, due to lacking a web-based centralized construction progress media center.

As a result, the construction management is still faced with the problem of how to digest and understand vast amounts of data in the dynamic and fragmented environment of construction. Proper coding structure, a variety of medium and easy access web-based server to communicate progress data will assist construction management in decision making.

4.1.4 Summary

Efforts will be spent on improving the above identified limitations by applying EVM, probabilistic forecasting and visualization. The following tools and systems will be used to achieve this goal: 1) PM+ system; 2) Microsoft Excel; 3) Microsoft Project; 4) VBA; 5) @Risk 5.0 for Excel; 6) Power Builder 9.0 from Sybase; and 7) SQL language.

4.2 Trending Accuracy Improvement

To improve the trending accuracy, 2 steps are needed: 1) integrate the estimate accuracy range into forecasting, 2) improve the selection and application of estimate accuracy range. @Risk 5.0 for Excel is chosen as the tool.

@Risk provides 37 types of probability distributions allowing the specification of nearly any type of uncertainty in cell values in excel and they are classified into discrete and continuous. Figure 4-1 provides the details of these 2 classes. Monte Carlo and Latin hypercube sampling technique are both available for simulation.

Since Latin Hypercube sampling will accurately recreate the probability distributions specified by distribution functions in less iteration, when compared with Monte Carlo sampling, Latin Hypercube is selected as the sampling technique. The Mersenne twister, a pseudorandom number generator (RNG) developed in 1997 by Makoto Matsumoto is chosen as a RNG. In this study, the iteration is set to 5000 in order to achieve higher simulation accuracy.

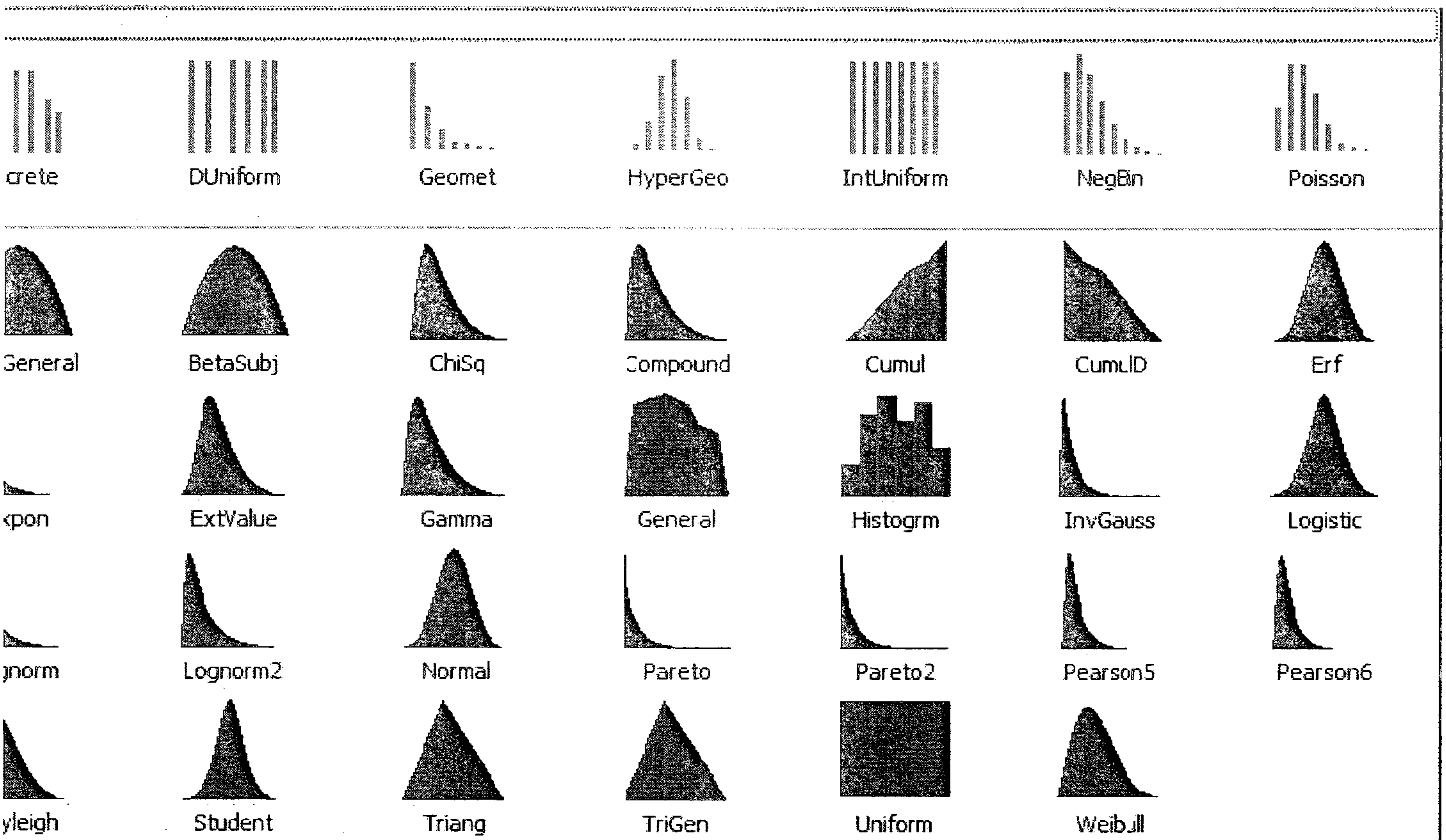


Figure 4-1 Probability Distribution Types (@Risk 2008)

The Beta distribution is often used as a starting point to derive other distributions to model events which are constrained to take place within an interval defined by a minimum and maximum value, such as PERT. The PERT distribution is rather like but is considered as superior to the Triangular distribution, in that it has the same set of three parameters. Technically it is a special case of a scaled Beta distribution. In PERT distribution, the shape parameter is calculated from the defined most likely value and the standard deviation. In this sense it can be used as a pragmatic and readily understandable distribution. The Triangular distribution is perhaps the most readily understandable distribution for basic risk models. But it has 1 main disadvantage, which is over-emphasis of the outcomes in the direction of the skew when the parameters result in a skewed distribution. (@Risk user guide, 2008). Sometime, Lognormal distribution is used to model an estimate of an unbounded range for maximum.

In practice, beside the most likely value, the estimators often provide trend estimate accuracy (TEA) between range of minus% and plus%, which are treated as the lower bound and upper bound of a range. To fit this nature, PERT method is chosen to improve the identified limitation of forecasting accuracy. The embedded function, RiskePert, from @Risk is used to facilitate this integration.

To apply this method to Cost Center Method, Equation 4-2 is generated to explain the idea, while equation 4-1 is the original one. This detail calculation is applied on the trend estimate detail level, but the result is integrated to purchase order and contract level. The sum of them is at project level.

$$FFC = TC + OC + Tr + UB \qquad \text{Equation 4-1}$$

$$FFC = TC + OC + Tr[(TEA(\pm)\%] + UB \qquad \text{Equation 4-2}$$

Two numerical examples are introduced to demonstrate this method and the output results will be compared. The numerical example A will describe the limitations of equation 4-1, while the numerical example B will demonstrate the improvements.

Numerical example A:

In contract C-3-901, the client asks for a quick estimate for a potential scope change on steel work and wants to integrate this uncertainty into the forecasting final cost. Based on available information and experiences, the estimator prepares a trend estimate and registers the results to project the forecasting according to equation 4-1. Table 4-1 and 4-2 demonstrate the results.

Table 4-1 Trend (T-001) Detail Registration for Contract C-3-901

Trend Number	Items	CP	Facility	CRC	Description	Most likely
T-001	01	C-3-901	12100	3110-Light Steel	LIGHT STEEL (X <= 30 KG/M)	3 000$
T-001	02	C-3-901	12100	3120-Medium Steel	MEDIUM STEEL (30 KG/M < X <= 80 KG/M)	5 000$
T-001	03	C-3-901	12400	3130-Heavy structure	HEAVY STEEL (X > 80 KG/M)	8 000$
T-001	04	C-3-901	12400	3200-Steel members	STEEL GIRDERS, BEAMS AND COLUMNS	6 500$
					TOTAL	**22 500$**

Table 4-2 Forecast Final Cost of the Project (2 CPs)

Commitment Package	TC	OC	Tr	UB	FFC
C-3-901	40 000.00$	- $	22 500.00$	- $	62 500.00$
C-1-901	30 000.00$	- $	- $	- $	30 000.00$
		Total			92 500.00$

As identified above, even though the FFC amount, 92500.00$, includes the potential scope change amount, which is 22500$, it can tell neither how accurate is this uncertainty, nor is what the probability that this potential scope change will be delivered within this estimate.

Numerical example B

In the proposed method, the trend estimate accuracy range is integrated into probability calculation. Table 4-3 is a data example, which includes 3 built-in functions from @Risk. Their syntaxes are as follows:

- *Syntax 1: RiskPert (minimum, most likely, maximum)*
    - *Example: in Excel cell "J4" =RiskPert(I4*(1+G4),I4,I4*(1+H4)).*
- *Syntax 2: RiskTarget (cell referred, target value)*
    - *Example: in Excel cell "F10"=RiskTarget(J8,G10)*
- *Syntax 3: RiskPercentile(cell referred, percentile)*
    - *Example: in Excel cell "F11" =RiskPercentile(J8,G11)*

Syntax 1 specifies a PERT distribution (as special form of the beta distribution) with a minimum and maximum value as specified. Cited from @Risk 5.0 for

Excel, (2008) Guide to Using @Risk, the definitions of this syntax are listed from equation 4-3 to 4-5. The probability density function is listed in equation 4-6.

$$\mu \equiv \frac{\min + 4 \cdot \mathrm{m.likely} + \max}{6} \quad \textbf{Equation 4-3}$$

$$\alpha_1 \equiv 6\left[\frac{\mu - \min}{\max - \min}\right] \quad \textbf{Equation 4-4}$$

$$\alpha_2 \equiv 6\left[\frac{\max - \mu}{\max - \min}\right] \quad \textbf{Equation 4-5}$$

$$f(x) = \frac{(x - \min)^{\alpha_1 - 1}(\max - x)^{\alpha_2 - 1}}{B(\alpha_1, \alpha_2)(\max - \min)^{\alpha_1 + \alpha_2 - 1}} \quad \textbf{Equation 4-6}$$

Where,

B = Beta function

μ = Mean

Syntax 2 returns the cumulative probability for target value, in the simulated distribution for cell referred.

Syntax 3 returns the value of the entered percentile of the simulated distribution for cell referred.

In this numerical example, the requested confidence level is set to 90 percent, which can be changed according to project needs. After running 1 simulation with

1000 iterations, the probability density and scatter plot can be provided for analysis. They are displayed in figure 4-2 and 4-3.

Detail Calculation with Proposed Method

	D	E	F	G	H	I	J
				Subjective			
				Accuracy Range			
	Facility	CRC	Description	Minus (-)%	Plus (+) %	Most likely	Sampled (@Risk output)
)1	12100	3110-Light Steel	LIGHT STEEL (X <= 30 KG/M)	-10.00%	15.00%	3 000$	3 025$
)1	12100	3120-Medium Steel	MEDIUM STEEL (30 KG/M < X <= 80 KG/M)	-10.00%	15.00%	5 000$	5 042$
)1	12400	3130-Heavy structure	HEAVY STEEL (X > 80 KG/M)	-10.00%	15.00%	8 000$	8 067$
)1	12400	3200-Steel members	STEEL GIRDERS, BEAMS AND COLUMNS	-10.00%	15.00%	6 500$	6 554$
			TOTAL			**22 500$**	**22 688$**

alue of 22500	37.7%	22 500
r 90.0% confidence	23 401.13$	90.0%
for 90.0% confidence	901.13$	

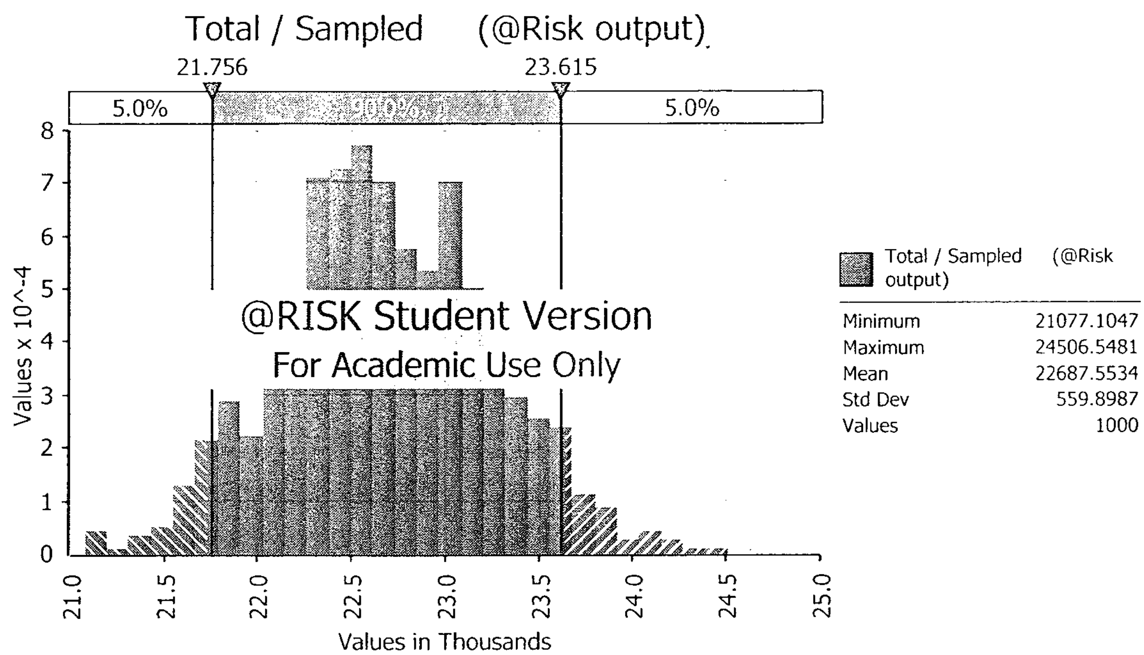


Figure 4-2 Probability Density of Trend T-001

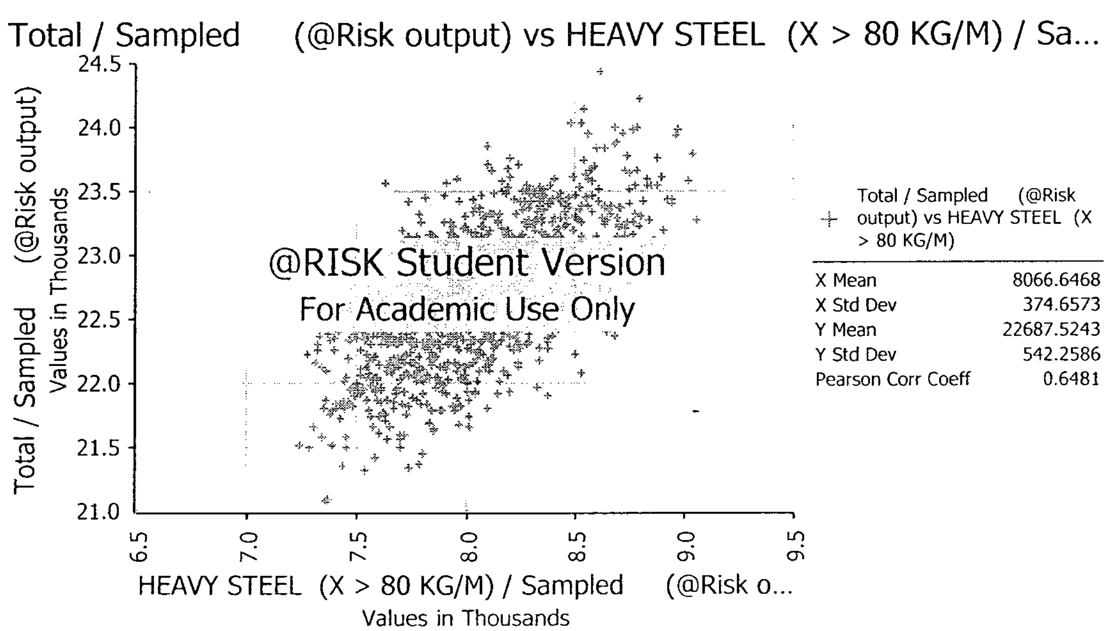


Figure 4-3 Scatter Plot for "Heavy Steel" Estimate Line

With this proposed method, after running simulation, immediately users can get answers to the above popularly asked questions:

- The estimate is based on an accuracy range of -10% to +15%
- The probability of meeting value of 22,500$ is 37.7%,
- Total budget required for 90% confidence is 23,401$
- Extra budgets required for 90% confidence is 901$

The cost controllers can have the option to register either the most likely trend value 22,500$ into the system, which has 37.7% of confidence after a simulation of 1000 iterations, or they can register the value of 23,401$, which has 90% of confidence into equation 4-2 and report the new FFC number to the client which is indicated in table 4-4. But rules should be set in planning phase of the project in order to have understandable and consistent reports.

Table 4-4 Forecast Final Cost with 90% Confidence on Registered Trend

Commitment Package	TC	OC	Tr	UB	FFC
C-3-901	40 000.00$	- $	23 401.13$	- $	63 401.13$
C-1-901	30 000.00$	- $	- $	- $	30 000.00$
		Total			93 401.13$

There is another challenge to overcome before the successful implementation of this method, which is the definition of the accuracy range. It has key impact to forecasting result when using PERT method. In order to facilitate the application and provide more accurate forecasting, 4 methods are proposed to improve this trend estimate accuracy (TEA) range. They are as follows and will be discussed in next 4 sections:

- Subjective accuracy range
- Accuracy range by engineering progress
- Self-adjustment accuracy range of a trend
- Self-adjustment cumulative accuracy range within a trend type

4.2.1 Subjective Accuracy Range

Probability analysis has been deemed useful when decision-making is characterized by risk rather than uncertainty. There are numbers of good reasons why subjective probabilities may be not only quite acceptable but even preferable to objective probabilities. Kuotsoyiannis (1982) makes the point that most of the decisions that a firm must take are unique, in the sense that the conditions of the economic environment change continuously. It is impossible to obtain past observations of similar events from which to estimate objective probabilities.

Subjective probabilities may be important for a second major reason. Subjective probabilities of individuals with the same experience and information may be very different. Personal differences of the decision maker can play an important role in decision-making. Subjective probabilities are not pulled out of thin air. They will usually be based upon knowledge and experience gained from similar projects. In addition, subjective probabilities should not be formed by one individual or group.

They should be subjected to testing and questioning through tried and tested techniques such as Delphi Method. (Flangagan and Norman, 1993)

In this research, the Subjective Accuracy Range (SAR%) will be utilized as one optional accuracy range to the trend estimate on CCM method. It provides users the opportunity to define an estimate accuracy range based on their experiences and current available information. For example, an estimate based on fixed prices quotation from suppliers has more accurate range than an estimate based on public pricing database in term of unit price information.

4.2.2 Accuracy Range by Engineering Progress

Engineering completion progress plays an important role to estimate accuracy. This impact mainly comes from scope and quantities variance. An estimate during detailed engineering stage is more accurate than that during equipment factored stage. The following figures 4-4 and 4-5 provide estimators a reference for choosing estimate accuracy range that will be applied to the proposed method.

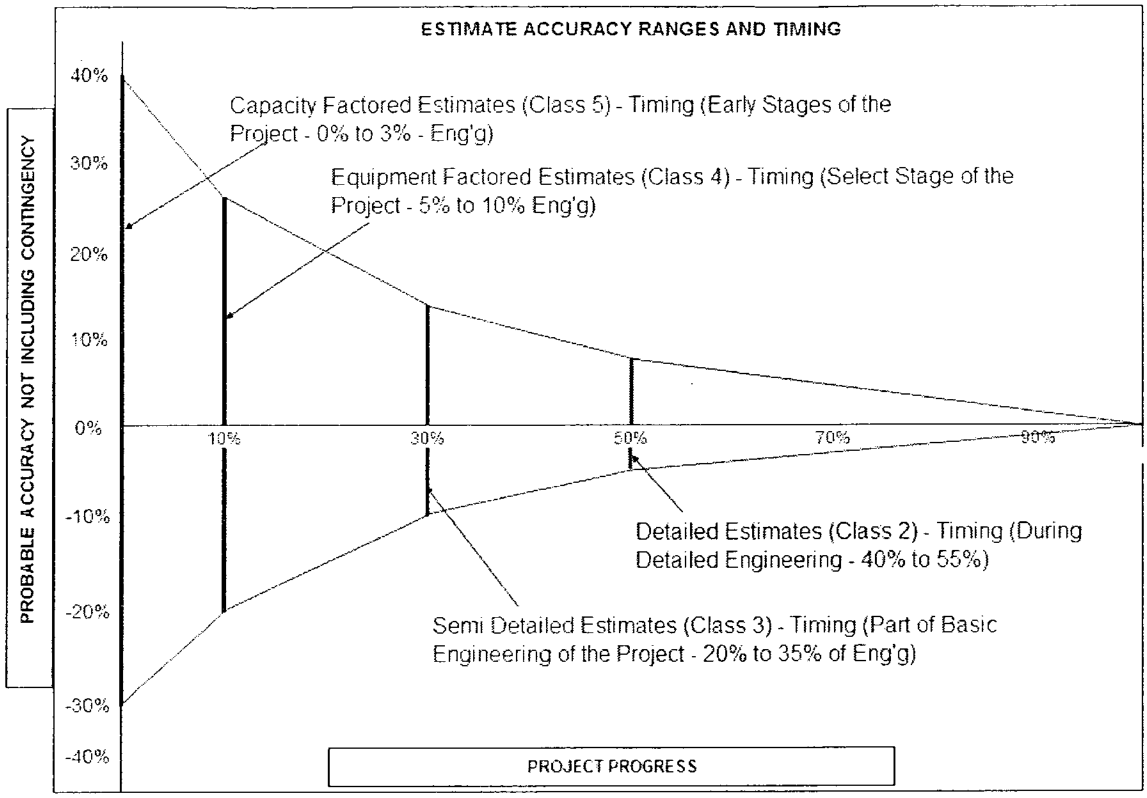


Figure 4-4 Estimate Accuracy Range and Timing (SNC procedure 3306)

ESTIMATE CLASSIFICATION

ESTIMATE CLASS	Level of Project Definition Expressed as % of Eng. Completion	Project Phase	Typical Purpose of Estimate	Typical Estimating Method	Expected Accuracy Range
Class 5	0% to 3%	Project Definition	Concept Screening	Capacity factored, Parametric models, Judgment, or Analogy	Average + 40 / -30%
Class 4	5% to 10%	Conceptual Design	Study or Feasibility	Equipment Factored or Parametric Model	Average: + 25 / -20%
Class 3	20% to 35%	Basic Design	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	Average: + 15 / -10%
Class 2	40% to 55%	Detailed Engineering EPC	Control or Bid/Tender	Detailed Unit Cost With Forced Detailed Take-off	Average: +10 / -5%
Class 1	55% to 100%	Detailed Engineering EPC	Check Estimate or Bid/Tender	Detailed Unit Cost With Detailed Take-off	Average: +5 / -3%

Figure 4-5 Estimate Classification (AACEI 2008)

4.2.3 Self- adjustment Accuracy Range of a Trend

Self-adjustment accuracy range is the third option to be integrated to improve the forecasting accuracy. Equation 4-7 and 4-8 are developed to provide self-adjustment accuracy range of a trend. These self-adjustment accuracy ranges will be applied only in situations that trend period variance percentages fall outside the default ranges.

$$LR_{sa}\% = IW \times LR\% + (1 - IW) \times \sum_{i=1}^{n} W_{lri} \times V_{lri}\% \qquad \textbf{Equation 4-7}$$

$$UR_{sa}\% = IW \times UR\% + (1 - IW) \times \sum_{i=1}^{n} W_{uri} \times V_{ur}\% \qquad \textbf{Equation 4-8}$$

Where,

$LR_{sa}\%$= the self-adjustment lower range of estimate accuracy

$LR\%$ = the default lower accuracy range from engineering progress

IW = the initial weight of default LR% from engineering progress, by default is 0.5

W_{lri} = the weight of trend variance which is outside default lower range. Sum of W_{lri} =1

$V_{lri}\%$ = the trend variance percentage which is outside default lower range

$UR_{sa}\%$= the self-adjustment upper range of estimate accuracy

$UR\%$ = the default upper accuracy range from engineering progress

W_{uri} = the weight of trend variance which is outside default upper range. Sum of W_{uri} =1

$V_{uri}\%$ = the trend period variance percentage which is outside default upper range

This method uses the historical variance between periods of a trend to forecast the accuracy range that will apply to this trend for next period. It is recommended to use under following 2 situations:

1) The evaluation of that trend estimate will last more than 3 periods, in order to provide enough historical information for self-adjustment.

2) This trend estimate is prepared by the same team, in order to screen out subjective errors.

A numerical example is used to demonstrate the method and Table 4-5 and figure 4-6 provide detail information and concept explanation:

Trend (T-008) is estimated to provide potential additional bulk piping for OSBL area. Since the quantity information is based on engineering drawings in basic design stage, then the default estimate accuracy is set to +15% and -10% due to the potential variation from quantities. The unit price is fixed at 20$ per meter.

- In period 1, the take off quantities of pipes are 1000 meters and the estimate is about 20,000.00$. In this case, the accuracy range is set to the default one, which is from -10% to +15%. The @Risk mean output of 20,166.67$.
- In period 2, the take off quantities of pipes drop to 950 meters and the modified estimate amount becomes 19,000.00$. Since the variance% (column 9) is -5% = (950-1000)/1000, which is within the accuracy range, so no action is needed.

- In period 3, the take off quantity of pipes dropped again to 820 meters and the modified estimate amount changed to 16,000.00$. But since the variance is -16% = (800-950)/950, which is outside the default lower range -10%. This causes a concern to estimator and it seems the take off quantities may drop again due to engineering optimization.

  According to equation 4-7,

$$LR_{sa}\% = IW \times LR\% + (1 - IW) \times \sum_{i=1}^{n} W_{lri} \times V_{lri}\%$$

$$LR_{sa}\% = 0.5 \times (-10\%) + (1 - 0.5) \times \sum_{i=1}^{1} 0.5 \times (-16\%)$$

$$= (-13\%)$$

  Where W is set to 0.5 subjectively

- In period 4, the estimator has an option to keep the default accuracy range, or chose the self-adjustment accuracy range, which indicates the estimate amount will be more confident due engineering optimization. The calculation of this self-adjustment accuracy range in period 4 is as follows. But no matter which option is chosen, the span of accuracy range will be kept the same, since the project is still in basic engineering stage.

  $LR_{sa}\%$= -13%, (adjust variance is (-13%) – (-10%) = (-3%))

  $UR_{sa}\%$= 15% + (-3%) =12%

Table 4-5 Self-adjustment Accuracy Range Example (T-008)

Self-Adjustment Estimate Accuracy Range of a Trend

onal bulk piping for OSBL

Initial Accuracy		Initial Weight (IW)
LR (-)%	UR (+)%	
-10%	15%	0.5

acy (+)%	Quantity	UoM	Unit Price	Estimate Amount	Mean @Risk Output	Variance (Cur. - Pre.)	Variance (V_i) %	Period Weights (W_i)
)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
%	1 000	Meter	20.00$	20 000.00$	20 166.67$	0	0	
%	950	Meter	20.00$	19 000.00$	19 158.33$	- 50.00	-5%	
%	800	Meter	20.00$	16 000.00$	16 133.33$	- 150.00	-16%	0.5
%	**800**	**Meter**	**20.00$**	16 000.00$	**15 978.95$**	-	0%	

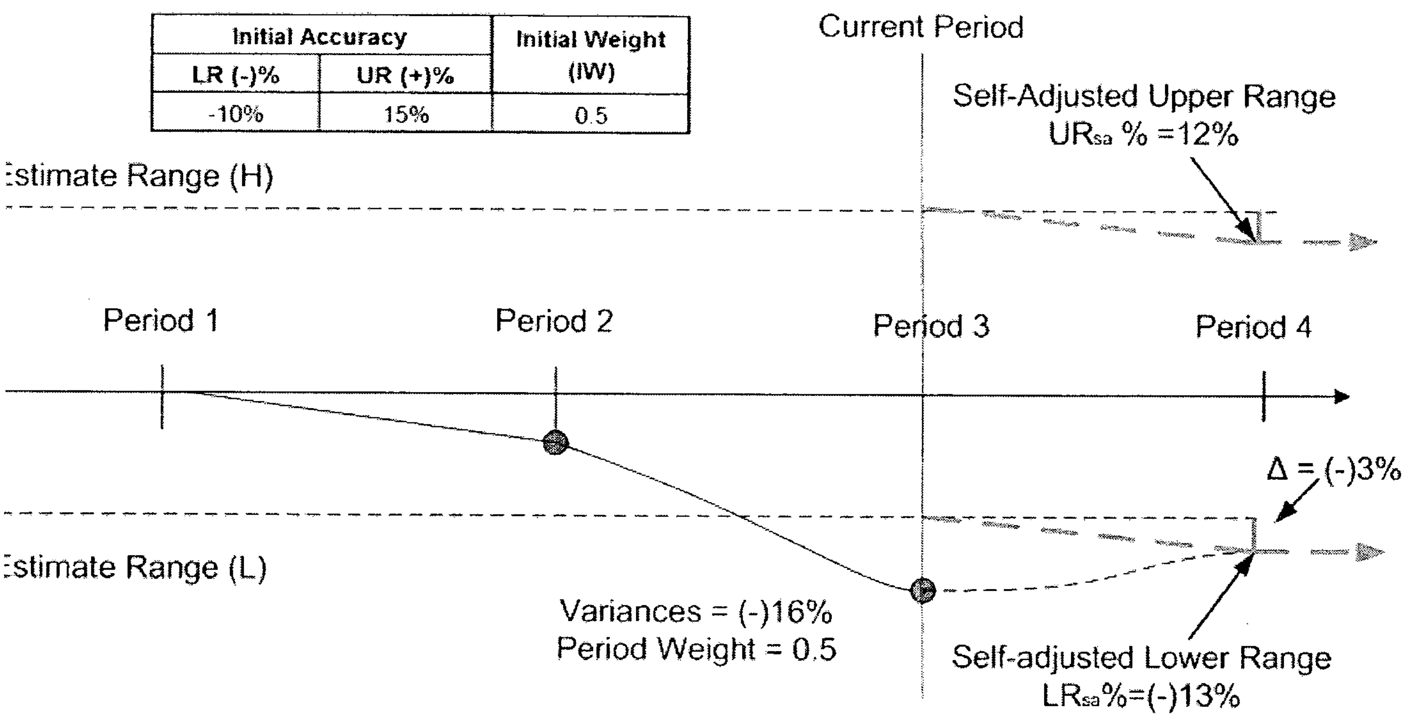


Figure 4-6 Self-adjustment Accuracy Range of Trend T-008

4.2.4 Self-adjustment Cumulative Accuracy Range by Trend Type

Self-Adjustment cumulative accuracy is an extension to self-adjustment accuracy range of a trend. The purpose of this option is to provide the default range for specific type of trend, which may not relate to engineering progress. For example, the pattern of historical accuracy of the trend type "Estimator Errors" will be very likely applied to the new trend estimate under this category.

Algorithm of this method is demonstrated through a series of equations from equation 4-9 to equation 4-20.

$$CTARN\% = \sum_{i=1}^{n} VWP_i\%$$ **Equation 4-9**

$$VWP_i\% = VP_i\% \times WP_i\%$$ **Equation 4-10**

$$\mathrm{VP}_i\% = \mathrm{V_i/TA_i} \times 100\%$$ **Equation 4-11**

$$\mathrm{WP}_i\% = \mathrm{AC_i/TCNV} \times 100\%$$ **Equation 4-12**

$$\mathrm{WP}_i\% = 0$$ **If the BO="Yes"**

$$TCNV = \sum_{1}^{n}(AC_i)$$ **Equation 4-13**

$$V_i = AC_i - TA_i$$ **Equation 4-14**

Where,

$CTARN\%$ = Cumulative trend accuracy range lower bound (negative)

$\mathrm{VWP}_i\% =$ Variance weight percentage with negative V_i

$\mathrm{WP}_i\% =$ Weight percentage with negative V_i

$\mathrm{VP}_i\% =$ Variance percentage with negative V_i

AC_i = Actual cost of a trend with negative variance V_i

TA_i= Trend amount that has negative variance V_i

$TCNV$ = Total trend actual cost with negative variance. It is a conditional sum of 2 criteria: 1) The trend is not blacked out, which means BO = "No"; 2) the variance V_i is negative.)

V_i = the difference between actual cost and trend amount, which is negative.

"i" is series trends to define lower accuracy range

$$CTARP\% = \sum_{j=1}^{n} VWP_j\%$$ **Equation 4-15**

$$VWP_j\% = VP_j\% \times WP_j\%$$ **Equation 4-16**

$$\mathrm{VP}_j\% = \mathrm{V_j/TA_j} \times 100\%$$ **Equation 4-17**

$$\mathrm{WP_j}\% = \mathrm{AC_j/TCPV} \times 100\%$$ **Equation 4-18**

$$\mathrm{WP}\% = 0$$ **If the BO="Yes"**

$$TCPV = \sum_{j=1}^{n} (AC_j)$$ **Equation 4-19**

$$V_j = AC_j - TA_j$$ **Equation 4-20**

Where,

$CTARP\%$ = Cumulative trend accuracy range upper bound (positive)

$VWP_j\%$ = Variance weight percentage with positive V_j

$WP_j\%$ = Weight percentage with positive V_j

$VP_j\%$ = Variance percentage with positive V_j

AC_j = *Actual cost of a trend with* positive V_j

TA_j= *Trend amount that has* positive V_j

$TCPV$ = *Total trend actual cost with negative variance. It is a conditional sum of 2 criteria: 1) The trend is not blacked out, which means BO = "No"; 2) the variance* V_j *is positive.)*

V_j = *the difference between actual cost and trend amount, which is negative.*

"j" is series to define upper accuracy range

A numerical example is used to demonstrate this algorithm in 3 steps.

Step 1, Define the trend type based on project needs. Table 4-6 is an example.

Table 4-6 Define the Trend Type (Example)

Type	Code	Description
1	BMR	Benchmark Reforecast
2	CCT	Claims from Sub-contractors
3	DDT	Design Development
4	EET	Estimating Errors
5	GAL	Growth Allowances
6	OST	Change in Project Scope
7	PCT	Price Changes
8	SCT	Site Conditions

Step 2, Register the trends by trend type.

Trends estimate details and actual cost details should be registered by trend type in order to cumulate information. This method also enables blacking out certain trends in which exceptional conditions are known to have prevailed, and not likely to be repeated beyond the reporting date. The trend estimate amount and actual cost amount were listed in table 4-7.

Table 4-7 Trend List of Trend Type - Design Development (DDT)

TREND TYPE

1 Design Development (DDT)

1	2	3	4	(5)=(4)-(3)	(6)=(5)/(3)	7	8
Trend Number (T)	Weigh (WP)%	Trend Amount (TA)	Actual Cost (AC)	Variance (V)	Variance (VP)%	Blackout (BO)	Variance Weight % (VWP)
DDT-01	0%	100$	130$	30$	30%	Yes	0.00%
DDT-02	21%	300$	330$	30$	10%	No	2.10%
DDT-03	12%	250$	230$	- 20$	-8%	No	-0.97%
DDT-04	27%	400$	425$	25$	6%	No	1.69%
DDT-05	52%	800$	816$	16$	2%	No	1.04%
DDT-06	40%	800$	750$	- 50$	-6%	No	-2.48%
DDT-07	48%	1 000$	910$	- 90$	-9%	No	-4.33%

Table 4-8 CTAR Results Display

Cumulative Trend Accuracy Range (CTAR) in this type

Minus(-) % CTARN%	Plus(+) % CTARP%
-7.79%	**4.83%**

	Dollars
Total trend actual cost with positive variance (TCPV)	1 571.0$
Total trend actual cost with negative variance (TCNV)	1 890.0$

In this example, according to equation xy

TCPV = (DDT-02) + (DDT-04) + (DDT-05) = 330$ + 425$ + 816$=1571$

TCNV = (DDT-03) + (DDT-06) + (DDT-07) = 230$ + 750$ + 910$=1890$

$WP\%_{(DDT\text{-}02)}$ = 330/1571= 21%

V $(_{DDT\text{-}02})$ = 330 – 300 = 30

$VP\%_{(DDT\text{-}02)}$ = 30/300 = 10%

$VWP\%_{(DDT\text{-}02)}$ = 10% X 21%=2.10%

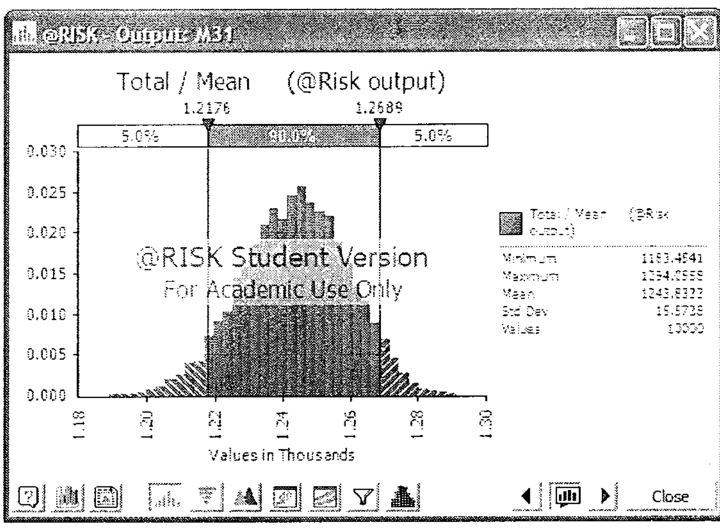
CTARN% = (-)0.97%+ (-)2.48% + (-)4.33% = (-)7.79%

CTARP% = 2.10% + 1.69% + 1.04% = 4.83%

From this CTARN and CTARP, we can tell that in the historical data in the trend type of "Design development", more trend amounts are turned into actual cost in optimistic direction than in pessimistic direction. Or we can tell we are over pessimistic. With this reference, estimators can apply this cumulative trend accuracy range (CTAR) to next trend estimate under the type of "Design development" and the table 4-9 is an example of this application.

nt Accuracy Range Is Applied to A New Trend within the Same Type

Facility	CRC	Description	Accuracy Minus (-)%	Accuracy Plus (+) %	Most likely	Mean (@Risk output)
12100	3110-Light Steel	LIGHT STEEL (X <= 30 KG/M)	-7.79%	4.83%	300$	299$
12100	3120-Medium Steel	MEDIUM STEEL (30 KG/M < X <= 80 KG/M)	-7.79%	4.83%	200$	199$
12400	3130-Heavy structure	HEAVY STEEL (X > 80 KG/M)	-7.79%	4.83%	500$	498$
12400	3200-Steel members	STEEL GIRDER, BEAMS AND COLUMNS	-7.79%	4.83%	250$	249$
		Total			**1 250$**	**1 244$**



Based on this proposed method, the project control people can decide or choose estimate accuracy range from available information and integrate estimate accuracy range to provide better trend forecasting.

4.3 Project Progress Integrated Control and Forecasting

After discussing with different project control people, the following factors are some of the reasons preventing the facilitation of project progress integrated control and forecasting:

1) The project baseline is established mainly based on WBS, but the project is executed mainly by internal work packages, purchase orders and construction contracts. This difference causes a gap between time planning and cost monitoring.
2) It is time consuming to distribute the commitment package values according to time. For example, a large size project has about 1000 commitment packages and some of these commitment packages have 500 budget lines.
3) Different unit of measures on progress measurement obstruct the integration of overall project progress curves. For example, it is more convenient to plan and monitor the engineering work by work hours; on the other hand, the dollar values will be more suitable to measure the procurement work.

In the following section, methods and workflows are proposed to provide project progress integrated control and forecasting. Figure 4-7 is the workflow and it is explained in coming sections.

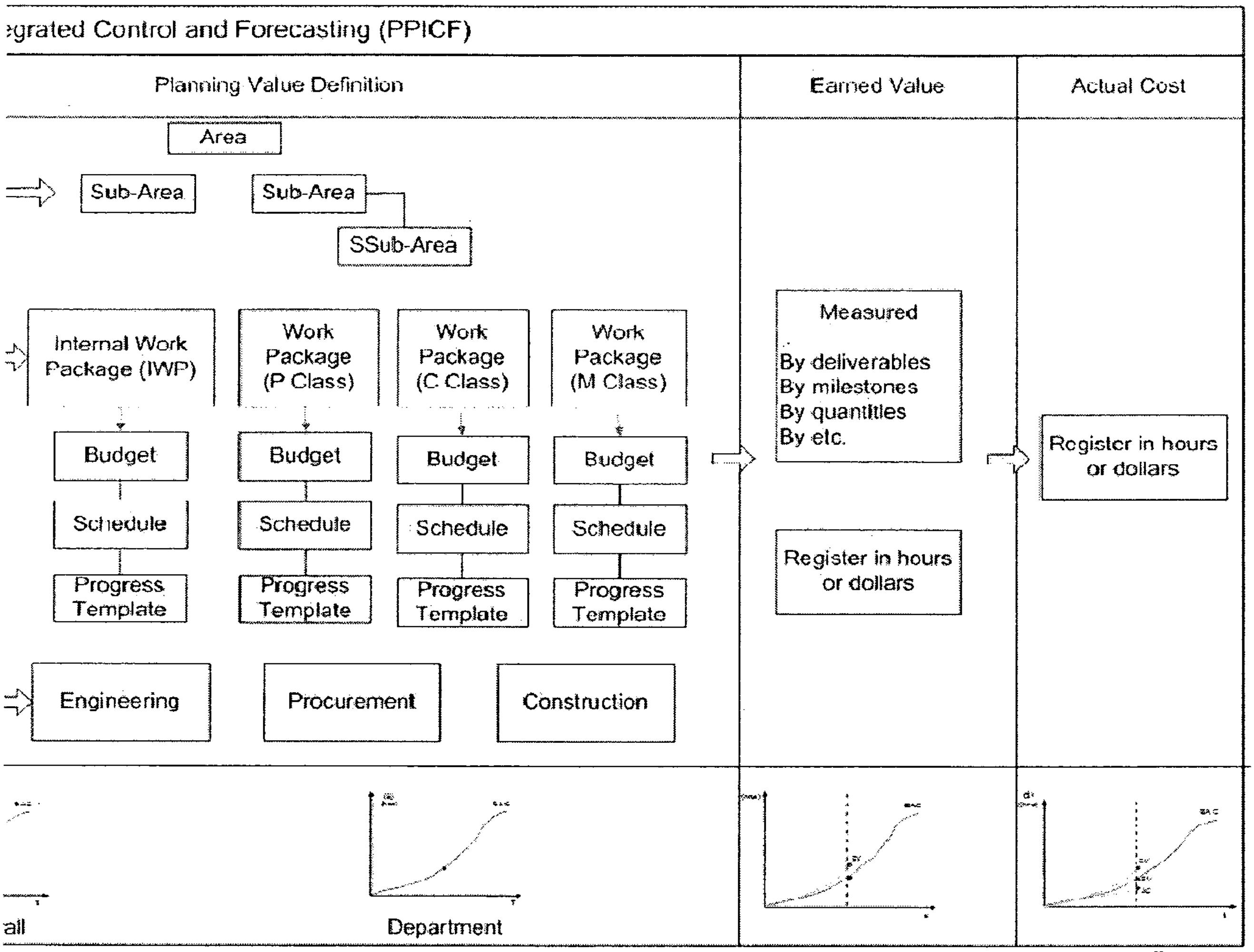


Figure 4-7 Project Progress Integrated Control and Forecasting –PPICF

4.3.1 Planned Value Definition

The first step is to define the level of control detail. Engineering work is planned at 3 levels but controlled at 2 levels. Procurement work is planned by P class of commitment packages and monitored by P class of purchase orders. Construction work is planned by C class of commitment packages and controlled by C class of contracts. Figures 4-8 and 4-9 outline the 2 key steps of this overall plan.

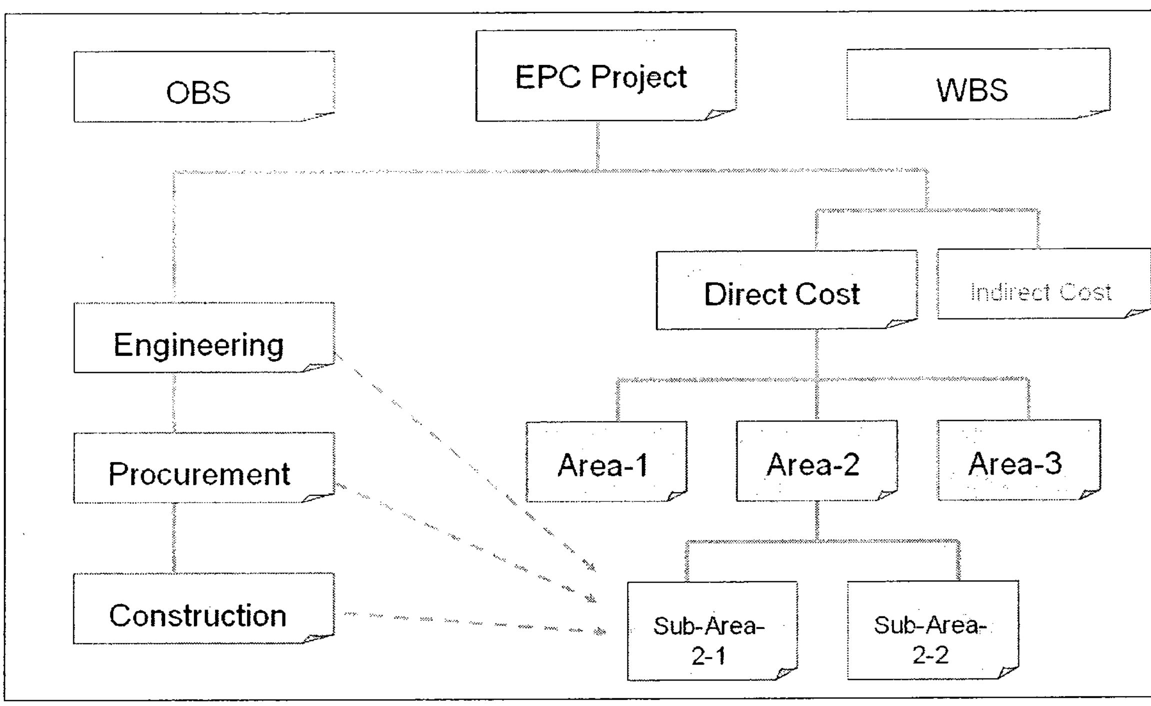


Figure 4-8 Prepare the OBS and WBS in EPC Project

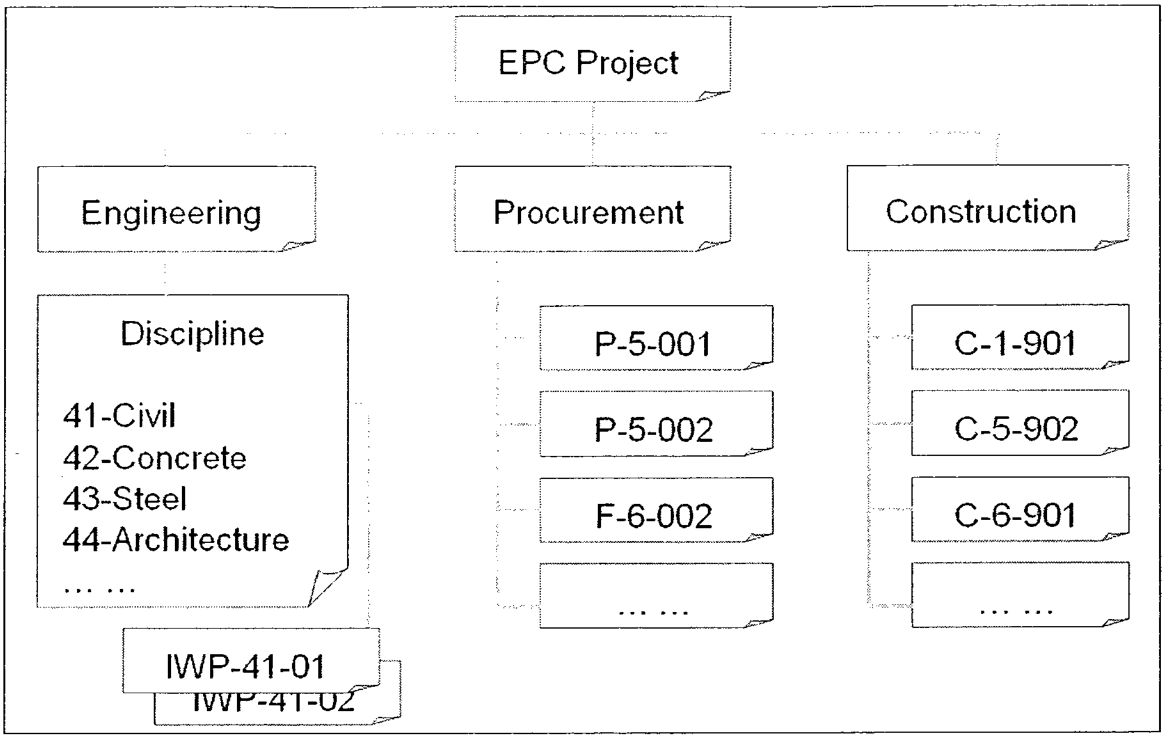


Figure 4-9 Define the Execution Strategy Packages

To apply the earned value, the planned values need to be distributed according to time. 5 steps are proposed to facilitate this function:

1) Use predefined progress templates to break down the commitment packages into different milestones.
2) Integrated the estimate accuracy into the budget definition by using PERT method and distribute the budget to milestone level.
3) Prepare schedule activities in order to provide schedule information for each milestone.
4) Use beta distribute function in excel to distribute the milestone value according to milestone dates automatically by selected shape factors.

5) Sum all work packages by department to generate the department planned value curve, or called performance measurement plan.

The following numerical example demonstrates these ideas in steps. In this example, it is a purchase order P-5-001 with value of 1000$. It is a major purchase order with different delivery dates.

Step 1, Define progress template in order to measure the earned value in a later stage. To improve the control of engineering work and subcontracts, a broad literature reviews were done to conclude progress measurement templates. Table 4-10 (PM+, 2004) and 4-11 (James and Kenneth 2005) are two examples of engineering work and construction work. More templates are documented in appendix B. Figure 4-10 is a practical template with weights on each milestone that can be applied to major purchase order.

Table 4-10 Progress Template for Civil Drawings

Code	Description	Weight (%)	Cumulative (%)
1	Initial Design	5	5
2	Started	15	20
3	Released - Internal review	40	60
4	Released - Client comments	10	70
5	Released - For tender	20	90
6	Released - For construction	5	95
7	As built received / Filed	5	100

Table 4-11 Progress Template for Concrete Work

Code	Description	Weight (%)	Cumulative (%)
1	Rebar in place	20	20
2	Forming complete	50	70
3	Concrete poured	10	80
4	Stripping complete	15	95
5	Dressed and patched	5	100

Code	Template Name	Milestone	Description	P %	C %	E	P	C
P01	Major PO Progress						P	
		MT-1	Award PO	5%	5%			
		MT-2	Initiate Vendor Drawing	5%	10%			
		MT-3	Vendor Drawing Approve	5%	15%			
		MT-4	Fabrication 1 - First Key Fabri.	25%	40%			
		MT-5	Fabrication 2 - Interim Key Fabri.	20%	60%			
		MT-6	Fabrication 3 - Final Key Fabri	20%	80%			
		MT-7	Deliver to ship Ex-work - 1 Major Delivery	5%	85%			
		MT-8	Deliver to ship Ex-work - 2 Other Delivery	5%	90%			
		MT-9	Deliver to ship Ex-work - 3 Final Delivery	5%	95%			
		MT-10	Deliver to Site	5%	100%			

Figure 4-10 Major PO Progress Template

Step 2, integrated the estimate accuracy into the budget definition by using PERT method and distribute the budget to milestone level. Figure 4-11 is an example. Where PO 5-001, rotating pumps, has original budget of 180,000 dollars. After integrating the accuracy range (-5% to +10%), The PO values, both original budget and probabilistic output value FFC (181,500 dollars), are broken down into 10 milestones for progress measurement purpose.

EPC Project Progress - Planned Value Definition

Work Package		Progress Template					Accuracy		Dollars	
WP-No.	WP Name	TMPL	MileStone	Description	P %	C %	Minus	Plus	Budget	EFC
									180 000 00$	
PO-5-001	Rotating Pumps	P01			100%		-5%	10%	180 000 00$	181 500 00$
			MT-1	Award PO	5%	5%			9 000 00$	9 075 00$
			MT-2	Initiate Vendor Drawing	8%	13%			14 400 00$	14 520 00$
			MT-3	Vendor Drawing Approve	8%	21%			14 400 00$	14 520 00$
			MT-4	Fabrication 1 - First Key Fabri.	20%	41%			36 000 00$	36 300 00$
			MT-5	Fabrication 2 - Interim Key Fabri.	20%	61%			36 000 00$	36 300 00$
			MT-6	Fabrication 3 - Final Key Fabri.	20%	81%			36 000 00$	36 300 00$
			MT-7	Deliver to ship Ex-work - 1 Major Delivery	5%	86%			9 000 00$	9 075 00$
			MT-8	Deliver to ship Ex-work - 2 Other Delivery	5%	91%			9 000 00$	9 075 00$
			MT-9	Deliver to ship Ex-work - 3 Final Delivery	5%	96%			9 000 00$	9 075 00$
			MT-10	Deliver to Site	4%	100%			7 200 00$	7 260 00$

Figure 4-11 Purchase Order Value Breakdown According to Milestones

Step 2, Prepare schedule activities in order to provide schedule information for each milestone. Schedule activities should be prepared in scheduling tool with predefined coding structure related to PO numbers and milestones. In this plan schedule, each activity has the schedule start and schedule finished date. This information will be exported from scheduling tool, then imported to link with predefined progress template milestones. Figure 4-12 is an example.

WBSC	Task Name	Duration	Start	Finish
P-5-001	**Rotating Pump (P-5-001)**	**49 days**	**Mon 08/03/17**	**Thu 08/05/22**
P-5-001-10	Award PO	2 days	Mon 08/03/17	Tue 08/03/18
P-5-001-20	Initiate Vendor Drawing	5 days	Wed 08/03/19	Tue 08/03/25
P-5-001-30	Vendor Drawing Approve	2 days	Wed 08/03/26	Thu 08/03/27
P-5-001-40	Fabrication 1 - First Key Fabri.	15 days	Fri 08/03/28	Thu 08/04/17
P-5-001-50	Fabrication 2 - Interim Key Fabri.	8 days	Fri 08/04/18	Tue 08/04/29
P-5-001-60	Fabrication 3 - Final Key Fabri.	5 days	Wed 08/04/30	Tue 08/05/06
P-5-001-70	Deliver to ship Ex-work - 1 Major Delivery	11 days	Fri 08/04/18	Fri 08/05/02
P-5-001-80	Deliver to ship Ex-work - 2 Other Delivery	11 days	Wed 08/04/30	Wed 08/05/14
P-5-001-90	Deliver to ship Ex-work - 3 Final Delivery	11 days	Wed 08/05/07	Wed 08/05/21
P-5-001-100	Deliver to Site	1 day	Thu 08/05/22	Thu 08/05/22

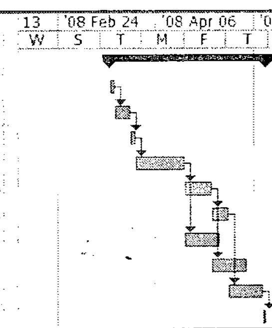


Figure 4-12 Prepare the Schedule Activities in Scheduling Tool

Step 4, Use Beta distribute function in excel to distribute the milestone value according to milestone dates automatically. As discussed in this chapter, Beta distribution is a continuous distribution defined over a range, both of its end points are fixed at exact locations. By choosing different shape factors α and β, the value can be distributed within the range. For this sake, Beta distribution is applied to distribute milestone value between milestones. In this research, the shape factors selection is subjective, but both Alpha and Beta are set to 2 by default.

For example, the activity "Fabrication 1 – First Key fabric" has 25% of weight, or it has a dollar value of 250$. It has duration of 15 days and the schedule start and finish date are 2008/03/28th and 2008/04/17th. The embedded function in Microsoft Excel, "betadist", is used to distribute the milestone value between these 2 milestone dates. The Syntax of this embedded function is:

$Betadist(X, Alpha, Beta, A, B)$

X, is the value between A and B at which to evaluate the function.

Alpha, is a parameter of the distribution or is called shape factor

Beta, is a parameter of the distribution or is called shape factor

A, is lower bound to the interval of X.

B, is upper bound to the interval of X.

In this example, the function is betadist(250, 2, 2, 2008/03/28, 2008/04/17).

When alpha and beta both equal to 2, the distribution curve is bell shape between lower and upper bound. Figure 4-13 demonstrates the distribution shape of 6 sets of alpha and beta values, based on a duration of 10 periods.

Range (L)	Range (H)	Beta Shape Factors Alpha	Beta	1	2	3	4	5	6	7	8	9	10
1	10	2	1	0%	1%	4%	6%	9%	11%	14%	16%	19%	21%
1	10	2	2	0%	3%	9%	13%	16%	17%	16%	13%	9%	3%
1	10	2	3	0%	6%	15%	19%	19%	17%	12%	7%	3%	1%
1	10	2	4	0%	10%	21%	23%	20%	14%	8%	4%	1%	0%
1	10	2	5	0%	13%	26%	25%	18%	11%	5%	2%	0%	0%
1	10	2	6	0%	18%	31%	25%	16%	7%	3%	1%	0%	0%

Period

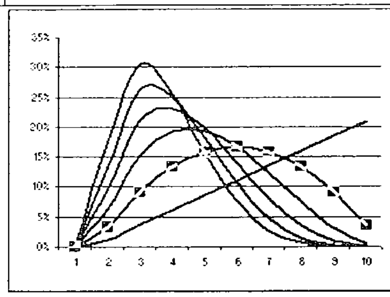


Figure 4-13 Beta Distribution Example with 6 Sets of Shape Factors

To let the system distribute the right value to the right period automatically, an improvement of this function is provided. It is a combination with the following functions:

IF(logical_test,value_if_true,value_if_false)

ISERR Value refers to any error value except #N/A.

MAX(number1,number2,...)

MIN(number1,number2,...)

Figure 4-14 is a scenario that demonstrates this concept. In this example, the Alpha and Beta are set to 2. In original plan, work package has the following information: 1) value Y (either in dollar or in hour), 2) start date is (SD1), 3) finish date is (FD1), 4) shape factors are both set to 2. By using the combined functions, value Y can be distributed to different periods accordingly. In the revised plan, everything is same, except for the finish date. By applying the combined functions, value on each period will be redistributed automatically. It saves planners huge amount of time for a project having 1000 activities.

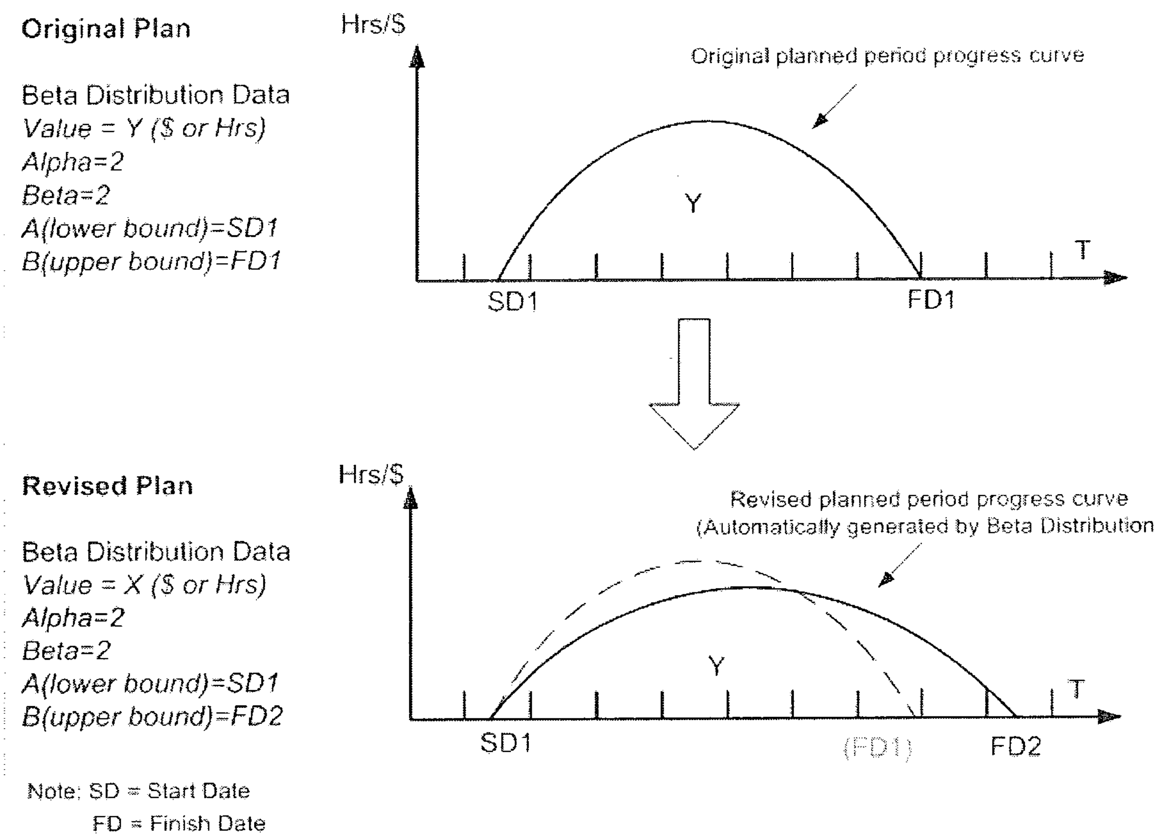


Figure 4-14 Generate Planned Progress Curve by Beta Distribution Function

Step 5, Sum all the work packages by department to generate the department planned value curve, or called performance measurement plan. By summing all the cumulative distributed value of all the milestones, commitment packages, and departments, the planned value curve at level of commitment package, department and project overall can be generated automatically.

Value accuracy range is also applied to commitment package level in order to get a probability output range on each planned value curve.

4.3.2 Earned Value Measurement and Registration

It is proposed that: 1) Earned value of engineering works are measured by deliverables progress and registered at IWP levels, 2) Earned value of procurement packages are measured and registered by milestones, 3) and Earned value of construction packages are measured and registered by milestones.

An individual data windows or spread sheet can be developed to register the EV in order to facilitate the registration and maintenance.

4.3.3 Actual Cost registration

Actual costs of engineering works are registered in work hours at IWP level. The information can be collected from a time sheet system. Actual costs of procurement packages are registered in incurred dollar value. This information can be collected from vendors' progress invoice and estimated accrual cost. Actual cost of construction packages is registered in incurred dollars or work hours values. This information can be collected from contractors' progress billing and estimated accrual cost.

An individual data windows or spread sheet can be developed to register the AC in order to facilitate the registration and maintenance.

4.3.4 Department and Project Overall Progress Curves

With the well defined data, it is easy to generate the progress curves for each department. If there are differences in unit of measure of progress between departments, weighting by dollars value can be applied to prepare the project overall progress curves, which use the dollar as the unit of measure.

4.4 Visualized Reporting

The purpose of this section is to provide an interactive multimedia database that can be accessed and used by different project team members to document and report progress in construction operations, as well as a tool to visualize the progress report. The database infrastructure and integrated coding structure for all multimedia is proposed.

4.4.1 Infrastructure

To facilitate the data collection, upload, store, manipulation and reporting, a proposed data infrastructure is demonstrated in figure 4-15. This infrastructure has 4 key components. The 1st component indicates that different media information, including text, audio, video and photos, can be collected from the construction site. The 2nd component is established based on the Microsoft windows SharePoint service. All the collected multimedia data will be uploaded and stored in this server. In the 3rd component, through internet, the project management team can easily access to the SharePoint server to extract and manipulate the multimedia information. The filtered results, such as photos of area A in certain period, with sub group of contracts, can be as embedded hyperlink in monthly progress report. In the 4th component, the client or management can easily explore this multimedia by clicking the hyperlink on the subject that they would like to see.

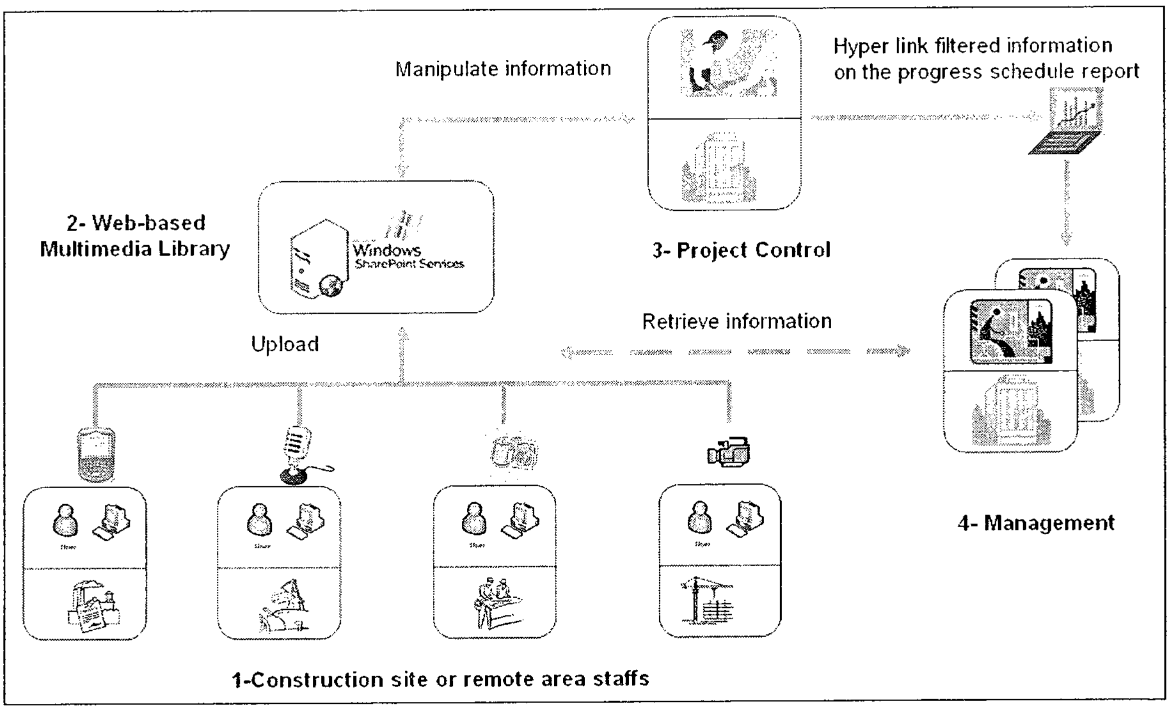


Figure 4-15 Progress Visualization Database Infrastructure

This approach can provide more multimedia information with better quality, also well organized.

4.4.2 Method of Coding Structures for Photos Records

Currently, digital camera is widely used to record construction progress, status or accidents, but most of these photos are stored and managed in the folders of personal computers. They lack of efficient management. A method to integrate construction images is proposed here for reporting purpose. For the project control, these construction progress media can be classified for different reporting purpose, such as regular progress reporting, regular construction safety reporting, and incident detail records reporting.

To manage the pictures and multimedia efficiently, a set of multimedia coding structure is established and displayed in table 4-12 and table 4-13. It is decomposed into 1 default level, 4 mandatory levels and 3 optional levels. Level 0 is the project level, which is the project code or number. This code will be used for photo import and export function. Level 1 is area and sub area, which is mandatory for progress reporting. Level 2 is package, which will help to group pictures by discipline or contract, such as civil work, steel work. Coding structure example is provided in table 4-14.

Table 4-12 Proposed Photo Coding Structure

Item	Name	Description
0	Project Number (Default)	Each project has an individual database, the level 0 is default during the actual photo input and it will not display in the coding. But when needed, this code will be displayed, such as exporting all the photos from one database to another database.
1	By Area or system	Physical progress report by area or system are needed.
2	Package (PO/Contract)	The project is executed by purchase orders and contracts.
3	Title	Title is mandatory
4	Description	It's field to provide detail text information.
5	Activity (Excavation)	Linking the photos and multimedia with milestone activities can provide visual progress report and traceability. Activities list can be imported from scheduling tool.
6	Photo taken date	This information will provide a reference point for progress tracking.
7	Direction	To identify from which direction the multimedia is taken

Table 4-13 Direction Coding at Level 7

Code	Direction	Code	Direction
E	East	NW	North West
S	South	NE	North East
W	West	SE	South East
N	North	SW	South West

Table 4-14 Photo Coding Structure Example

Level	Description	Example
0	Project Number	001468 (Poly Project)
1	By Area or system	12050 (Site preparation)
2	Package	1-902
3	Title	site excavation
4	Description	The equipment is broken
5	Activity	OSBL1902-50 (Excavation)
6	Photo taken date	04052005 (dd/mm/yyyy)
7	Direction	E (from east to west)

After setting this coding for any multimedia, it is very easy to report or track site progress photos by different criteria. For example, in order to generate a site progress photos list about Area 12050 in last month, users can just set the filter for Area = 12050 and time period, such as between current date minus 30 days and current date.

4.4.3 Integration between Progress Report and Multimedia Center

A set of filters can be defined at the beginning of a project. These filters can group stored multimedia by work package, by area, or other criteria which may interest the management. The addresses, or hyperlinks, information of saved filters can be embedded on monthly progress report as per need.

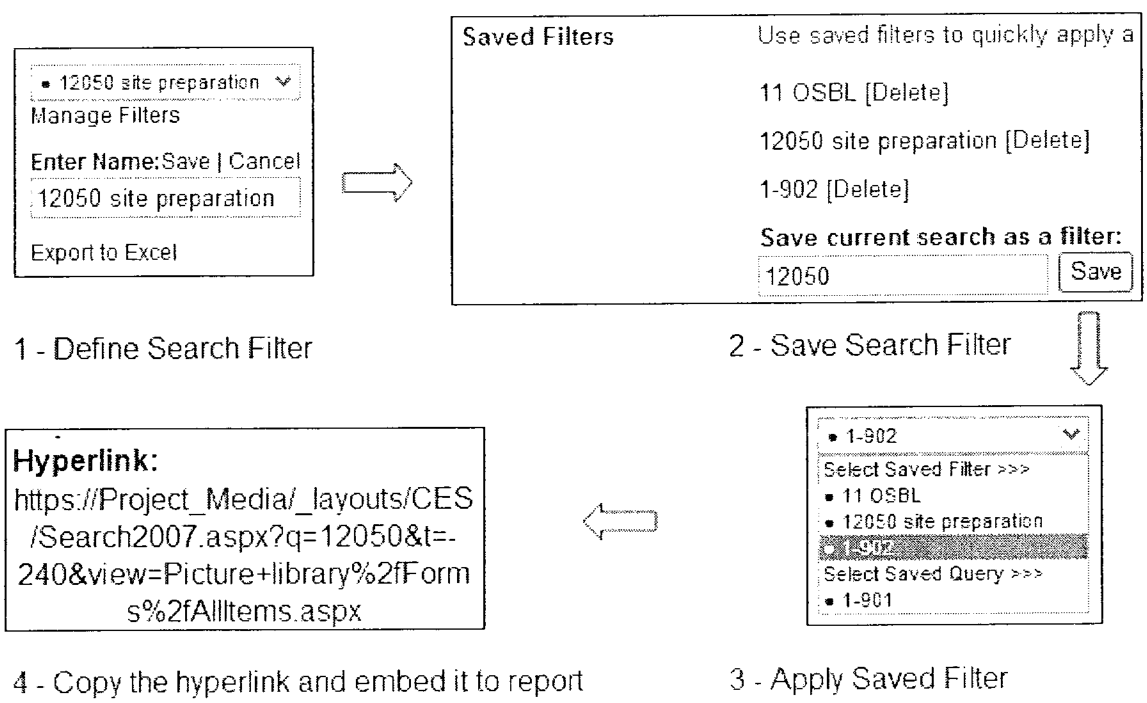


Figure 4-16 Multimedia Filter for Reporting

4.4.4 Security and Safety

Information is only accessible to the authorized personnel. Different security levels can be applied to different folders on different users. User access security can be by members, by user types and by user groups. The permissions are cumulative. The highest prevails over the lowest. For example, if a user having accesses in reading is attached to a group having administrator's permissions; this user will thus have administrator's accesses. A backup database should be provided also in case of disaster.

5 CHAPTER FIVE: ADD ON TOOLS DEVELOPMENT

The proposed programs will work as add on tools to PM+ or other project management systems to improve the identified limitations. These tools are also stand-alone to provide more accurate trending, forecasting and better progress visualization information to project team. Interface of information exchange between PM+, scheduling tool and proposed programs is considered.

5.1 Add on Tools Infrastructure

3 add on tools are developed to implement the 3 proposed methodologies. The following tools and systems are used to achieve this goal: 1) PM+ system; 2) Microsoft Excel; 3) Microsoft project; 4) VBA; 5) @Risk 5.0 for Excel; 6) Power Builder 9.0 from Sybase; 7) SQL language; 8) Windows SharePoint Services 3.0.

Add on tool 1 is named trend estimate (TE). It applies probabilistic forecasting to providing trend estimate results output utilizing estimate range. It is built in the environment of @Risk 5.0 for excel. Output can be used to upload into PM+ for integration reporting purpose. A set of prototype data windows is developed in Power Builder 9.0.

Add on tool 2 is named project progress integrated control and forecasting (PPICF). The objectives of this tool are: 1) to provide an easy way to prepare the performance measurement base line by using the information from PM+, 2) to facilitate the utilization of EVM into progress control and forecasting for construction projects. It is built in the environment of @Risk 5.0 for excel, with integration with PM+ and scheduling tool, Microsoft Project. VBA is also applied to provide simple automation function.

Add on tool 3 is named progress visualization database (PVD). It is developed based on Windows SharePoint Services 3.0. The output from this tool is integrated with the PPICF for visualization progress reporting purpose.

Figure 5-1 outline this infrastructure and relationships between the add on tools and existing systems.

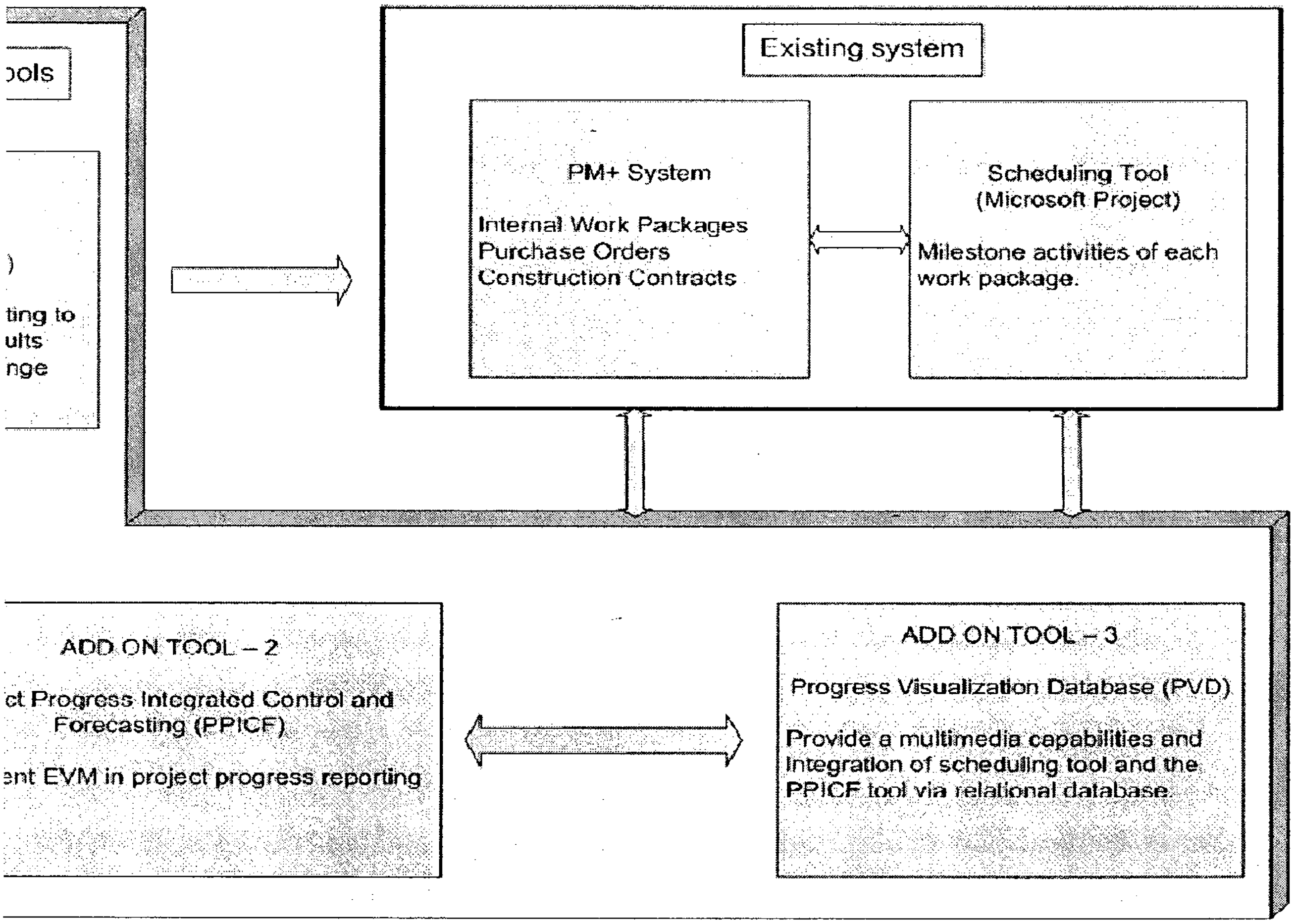


Figure 5-1 Add on Tools Infrastructure

5.2 *Trend Estimate Accuracy*

Figure 5-2 is the detail structure of this tool and Figure 5-3 identifies the mandatory information for trend estimate from PM+. The proposed tool trend estimate (TE) should be able to provide all these mandatory information accordingly in order to import into PM+ in a later stage. To simplify the demonstration, a unit price material purchasing estimate is presented.

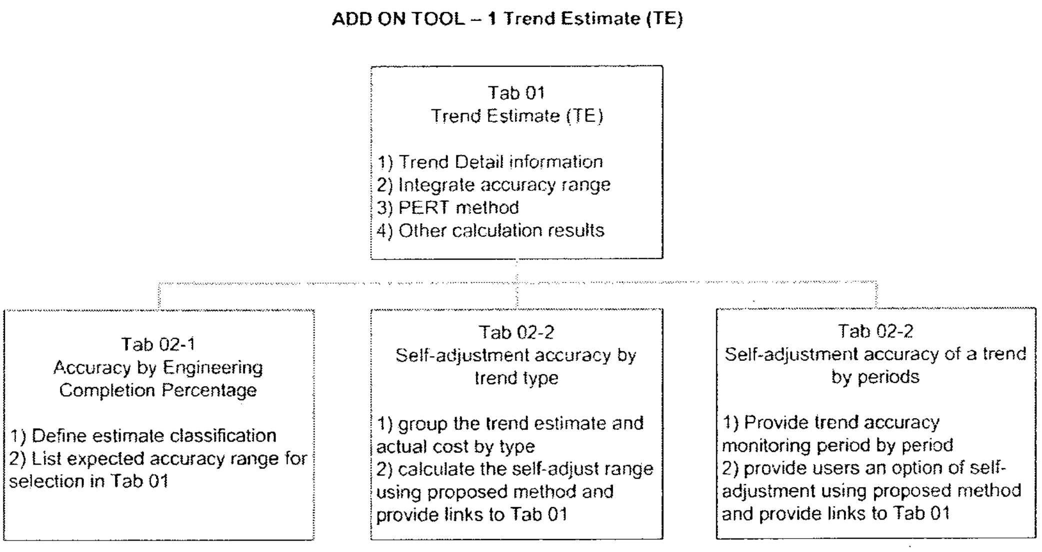


Figure 5-2 Detail Structure of Add on Tool 1-TE

Table 5-1 displays that all the mandatory information for PM+ is provided in this excel tool. They are listed from column A to column L. Additional to that, 3 extra columns are added and displayed in table 5-2. Column G and H are for the registration of accuracy range, with low and high bounds. Column M is for the application of PERT method. @Risk is to provide a platform to use the Monte Carlo simulation engine to provide probability results in both graphical and tabular format.

Trend T-0001

	Facility	CRC	Description	Total
Temporary	29150 - SITE OFFICE	9435 - ELECTRICAL SERVICES	COMMITMENT GROWTH FOR 1-901.1	4,216.00
Temporary	29150 - SITE OFFICE	9435 - ELECTRICAL SERVICES	COMMITMENT GROWTH FOR 1-901.1item 2	4,000.00
Temporary	29150 - SITE OFFICE	9435 - ELECTRICAL SERVICES	COMMITMENT GROWTH FOR 1-901.1 item 3	3,920.00

Figure 5-3 Trend Detail Information (Partial)

Table 5-1 Mandatory Trend Detail Information in TE

Facility	CRC	Description	Quantity	UoM	Unit Price	Most likely
12100	3110-Light Steel	LIGHT STEEL (X <= 30 KG/M)	20.00	Ton	600.0$	12 000$
12100	3120-Medium Steel	MEDIUM STEEL (30 KG/M < X <= 80 KG/M)	18.00	Ton	700.0$	12 600$
12400	3130-Heavy structure	HEAVY STEEL (X > 80 KG/M)	25.00	Ton	1 000.0$	25 000$
12400	3200-Steel members	STEEL GIRDERS, BEAMS AND COLUMNS	100.00	Ton	550.0$	55 000$
		Total				**104 600$**

Table 5-2 Additional Trend Detail Information in TE

	E	F	G	H	I	J	K	L	M
			Subjective						
			Accuracy Range						
/	CRC	Description	Minus (-)%	Plus (+) %	Quantity	UoM	Unit Price	Most likely	Sampled (@Risk output)
)	3110-Light Steel	LIGHT STEEL (X <= 30 KG/M)	-10.00%	15.00%	20.00	Ton	600.0$	12 000$	12 100$
)	3120-Medium Steel	MEDIUM STEEL (30 KG/M < X <= 80 KG/M)	-10.00%	15.00%	18.00	Ton	700.0$	12 600$	12 705$
)	3130-Heavy structure	HEAVY STEEL (X > 80 KG/M)	-10.00%	15.00%	25.00	Ton	1 000.0$	25 000$	25 208$
)	3200-Steel members	STEEL GIRDERS, BEAMS AND COLUMNS	-10.00%	15.00%	100.00	Ton	550.0$	55 000$	55 458$
		Total						**104 600$**	**105 472$**

The built in formula in column of "Sample @Risk output" is "RiskPert(Min, Most likely, Max)". In table 5-2, for example, formula is cell "M4" is "=RiskPert(L4*(1+G4),L4,L4*(1+H4))". After entering the subjective accuracy range in column G and H accordingly, automatically, the mean output is listed in column M with a total amount. In order to get a probability density, we set the iteration to 5000 in 1 simulation. After clicking the start of simulation, all needed information can be provided in both tabular and graphical format. Some of them are listed in table 5-3 and figure 5-4

Table 5-3 Tabular Output from TE

01- Trend Estimate Accuracy (TE)

3-Self-adjustment of a trend type

4-Self-adjustment of a trend

Facility	CRC	Description	**Subjective Accuracy Range** Minus (-)%	Plus (+) %	Most likely	Sampled (@Risk output)
12100	3110-Light Steel	LIGHT STEEL (X <= 30 KG/M)	-10.00%	15.00%	12 000$	12 100$
12100	3120-Medium Steel	MEDIUM STEEL (30 KG/M < X <= 80 KG/M)	-10.00%	15.00%	12 600$	12 705$
12400	3130-Heavy structure	HEAVY STEEL (X > 80 KG/M)	-10.00%	15.00%	25 000$	25 208$
12400	3200-Steel members	Steel girders, beams and columns	-10.00%	15.00%	55 000$	55 458$
		Total			**104 600$**	**105 472$**

e of 104600	40.2%	104 600
)0.0% confidence	109 434.56$	90.0%
90.0% confidence	4 834.56$	

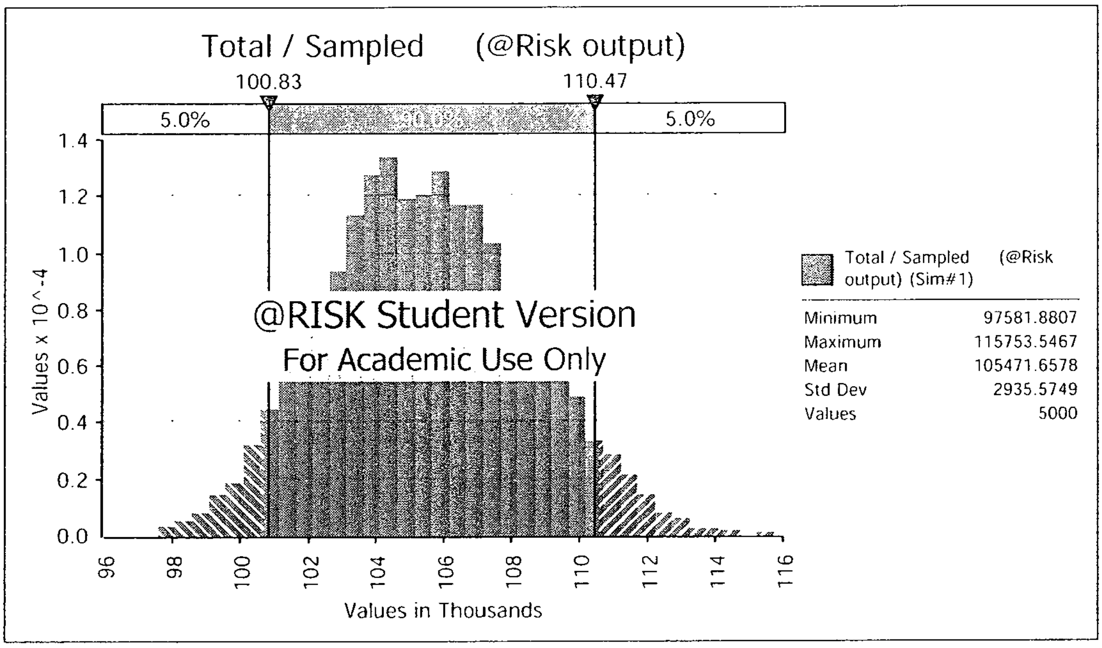


Figure 5-4 Graphical Output from TE with @Risk

To provide above proposed accuracy range options to users, 3 sub tabs were built based on: 1) engineering completion stage, 2) self- adjustment accuracy by trend type, 3) self-adjustment accuracy of a trend by period. These 3 tabs are linked together to the master tab, the trend estimate (TE). No matter which option is selected, the user can overwrite it. Table 5-4 is the sub tab named "02-1 Estimate accuracy range based on engineering completion percentage".

e 5-4 Estimate Accuracy Range Based on Engineering Completion Percentage

imate Accuracy Range based on Engineering Completion percentage

Project ɔressed as ompletion	Project Phase	Typical Purpose of Estimate	Typical Estimating Method	Expected Accuracy Range	
				Minus (-)%	Plus (+) %
3%	Project Definition	Concept Screening	Capacity factored, Parametric models, Judgment, or Analogy	**-30%**	**40%**
10%	Conceptual Design	Study or Feasibility	Equipment Factored or Parametric Model	**-20%**	**25%**
35%	Basic Design	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	**-10%**	**15%**
55%	Detailed Engineering EPC	Control or Bid/Tender	Detailed Unit Cost With Forced Detailed Take-off	**-5%**	**10%**
100%	Detailed Engineering EPC	Check Estimate or Bid/Tender	Detailed Unit Cost With Detailed Take-off	**-3%**	**5%**

uracy by ES / 02-2-Accuracy Trend Type / 02-3 Self-adjustment Accuracy / Trend Details /

Efforts have been spent to interpret this trend estimate TE method by developing a set of prototype data windows in power builder environment. System screen captures are listed in appendix C

5.3 Project Progress Integrated Control and Forecast

The 2nd add on tool PPICF is broken down into 2 main functions: 1) data preparation and manipulation function, and 2) reporting function. Figure 5-5 shows the flowchart of this add on tool. In order to prepare the planned value, or performance measurement baseline, information exchange from PM+ and scheduling tool is needed. Sub tab-91 is designed to store activities list imported from scheduling tool, including the following key information: 1) activity code, 2) activity name, 3) schedule start date, 4) schedule finish date, 5) actual started date, and 6) actual finished date. Another 2 tabs, tab-90 and tab-92, are also created to provide predefined progress template and beta distribution curve shape examples with 36 sets of different shape factors.

To provide the reporting function, 4 separate tabs are created to provide 2 levels of progress curves for monitoring and control. The 2nd level progress curve includes: 1) engineering progress curve, which is reported in work hours value completion, 2) procurement progress curve, which is reported in dollar value completion, 3) construction progress curve, which is reported in either dollar value completion or labor hours completion. The 1st level progress curve is the overall project progress. It combines the information from 2nd level progress, and the dollar values is the unit of measure to unite all the information by putting adequate weight on E, P and C.

The earned value method is applied to all levels of progress. CPI and SPI are calculated automatically. By using the formula of EAC = BAC/CPI, the estimate at completion is calculated and this value can be used to compare with the FFC that calculated from CCM. Since using the @Risk simulation, a probability output of the estimate at completion is generated and displayed.

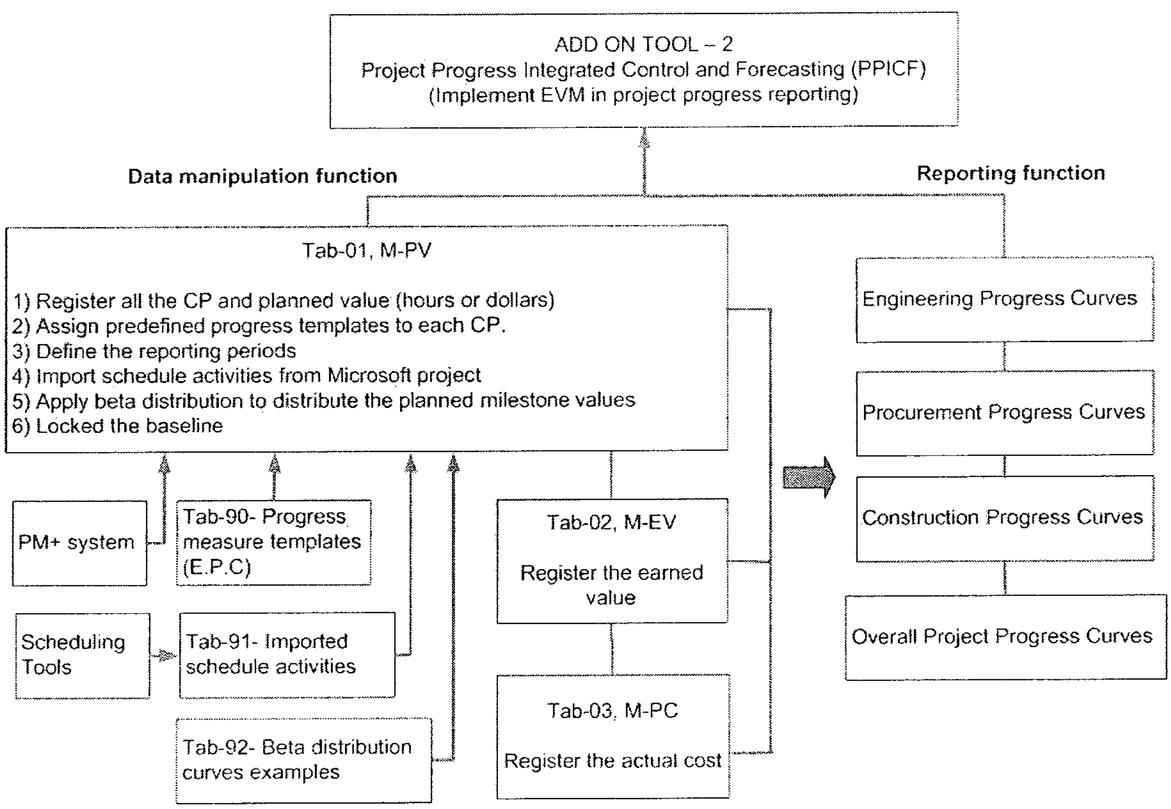


Figure 5-5 Flowchart of Add on Tool 2 -PPICF

The proposed method of applying the beta distribution to distribute the planned milestone value is integrated in the main tab of Tab-01, M-PV. 5 figures from figure 5-6 to figure 5-10 provide detail demonstrations between the functions of data manipulation and reporting function. in figure 5-6, the planned value definition interface is divided into 6 sections. Section 1 is called work package, which is to input basic information, such as package no; Section 2 allows users to select and define the progress measure templates, with default or customized progress percentage on each milestone; Section 3 contains the budget information, including estimate accuracy range; Section 4 accommodates the schedule activities information, which can be imported from external scheduling tools; Section 5 is the BETA shape factors area, where users can enter or view different plan curves; Section 6, the last section, is the work calendar (weekly). For example, W1 is the week of 1st/January/2008.

Beta distribution curve examples with 36 sets of different shape factors were created and partial displayed in figure 5-11. More examples are provided in appendix D.

gress Template			3 - Budget			4 - Schedule Section			5 - Shape Factor		6 - Calender			
Project Progress - Planned Value Definition														
ess Template			Accuracy		**Hrs**	Activities	Date		Distribution Example		W1	W2	W3	W4
ion	P %	C %	Minus	Plus	Budget		S-ST	S-FN			1-Jan-08	7-Jan-08	14-Jan-08	21-Jan-08
	100%		-5%	10%	605.0	41-IWP-01	2008/01/01	2008/06/15	Alpha	Beta	0.00	85.78	136.52	218.15
ɜsign	5%	5%			30.3	41-IWP-01-10	2008/01/01	2008/01/02	2	2	0.00	30.25	30.25	30.25
	15%	20%			90.8	41-IWP-01-20	2008/01/03	2008/01/09	2	2	0.00	55.53	90.75	90.75
d - Internal review	30%	50%			181.5	41-IWP-01-30	2008/01/10	2008/01/30	2	2	0.00	0.00	15.52	97.15
d - Client comments	25%	75%			151.3	41-IWP-01-40	2008/01/31	2008/02/12	2	2	0.00	0.00	0.00	0.00
d – for tender	15%	90%			90.8	41-IWP-01-50	2008/02/13	2008/02/21	2	2	0.00	0.00	0.00	0.00
d – for construction	10%	100%			60.5	41-IWP-01-60	2008/02/22	2008/02/28	2	2	0.00	0.00	0.00	0.00
			-5%	10%	705.8	41-IWP-02	2008/02/01	2008/04/01	Alpha	Beta	0.00	0.00	0.00	0.00
ɜsign	5%	5%			35.3	41-IWP-02-10	2008/02/05	2008/02/15	2	2	0.00	0.00	0.00	0.00
	15%	20%			105.9	41-IWP-02-20	2008/02/16	2008/02/24	2	2	0.00	0.00	0.00	0.00
d - Internal review	15%	35%			105.9	41-IWP-02-30	2008/02/25	2008/03/01	2	2	0.00	0.00	0.00	0.00
d - Client comments	20%	55%			141.2	41-IWP-02-40	2008/03/02	2008/03/10	2	2	0.00	0.00	0.00	0.00
d – for tender	30%	85%			211.8	41-IWP-02-50	2008/03/11	2008/03/21	2	2	0.00	0.00	0.00	0.00
d – for construction	15%	100%			105.9	41-IWP-02-60	2008/03/22	2008/04/01	2	2	0.00	0.00	0.00	0.00

Figure 5-6 Planned Value Preparation – Spread Sheet M-PV

Project Progress - Earned Value Registration														
s Template			Accuracy		Hrs			Activities	Date		W1	W2	W3	W4
	P %	C %	Minus	Plus	Budget	Progress %	Earned Value (EV)		A-ST	A-FN	1-Jan-08	7-Jan-08	14-Jan-08	21-Jan-08
	100%		-5%	10%	605.0	100%	605.0	41-IWP-01	2008/01/01	2008/06/15	0.00	57.26	122.69	159.07
n	5%	5%			30.3	100%	30.3	41-IWP-01-10	2008/01/01	2008/01/03	0.00	30.25	30.25	30.25
	15%	20%			90.8	100%	90.8	41-IWP-01-20	2008/01/04	2008/01/11	0.00	27.01	90.75	90.75
Internal review	30%	50%			181.5	100%	181.5	41-IWP-01-30	2008/01/12	2008/02/10	0.00	0.00	1.69	38.07
Client comments	25%	75%			151.3	100%	151.3	41-IWP-01-40	2008/01/31	2008/02/12	0.00	0.00	0.00	0.00
for tender	15%	90%			90.8	100%	90.8	41-IWP-01-50	2008/02/13	2008/02/21	0.00	0.00	0.00	0.00
for construction	10%	100%			60.5	100%	60.5	41-IWP-01-60	2008/02/22	2008/02/28	0.00	0.00	0.00	0.00
			-5%	10%	705.8	41%	289.4	41-IWP-02	2008/02/01	1900/01/00	0.00	0.00	0.00	0.00
n	5%	5%			35.3	100%	35.3	41-IWP-02-10	2008/02/05	2008/02/15	0.00	0.00	0.00	0.00
	15%	20%			105.9	100%	105.9	41-IWP-02-20	2008/02/16	2008/02/24	0.00	0.00	0.00	0.00
Internal review	15%	35%			105.9	100%	105.9	41-IWP-02-30	2008/02/25	2008/03/01	0.00	0.00	0.00	0.00
Client comments	20%	55%			141.2	30%	42.4	41-IWP-02-40	2008/03/02	2008/03/10	0.00	0.00	0.00	0.00
for tender	30%	85%			211.8			41-IWP-02-50						
for construction	15%	100%			105.9			41-IWP-02-60						

Figure 5-7 Earned Value Registration – Spread Sheet M-EV

EPC Project Progress -Actual Cost Registration

Work Package		Progress Template		W1	W2	W3	W4	W5	W6
	WP Name	TMPL		1-Jan-08	7-Jan-08	14-Jan-08	21-Jan-08	28-Jan-08	4-Feb-08
1	Site Preparation Drawings - Area 1	E01	Period	0.00	85.78	50.40	80.10	89.50	42.40
			Cumulative	0.00	80.00	130.40	210.50	300.00	342.40
2	Site preparation Drawings - Area 2	E02	Period	0.00	0.00	0.00	0.00	0.00	0.00
			Cumulative	0.00	0.00	0.00	0.00	0.00	0.00
			Period	0.00	0.00	0.00	0.00	0.00	34.00
			Cumulative	0.00	0.00	0.00	0.00	0.00	34.00
			Period	0.00	0.00	0.00	0.00	0.00	0.00
			Cumulative	0.00	0.00	0.00	0.00	0.00	0.00
			Period			10.00	70.00	70.00	100.00
			Cumulative	0.00	0.00	10.00	80.00	150.00	250.00
			Period			0.00	0.00	21.40	189.10
			Cumulative	0.00	0.00	0.00	0.00	21.40	210.50
			Period			0.00	0.00	0.00	0.00
			Cumulative	0.00	0.00	0.00	0.00	0.00	0.00
			Period			0.00	0.00	0.00	0.00
			Cumulative	0.00	0.00	0.00	0.00	0.00	0.00
				0.00	80.00	140.40	290.50	471.40	836.90

Figure 5-8 Actual Cost Registration – Spread Sheet M-AC

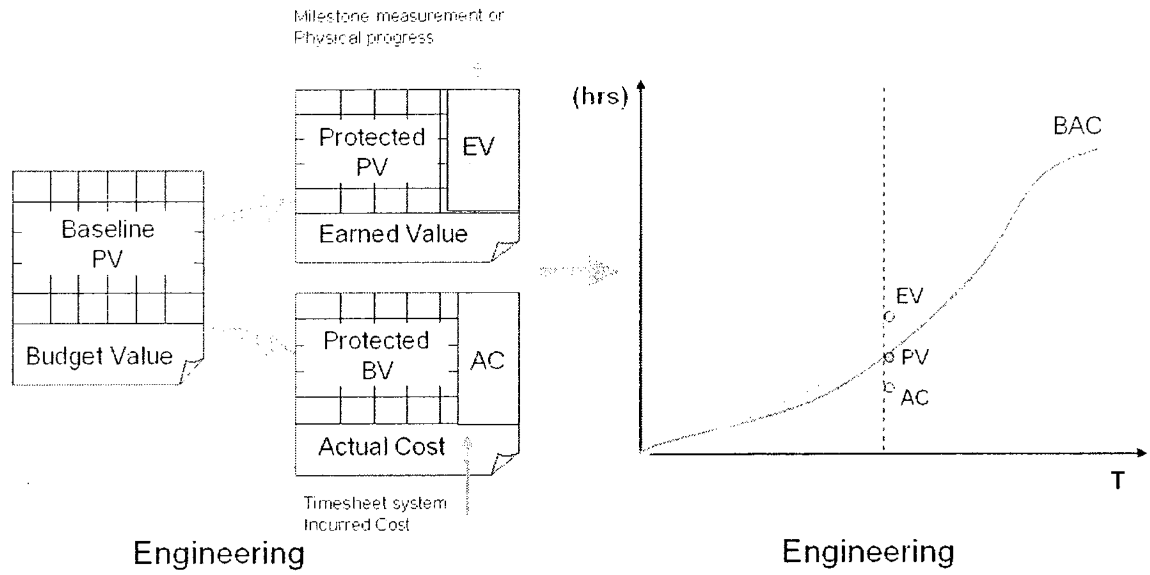


Figure 5-9 Relationship between PV, EV, AC and Engineering Progress Curve

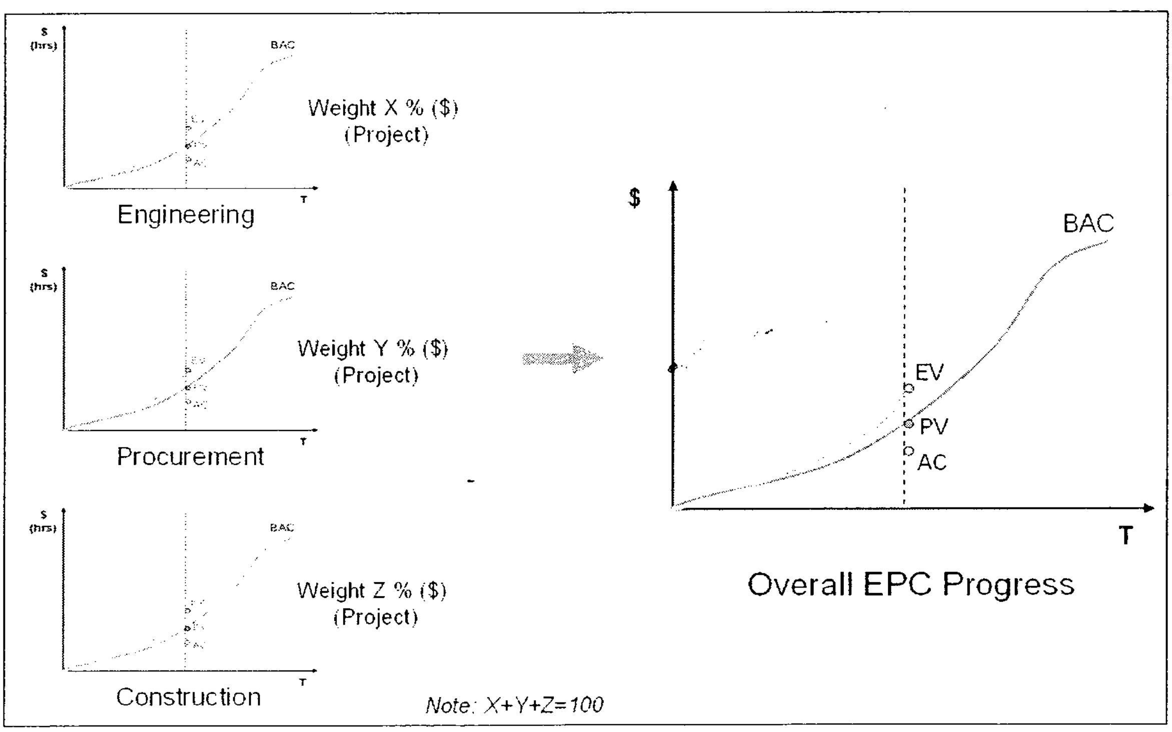


Figure 5-10 Department Progress Curves and Overall Project Progress Curve

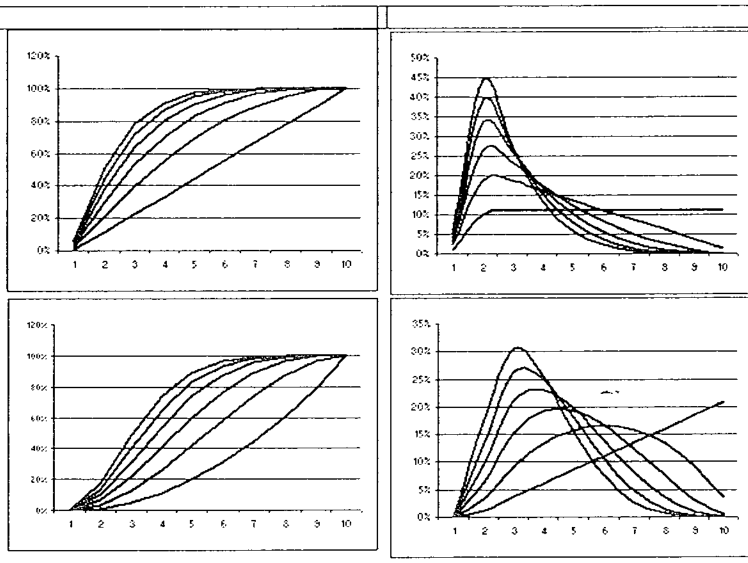
BETA DISTRIBUTION EXAMPLES WITH DIFFERENT SHAPE FACTORS

Return to M-PV

4	5	6	7	8	9	10
3%	44%	56%	67%	78%	89%	100%
6%	69%	80%	89%	95%	99%	100%
0%	83%	91%	96%	99%	100%	100%
8%	90%	96%	99%	100%	100%	100%
7%	95%	98%	100%	100%	100%	100%
1%	97%	99%	100%	100%	100%	100%
1%	20%	31%	44%	60%	79%	100%
6%	42%	58%	74%	87%	97%	100%
1%	60%	77%	89%	96%	99%	100%
4%	74%	87%	95%	99%	100%	100%
5%	83%	93%	98%	100%	100%	100%
4%	89%	97%	99%	100%	100%	100%

Cumulative

Period



1	2	3	4	5	6	7	8	9	10
1%	10%	11%	11%	11%	11%	11%	11%	11%	11%
2%	19%	19%	16%	14%	11%	9%	6%	4%	1%
3%	26%	23%	17%	12%	8%	5%	3%	1%	0%
4%	33%	26%	17%	10%	6%	3%	1%	0%	0%
5%	39%	27%	15%	8%	4%	1%	0%	0%	0%
6%	44%	27%	13%	6%	2%	1%	0%	0%	0%
0%	1%	4%	6%	9%	11%	14%	16%	19%	21%
0%	3%	9%	13%	16%	17%	16%	13%	9%	3%
0%	6%	15%	19%	19%	17%	12%	7%	3%	1%
0%	10%	21%	23%	20%	14%	8%	4%	1%	0%
0%	13%	26%	25%	18%	11%	5%	2%	0%	0%
0%	18%	31%	25%	16%	7%	3%	1%	0%	0%

Figure 5-11 Beta Distribution Curves Example with Different Shape Factor

ɔvided in appendix D.

5.4 Progress Visualization Database (PVD)

Microsoft Windows SharePoint Services 3.0 is chosen as the database for storage and query. It is a versatile technology that all sizes of projects can use to increase the efficiency and improve team productivity. With tools for collaboration, it helps people stay connected across organizational and geographic boundaries.

5.4.1 PVD Infrastructure

To develop this tool, 4 steps are needed as demonstrated in figure 5-12. The details of them are:

Step1, Set-up the SharePoint site, which mainly includes site creation, user and permission setting, building up the multimedia library, defining the multimedia coding structure and preparing the user defined tables.

Step 2, Upload multimedia data from construction site. Based on the upload procedure, users will upload the progress multimedia in a least a weekly base in different formats. The multimedia is stored in library by either area or by contract, but it is available for searching and grouping.

Step 3, Project control staffs access to the database and search information as needed. The hyper links with filter criteria can be placed in the monthly progress report.

Step 4, By clicking the interested subjects, for example CP 1-902 visualization, the project team can easily access to variable multimedia information related to CP 1-902 in passed month only.

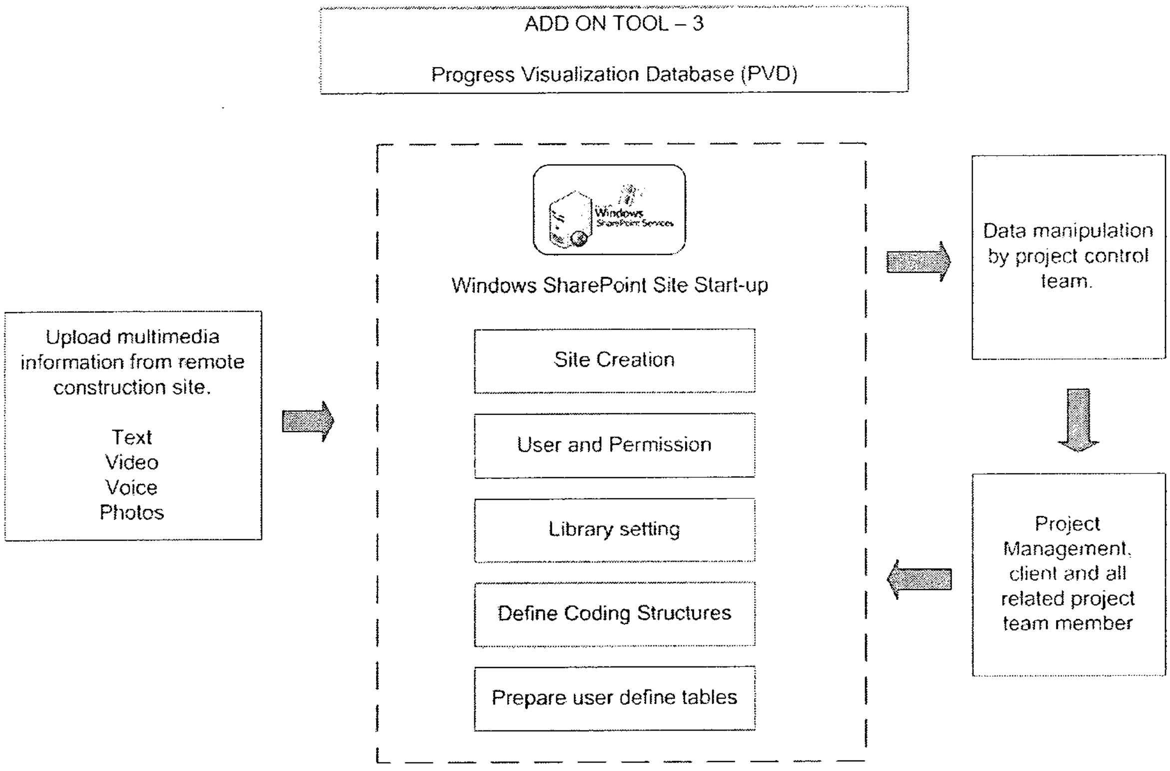


Figure 5-12 Infrastructure of Progress Visualization Database -PVD

5.4.2 PVD Site Start-up in Windows SharePoint Server

Figures from figure 5-13 to 15 show the functions of site creation, coding structure and to prepare user defined tables.

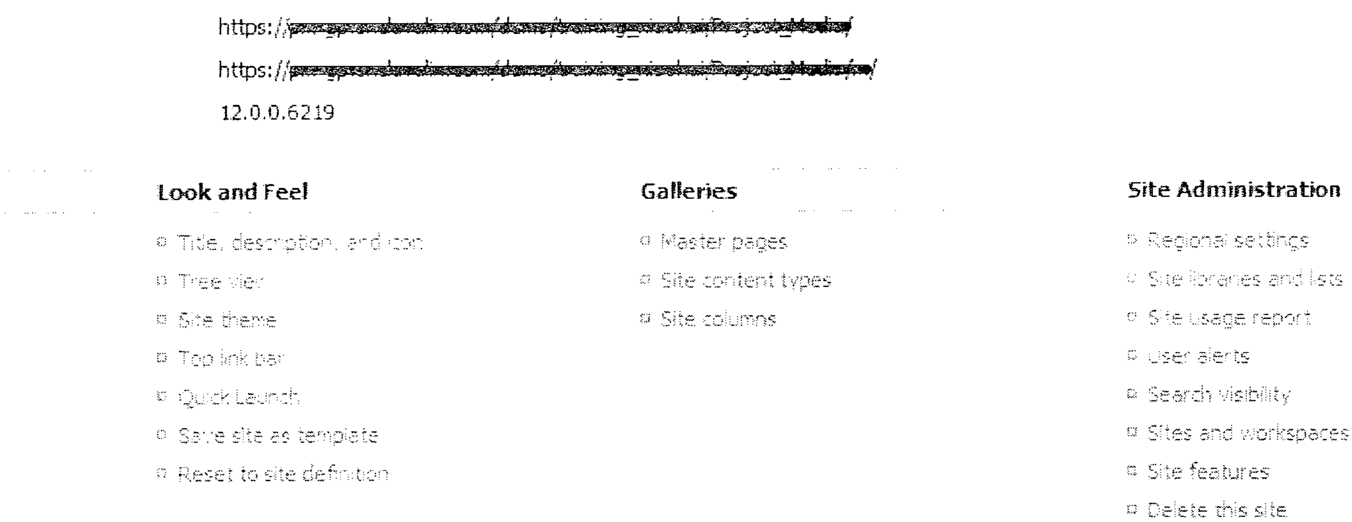


Figure 5-13 Site Setting

icture library

›n about each document in the document library. The following columns are currently available in this document library:

Type	Required
Choice	
Choice	
Choice	
Date and Time	
Single line of text	
Multiple lines of text	
Multiple lines of text	
Person or Group	
Person or Group	
Person or Group	

Figure 5-14 Define Coding Structure for Multimedia

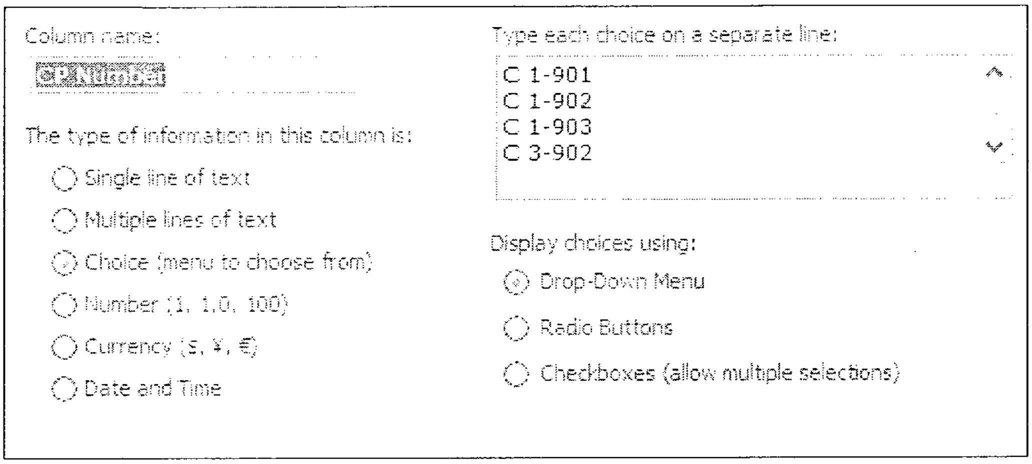


Figure 5-15 Prepare Predefined Drop Down Table or List

5.4.3 Data Manipulation and Visualized Progress Report

Uploaded multimedia is stored by either area folders or contract folders. Based on the predefined coding structure, project control staffs can easily use the functions of search media and select media to group the media data. The grouped information is stored in the hyperlink address as shown in figure 5-17. Figures 5-16 and 5-18 give demonstrations. This link can be placed in the monthly report.

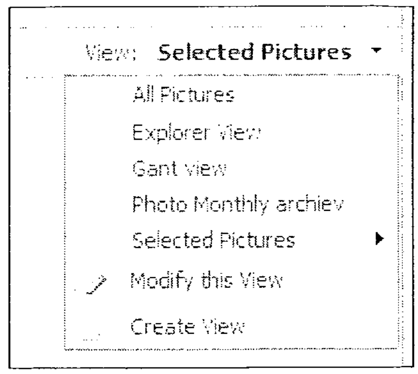


Figure 5-16 Select Filter Pictures

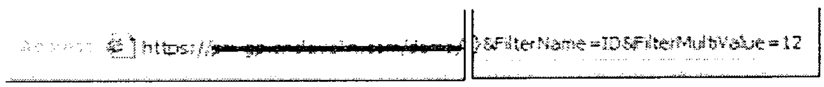


Figure 5-17 Copy the Filter Picture Link

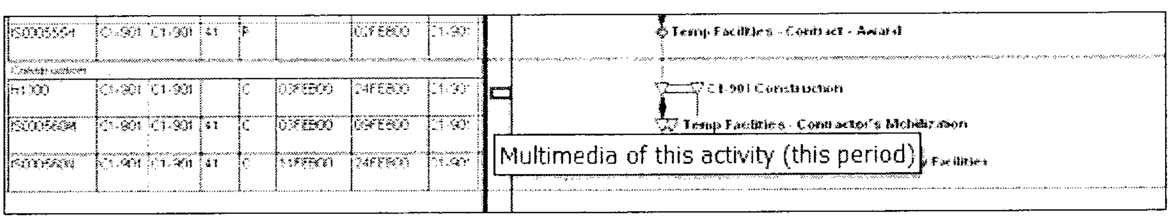


Figure 5-18 Place the Link to Related Activity

6 Chapter SIX: System Implementations and Validation

In this chapter, data from a field study based on a training project are analyzed and numerical examples are presented to illustrate the essential functions of 3 add-on tools: 1) TE, 2) PPICF and 3) PVD.

6.1 Poly Training Project Description

Project description (the cost information is based on a set of data from the training project, which was elaborated to respect confidentiality).

- Sector of activity: Petrochemicals
- Client: Poly Canada Inc. (fictitious)
- Year of completion: 2004
- Total project cost: Multi-million Canadian dollars
- Capacity: 95,000 ton of PTT per year.
- Services provided: EPC
- Description: The first industrial scale PTT plant using a process developed by the clients. The project involves the construction of a 300 metric tones per day PTT plant in Montréal, Quebec.

SNC-Lavalin's mandate is to provide the following services up to mechanical completion:

- Overall project management
- Detailed engineering for OSBL

- Supply of OSBL equipment and material
- Construction management
- Engineering partner acting as the main subcontractor to SLS, will provide
    - Revision ISBL engineering
    - Supply of ISBL equipment/material
    - Technical assistance during construction

Cost breakdown by cost type and by commitment package class are indicated in table 6-1 and table 6-2. The cost data was modified to respect confidentiality. The ratio between direct and indirect cost may not necessary in consistency with the original cost information.

Table 6-1 Cost Breakdown by Project Cost Type

Project WBS (Level 1)	Total Budget
Project Direct Costs	14 278 916.00$
Project Indirect Costs	9 635 553.00$
Project Total	23 914 469.00$

Table 6-2 Cost Breakdown by Commitment Package Class

Commitment Package Class	Total Budget (CAD)	Budget Percentage	Commitment Package No.
C - Construction	10 685 029.00$	45%	22
M - Miscellaneous	9 322 609.00$	39%	39
P - Purchasing	3 906 831.00$	16%	17
Project Total	**23 914 469.00$**	**100%**	**78**

6.2 Trend Estimate

One set of trend estimate information in this training project is exported from PM+ to excel format and is imported into the proposed tool, Trend Estimate (TE). Because of lacking enough historical trend information, the self-adjustment accuracy range method can not be validated. But the accuracy range based on engineering completion progress is used. Since the engineer is on basic engineering stage, so that the accuracy range is set to -10% to 15%.

Simulation setting is displayed in figure 6-1. Iteration is set to 10000 to get sample data as much as possible. The simulation results are presented from figure 6-2 to figure 6-4.

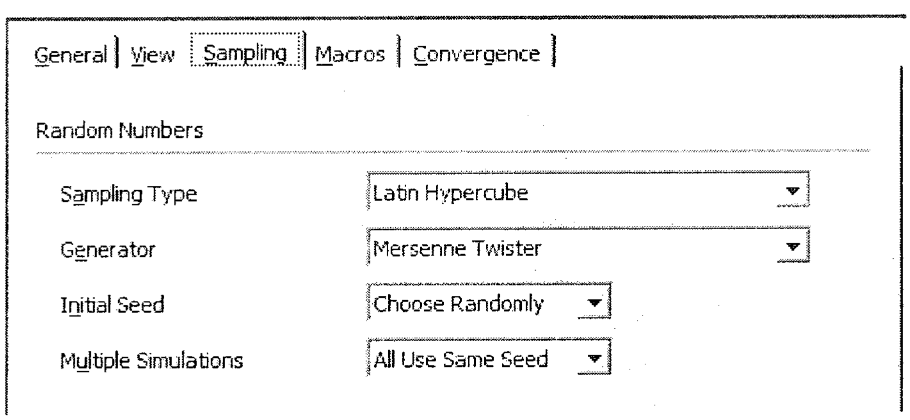


Figure 6-1 Simulation Settings

Facility	CRC	Description	Accuracy Range Minus (-)%	Accuracy Range Plus (+) %	Most likely	Sampled (@Risk output)
12200	3000 - STRUCTURAL	Collector Road	-10.00%	15.00%	124 502	125 539$
12200	3000 - STRUCTURAL	Fence to Rail Track	-10.00%	15.00%	127 121	128 180$
12200	3000 - STRUCTURAL	Pedestrian Crossing (One)	-10.00%	15.00%	6 008	6 058$
12200	3000 - STRUCTURAL	Incremental Cost Increase to Maintenance Bui	-10.00%	15.00%	34 422	34 709$
12200	3000 - STRUCTURAL	New Communications System	-10.00%	15.00%	703 206	709 066$
12200	3000 - STRUCTURAL	500 additional Railway Ties	-10.00%	15.00%	1 875	1 891$
12200	3000 - STRUCTURAL	6% Administration Fee	-10.00%	15.00%	59 828	60 327$
		Total			**1 056 961$**	**1 065 769$**

Figure 6-2 Define Distribution for Simulation Calculation

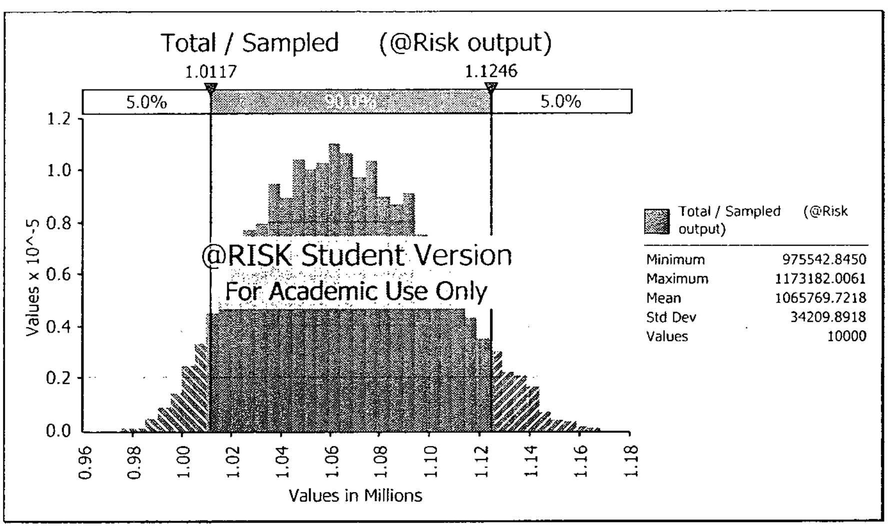


Figure 6-3 Probability Density Curve

Probability of meeting value of 1056961	42.0%	1 056 961
Total budget required for 90.0% confidence	1 112 222.76$	90.0%
Extra budgets required for 90.0% confidence	55 261.41$	

Figure 6-4 Calculate 3 Key Information with Simulation -1000 iterations

Result analysis:

- Estimate accuracy range is integrated into trend estimate.
- Probability percentage can be provided to meet certain requested amount
- Determined (+/-)% can be provided to define accuracy range based on experience or other project information.
- Self adjustment accuracy range can be provided as a reference for next period or next new trend estimate, as long as enough historical data are available.

The trend amount with certain level of confidence, for example 90%, can be registered in PM+ and integrated into its built formula, which is FFC = TC + OC + TR + UB. By doing this, the new FFC can be presented with a registered trend amount of 90% of confidence.

6.3 Project Progress Integrated Control and Forecast

Implementation is broken into 3 key steps: 1) prepare the project baseline, 2) monitor the earned value, and 3) register the actual cost. The step 1 includes an integration of cost and time from PM+ and scheduling tool. The cost and time data are elaborated to respect confidentiality.

6.3.1 Prepare the Project Baseline

Breaking down the project by WBS and OBS and registering them in PPICF is the first step to prepare the project baseline. This matrix presentation in figure 6-5 indicates that: 1) OBS is broken down to 3 departments, and 2) the scope of work from WBS is grouped in the internal work packages for engineering works, potential purchase orders for procurement works and potential contracts for construction and installation works. The EPC project duration is 8 months.

			Budget		P1	P2	P3	P4	P5	P6	P7	P8
			$	Hrs								
Engineering					20	100	190	240	250	250	250	
	Discipline											
		IWP		100	20	50	30					
		IWP		150		30	60	50	10			
Procurement					0	0	1000	7000	9000	9500	9500	
	PO		5000				1000	4000				
	PO		4500					2000	2000	500		
Construction					0	0	1000	4000	8000	9000	9300	9400
	Contract			3000			1000	1000	1000			
	Contract			6400				2000	3000	1000	300	100

Figure 6-5 WBS and OBS Matrix Presentation

A set of progress templates for IWP, PO and Contract is prepared and listed in table 6-3, table 6-4 and table 6-5. They are in the sequence of engineering progress template, procurement progress template, and construction progress template.

Table 6-3 Progress Template for Engineering Works (Example)

Code	Template Name	Milestone	Description	P %	C %	E	P	C
E01	Drawing Progress					E		
		MT-1	Initial Design	5%	5%			
		MT-2	Started	20%	25%			
		MT-3	Released - Internal review	15%	40%			
		MT-4	Released - Client comments	30%	70%			
		MT-5	Released – for tender	15%	85%			
		MT-6	Released – for construction	10%	95%			
		MT-7	As builds received/filed	5%	100%			
E02	3D Modeling Progress					E		
		MT-1	Initiate 3D model	5%	5%			
		MT-2	Start 3D model	5%	10%			
		MT-3	Develop 3D for first review	40%	50%			
		MT-4	Review / inorporate comments	5%	55%			
		MT-5	Develop 3D for second review	35%	90%			
		MT-6	Issue model for Constr.	5%	95%			
		MT-7	Incorporate Review	5%	100%			

Table 6-4 Progress Template for Purchase Order (Example)

Code	Template Name	Milestone	Description	P %	C %	E	P	C
P01	Major PO Progress						P	
		MT-1	Award PO	5%	5%			
		MT-2	Initiate Vendor Drawing	5%	10%			
		MT-3	Vendor Drawing Approve	5%	15%			
		MT-4	Fabrication 1 - First Key Fabri.	25%	40%			
		MT-5	Fabrication 2 - Interim Key Fabri.	20%	60%			
		MT-6	Fabrication 3 - Final Key Fabri.	20%	80%			
		MT-7	Deliver to ship Ex-work - 1 Major Delivery	5%	85%			
		MT-8	Deliver to ship Ex-work - 2 Other Delivery	5%	90%			
		MT-9	Deliver to ship Ex-work - 3 Final Delivery	5%	95%			
		MT-10	Deliver to Site	5%	100%			

Table 6-5 Progress Template for Construction Contract (Example)

Code	Template Name	Milestone	Description	P %	C %	E	P	C
C3	Foundations							C
		MT-1	Lean Concrete	5%	5%			
		MT-2	Formwork	45%	50%			
		MT-3	Rebar and embedment	30%	80%			
		MT-4	Pour Concrete	7%	87%			
		MT-5	Strip cure and grout	8%	95%			
		MT-6	Hand over	5%	100%			

The cost and work-hours information are exported from PM+ by commitment packages and internal work packages, and then manipulated in the PPICF. The schedule information is first prepared in Microsoft project. The numbers of IWP, PO and Contract are used as part of the activity codes. This approach facilitates a lot in the process of linking Microsoft project activities to PPICF milestones. The figures from 6-6 to 6-8 demonstrate these steps.

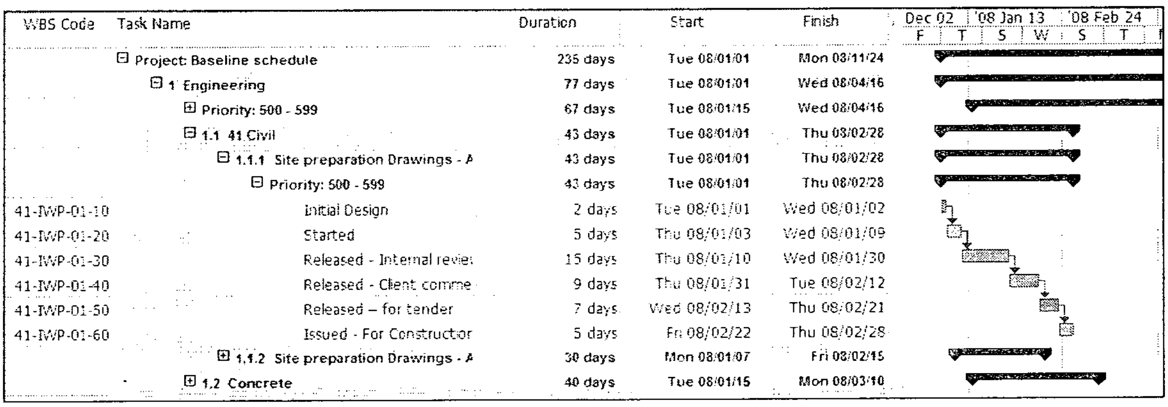


Figure 6-6 Schedule Prepared in Microsoft Project

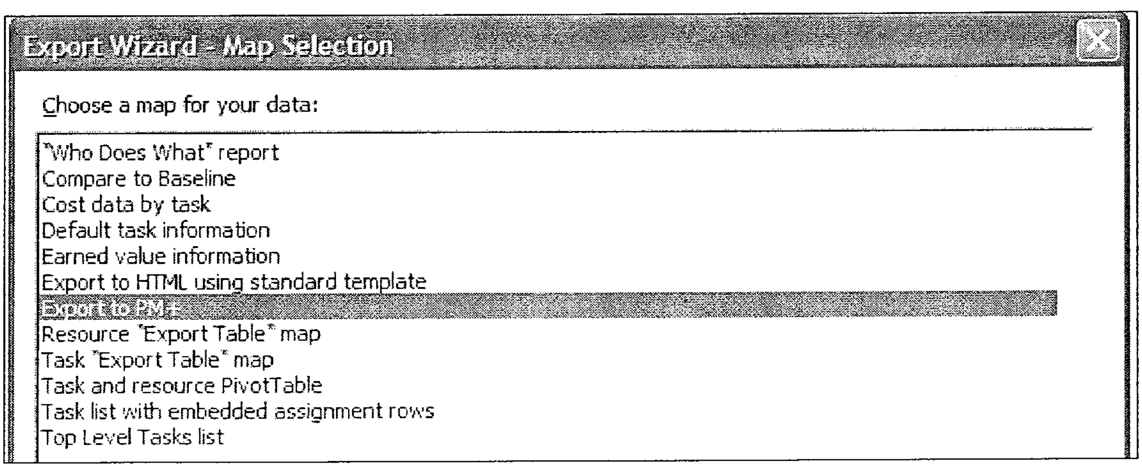


Figure 6-7 Export Activities to PM+ Format for Importing to PPICF

Activity Code	Description	S-ST	S-FN	A-ST	A-FN
40	Engineering	2008/01/01 8:00	2008/05/08 17:00	NA	NA
41	41-Civil	2008/01/01 8:00	2008/02/28 17:00	NA	NA
41-IWP-01	Site preparation Drawings - Area1	2008/01/01 8:00	2008/02/28 17:00	NA	NA
41-IWP-01-10	Initial Design	2008/01/01 8:00	2008/01/02 17:00	NA	NA
41-IWP-01-20	Started	2008/01/03 8:00	2008/01/09 17:00	NA	NA
41-IWP-01-30	Released - Internal review	2008/01/10 8:00	2008/01/30 17:00	NA	NA
41-IWP-01-40	Released - Client comments	2008/01/31 8:00	2008/02/12 17:00	NA	NA
41-IWP-01-50	Released "C for tender	2008/02/13 8:00	2008/02/21 17:00	NA	NA
41-IWP-01-60	Issued - For Construction	2008/02/22 8:00	2008/02/28 17:00	NA	NA
41-IWP-02	Site preparation Drawings - Area2	2008/01/07 8:00	2008/02/15 17:00	NA	NA
41-IWP-02-10	Initial Design	2008/01/07 8:00	2008/01/08 17:00	NA	NA
41-IWP-02-20	Started	2008/01/09 8:00	2008/01/11 17:00	NA	NA
41-IWP-02-30	Released - Internal review	2008/01/14 8:00	2008/01/22 17:00	NA	NA
41-IWP-02-40	Released - Client comments	2008/01/23 8:00	2008/02/04 17:00	NA	NA
41-IWP-02-50	Released "C for tender	2008/02/05 8:00	2008/02/12 17:00	NA	NA
41-IWP-02-60	Issued - For Construction	2008/02/13 8:00	2008/02/15 17:00	NA	NA

Figure 6-8 Imported Activities in PPICF

The next step after getting the cost and time data in the add-on tool is to distribute the cost information according to time. In this study, the progress distribution of milestone value is symmetric and the shape factors, Alpha and Beta, are both set to 2. With the information of value, alpha, beta, schedule start date (the low bound) and the schedule finish date (the high bound), the built-in function can distribute the milestone value to reporting periods automatically. One internal work package is chosen and an example and presented in figure 6-9.

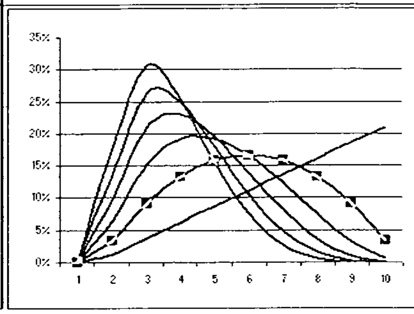
EPC Project Progress - Planned Value Definition

Progress Template			Accuracy		Hrs	Activities	Date		Distribution Example		W1	W2	W3
Description	P %	C %	Minus	Plus	Budget		S-ST	S-FN			1-Jan-08	7-Jan-08	14-Jan-08
	100%		-5%	10%	605.0	41-IWP-01	2008/01/01	2008/06/15	Alpha	Beta	0.00	85.78	136.52
Initial Design	5%	5%			30.3	41-IWP-01-10	2008/01/01	2008/01/02	2	2	0.00	30.25	30.25
Started	15%	20%			90.0	41-IWP-01-20	2008/01/03	2008/01/09	2	2	0.00	55.53	90.75
Released - Internal review	30%	50%			181.5	41-IWP-01-30	2008/01/10	2008/01/30	2	2	0.00	0.00	15.52
Released - Client comments	25%	75%			151.3	41-IWP-01-40	2008/01/31	2008/02/12	2	2	0.00	0.00	0.00
Released – for tender	15%	90%			90.8	41-IWP-01-50	2008/02/13	2008/02/21	2	2	0.00	0.00	0.00
Released – for construction	10%	100%			60.5	41-IWP-01-60	2008/02/22	2008/02/28	2	2	0.00	0.00	0.00

Figure 6-9 Distribute the Milestone Value to Cost Periods Automatically

Period

Range (L)	Range (H)	Beta Shape Factors Alpha	Beta	1	2	3	4	5	6	7	8	9	10
1	10	2	1	0%	1%	4%	6%	9%	11%	14%	16%	19%	21%
1	10	2	2	0%	3%	9%	13%	16%	17%	16%	13%	9%	3%
1	10	2	3	0%	6%	15%	19%	19%	17%	12%	7%	3%	1%
1	10	2	4	0%	10%	21%	23%	20%	14%	8%	4%	1%	0%
1	10	2	5	0%	13%	26%	25%	18%	11%	5%	2%	0%	0%
1	10	2	6	0%	18%	31%	25%	16%	7%	3%	1%	0%	0%



Range (L)	Range (H)	Beta Shape Factors Alpha	Beta	1	2	3	4	5	6	7	8	9	10
1	10	2	1	0%	1%	5%	11%	20%	31%	44%	60%	79%	100%
1	10	2	2	0%	3%	13%	26%	42%	58%	74%	87%	97%	100%
1	10	2	3	0%	6%	22%	41%	60%	77%	89%	96%	99%	100%
1	10	2	4	0%	10%	31%	54%	74%	87%	95%	99%	100%	100%
1	10	2	5	0%	14%	40%	65%	83%	93%	98%	100%	100%	100%
1	10	2	6	0%	18%	48%	74%	89%	97%	99%	100%	100%	100%

Cumulative

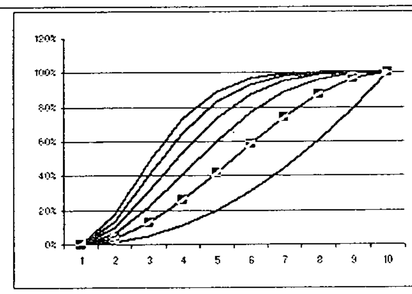
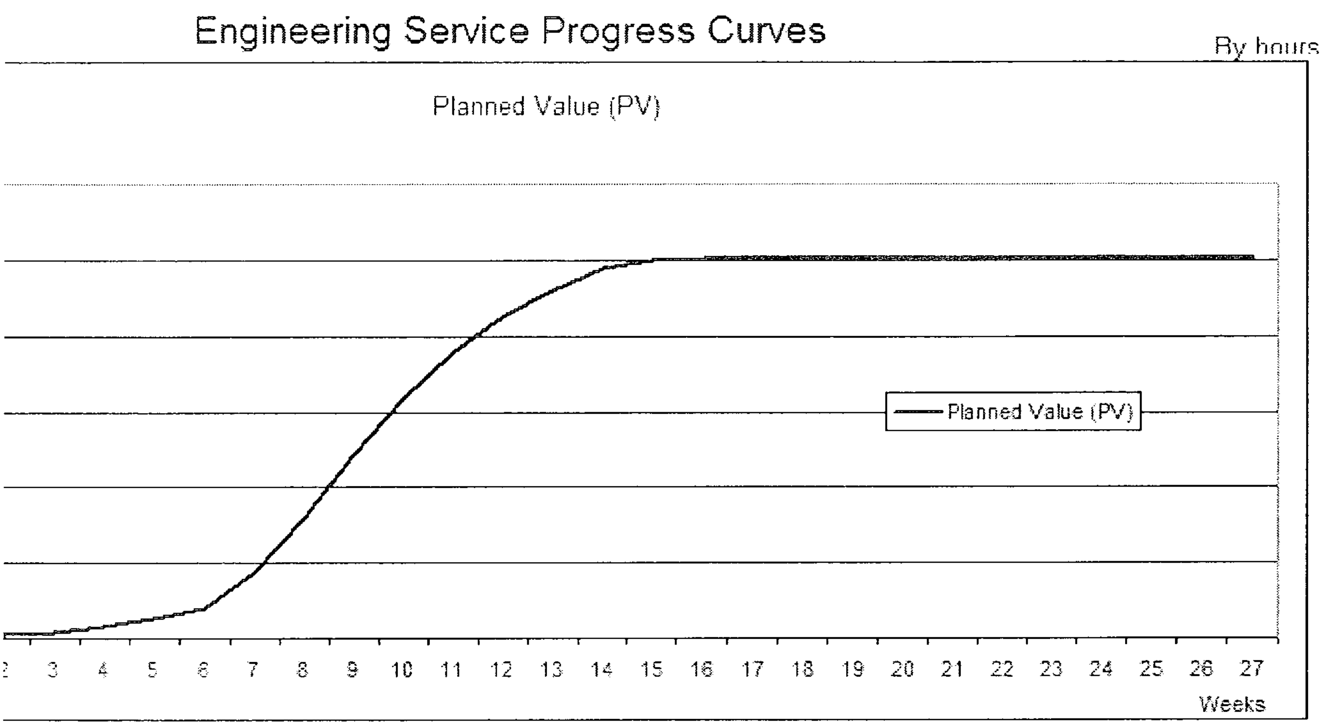


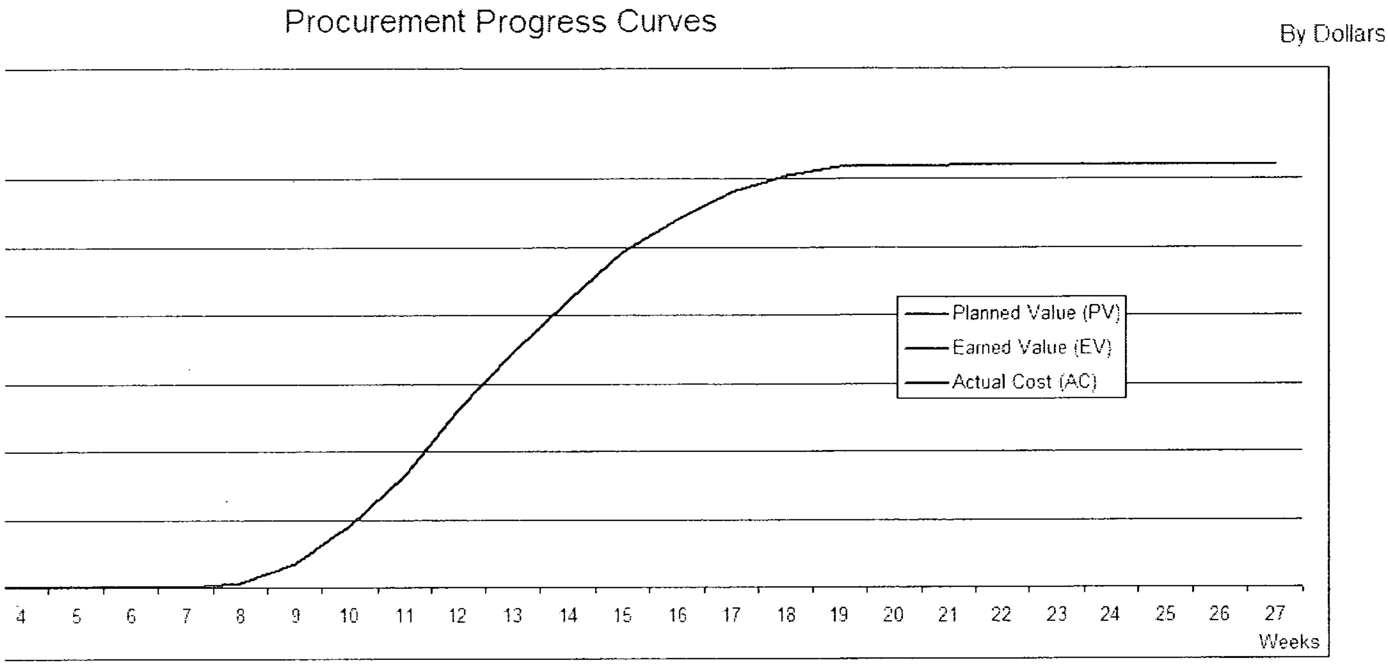
Figure 6-10 Distribute Curve Demonstration When Shape Factors both Equal to 2

Baselines of each department and overall project can be generated automatically and reported from figure 6-11 to 6-15. By using the probabilistic forecasting, a range at any period of each planned value can be calculated and reported by graphical curve. Figure 6-16 is an example for engineering works trend variation.



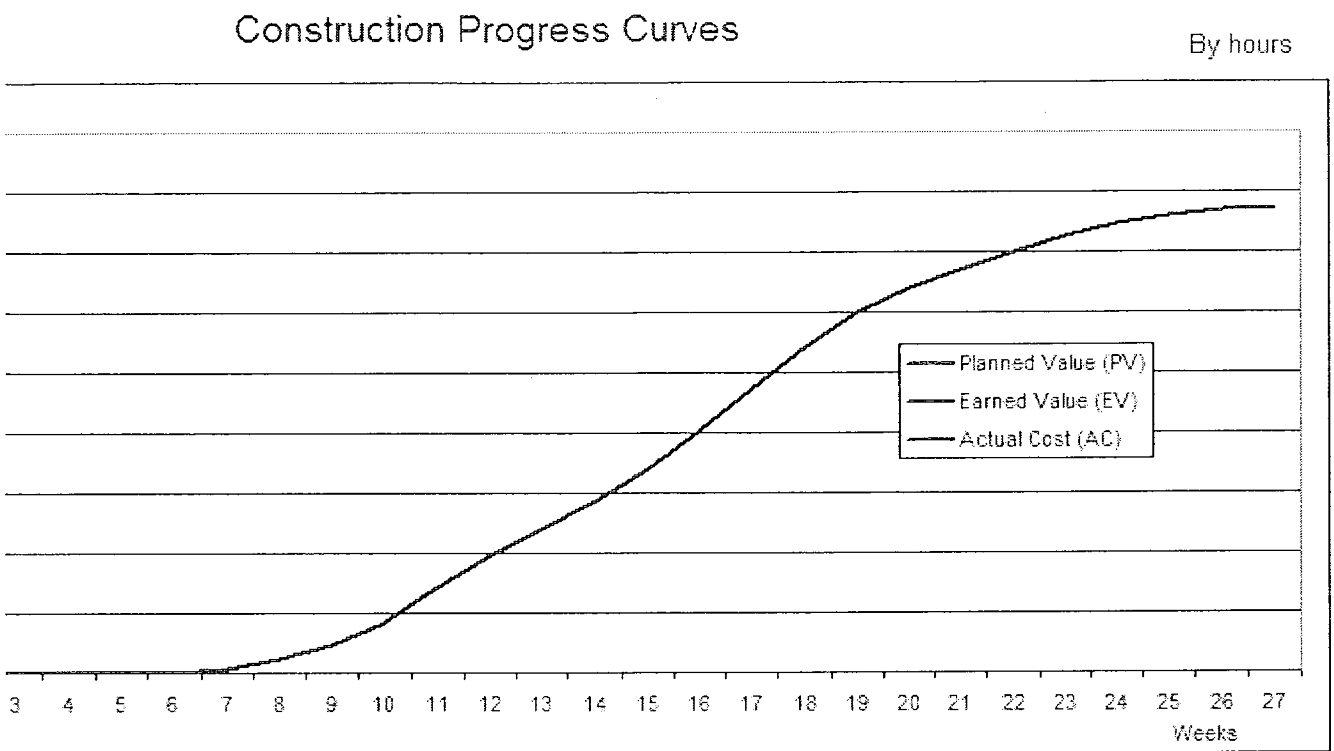
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27		
86	151	312	515	817	1743	3170	4852	6334	7555	8515	9218	9769	10011	10032	10032	10032	10032	10032	10032	10032	10032	10032	10032	10032	10032		

Figure 6-11 Engineering Planned Value Baseline



1	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27		
0	0	0	0	12773	68449	173935	331951	517320	690078	843525	984133	1082632	1161302	1212619	1235465	1238179	1239952	1240250	1240250	1240250	1240250	1240250	1240250		
%	0%	0%	0%	0%	0%	0%	0%																		

Figure 6-12 Procurement Planned Value Baseline



3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27			
0	0	0	15	150	443	948	1644	2889	3934	4823	5706	6827	8056	9464	10847	12009	12806	13409	14011	14532	14916	15218	15392	15428			

Figure 6-13 Construction Planned Value Baseline

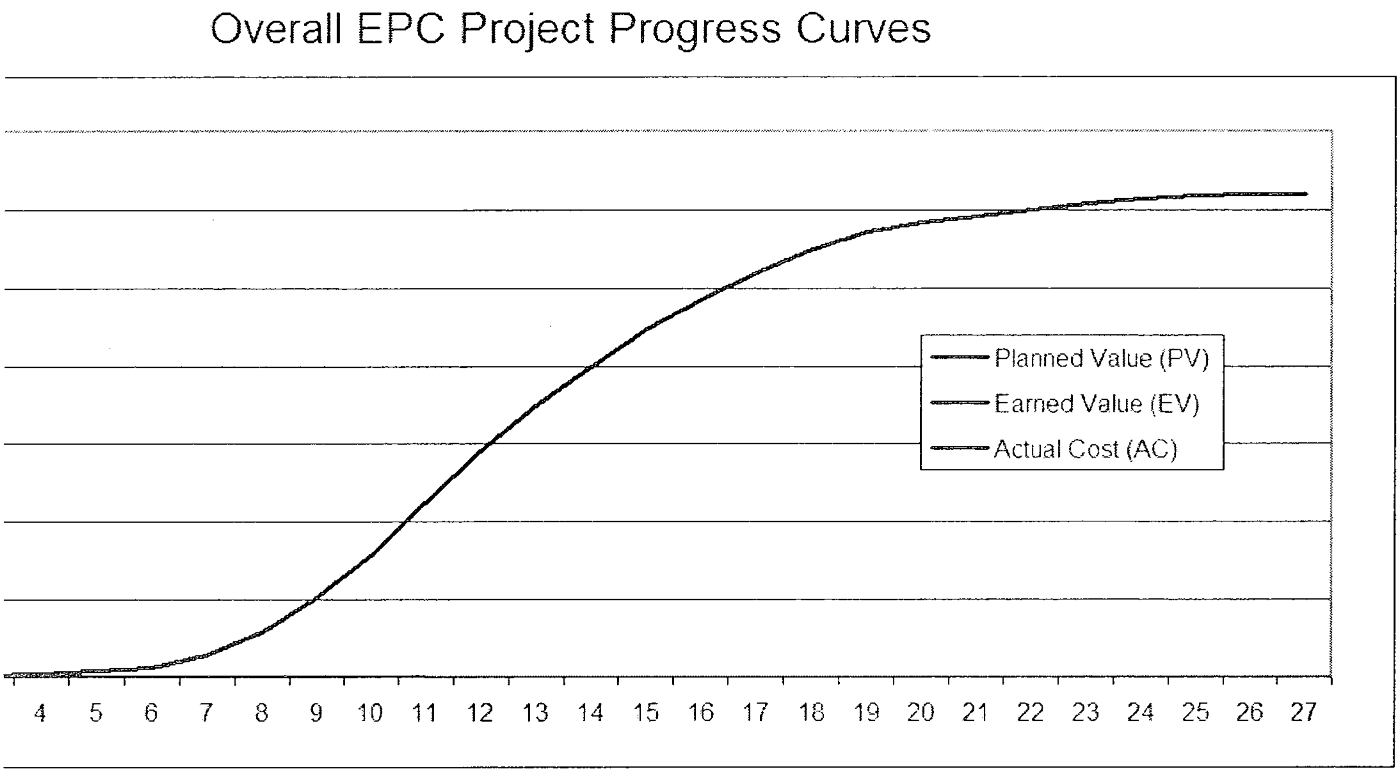
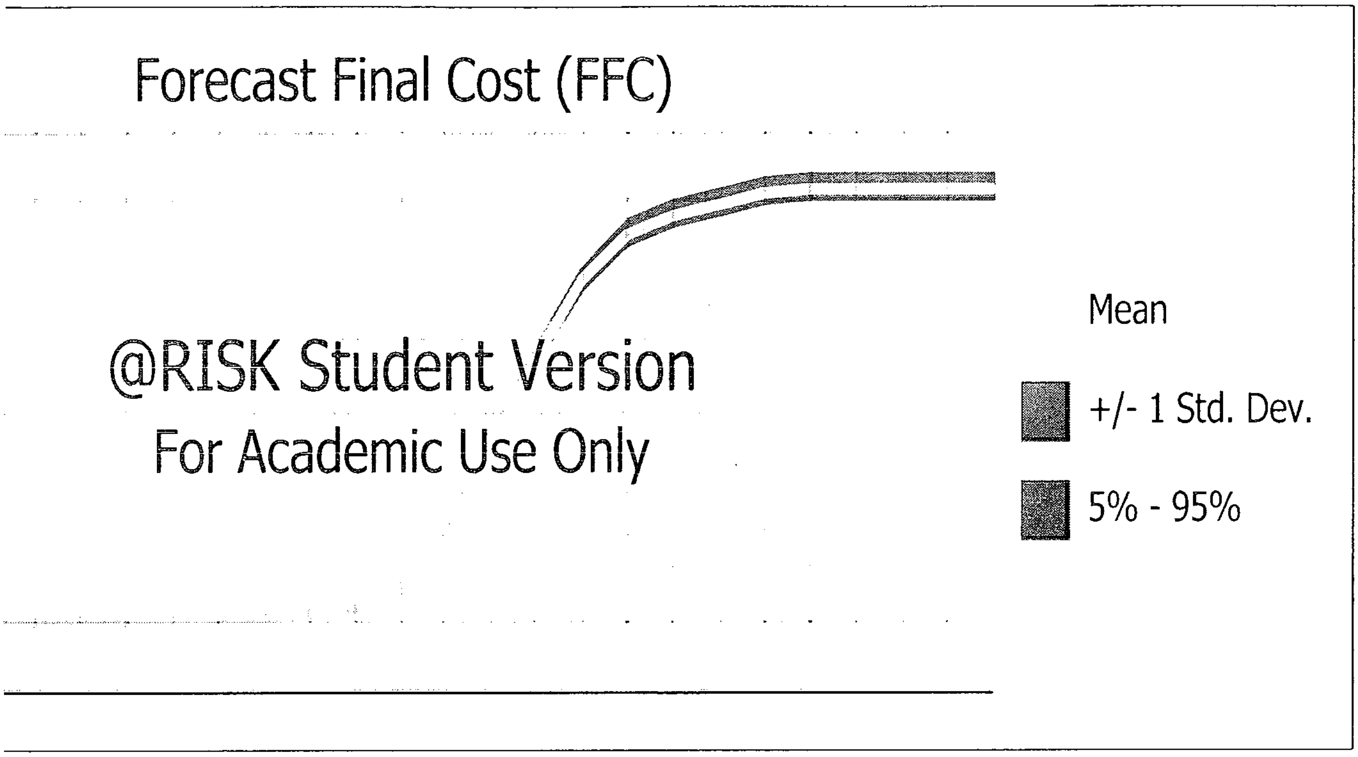


Figure 6-14 Overall EPC Project Planned Value Baseline

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PV)	0	86	151	312	515	817	1743	3170	4952	6334	7555	8515	9218	9769	10011
V)												0	0	0	0
:)												0	0	0	0
PV ($) K	-	6 628	11 673	24 133	39 768	63 109	134 694	244 956	374 946	489 413	583 800	657 985	712 263	754 834	773 534
:arned ($)	-	-	-	-	-	-	-	-	-	-	-				
AC($)	-	-	-	-	-	-	-	-	-	-	-				
PV)	0	0	0	0	0	0	0	12773	68449	179935	331951	517320	680078	843525	984133
V)												0	0	0	0
:)												0	0	0	0
PV)	0	0	0	0	0	15	150	443	948	1644	2889	3934	4823	5706	6827
V)															
:)															
PV ($)	0	0	0	0	0	1028	10566	31158	66704	115666	203250	276735	339267	401408	480220
:arned ($)	0	0	0	0	0	0	0	0	0	0	0				
AC($)	0	0	0	0	0	0	0	0	0	0	0				

Figure 6-15 Overall EPC Progress Curve Data Table (W1 to W15)



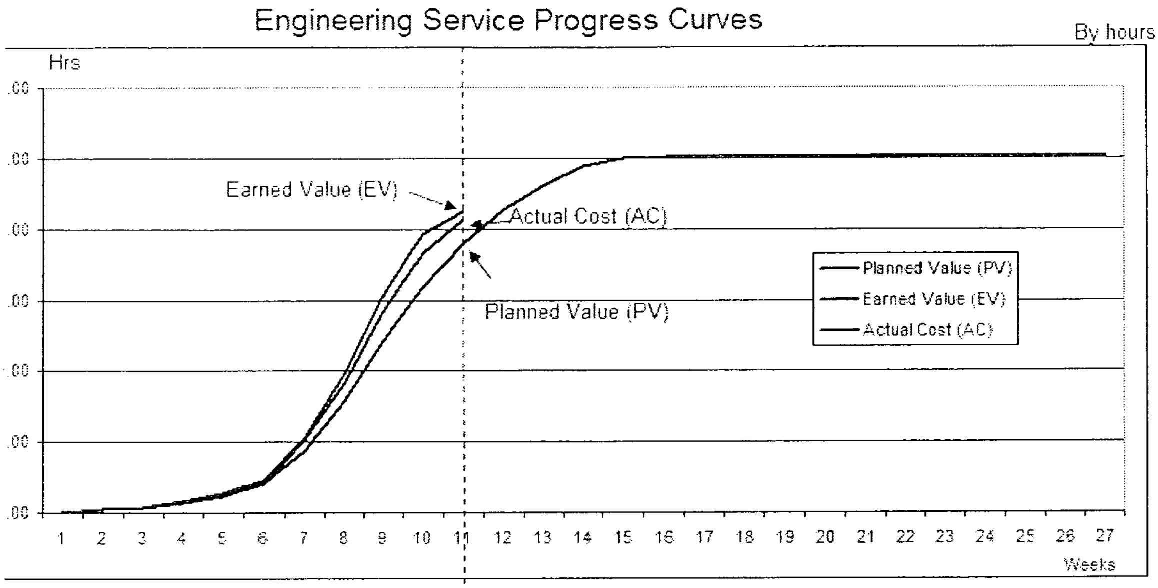
ure 6-16 Procurement Work Planned Value Variation Range in Future Periods

6.3.2 Register the Earned Value and Actual Cost

Earned value and actual cost are registered in 2 separate spread sheets, since they are maintained by different people in different locations in large scale projects. Earned value of work packages are measured following the predefined progress measurement templates. While assessing the completion percentage between milestones, different methods are applied. For example, the quantities of installed pipes are counted as earned value. This detail data collection and calculation is done outside PPICF. Data coloration and protection help the users to easily focus on their data and keep the data safe. In this tool, planned value is colored light turquoise, earned value is colored lime and actual cost is colored light yellow.

6.3.3 Provide Project Progress Curve with Performance Index

With the integrated information of PV, EV and AC, the tool can generate progress curves by either department or at overall project level. The predefined report template also provides CPI, SPI and EAC calculation. Probability density of the EAC can be provided after running 1000 iterations in 1 simulation. Figures from 6-19 to 6-23 provide the detail results of each department and overall project. The value of EAC is normally different from the calculation results of FFC from PM+, since EAC is calculated from BAC and CPI, while the FFC is based on the total commitments, outstanding changes, trends and unallocated budgets. FFC is more preferable in this thesis, as we can get different EAC value if we choose different parameters which were described in equation 2-1.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(PV)	0	86	151	312	515	817	1743	3170	4852	6334	7559	8515	9218	9769
(EV)	0	86	151	312	528	934	2114	3906	6094	7858	8497			
C)	0	80	140	291	471	837	2045	3669	5671	7296	8251			
	0%	1%	2%	3%	5%	9%	21%	39%	61%	78%	85%			

	15	16	17	18	19	20	21	22	23	24	25	26	27		
(PV)	10011	10032	10032	10032	10032	10032	10032	10032	10032	10032	10032	10032	10032		
(EV)															
C)															

Man-Hours

	This Period	To date	BAC
(PV	1221	7555	10032
(EV)	638	8497	
C)	955	8251	EAC
PI	**0.67**	**1.03**	9741
PI	**0.52**	**1.12**	

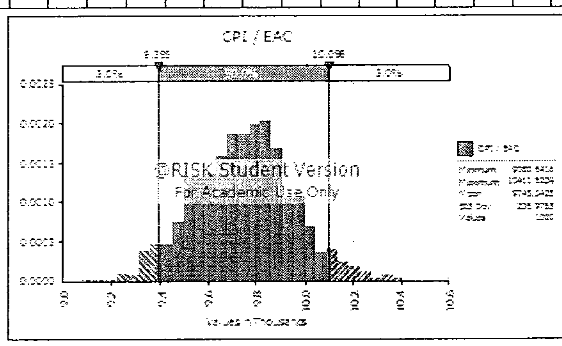
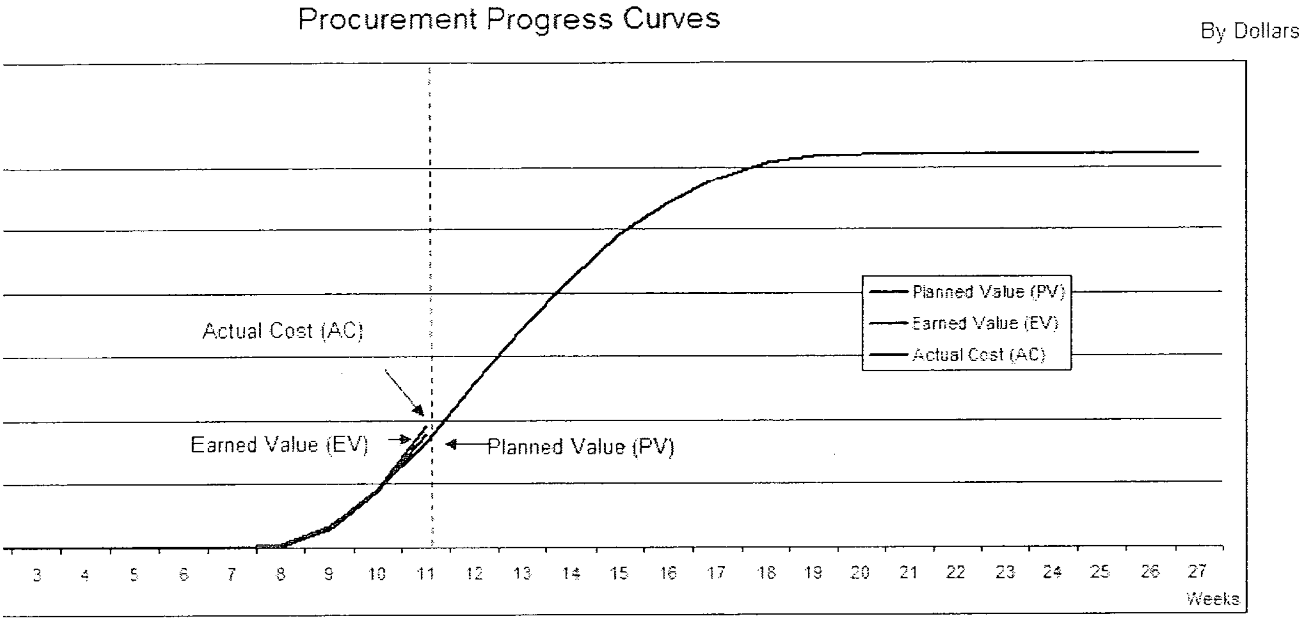


Figure 6-17 Engineering Service Progress Curves (11th Period)



3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27		
0	0	0	0	0	12773	68449	179935	331951	517320	####	843525	984123	1082632	1161302	1212619	1235465	1238179	1239952	1240250	1240250	1240250	1240250	1240250	1240250		
0	0	0	0	0	4703	55013	176822	355469																		
0	0	0	0	0	4600	59303	183821	382459																		
0%	0%	0%	0%	0%	0%	4%	14%	29%																		

iod	To date	BAC
6	331951	1240250
7	355469	
8	382459	EAC
	0.93	1334419
	1.07	

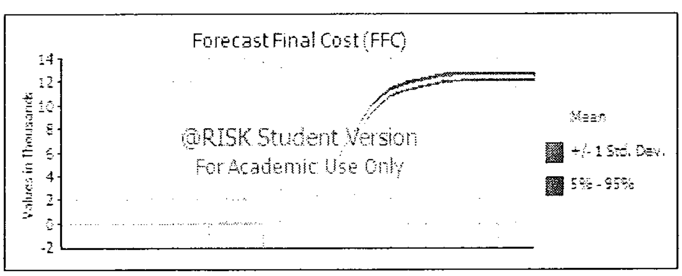
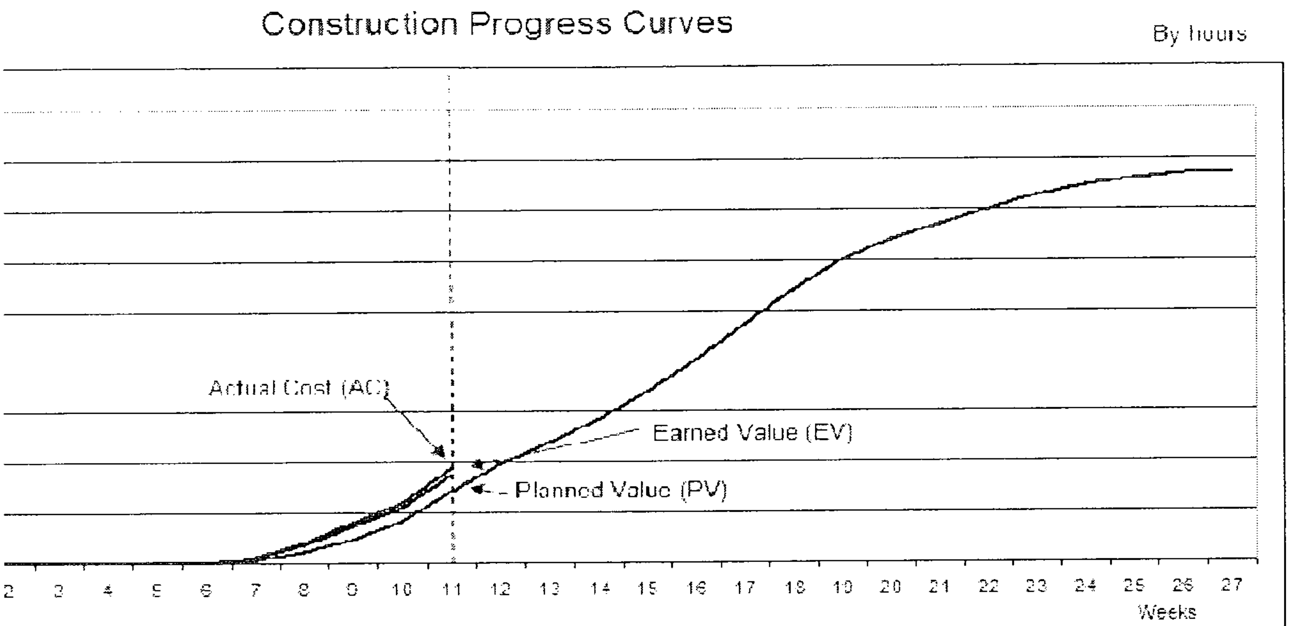


Figure 6-18 Procurement Progress Curves (11th Period)



2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27			
0	0	0	0	15	150	443	948	1644	2889	3934	4823	5706	6827	8056	9464	10847	12009	12806	13409	14011	14532	14916	15218	15392	15428			
0	0	0	0	25	244	736	1451	2209	3563																			
0	0	0	0	28	264	804	1598	2406	3833																			
0%	0%	0%	0%	0%	2%	5%	9%	14%	23%																			

Man-Hours

s Period	To date	BAC
1245	2889	15420
1354	3563	
1427	3833	EAC
0.95	0.93	16695
1.09	1.23	

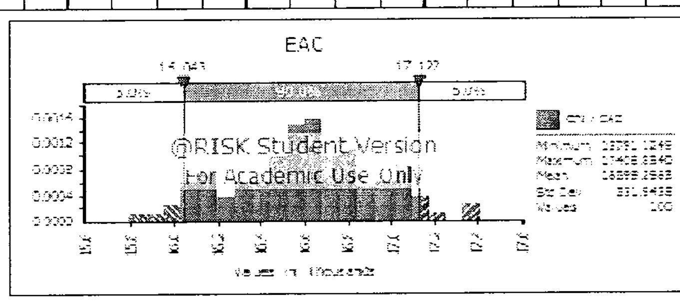


Figure 6-19 Construction Progress Curves (11th Period)

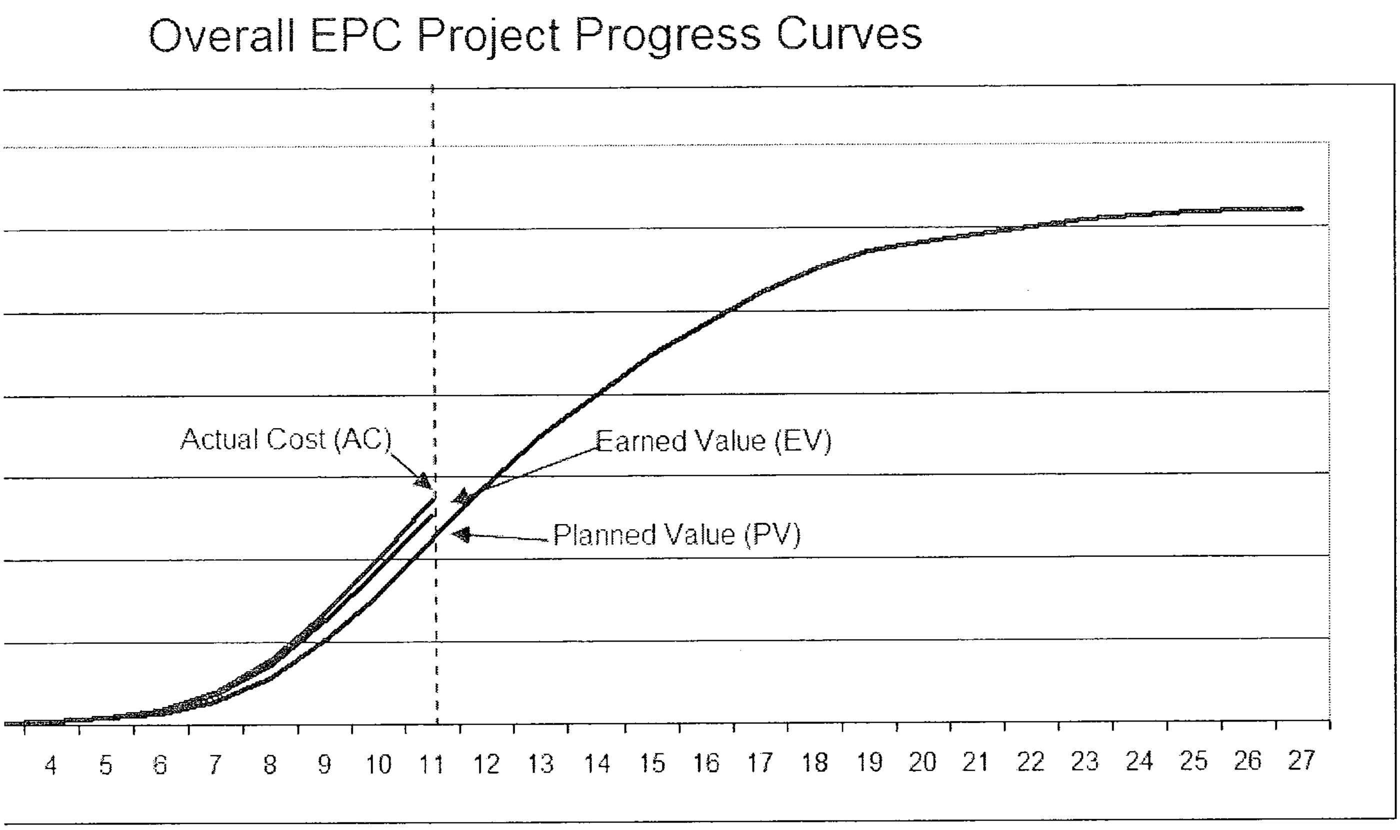


Figure 6-20 Overall Project Progress Curves (11th Period)

	1	2	3	4	5	6	7	8	9	10	11
ned Value (PV)	0	86	151	312	515	817	1743	3170	4852	6334	7555
ed Value (EV)	0	86	151	312	528	934	2114	3306	6094	7858	8497
ual Cost (AC)	0	77	140	309	548	1033	2328	4267	6589	8423	9156
PV ($) K	-	6 628	11 673	24 133	39 768	63 109	134 694	244 955	379 946	489 412	582 800
Earned ($)	-	6 626	11 673	24 133	40 400	72 194	163 261	301 542	470 661	607 239	696 272
AC($)	-	5 965	10 342	23 902	42 342	90 259	179 952	329 649	509 442	650 996	707 494
ned Value (PV)	0	0	0	0	0	0	0	12773	68449	173935	331951
ed Value (EV)	0	0	0	0	0	0	0	4703	56013	176822	356469
ual Cost (AC)	0	0	0	0	0	0	0	4600	59303	183821	382459
ned Value (PV)	0	0	0	0	0	15	150	443	948	1641	2899
ed Value (EV)	0	0	0	0	0	25	244	736	1457	2209	3563
ual Cost (AC)	0	0	0	0	0	28	269	809	1598	2406	3833
PV ($)	0	0	0	0	0	1028	10566	31158	66704	115666	203250
Earned ($)	0	0	0	0	0	1759	17196	51751	102457	155905	[illegible]
AC($)	0	0	0	0	0	1939	16916	56526	112415	164272	264635
PV ($)	-	6 628	11 673	24 133	39 768	64 137	145 260	288 887	510 098	785 014	1 119 001
Earned($)	-	6 628	11 673	24 133	40 800	73 957	180 557	358 297	628 352	939 462	1 262 705
Actual ($)	-	5 065	10 040	23 002	42 042	02 100	190 770	391 225	600 065	1 003 979	1 359 570
Earned %	0.0%	0.2%	0.4%	0.8%	1.3%	2.4%	5.8%	11.6%	20.3%	30.3%	40.7%

Figure 6-21 Overall EPC Project Progress Data

This case study indicates that the EVM is successfully implemented and validated. It provides important and more accurate information than the existing ones. Results comparison is displayed in table 6-6.

Table 6-6 Results Comparison

Item	Information and Functions	Availability In Existing Reports	Availability In PPICF
1	Planned Value	Yes	Yes
2	Actual Cost	Yes	Yes
3	Earned Value	No	Yes
4	CPI	No	Yes
5	SPI	No	Yes
6	Probabilistic forecasting	No	Yes
7	Planned value can be distributed according to time automatically	No	Yes
8	Distribute values according to time at work package level	No	Yes
9	Overall project progress curve	No	Yes

6.4 Progress Visualization Database Implementation

Step 1, project database site start-up.

A SharePoint site is created and all the needed steps to start-up the site are done, such as user permission and coding structure. In the study project, the original multimedia is stored by commitment packages as indicated figure 6-22.

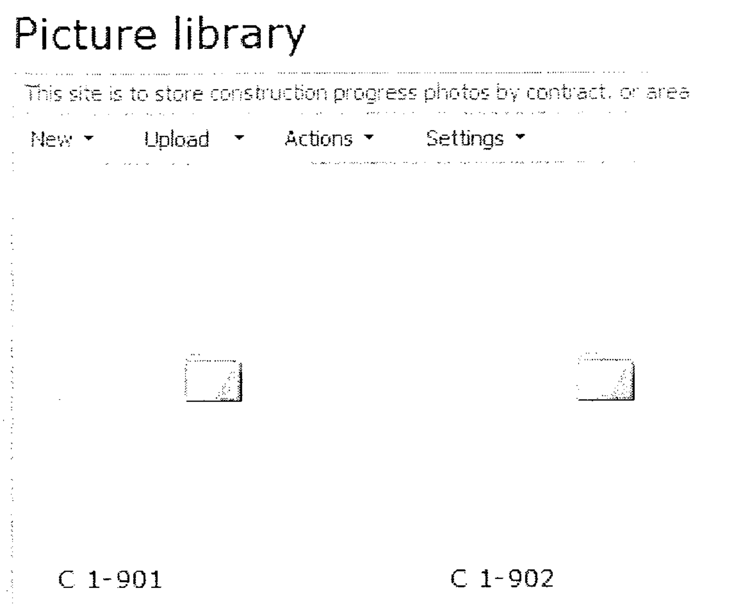


Figure 6-22 Multimedia is Stored by Commitment Package

Step 2, Upload a set of photos from remote site to the web service database and store them in related commitment packages. Each photo or video should be coded according the predefined coding structure. Figure 6-23 and 6-24 present these actions.

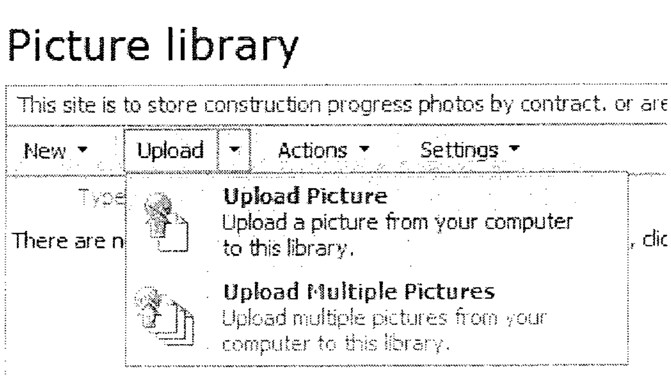
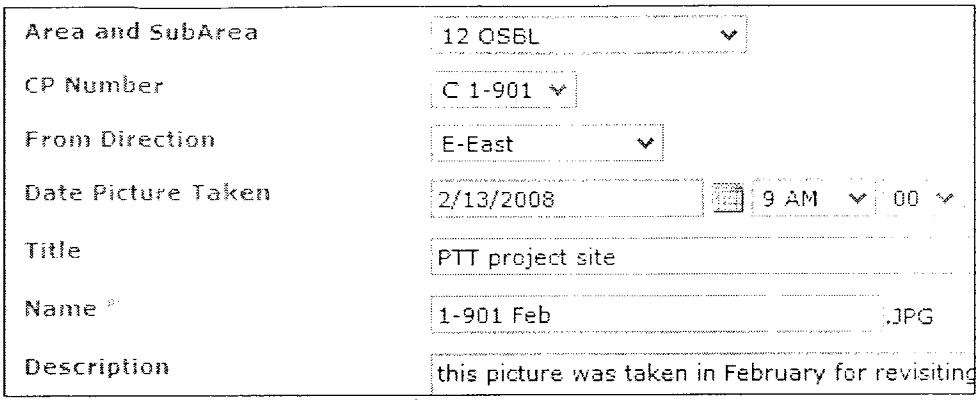


Figure 6-23 Upload Photos to Database



Area and SubArea	12 OSBL
CP Number	C 1-901
From Direction	E-East
Date Picture Taken	2/13/2008 9 AM 00
Title	PTT project site
Name *	1-901 Feb .JPG
Description	this picture was taken in February for revisiting

Figure 6-24 Enter Information of Each Photo According to Coding Structure

Step 3, Data manipulation. The project control staffs can immediately share these uploaded multimedia information in the project management office via internet access. The action of viewing, sorting and filtering can be performed easily. After the photo selection by applying the filter function, the hyper link can be placed and integrated into the monthly progress schedule report. The filter selection can be done by area, by date or other criteria. In this case, it is filtered by milestone of each commitment package. A set of figures from 6-25 to 6-29 describe these operations in detail.

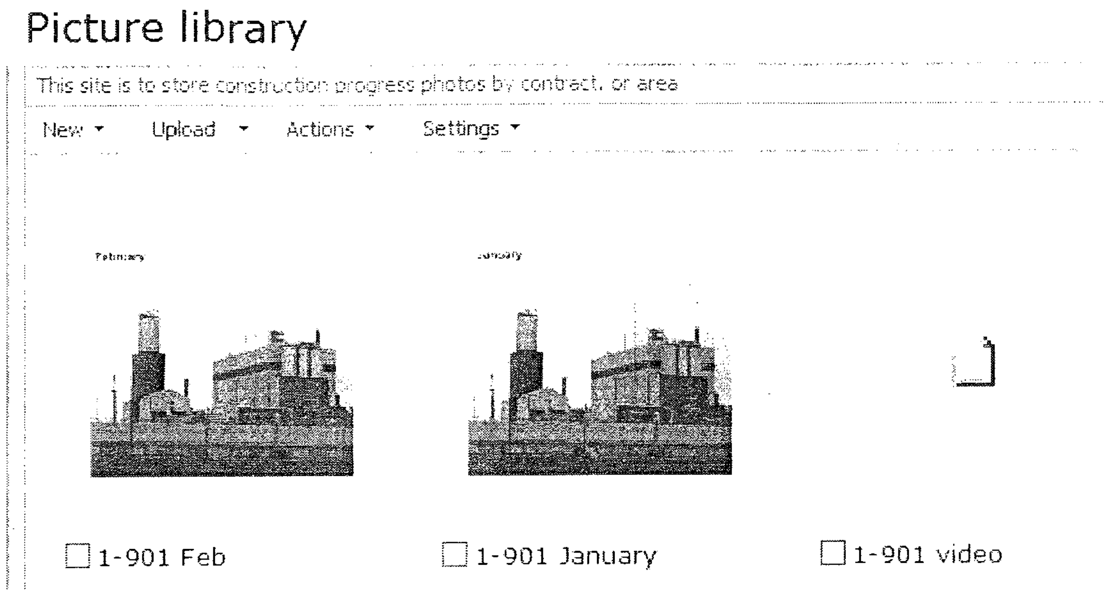


Figure 6-25 View Uploaded Information

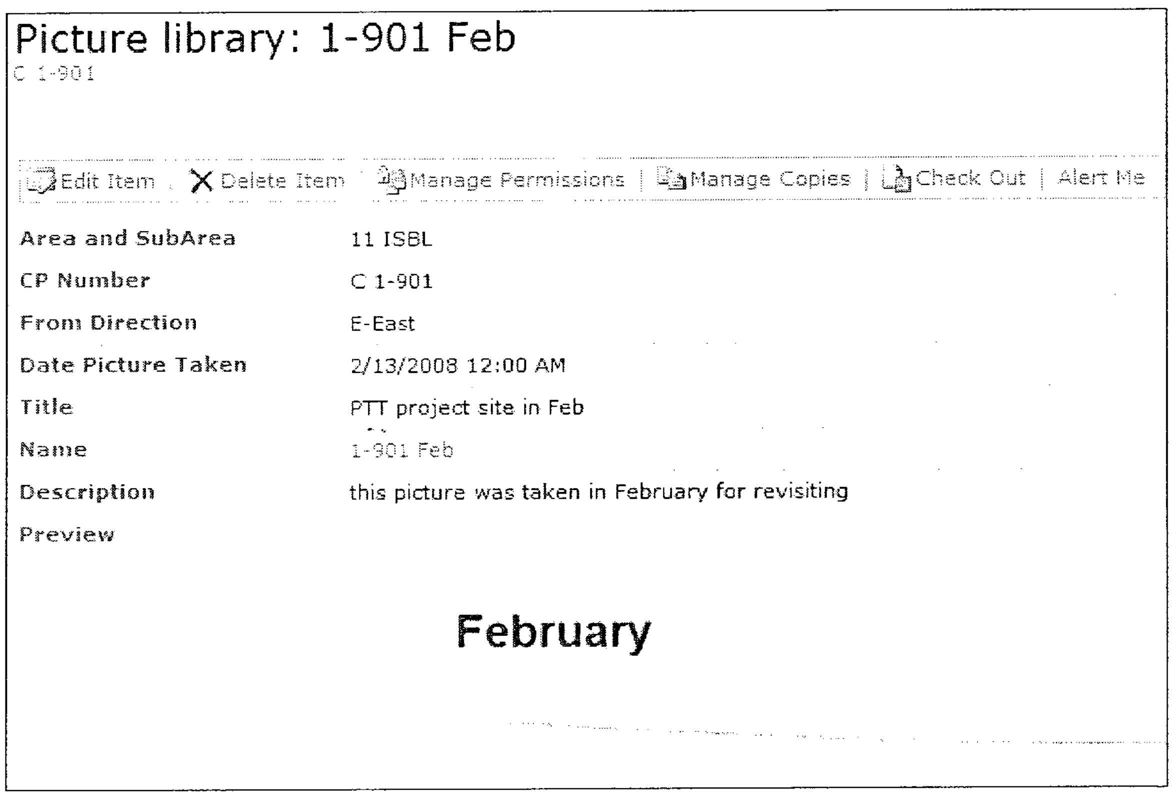


Figure 6-26 View Detail Information of Each Photo

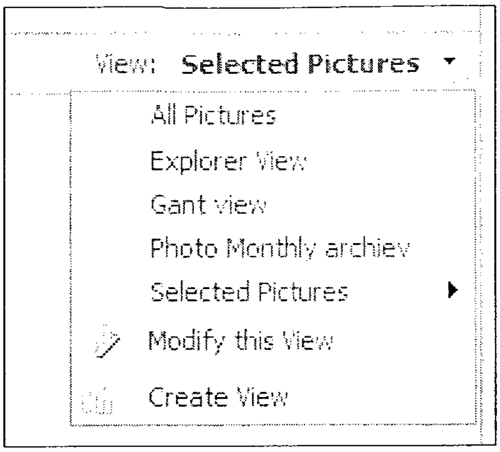


Figure 6-27 Select Needed Pictures

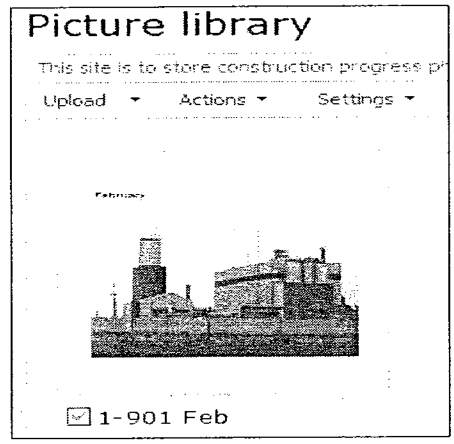


Figure 6-28 View Selected Pictures

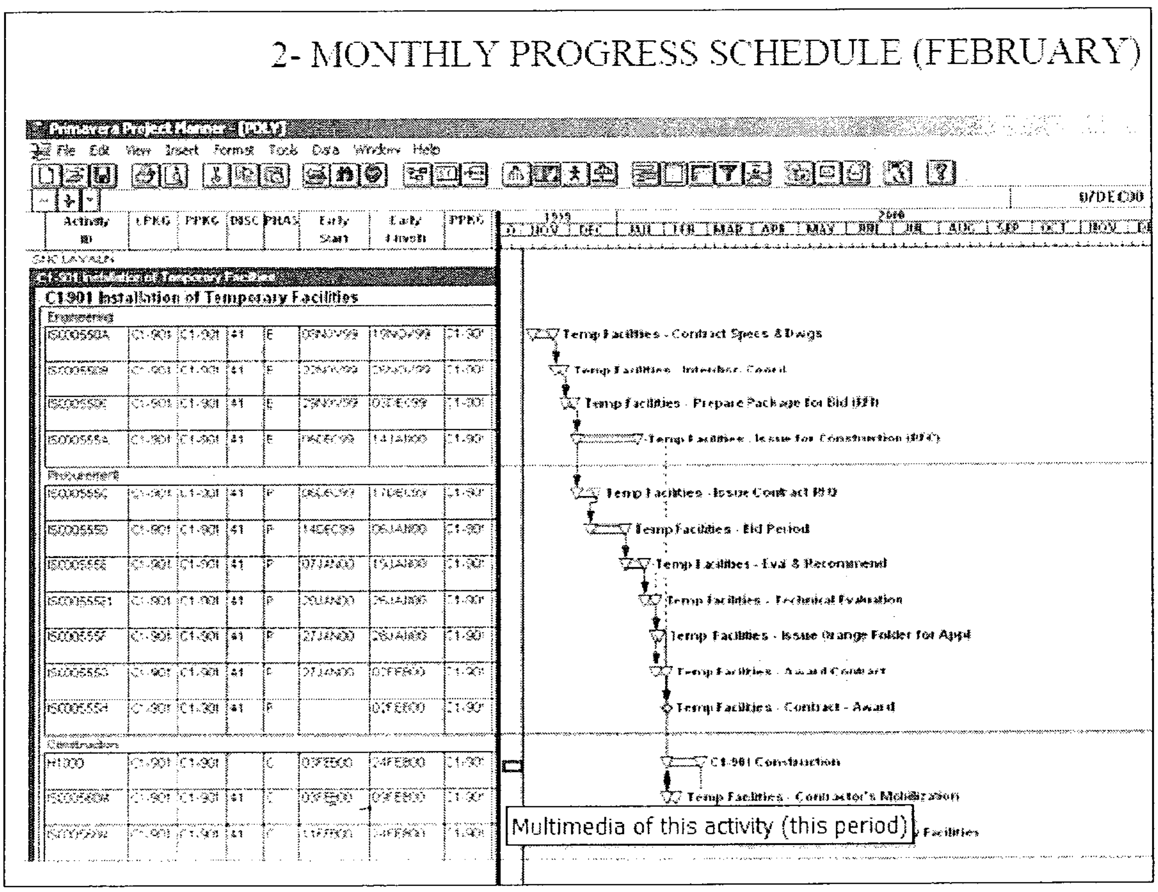


Figure 6-29 Schedule with filtered hyperlinks

Step 4, By clicking the activity in monthly report, the management, clients and all authorized project team members can view the selected photos immediately, without losing time in photos mining. Figure 6-30 and figure 6-31 are results when clicking the link from client's computer through internet.

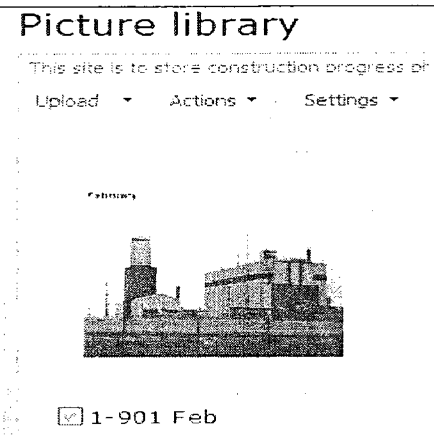


Figure 6-30 View Selected Photos Related to C-1-901

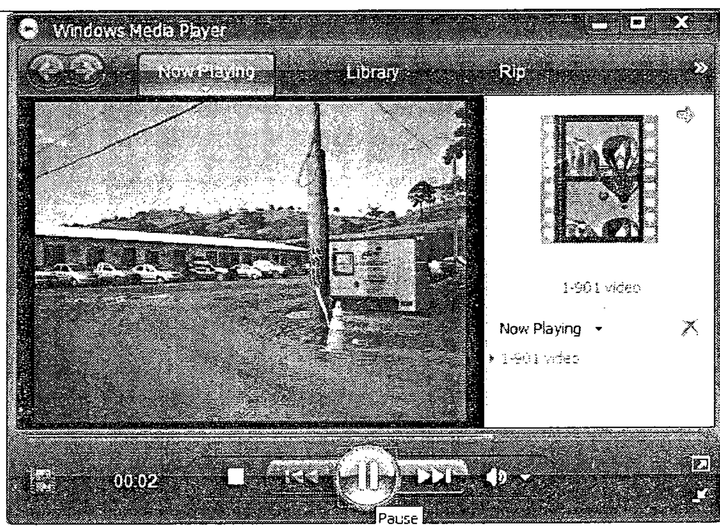


Figure 6-31 View Selected Video Related to C-1-901

7 Chapter SEVEN: Conclusions and Recommendations

7.1 Summary and Contributions

Aiming to provide an efficient methodology for trending and control of cost/time in construction management in EPC project, the contributions of this research can be summarized as follows:

- A comprehensive literature review of the project planning and scheduling, performance evolution, trending and forecasting, and reporting method was done.
- A broad study of CCM method and PM+ project management system provided by SNC-Lavalin was done. Comparison of earned value method and CCM method was done; the pros and cons of each other are outlined.
- Templates for measuring the progress of engineering, procurement, and construction work were summarized from literature review and industrial practice.
- Methodology was presented to improve the Forecast Final Cost by integrated estimate accuracy range into calculation, based on CCM method.
- Development of project progress integrated cost and forecast method to perform better progress reporting
- Two computer technologies, @Risk 5.0 for excel, SQL, Power builder 9.0, PM+ Microsoft Project and VBA were studied. 3 add-on tools, TE, PPICF and PVD were developed to implement the proposed methods.

- Validation and demonstration of the capabilities of the developed methods through a training project case from SNC-Lavalin.

7.2 Limitations and Future work

The developed methods and add-on tools, however, suffer a number of limitations as described below:

- The trend estimate accuracy is only applied to cost or work-hours.
- More information should be classified to provide more reference to users when choosing the subjective accuracy range in trend estimate.
- The earned value measurement in PPICF is based on progress templates. Flexibility for measuring the unit price contract by actual quantities is not available.
- The validation of 3 add-on tools is not actually linked with the PM+ system, due to security reason. It is done in a simulation environment.

To expand the potential application of these methods, the following future work can be made:

- Develop a model to find out distribution type, or called distribution fitting, by using historical data.
- Develop impact factors relationship for each trend type, such as building up relationship between escalation and geological condition.
- Use fuzzy parameters to integrate the confidence intervals for different probability levels into trend estimate and forecasting.

- Provide flexibility to plan and measure progress by both templates and by quantity.
- Integrate these proposed methods and tools, which can be stand-alone or add on to other project management systems, such as PM+.

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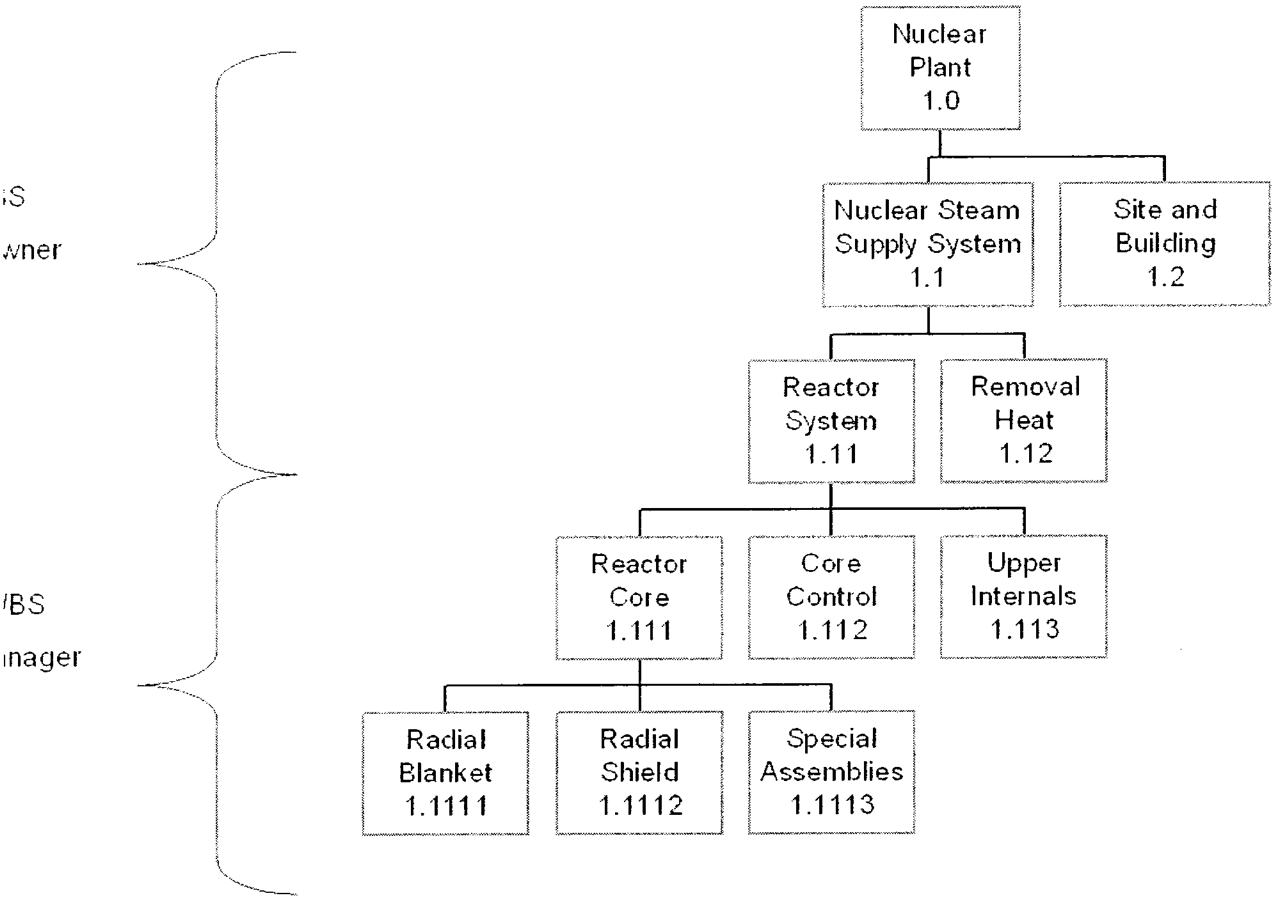
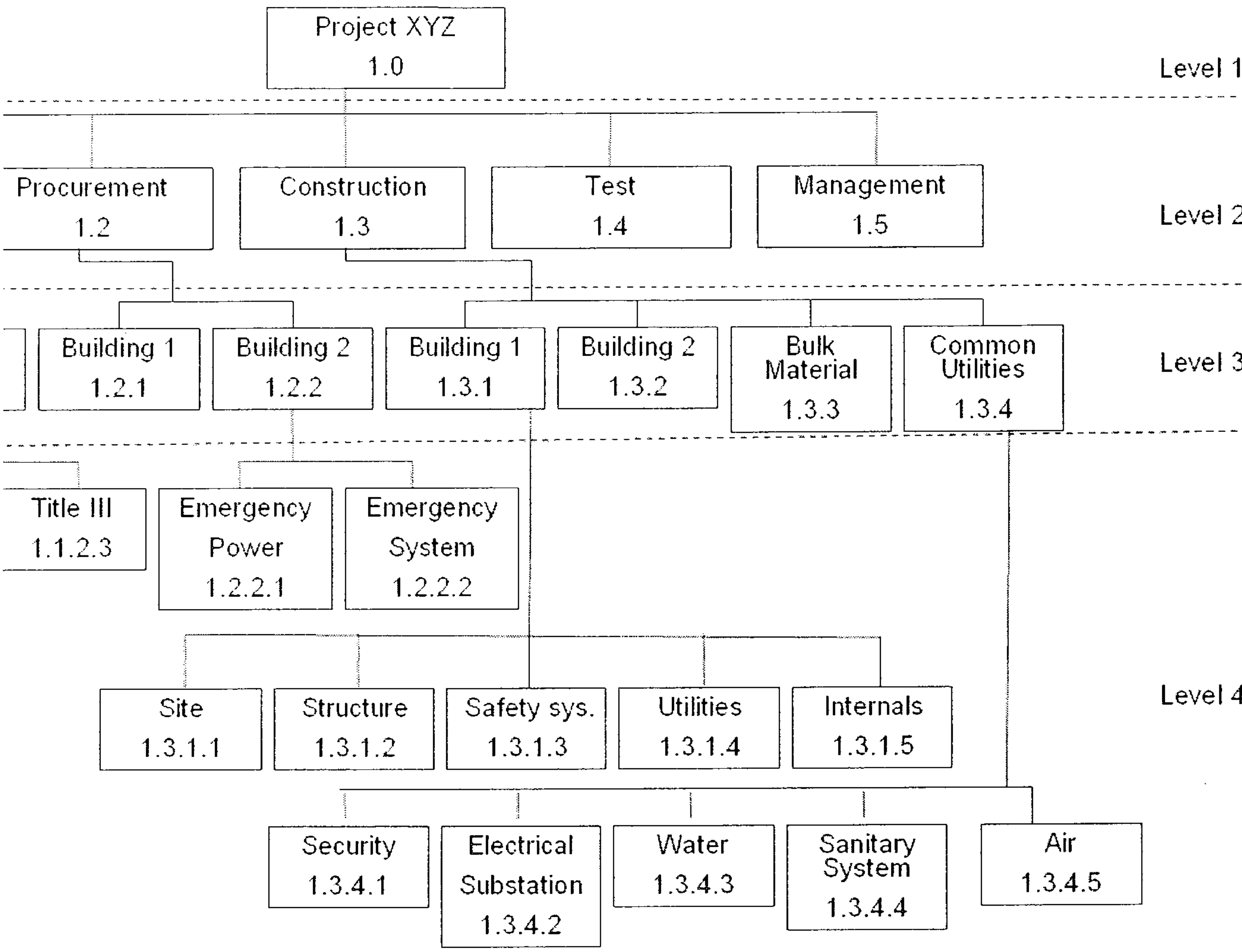
Appendix A. WBS EXAMPLES



Source: DOE Manual

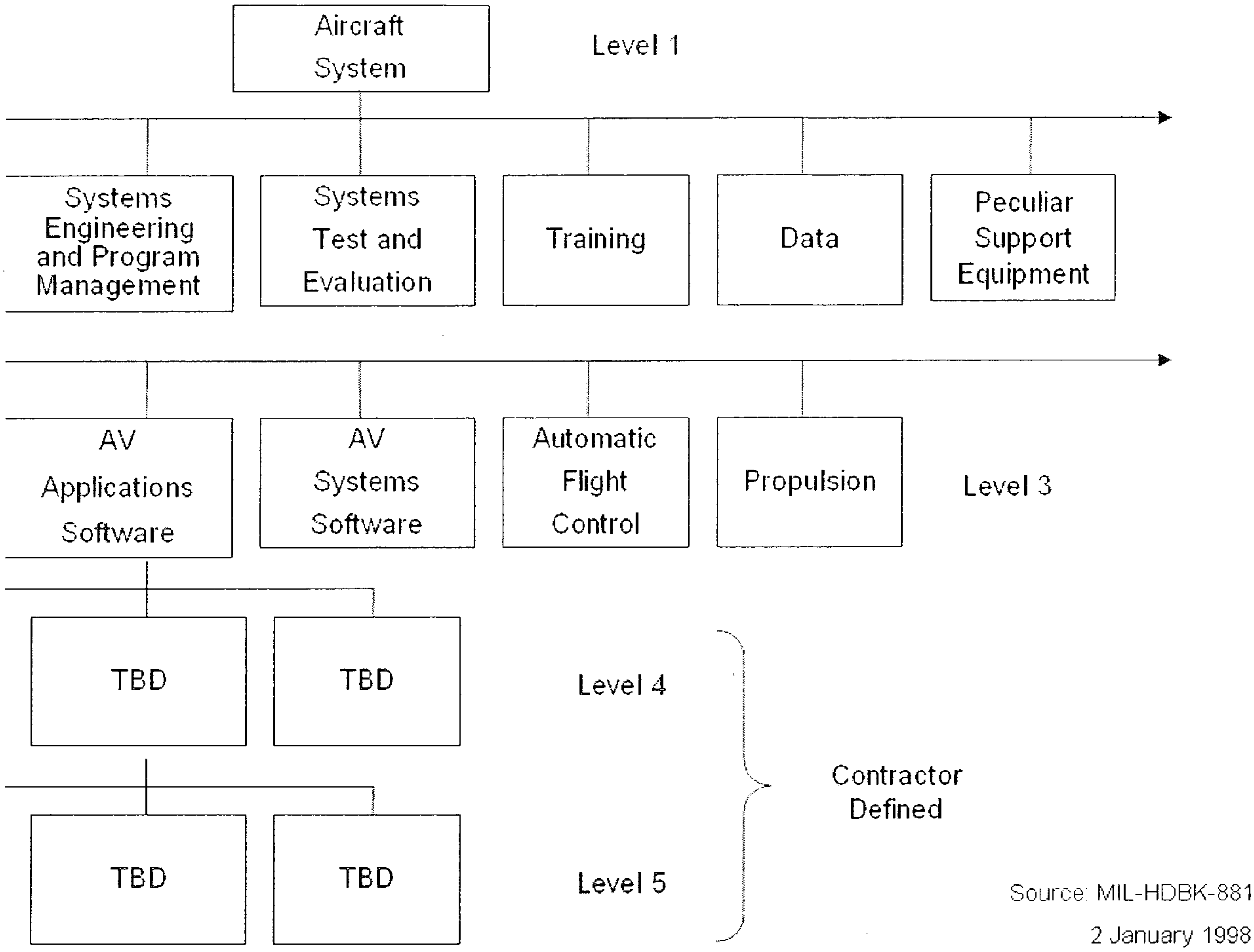
WBS for an Energy Project



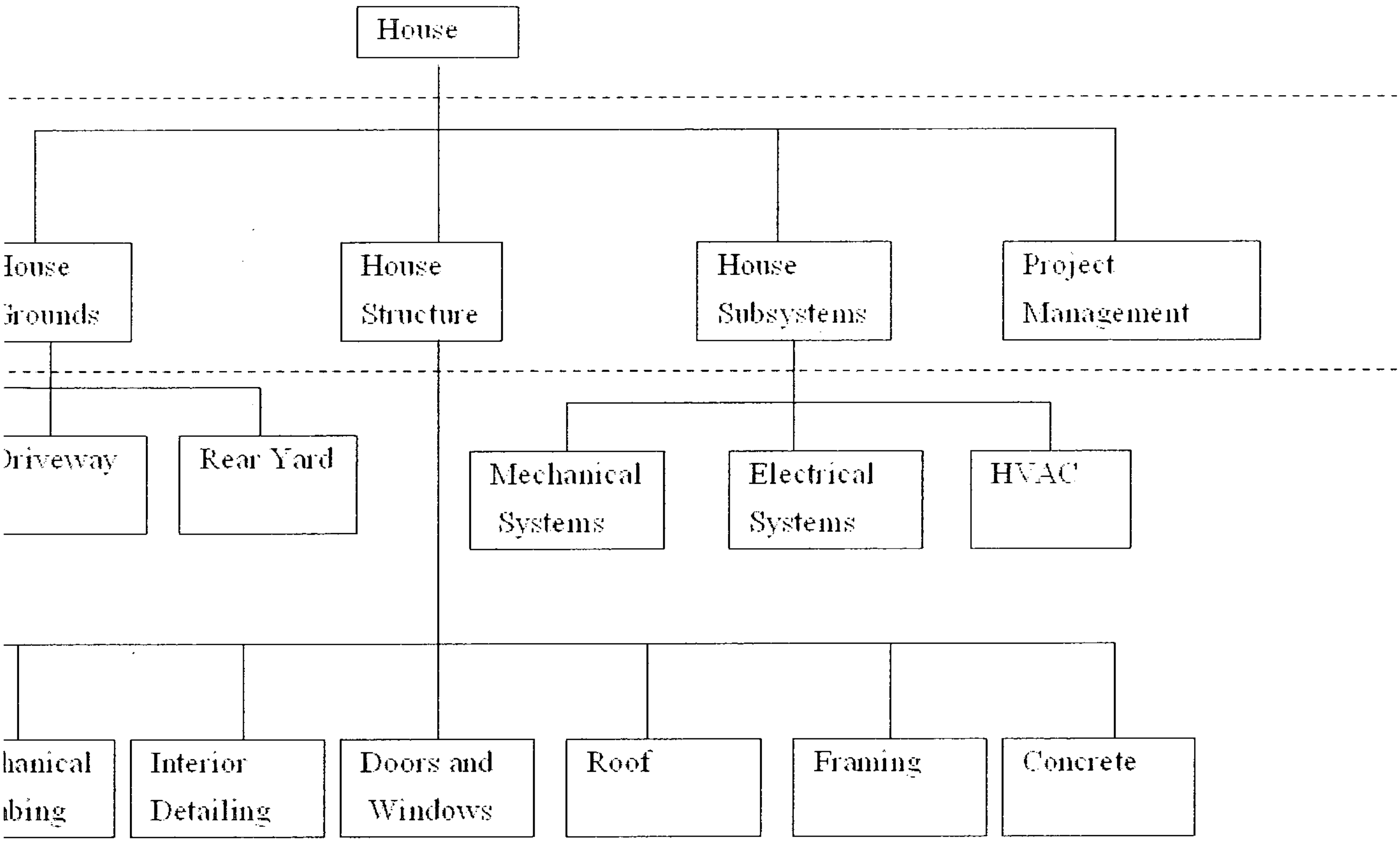
s the way a project has been planned, cost estimated and will be managed."

Source: DDE PCS Manual

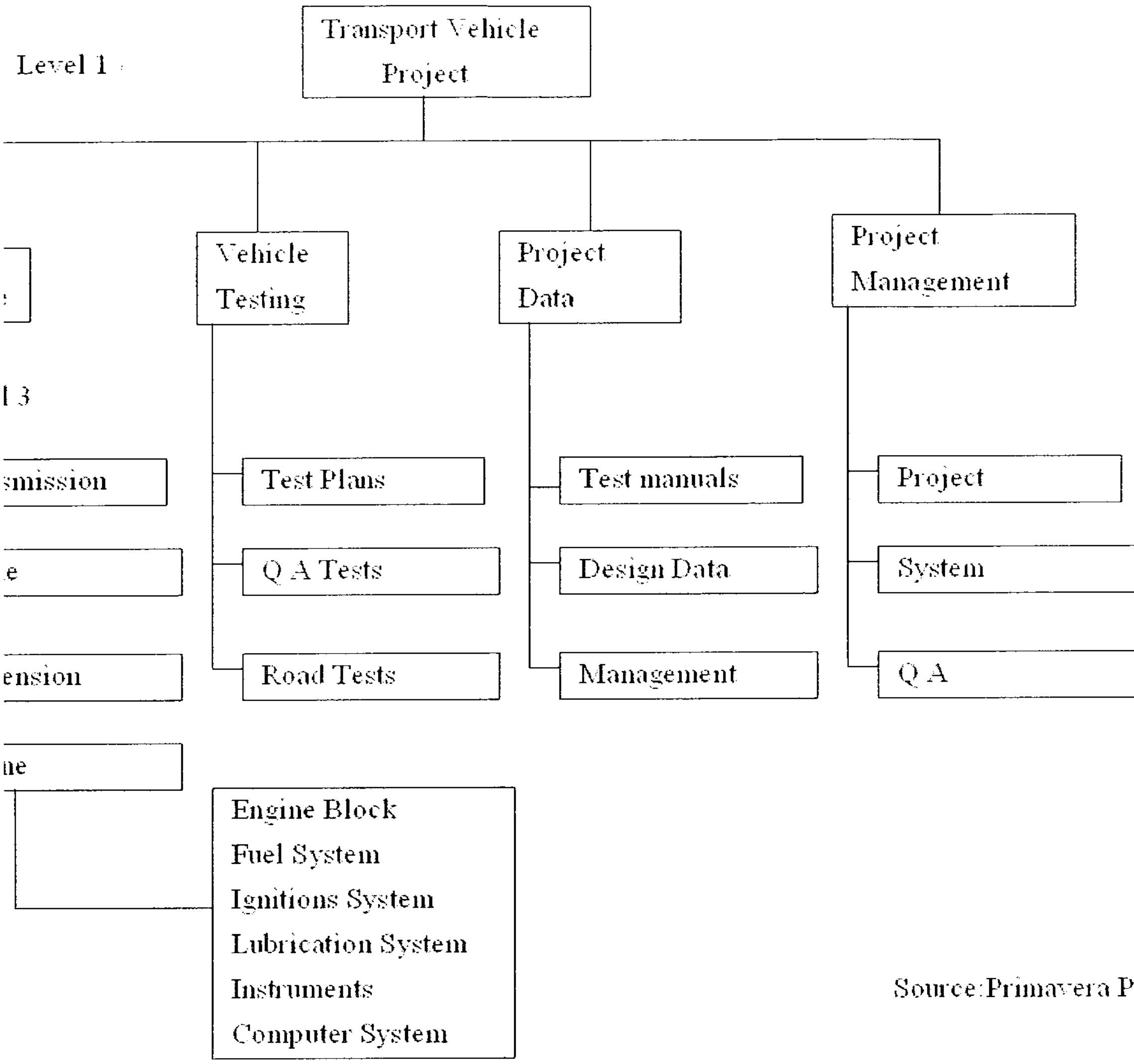
WBS for an Energy Construction Project



WBS for an Aircraft System

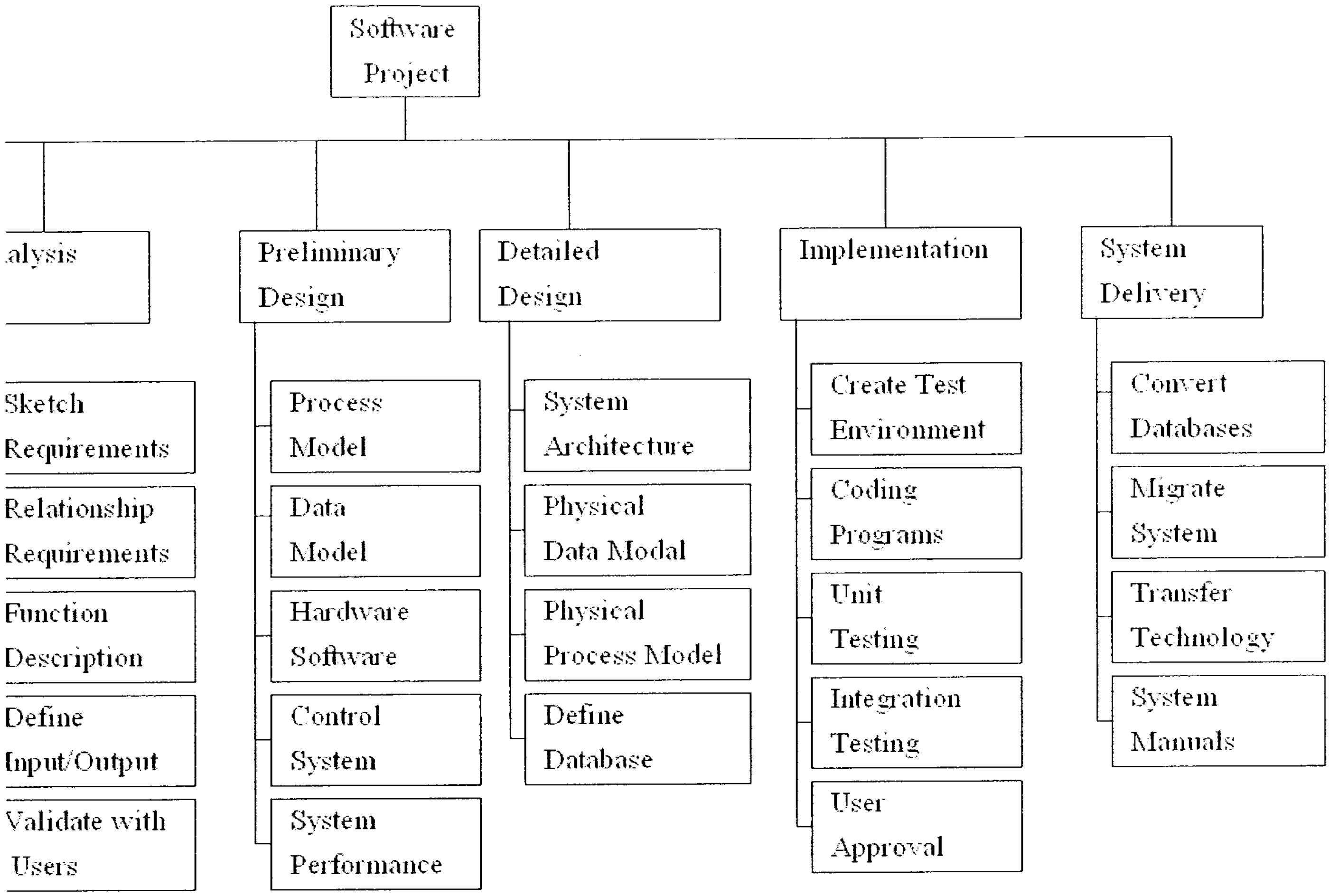


WBS to Build a House

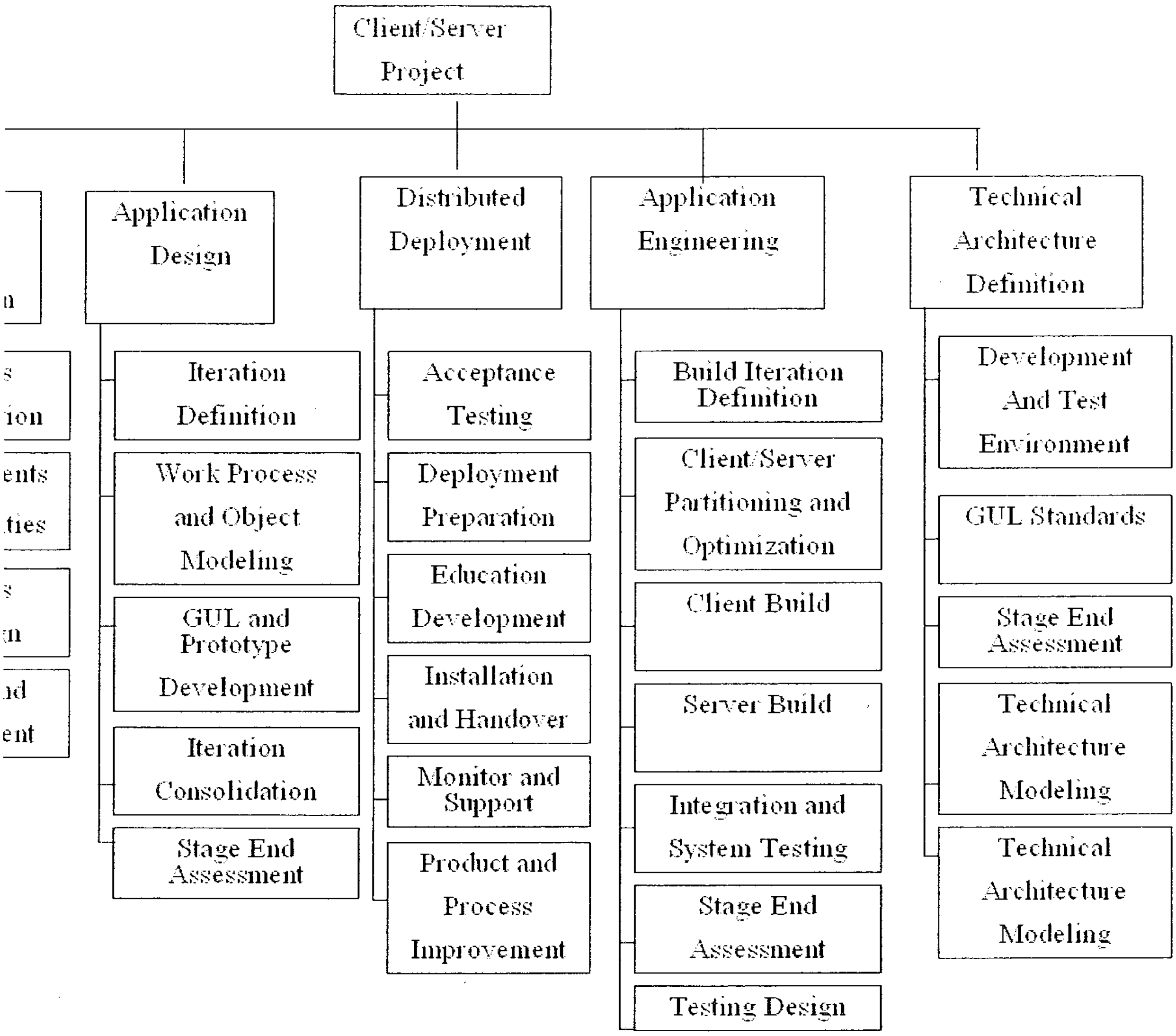


Source:Primavera P3 Manual

WBS for a Transportation Vehicle



WBS for a Software Project



WBS for a Client/Server Software Project

Appendix B. PROGRESS MEASUREMENT TEMPLATES

Accurate assessment of work in progress is essential, and good judgment is needed in order to assess the status of partially completed work. The guidance contained in this section covers major categories of work. Each discipline is listed, and work items are broken down into major tasks and recommended percentages for completion of the work are shown:

Site preparation and earthwork: report by percent of total cubic yards involved

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Earth tank pads, percent of compacted earth in place	85	85
2	Final dressing	15	100

2. Concrete Work: report by percent of total cubic yards involved, with the following allowances:

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Rebar in place	20	20
2	Forming complete	50	70
3	Concrete poured	10	80
4	Stripping complete	15	95
5	Dressed and patched	5	100

Piles: report by number in place as percent of total required

Paving: report by square feet installed against total square feet required

Sewers and access holes (prefabricated)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Access holes and catch basins installed	65	65
2	Hookup and connections complete	25	90
3	Test and checkout complete	10	100

Steel structures, piping supports and miscellaneous steel

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Report by tons erected in place	90	90
2	Bolting tension checked and completed	10	100

Buildings (excluding foundations):

7-1 Shelter-type (no interior work)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Steel erected	50	50
2	Walls and roof complete	40	90
3	Checked out complete	10	100

7-2 Masonry-type

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Walls erected	30	30
2	Roofs and windows installed	15	65
3	Interior complete	35	100

Equipment installation

Columns and vessels

8-1 Shop-fabricated, no internals

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Set in place	60	60
2	Secured and grouted	30	90
3	Tested and bolted up	10	100

8-2 Shop-fabricated, with trays or internals

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Secured and grouted	10	35
2	Internals complete	55	90
3	Tested and bolted up	10	100

8-3 Field-fabricated: report by number of prefabricated sections or rings and internals installed; allow appropriate percent complete for partly completed work elements

8-4 Storage tanks, field-fabricated: report by base, number of rings installed, roof, and internals from subcontractor erection schedule; allow appropriate complete for partly completed work elements

Exchangers

9-1 Shell and tube (per unit)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Set in place	60	60
2	Secured and grouted	30	90
3	Tested and accepted	10	100

9-2 Fin-tube (per unit)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Set in place	60	60
2	Secured and grouted	30	90
3	Tested and accepted	10	100

9-3 Fin fans (per unit)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Steel structure erected	20	20
2	Housing erected	10	30
3	Fan and driver assembled	20	50
4	Coils installed	20	70
5	Run-in and fan balance	20	90
6	Tested and accepted	10	100

Heaters

10-1 Vertical heater (package unit)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Heater set in place	50	50
2	Stack erected	20	70
3	Secured and grouted	20	90
4	Tested and accepted	10	100

10-2 Heater (field-assembled)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Substructure complete	20	20
2	Refractory installed	35	55
3	Tubes installed	20	75
4	Stack and breeching installed	10	85
5	Burners installed	5	90
6	Tested and accepted	10	100

10-3 Pumps and drivers

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Pump set in place	40	40
2	Aligned and grouted	50	90
3	Run-in and accepted	10	100

Compressors and drivers

11-1 Package compressor (with driver)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Set in place	50	50
2	Secured and grouted	40	90
3	Run-in and accepted	10	100

11-2 Package compressor (with driver separate)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Compressor in place	25	25
2	Driver in place	25	50
3	Unit coupled and aligned	35	85
4	Secured and grouted	5	95
5	Run-in and accepted	10	100

Piping: percent complete in this account can be reported in the following categories by the method indicated:

- Fabricated pipe spools: as completed by count ,tons, or feet pipe spools installed: as installed by counts, tons, or feet straight run racked pipe: by percent of linear feet installed underground lines: by percent of linear feet installed hangers and supports: as completed by count or percent allowance
- Hydrotesting: by subsystem or by holding back 10% of pipe spools for hydrotest and punchlist work
- Handling: laydown to work area, percentage basis (by judgment)
- 2.5 inch and less in diameter: by feet, screwed or socket weld, by size
- 3-inch and more in diameter: by each fit-up and tack, by size, schedule, and type of material
- Weld out: by cubic inches of weld plus per operation
- Hydrostatic test: percentage basis or by subsystem
- Punch out: percentage basis (by judgment)

- Rework: percentage basis (by judgment)
- Pipe fabrication, pipe supports, and hangers: unit job hours

Electrical

- Power and control equipment: as installed, by count
- Lighting equipment (pole assemblies): percent installed, by count
- Underground conduit and duct: percent of linear feet installed
- Above-ground conduit (power): percent of linear feet installed
- Above-ground conduit (lighting): percent of linear feet installed
- Power and control wire: percent of total feet pulled
- Power connections: percent of total complete
- Grounding: percent of feet installed
- Lighting wire: percent of feet installed
- Push-buttons and receptacles: percent of total installed
- Communications: by system complete

Instrumentation of control panels (including shop-mounted instruments)

CODE	DESCRIPTION	WEIGHT (%)	CUM. %
1	Install panels	25	25
2	Hook up and connect	60	85
3	Test and check out	15	100

Instruments and instrument materials

- Wire and conduit: percent of linear feet installed
- Pipe and tubing: percent of linear feet installed
- Field-mounted instruments: percent installed, by count
- Control and relief valves: percent installed, by count
- Racks and supports: percent of linear feet installed
- Hookups: as completed, by count
- Loop check: as complete, by system

Insulation

- Vessels and towers: percent of square feet installed
- Piping: percent linear feet installed

Painting

- Vessels, tanks, towers, and structural steel: percent of square feet installed
- Piping: percent of linear feet covered

- Good systems will be based on quantities, earned value, and a productivity assessment based on actual hours versus earned hours.

Table Generalized Progress Measurement Template

Task Specified Progress Measurement Template		
Task	**Work Content**	**Cumulative % Earned**
Piling		
1	Rig in position	40
2	Drive and inspect	80
3	Trim and finish	95
4	Hand over	100
Earthworks		
1	Excavation	50
2	Backfill	60
3	Compact	90
4	Fine grade	95
5	Hand over	100
Foundations		
1	Building	5
2	Formwork	50
3	Rebar and embedment	80
4	Pour	87
5	Strip cure and grout	95
6	Hand over	100
Main steel structures		
1	Columns	20
2	Beams Gratings, handrails	40
3	Ladders	80
4	Final alignment	85
5	Punch and fix	95
6	Hand over	100
Paving		
1	Lay mesh and formwork	70
2	Pour concrete	90
3	Strip cure	95
4	Hand over	100

Table Generalized Progress Measurement Template (Continue)

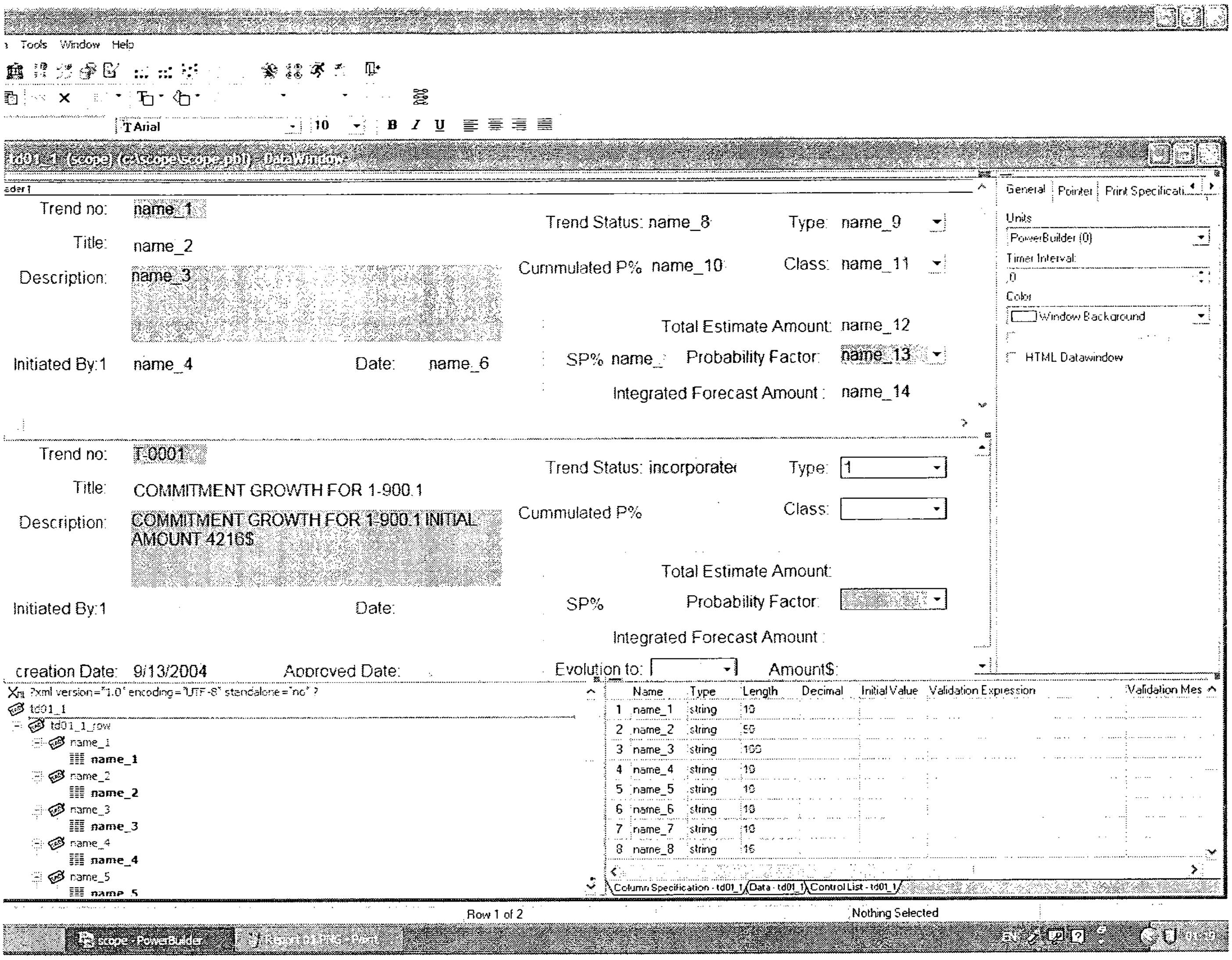
Task	Work Content	Cumulative % Earned
Buildings		
1	Erect structure	20
2	Complete roof	40
3	Complete external walls	55

4	Utilities	95
5	Utilities	95
6	Hand over	100
Piping underground		
1	Install pipe	15
2	Level, butt and joint	40
3	Install fittings and wrap	70
4	Punch and fix	80
5	Hydro test	95
6	Hand over	100
HVAC		
1	Supports	10
2	Ducting and fitting	65
3	Install unit	80
4	Complete and test	90
5	Punch and fix	95
6	Hand over	100

Table Generalized Progress Measurement Template (Continue)

COST	**DURATION**		
	Very Short	**Short**	**Long**
Low	0,100	50,100	20,100
High	0,100	20,100	20,100
		30,100	

Appendix C. PROTOTYPE SYSTEM DEVELOPMENT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td01_1 (scope) (c:\scope\scope.pbl) - DataWindow
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Title: name_2
Description: name_3
Initiated By:1 name_4
Date: name_6
Trend Status: name_8
Type: name_9
Cummulated P% name_10
Class: name_11
Total Estimate Amount: name_12
SP% name_
Probability Factor: name_13
Integrated Forecast Amount : name_14
Trend no: T-0001
Title: COMMITMENT GROWTH FOR 1-900.1
Description: COMMITMENT GROWTH FOR 1-900.1 INITIAL AMOUNT 4216$
Initiated By:1
Date:
Trend Status: incorporate
Type: 1
Cummulated P%
Class:
Total Estimate Amount:
SP%
Probability Factor:
Integrated Forecast Amount :
creation Date: 9/13/2004
Approved Date:
Evolution to:
Amount$:
General Pointer Print Specificati
Units
PowerBuilder (0)
Timer Interval
0
Color
Window Background
HTML Datawindow
?xml version="1.0" encoding="UTF-8" standalone="no" ?
td01_1
td01_1_row
name_1
name_2
name_3
name_4
name_5
Name Type Length Decimal Initial Value Validation Expression Validation Mes
1 name_1 string 10
2 name_2 string 50
3 name_3 string 100
4 name_4 string 10
5 name_5 string 10
6 name_6 string 10
7 name_7 string 10
8 name_8 string 15
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Row 1 of 2
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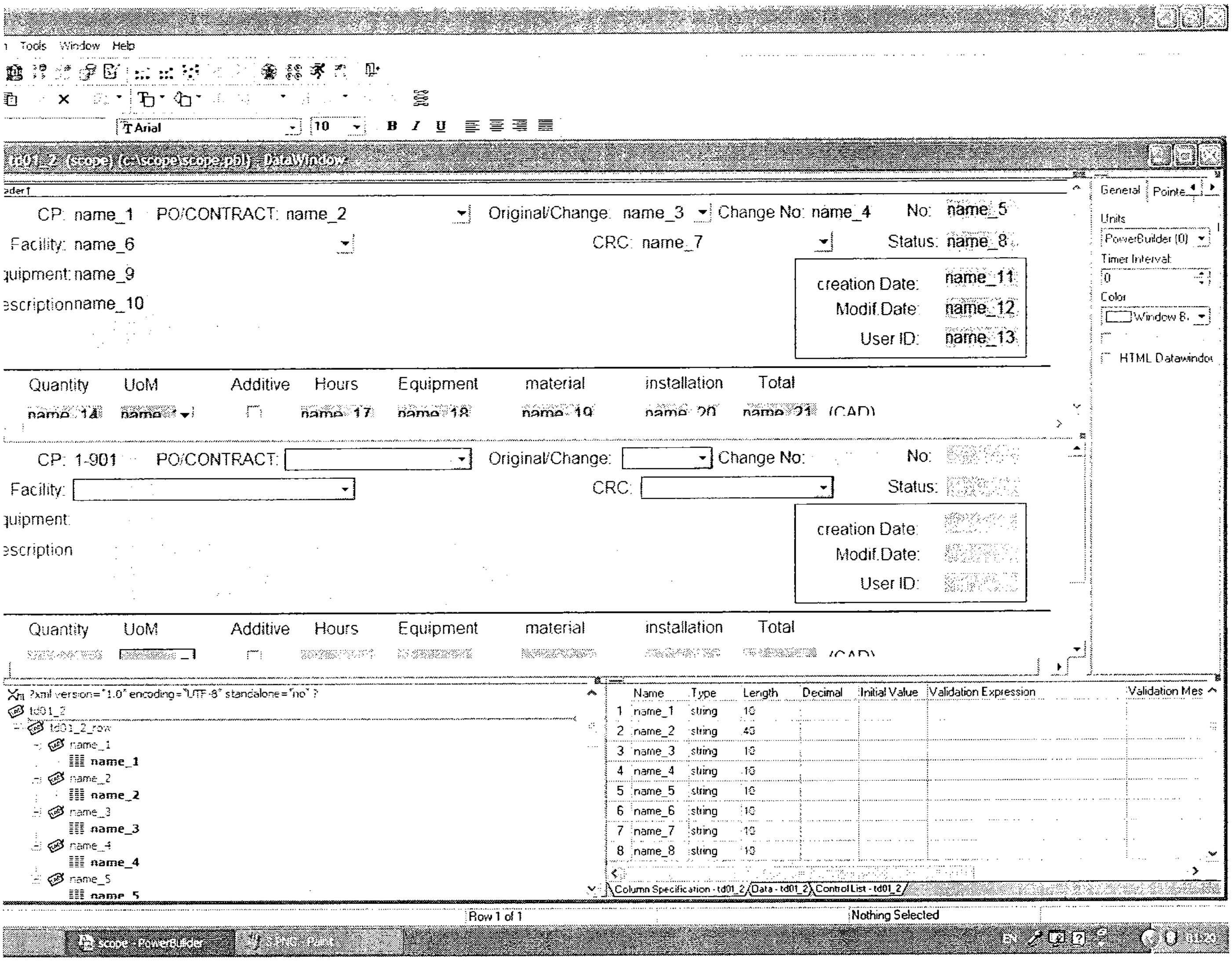
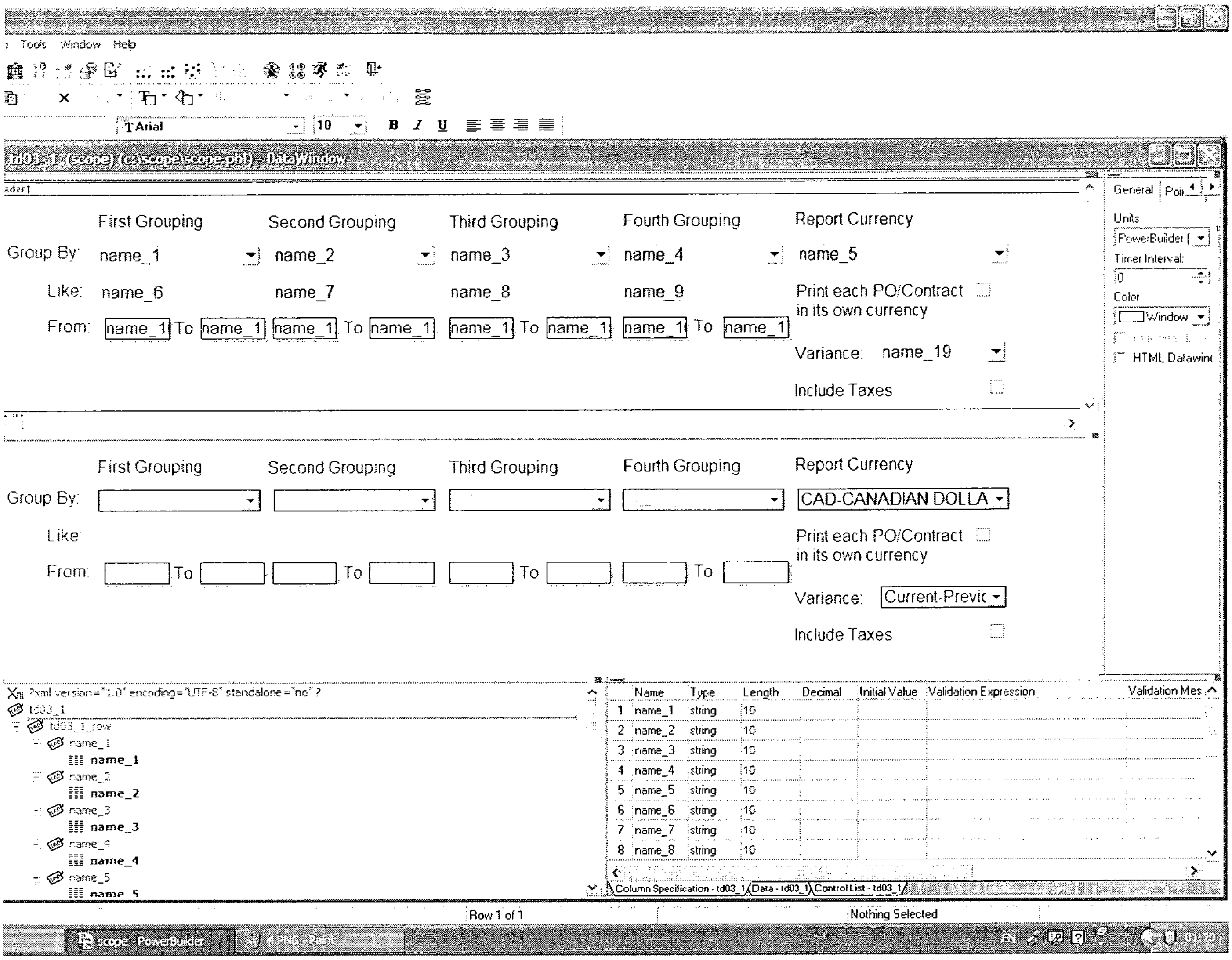
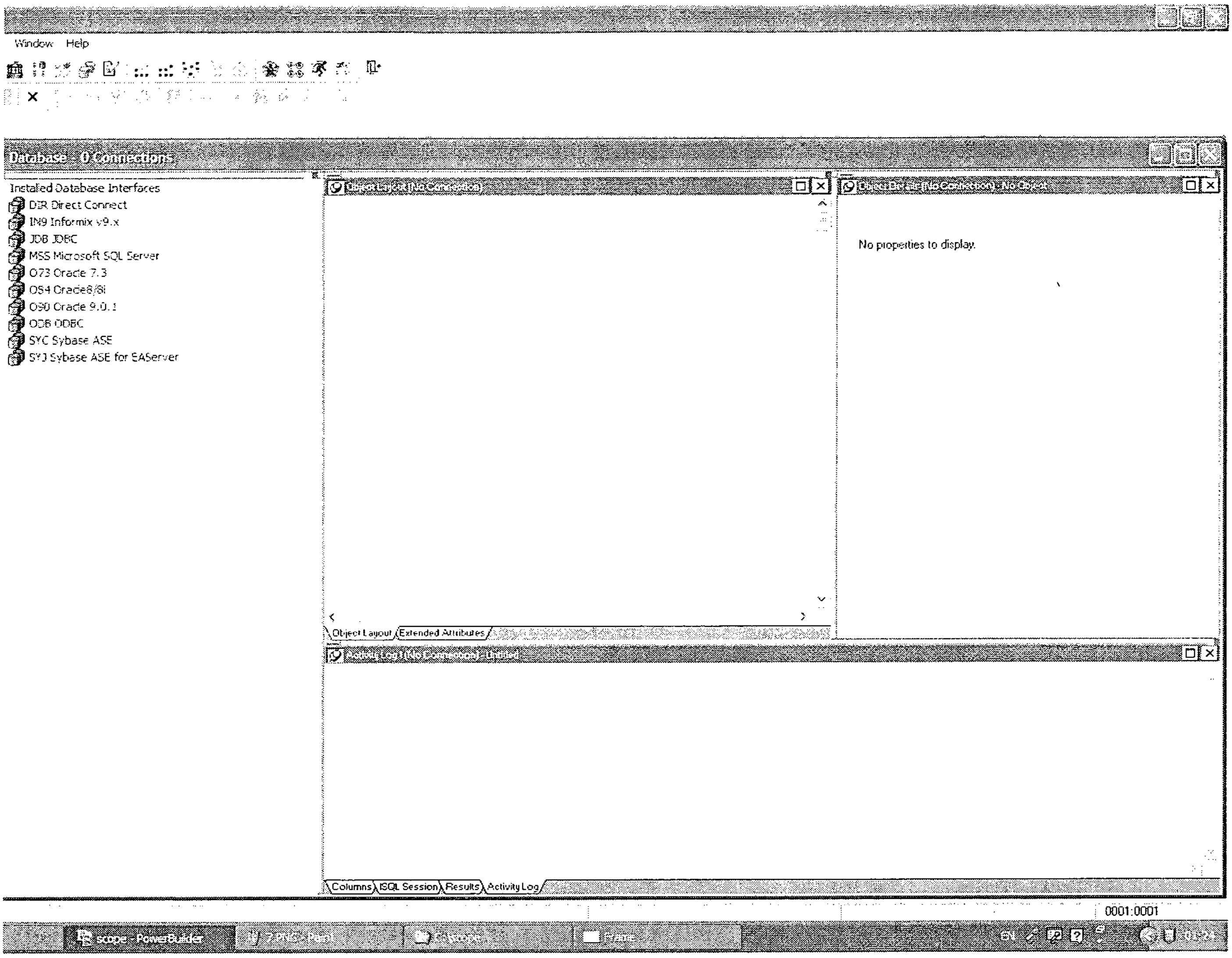
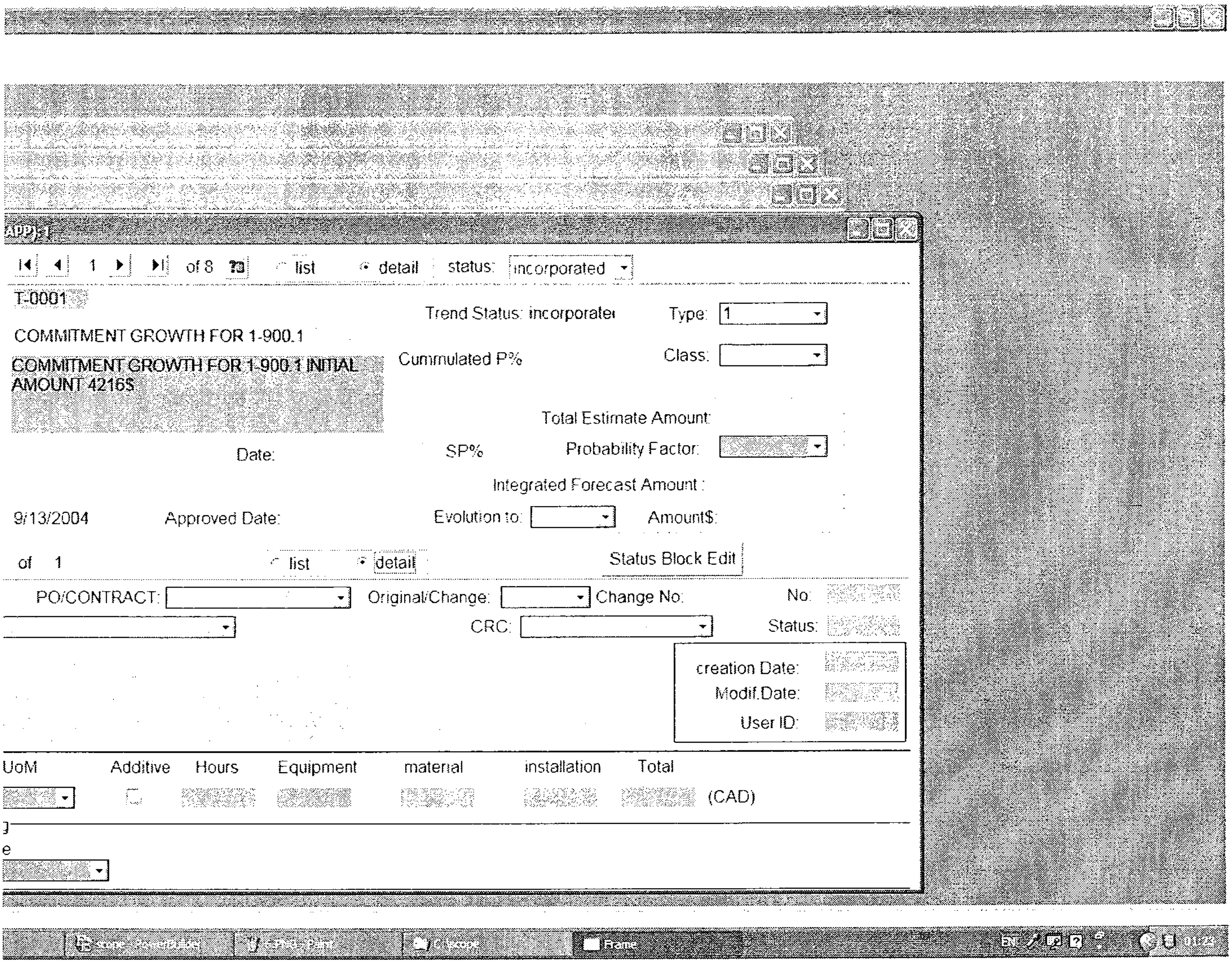
scope - PowerBuilder




Tools Window Help
td03_1 (scope) (c:\scope\scope.pbl) - DataWindow
First Grouping
Second Grouping
Third Grouping
Fourth Grouping
Report Currency
Group By
name_1
name_2
name_3
name_4
name_5
Like
name_6
name_7
name_8
name_9
Print each PO/Contract in its own currency
From
To
Variance
name_19
Include Taxes
CAD-CANADIAN DOLLA
Current-Previc
General
Units
Timer Interval
Color
Window
HTML Datawin
Name
Type
Length
Decimal
Initial Value
Validation Expression
Column Specification - td03_1
Data - td03_1
Control List - td03_1
Row 1 of 1
Nothing Selected
scope - PowerBuilder

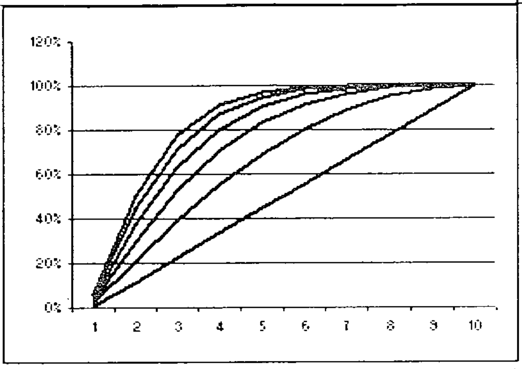

Window Help
Database - 0 Connections
Installed Database Interfaces
DIR Direct Connect
IN9 Informix v9.x
JDB JDBC
MSS Microsoft SQL Server
O73 Oracle 7.3
O84 Oracle8/8i
O90 Oracle 9.0.1
ODB ODBC
SYC Sybase ASE
SYJ Sybase ASE for EAServer
No properties to display.
Object Layout
Extended Attributes
Columns
ISQL Session
Results
Activity Log
0001:0001
scope - PowerBuilder

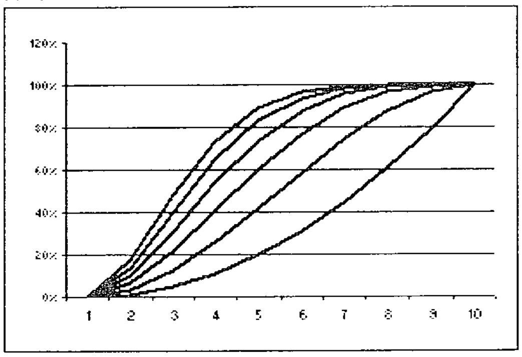

APP-1
1 of 8
list
detail
status: incorporated
T-0001
COMMITMENT GROWTH FOR 1-900.1
COMMITMENT GROWTH FOR 1-900.1 INITIAL AMOUNT 4216$
Trend Status: incorporate
Type: 1
Cummulated P%
Class:
Total Estimate Amount:
Date:
SP%
Probability Factor:
Integrated Forecast Amount :
9/13/2004
Approved Date:
Evolution to:
Amount$:
of 1
list
detail
Status Block Edit
PO/CONTRACT:
Original/Change:
Change No:
No:
CRC:
Status:
creation Date:
Modif.Date:
User ID:
UoM
Additive
Hours
Equipment
material
installation
Total
(CAD)

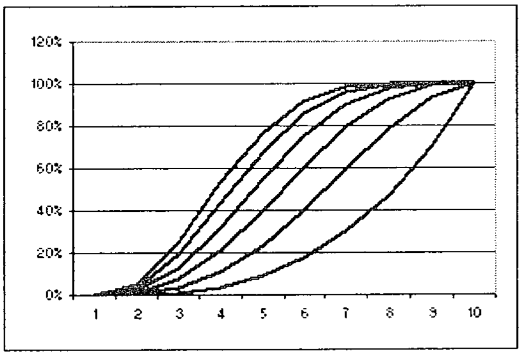
Appendix D. BETA DISTRIBUTION EXAMPLES

Beta Shape Factors											
Alpha	Beta	1	2	3	4	5	6	7	8	9	10
1	1	1%	11%	22%	33%	44%	56%	67%	78%	89%	100%
1	2	2%	21%	40%	56%	69%	80%	89%	95%	99%	100%
1	3	3%	30%	53%	70%	83%	91%	96%	99%	100%	100%
1	4	4%	38%	63%	80%	90%	96%	99%	100%	100%	100%
1	5	5%	45%	72%	87%	95%	98%	100%	100%	100%	100%
1	6	6%	51%	78%	91%	97%	99%	100%	100%	100%	100%
2	1	0%	1%	5%	11%	20%	31%	44%	60%	79%	100%
2	2	0%	3%	13%	26%	42%	58%	74%	87%	97%	100%
2	3	0%	6%	22%	41%	60%	77%	89%	96%	99%	100%
2	4	0%	10%	31%	54%	74%	87%	95%	99%	100%	100%
2	5	0%	14%	40%	65%	83%	93%	98%	100%	100%	100%
2	6	0%	18%	48%	74%	89%	97%	99%	100%	100%	100%
3	1	0%	0%	1%	4%	9%	17%	30%	47%	70%	100%
3	2	0%	1%	4%	11%	23%	40%	59%	78%	94%	100%
3	3	0%	1%	8%	21%	40%	60%	79%	92%	99%	100%
3	4	0%	2%	13%	32%	55%	75%	90%	98%	100%	100%
3	5	0%	3%	19%	43%	67%	85%	95%	99%	100%	100%
3	6	0%	5%	25%	53%	77%	92%	98%	100%	100%	100%

Cumulative

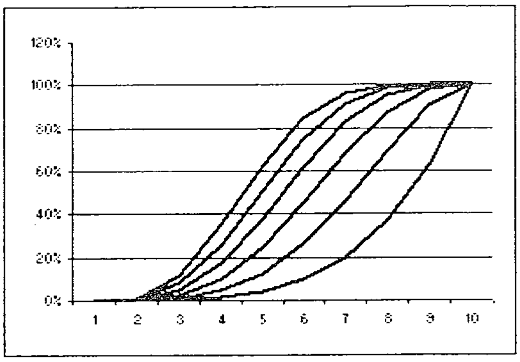


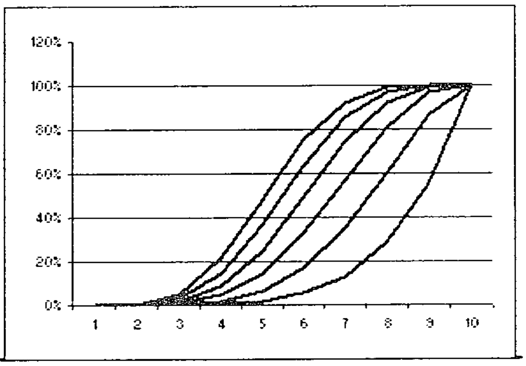


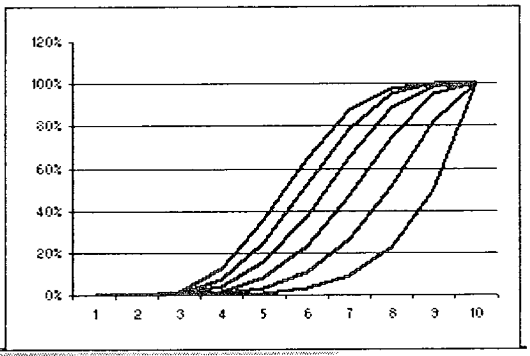


Beta Shape Factors											
Alpha	Beta	1	2	3	4	5	6	7	8	9	10
4	1	0%	0%	0%	1%	4%	10%	20%	37%	62%	100%
4	2	0%	0%	1%	5%	13%	26%	46%	69%	90%	100%
4	3	0%	0%	2%	10%	25%	45%	68%	87%	98%	100%
4	4	0%	0%	5%	17%	38%	62%	83%	95%	100%	100%
4	5	0%	1%	8%	26%	51%	75%	91%	98%	100%	100%
4	6	0%	1%	12%	35%	63%	84%	96%	99%	100%	100%
5	1	0%	0%	0%	0%	2%	5%	13%	28%	55%	100%
5	2	0%	0%	0%	2%	7%	17%	35%	60%	86%	100%
5	3	0%	0%	1%	5%	15%	33%	57%	81%	97%	100%
5	4	0%	0%	2%	9%	25%	49%	74%	92%	99%	100%
5	5	0%	0%	3%	14%	37%	63%	86%	97%	100%	100%
5	6	0%	0%	5%	21%	48%	75%	92%	99%	100%	100%
6	1	0%	0%	0%	0%	1%	3%	9%	22%	49%	100%
6	2	0%	0%	0%	1%	3%	11%	26%	52%	82%	100%
6	3	0%	0%	0%	2%	8%	23%	47%	75%	95%	100%
6	4	0%	0%	1%	4%	16%	37%	65%	88%	99%	100%
6	5	0%	0%	1%	8%	25%	52%	79%	95%	100%	100%
6	6	0%	0%	2%	12%	35%	65%	88%	98%	100%	100%

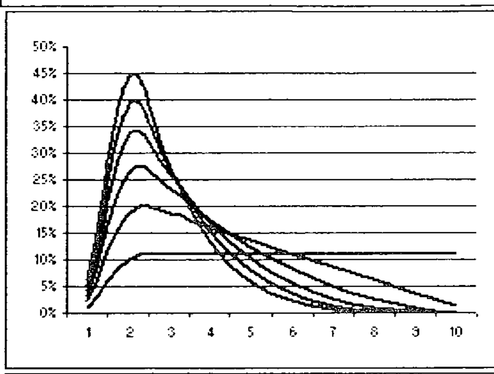
Cumulative



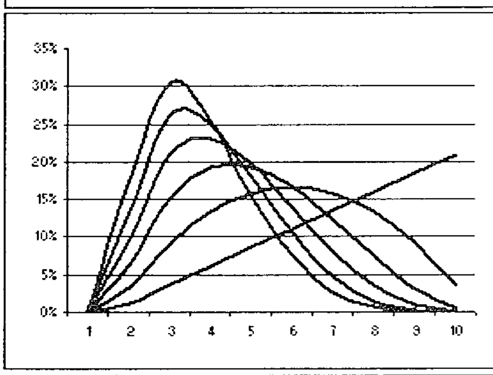




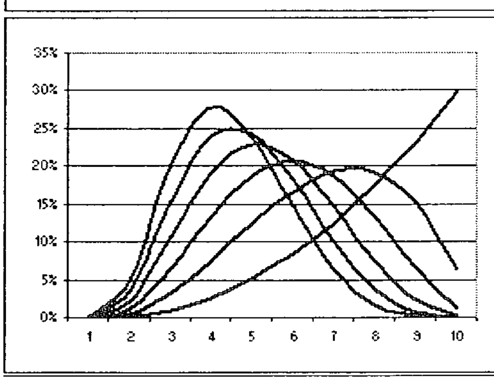
Beta Shape Factors		Period									
Alpha	Beta	1	2	3	4	5	6	7	8	9	10
1	1	1%	10%	11%	11%	11%	11%	11%	11%	11%	11%
1	2	2%	19%	19%	16%	14%	11%	9%	6%	4%	1%
1	3	3%	26%	23%	17%	12%	8%	5%	3%	1%	0%
1	4	4%	33%	26%	17%	10%	6%	3%	1%	0%	0%
1	5	5%	39%	27%	15%	8%	4%	1%	0%	0%	0%
1	6	6%	44%	27%	13%	6%	2%	1%	0%	0%	0%



Alpha	Beta	1	2	3	4	5	6	7	8	9	10
2	1	0%	1%	4%	6%	9%	11%	14%	16%	19%	21%
2	2	0%	3%	9%	13%	16%	17%	16%	13%	9%	3%
2	3	0%	6%	15%	19%	19%	17%	12%	7%	3%	1%
2	4	0%	10%	21%	23%	20%	14%	8%	4%	1%	0%
2	5	0%	13%	26%	25%	18%	11%	5%	2%	0%	0%
2	6	0%	18%	31%	25%	16%	7%	3%	1%	0%	0%



Alpha	Beta	1	2	3	4	5	6	7	8	9	10
3	1	0%	0%	1%	3%	5%	8%	12%	17%	23%	30%
3	2	0%	1%	3%	7%	12%	17%	19%	19%	15%	6%
3	3	0%	1%	6%	13%	19%	21%	19%	13%	6%	1%
3	4	0%	2%	11%	19%	23%	21%	15%	8%	2%	0%
3	5	0%	3%	15%	24%	24%	18%	10%	4%	1%	0%
3	6	0%	5%	20%	28%	24%	15%	6%	2%	0%	0%



Beta Shape Factors		Period									
Alpha	Beta	1	2	3	4	5	6	7	8	9	10
4	1	0%	0%	0%	1%	3%	6%	10%	17%	26%	38%
4	2	0%	0%	1%	4%	8%	14%	20%	23%	21%	10%
4	3	0%	0%	2%	8%	15%	21%	23%	19%	11%	2%
4	4	0%	0%	4%	13%	21%	24%	21%	13%	4%	0%
4	5	0%	1%	7%	18%	25%	24%	16%	7%	2%	0%
4	6	0%	1%	11%	23%	28%	22%	11%	4%	1%	0%
5	1	0%	0%	0%	0%	1%	4%	8%	15%	27%	45%
5	2	0%	0%	0%	2%	5%	11%	18%	25%	26%	14%
5	3	0%	0%	1%	4%	10%	18%	24%	24%	15%	3%
5	4	0%	0%	2%	7%	16%	24%	25%	18%	7%	1%
5	5	0%	0%	3%	11%	22%	27%	22%	11%	3%	0%
5	6	0%	0%	5%	16%	27%	27%	17%	7%	1%	0%
6	1	0%	0%	0%	0%	1%	2%	6%	13%	27%	51%
6	2	0%	0%	0%	1%	3%	7%	16%	25%	31%	18%
6	3	0%	0%	0%	2%	6%	15%	24%	28%	20%	5%
6	4	0%	0%	1%	4%	11%	22%	28%	23%	11%	1%
6	5	0%	0%	1%	7%	17%	27%	27%	16%	5%	0%
6	6	0%	0%	2%	10%	23%	29%	23%	10%	2%	0%