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PROJECT TRACKING TO IMPROVE LABOR PRODUCTIVITY FOR MECHANICAL, HVAC, AND SHEET METAL CONTRACTORS

THE EARNED VALUE APPROACH

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THE EARNED VALUE APPROACH

2010 Prepared By:

Awad S. Hanna, Ph.D., P.E., Professor

Chair, Construction Engineering & Management Program

Department of Civil and Environmental Engineering,

University of Wisconsin – Madison

President, Hanna Consulting Group, Inc.

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The Earned Value spreadsheet referenced in this book is available for download as an additional resource at **http://www.newhorizonsfoundation.org/proj_tracking/EV_Spreadsheet.xls**

About the Author

Awad S. Hanna is a professor and chair of the construction engineering and management program at the University of Wisconsin – Madison, Department of Civil and Environmental Engineering. Dr. Hanna holds M.S. and Ph.D. degrees from Penn State University and is a Registered Professional Engineer in the United States and Canada. An active construction practitioner, educator, and researcher for over 30 years, he has taught construction management courses at Penn State University, Memorial University in Canada, and the University of Wisconsin – Madison.

Dr. Hanna has conducted several research projects for the New Horizons Foundation including landmark studies on the cumulative impact of change orders on sheet metal contractors' labor productivity, schedule compression and acceleration, and preconstruction planning. Dr. Hanna has also conducted research for other national organizations including the Electrical Contracting Foundation, Mechanical Contracting Foundation, Construction Users Roundtable (CURT), and the Construction Industry Institute (CII). In 2006, he received the prestigious CII Outstanding Researcher Award. Dr. Hanna has taught more than 300 successful seminars and workshops in more than 35 states on topics such as change order impacts, project scheduling, earned value analysis, labor productivity, construction delay claims, schedule compression, and preconstruction planning.

Dr. Hanna is also a national consultant representing many contractors to recover productivity losses related to change orders, acceleration and compression, delay, and trade stacking.

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Richard Rivera (Key Air Conditioning Contractors, Inc.)

Ron Rodgers

Howard Stine (Charles E. Jarrell Contracting Co.)

Steven L. Streimer, Vice President (Streimer Sheet Metal Works, Inc.)

Susie Young (Key Air Conditioning Contractors, Inc.)

Abstract

Project managers frequently lack sufficient information to accurately determine the status of their projects, due to uncertainties in the original baseline values and disorganized cost and schedule tracking practices. With labor costs and labor productivity being the highest risk in mechanical, HVAC, and sheet metal contracting, an effective project tracking system needs to be employed. This book first introduces a simplified approach to using earned value as an effective project tracking tool and then describes the comprehensive Earned Value Tracking System. This system allows mechanical, HVAC, and sheet metal contractors to monitor the construction progress, forecast the final manhours and completion date for the project, uncover problems occurring on site, and therefore to respond accordingly early in the project. Three case studies from mechanical, HVAC, and sheet metal contracting are described, along with their results, to supplement the application of the Earned Value Tracking System. In the case studies, several progress reports were used for the Earned Value Tracking System to benchmark the manpower loading curves, Hanna's control points, S-curves, performance factor profiles, total estimated weeks to complete work, and manhour forecasts at project completion, among others. The Earned Value Tracking System proved to be very useful and enabled project management to accurately and confidently predict the cost (based on labor) and schedule outcomes of a project as early as 20% complete.

1 INTRODUCTION AND EARNED VALUE ANALYSIS

1.1 Introduction

Project managers frequently do not have enough information to accurately determine the status of their projects, due to uncertainties in the original baseline values and disorganized cost and schedule tracking practices. Earned value is a project management technique used for objectively measuring project progress by comparing the work completed in the field (used to compute earned hours) against the actual hours for cost performance and against the budgeted hours for schedule performance (Wikipedia, 2008). Earned value project tracking allows mechanical, HVAC, and sheet metal contractors to track construction progress and overall physical percent (%) complete for a combination of unlike work tasks, thereby providing a more accurate total project view and forecast. Project tracking can also be an essential tool in reversing a worrisome trend in the construction industry over the last 40 years. Studies have shown that, over this time period, labor productivity has steadily decreased on construction projects despite advancements in project design, standardization, and technology (Teicholz, 2004). With an integrated project control system of the budget, work scope, schedule, and actual costs, a contractor can increase project profitability through the early recognition of possible cost or time overruns. Early recognition by project managers of potential overruns allows for a proactive response on site by the implementation of corrective measures.

Mechanical, HVAC, and sheet metal trades rely heavily on labor to complete their work. Labor costs typically represent 40% of a mechanical, HVAC, or sheet metal project budget, thereby making labor productivity the single most important issue for mechanical, HVAC, and sheet metal contractors (Hanna, 2004). Additionally, these trades typically have a high peak labor, meaning that any productivity issue on site would be significantly magnified if it occurred during the project peak. Lastly, mechanical, HVAC, and sheet metal work is a connected and follow-up trade in that their work is dependent on all other related work completed on the project, as well as all work that took place prior to their arrival. It is for these reasons that the labor productivity should be tracked using earned value for every mechanical, HVAC, and sheet metal project.

Though many systems for project tracking exist, many are cost based and fail to accurately measure key project characteristics such as labor productivity. Also, none have been directly tailored for the unique attributes and specific characteristics of mechanical, HVAC, and sheet metal construction. This book presents the most effective project tracking method for collecting and monitoring cost (based on labor) and schedule data to accurately evaluate a project's progress. This research aimed to minimize the effort needed by the contractor to implement these techniques. This book will succeed where the rest of the available earned value literature falls short: it will present a clear, detailed, and simplified explanation of the earned value technique and its implementation in actual projects.

The Earned Value spreadsheet referenced in this book is available for download as an additional resource at **http://www.newhorizonsfoundation.org/proj_tracking/EV_Spreadsheet.xls**

1.1.1 Why Project Tracking Is Essential

The purpose of this research is to provide a guideline for how the earned value technique can best be used in mechanical, HVAC, and sheet metal construction to maximize contractor performance. This is accomplished by presenting a set of guidelines for the implementation of the Earned Value Tracking System, followed by three case studies and their results to further supplement the guidelines. The earned value guidelines and case studies contain and address the following information:

- Investigation into the use and applicability of earned value analysis in the mechanical, HVAC, and sheet metal construction industry. The investigation includes standard terminology and methodology for the development of work breakdown structures (WBS) and use of earned value analysis;
- Determining at what percent completion of a project that earned value analysis can accurately (within 5 to 10%) predict the final project outcomes in terms of manhours and completion time/date for that project;
- Investigation into the accuracy and conditions for the use of subjective evaluation of percent complete versus actual field measurement (quantity installed) at the activity level;
- Investigation into the accuracy and conditions for the use of the binary system of measurement including the 0-100% and 0-50-100% complete methods at the activity level;
- Analysis to determine the accuracy and predictability of manhour forecasts and schedule completion forecasts for use as early warning signs for possible cost and/or schedule overruns;
- Evaluation of the use of performance factors (PF) as a prediction tool for forecasting project outcome as well as looking for trends in performance factor values;
- Testing of the accuracy and applicability of control points for project progress benchmarking and use as an early warning system to allow contractors to react effectively to adverse project scenarios;
- Determining how change orders and change order work can be effectively tracked, and how change orders affect activity and overall project productivity; and
- Analysis to determine optimal journeyman-to-apprenticeship ratios and foreman-to-apprentice/journeyman ratios and how they affect labor productivity for mechanical, HVAC, and sheet metal construction.

The case studies that were monitored for this research are the first to document the accuracy of the Earned Value Tracking System along with a comparison of alternative project tracking methods. The four activity output tracking methods that were used are the quantity installed, the subjective evaluation, the 0-50-100% complete, and the 0-100% complete methods. This research covered a variety of projects that exhibited different characteristics of project type, size, and complexity. This allowed many different issues, both management based and construction based, to be revealed.

The guidelines for implementing the Earned Value Tracking System were developed from previous research as well as results and lessons learned from the case study projects. Interviews were conducted with current industry professionals, both those who employ some sort of project tracking system, as well as those who only wish to employ a better system than they currently use. This information was used when developing the earned value guidelines and principles detailed in this research. Additionally, the implementation of the tracking system on several case studies, from the start of the project to the finish, was guided by this information. This book contains three case study projects. Appendix A includes descriptions and definitions of the key terminology used in this book.

1.1.2 Earned Value Importance

The importance of earned value in construction as a tool for project tracking is evident based on the actual use on projects. On most projects (99% of them) that are not major systems acquisitions by government entities, the risks of cost growth are not on the buyers or the owners, but rather on the performers – the project managers – because they have elected to contract with a lump sum, or firm-fixed-price type contract. Therefore, there is vast potential in the universal employment of a simple, broad-based application of the earned value concept. Earned value is important in assisting the contractor with the following items:

- Determining physical project percent complete;
- Determining the project performance factor (or project productivity);
- Determining which activities are working above planned productivity and which are working below planned productivity;
- Forecasting, early in the project duration, how many manhours will be required to complete the project; and
- Forecasting, early in the project duration, the completion date for the project.

In order to effectively use earned value data, a contractor must retain project data for future use. Too often, in the haste to finish one project and get on with another, or the effort to minimize overall costs, the opportunity to systematically keep records of what it took to complete a given project is often lost. Projects are completed, the final profit or loss position is determined, and then the historical records are discarded or vanish with the workforce. A wise, more strategic long-range approach would suggest that records of actual project performance be maintained, including records on both cost and schedule performance. Cost data would be classified in a number of ways, including by functional organization, the project WBS, element of cost, and non-recurring versus recurring costs (Fleming and Koppelman, 1994).

Additionally, earned value data for a project can greatly assist a contractor when attempting to prove construction inefficiency as a result of the cumulative impact of change orders or other owner or subcontractor factors. This data is very effective for the "measured mile" method, which is the most desirable method because courts look with disfavor on inefficiency claims based upon the total cost approach (actual cost less bid estimate equals compensable overrun). In the measured mile method, a comparison is made between the unit productivity costs in an unimpeded time period or area to that achieved in the claimed disrupted time period or area. With this said, it is important to note that it is typically assumed that the first and last 10% of total work-hours in a project are not valid because they are not representative of expected or average sustained labor productivity. Lastly, when using the measured mile method, the sample size must also be reasonable, meaning that, for example, using only 2% of the project work as the "unimpacted" time period will not suffice (Zink, 1986).

1.1.3 Past Research

Prior to the development of any type of earned value, it has been the industry standard to track only a budgeted plan versus actual expenditures either in dollars or in hours. This type of tracking has its faults. It has no ability to determine the amount of work completed or whether there will be any scheduling issues. It can only show whether expenses have been greater than the amount that had been budgeted for that period.

While earned value has been in existence for more than 40 years, no research has been exclusively completed for the mechanical, HVAC, and sheet metal trades. Additionally, very few, if any, past research on earned value has used actual case studies to determine the accuracy of the forecasted obtained from earned value project tracking. Department of Defense (DoD) research suggests that project forecasting in general is meaningful after as little as 15% of the project is completed. Another study states that the cost performance index or project performance factor has been proven, by using over 700 DoD projects, to stabilize at the 20 to 30% completion point of a project (DoD, 1998). These ideas will be tested in this research. Lastly, no past studies have attempted to determine which methods of determining percent complete are the most accurate. This study does just that.

1.1.4 Tracking Units

It is essential that the project labor be broken down and tracked by manhours rather than by dollars. Several motives are behind using manhours as opposed to dollars as the unit for analysis. Labor is regarded as the largest risk in construction. In mechanical, HVAC, and sheet metal construction, 33% to 50% of a project's total contracted budget constitutes labor costs (Hanna, 2004). If a budget is overrun, typically it is due to the labor hours. Therefore, if it is possible to control manhour usage more productively, then that risk is effectively lowered.

When dollars are used, many other items are inherently included in the performance values. Each dollar includes a portion that corresponds to labor, equipment, material, and overhead, etc. Cost is not comparable over different geographic regions. Both labor rates and material costs can vary significantly. In addition, costs are often not completely known until the billing is processed and recorded. Therefore, the tracking system is not constantly up to date. The whole purpose of earned value is to have current data that will show an accurate project view.

Additionally, many contractors front load their bids (put higher unit prices on work that will be done earlier in the project) so that they do not have to finance as much of the project themselves. Because of this, many contractors will look at dollars received and divide that number by the total contract value to track their work progress. This is a very dangerous practice and can often lead the contractor to think the project is in a good position financially, when actually it is not. In this situation, a contractor could have received 50% of the dollars denoted in the contract, and therefore assume the project is 50% complete, while only 40% of the work is actually completed due to front loading of the bid. This sort of project view and tracking can lead to disastrous results from a manhour and schedule perspective later in the project when this discrepancy is realized.

The last motive behind using manhours instead of dollars is that there are situations in which a contractor can make money on a project and not end up within the contract's manhour estimate. This can occur when the contractor purchases the materials for construction and includes a cost markup, when the cumulative wage rate that was bid was higher than the wage rate that was actually intended to be used on the project, or through the pricing of change orders. These are not the only possible scenarios in which a contractor can make money when not meeting manhour expectations. Still, it is almost guaranteed that a contractor will see a profit if the contractor is able to come in under the contract manhours for the project.

Overall, tracking by dollars is a seriously flawed method because it is impossible to quantify the dollar value of work put in place at any point in time. Assigning an appropriate dollar value for the given work is very difficult. Second, many payments from the owner do not occur until weeks after the work has been put in place. Therefore, if money earned to date is used and can be accurately determined, then this project status would be the status of the project at an earlier point. This would not be of any value to the project management staff.

1.1.5 Project Characteristics

This research is limited to typical construction conducted by mechanical, HVAC, and sheet metal contractors. The case studies specifically are from numerous contractors and locations, and the projects themselves represent all facets of the mechanical, HVAC, and sheet metal construction industry. The guidelines described throughout this book are the results of published literature on the topic, interviews and site visits with mechanical, HVAC, and sheet metal contractors that employ some sort of earned value project control in their projects, as well as the knowledge and opinions of the research team. There was no restriction as to the project delivery method that needed to be used for the case studies. However, it turned out that the projects studied were design-bid-build construction, with the exception of one project that was design-build.

The delivery methods employed by the participating contractors included fixed price and guaranteed maximum price. Still, earned value methods are effective for determining an overall project view for different delivery methods, such as time and materials, cost plus fixed fee, and other methods. For that reason, there is no requirement for the type of contract needed to employ this system; rather this research represents only the two types that were previously mentioned. Also, due to the limited number of projects studied in this research, the Earned Value Tracking System was tested only on projects between 2,000 manhours and 25,000 manhours. Therefore, the results are inclusive of those manhour boundaries. However, earned value can be effectively used to track construction progress on a project of any size.

It is especially important to detail the type of hours on the projects tracked. Indirect labor hours or overhead hours are usually earned as soon as they are expended and typically have no relation to work being completed in the field. In addition, including overhead hours in the project tracking can alter the real project view. Oftentimes, many overhead hours are expended on a project in the form of office employees' and managers' salaries while no work is being achieved in the field. Productivity is determined by dividing work that is earned or completed on an activity by the actual work spent on that activity. Therefore, the productivity of that particular activity in the field should not be affected by how many secretaries are working in the office. For those reasons, this research is limited to direct labor hours.

Furthermore, it is understood that different wage rates can have an impact on the successful outcome of a project. However, it is out of the scope of this research to determine the impact of unscheduled overtime or the addition of shifts to increase the manpower level per period on the project. Management must take this crew cost information into consideration. However, this research will look into the differing performance factors associated with different crew mixes.

1.1.6 Introduction Summary

Most previous publications have dealt with earned value as an owner's way of monitoring a contractor. In addition, most placed the responsibility for earned value management with the financial department, rather than with actual project management. Still, the system is perfectly adaptable to be used as a control system for a contractor. There is not a significant amount of literature that has described implementation by contractors. In addition, most of the tracking that was done was measured monetarily. When developing an earned value system for contractors, it may be more beneficial and simpler to measure costs by direct labor hours.

The existing literature on earned value is extensive although somewhat limited when applied to actual construction labor. An earned value management system can be directly tailored to mechanical, HVAC, and sheet metal construction for the purpose of improving mechanical, HVAC, and sheet metal project control. The reasons are listed below:

- Mechanical, HVAC, and sheet metal construction is a labor-intensive industry in which the profit margin is determined largely by the labor performance in the field. Therefore, tracking labor is crucial to understanding the performance of field personnel.
- The traditional use of earned value by owners requires understanding the breakdown of work of all types of construction across all contractors employed. Tailoring the system to mechanical, HVAC, and sheet metal construction allows the work breakdown to be much simpler than that of the general contractor or owner, allowing for far more indicative and accurate percent complete determinations.

However, in proceeding to implementing earned value in the construction industry, the earned value analysis must address the common reasons that some contractors currently do not use earned value. Some of these include

- The lack of comprehension/familiarity of how the technique works;
- The perception that earned value is overly complicated, since it has never been presented in a simple, concise form such as in this book;
- The view that use of the earned value tool is too time consuming (our proposed subjective evaluation method neutralizes this concern);
- The lack of performance factor (productivity) predictability;
- Unsuccessful prior experience in the use of other techniques (Association for Advancement of Cost Engineering (AACE) sources).

This book will help dispel many of these ideas and show why earned value is the best project-tracking tool available to mechanical, HVAC, and sheet metal contractors. Additionally, it will show how earned value can be easily used to effectively track work for all trades in the construction industry.

1.2 Earned Value Analysis

1.2.1 Earned Value Fundamentals

Throughout this book, the term "earned value" has been used extensively with only some information as to what "earned value" actually entails. Earned value is equal to the base or estimated (budgeted) hours for an activity multiplied by the percent complete for that activity. This is Equation 1 shown below, and it should be used when the percent complete is measured by subjective judgment. Earned value can also be found using quantities, in which case the earned value is equal to the quantity installed for an activity multiplied by the estimated unit rate (production rate) for that activity. This is Equation 2 shown below, and it should be used when the percent complete is determined by actually measuring work installed.

(1) $EarnedValue = BaseHours \times PercentComplete$

(2) $EarnedValue = QuantityInstalled \times EstimatedUnitRate$

(Hanna, 2004)

Earned value is tied to the budget and the physical work accomplished on a project. Earned value provides a value (in this case "value" has units of manhours) for the amount of work physically completed on a job task that can be directly compared to the budgeted value allocated for that task, irrespective of whether the budgeted value is a good estimate. When a task is 100% complete or the quantity has been completely installed, only then will a task's earned hours be equal to the total budgeted hours for that task. It is important to note that the earned hours for an activity can never and should never exceed the budgeted hours for that activity. The budgeted hours for an activity can be adjusted if it is determined that the original budget is incorrect, but the earned hours can never exceed this value. In addition, the issue of rework is worth mentioning. Where rework is needed, earned hours will not increase until the physical work has exceeded that which required rework.

Explanation of earned value using an example can be very helpful in understanding it. Assume a job activity has a labor budget of 1,000 manhours. Therefore, if this is a quality estimate and the work is performed at planned productivity, the task should be able to be completed in 1,000 manhours. Now at a point in time between the start and finish of work on the project activity, if, for example, 750 manhours have been expended but it is clear that the task is only 50% complete (50% of quantity is installed), then only 500 manhours have been earned. The 500 manhours that have been earned are not dependant on the 750 manhours that have been expended, but rather they are a representation of how many hours should have been used to date in order to install the amount of work that has been completed. At this point in time in the example, management may see several different things occurring. About the work performance to date, management may say one or more of the following: the labor has been only 66% efficient, from the number of hours earned (500) divided by the number of hours expended (750); the estimate was inaccurate; outside forces hampered work efficiency, etc. (Hanna and Kleckner, 2005). About cost and schedule implications, management may say that the job activity is going to slip in the schedule and/or exceed the budgeted cost. In addition, management may forecast that the job task will require a total of 1,500 manhours to complete (number of hours expended (750) divided by the percent complete (50%). Upon inspection with the use of earned value, there are many different observations management can analyze as to the progress of a project. In turn, management can then take a proactive approach to assuring a successful outcome on the project. The previous example demonstrates the basics of what earned value actually represents and briefly shows how it can be applied in a project setting. The following material will expand upon this introduction to more fully develop the tools used in the Earned Value Tracking System. The values obtained in the previous example use formulas that will be introduced in the following sections.

1.2.2 Simplified Earned Value Project Tracking

Expanding on the example described in the section above, a simple earned value spreadsheet contains the activities, budgeted hours, percent completes, earned hours, actual hours, and performance factors. An example project with this information shown can be seen in Table 1-1. The percent complete (Column 3) for each activity can be determined in a number of ways, all of which will be described later in this section.

(1) Activity	(2) Budgeted Hours	(3) Percent Complete	(4) Earned Hours	(5) Actual Hours	(6) Activity Performance Factor
Ductwork 1st Floor Area A	973	78%	759	867	0.88
Ductwork 1st Floor Area B	821	59%	484	579	0.84
Ductwork 2nd Floor Area A	325	30%	98	65	1.50
Ductwork 2nd Floor Area B	151	15%	23	15	1.51
Piping 1st Floor Area A	383	100%	383	366	1.05
Piping 1st Floor Area B	574	40%	230	248	0.93
Piping 2nd Floor Area A	456	5%	23	23	0.99
Piping 2nd Floor Area B	195	0%	0	0	N/A
AHU on 2nd Floor	160	35%	56	65	0.86
Grilles/Flex	240	25%	60	55	1.09
VAVs	38	50%	19	24	0.79
Linear Diffusers 1st Floor	75	95%	71	85	0.84
Linear Diffusers 2nd Floor	58	0%	0	0	N/A
Misc. Metal Install	20	25%	5	5	1.00
Set Equipment	54	30%	16	12	1.35
Project Totals	4,523	49%	2,226	2,409	0.92

Table 1-1: *Simplified Earned Value Example*

Again, the earned hours (Column 4) are calculated by taking the budgeted hours (Column 2) multiplied by the percent complete (Column 3), while the performance factor (Column 6) is calculated by taking the earned hours (Column 4) divided by the actual hours (Column 5). This project is currently 49% complete as a whole (determined by taking total project earned hours divided by total project budgeted hours), and work is progressing at 92% of planned productivity (based on 0.92 project performance factor value). Therefore, work on site has been less productive than planned. A value of 1.0 is exactly planned productivity. The performance factor or work efficiency can be seen for every activity on the project to determine which activities are working above planned productivity and which are working below planned productivity. For the project shown in Table 1-1, the project manager should look at Column 6 to explain performance factors that are lower than 1.0. It is very clear that the ductwork installation on the 1st floor is underperforming. Management should be able to rectify the performance on the 1st floor ductwork installation before it is too late.

The following are the general steps for using the simplified Earned Value Tracking System:

Step 1: Divide the job into activities.

- This process is called work breakdown structure (WBS). Examples of WBS will be presented in the sections that follow.
- Activities should be developed according to the type of work (e.g., ductwork, piping work, etc.) or according to the area (Area A, Area B, etc.).
- An activity should not represent more than 5 to 10% of the total project hours.

Step 2: Describe the activities.

- The description should be brief, accurate, and understood by all levels of management.

Step 3: Enter estimated hours for each activity.

- Estimated hours can be taken directly from the estimate.
- Hours should be estimated using judgment and experience.
- Hours can be calculated as Estimated Hours = (Estimated Quantity) × (Production Rate) where the production rate can be estimated from company records or taken from a standard estimating manual.

Step 4: Subjectively estimate activity percent complete.

- The estimate should be completed by two management levels such as a foreman and project manager (or superintendent).
- The estimate should be completed at regular intervals. Every two weeks is typical but it can be done every month or every week, depending on job size and duration.

1.2.3 Earned Value Tracking System Description

Any earned value project control system starts in the project preplanning stage. This is when the contractor reviews the design and engineering, puts together the WBS and the estimate, and develops the project construction schedule. From this point the contractor can plan out how many workers will be needed at any point in the project to meet scheduling deadlines. This is called the manpower loading curve. All these activities are important to the successful use of an earned value system. Finally, the earned value spreadsheet, which is designed to control project cost and schedule, will be introduced along with a section describing different approaches to determine the physical percent complete for an activity or project.

1.2.4 Work Breakdown Structures

A WBS is a tool used by project managers when defining and managing a project. The WBS defines the entire scope of the project's contracted work along with identifying the critical milestones a project may have throughout its duration. It provides a formal structure to breaking down the project into successively smaller entities to ensure that all project requirements are fulfilled. A mechanical, HVAC, or sheet metal contractor would look at each category of work for a project and determine which categories would require mechanical, HVAC, or sheet metal construction and expand those to a point where the mechanical, HVAC, or sheet metal subcontract requirements are completely fulfilled. An example of a WBS for a mechanical, HVAC, or sheet metal contractor can be seen in Figure 1-1. This WBS includes only the fieldwork breakdown since it would include "Shop Fabrication" as another heading if the shop labor were included.

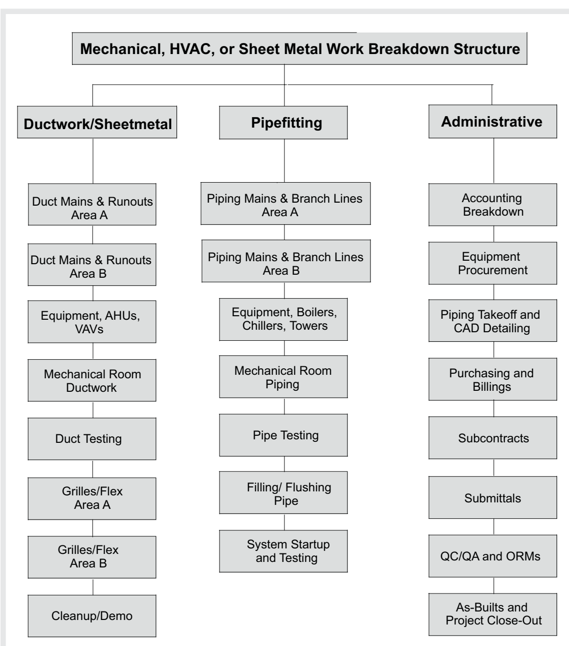

Figure 1-1: *Mechanical, HVAC, or Sheet Metal WBS Example*

WBSs can come in many forms and varieties. Therefore, it is important to show a few examples. Shown in Figure 1-2 is another WBS example for heating, ventilation, and air conditioning (HVAC) and sheet metal work. Again, this breakdown includes only the fieldwork since another heading titled "Shop Fabrication" would be included if all work were detailed. The shop fabrication would be completed to coincide with the field installation schedule.

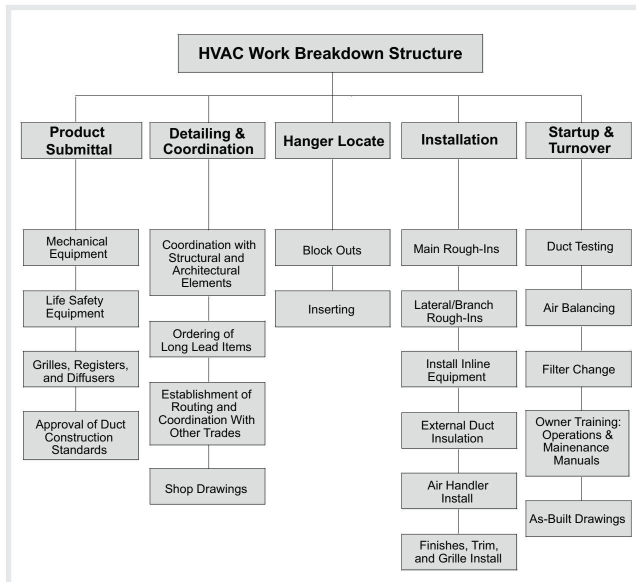

Figure 1-2: *HVAC WBS Example*

Finally, a third WBS structure example is shown in Figure 1-3 for plumbing work.

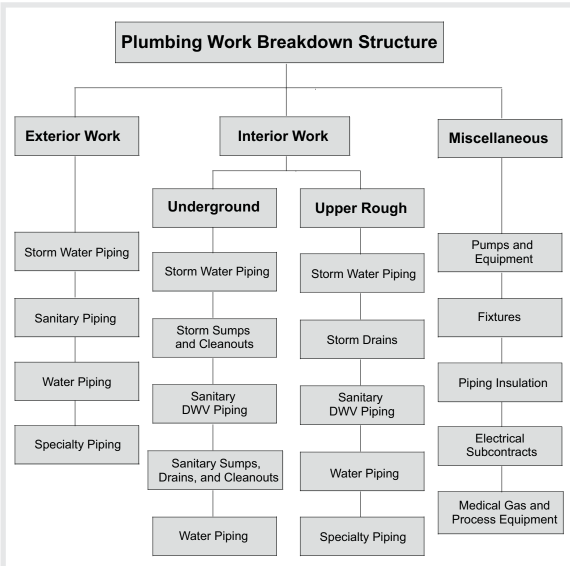

Figure 1-3: *Plumbing WBS Example (Hanna, 2008)*

1.2.5 Activity Definition

Often, activity definition is included in sections dealing with schedule development. Still, it is imperative to show the interrelationship between activities and the WBS. An activity is a unique unit of the project that can be described within prescribed limits of time (Hanna, 2004). It is a task that one or more persons finish in an effort to complete a work package. A typical schedule development process, after the creation of a WBS, would include the development of an activity list, followed by creating activity logic dependencies and estimating activity duration in an effort to create a schedule diagram.

In any case, activities are important no matter if they are shown in the WBS or whether they are first shown in the schedule, and there are a few key elements to the definition of activities (Phelps, 2004).

- **Short duration**. Activities should be short so progress can be readily seen. If an activity is short and discrete, it is far easier to make a judgment as to the physical percent complete of that activity. A guideline would be to try to keep most activities between 1 and 15 days required for completion based on the size or number of crews working on that activity. Another way to look at it would be to try to keep each activity at or below 80 manhours if it is to be completed by one worker.

- **Representative**. Activities should represent how the work is built. For example, sheet metal contractors may have one activity for the several components of installing ductwork. This activity may include the detailing/coordination work, installing the hangers, rough-in, and finish/trim work. On the other hand, a sheet metal contractor may separate it into other items since the activity is installed over a long period of time with distinct phases. Phased activities are further discussed in Section 1.2.12.

- **Understandable**. Each activity must be completely understood, not only by the project manager but also by the field personnel who will be completing the activity. If the field personnel do not understand every component included in the task, it will be virtually impossible to determine when the activity has been fully completed.

1.2.6 Guidelines For Construction With WBS

In some instances in mechanical, HVAC, and sheet metal construction, a contractor may have a separate estimating department, independent of the project team, that will be managing the construction. In this case, the estimator should meet several times with the project manager on the project and with the superintendent or foreman if needed. At this meeting the construction team members can voice their opinions as to how they believe the project needs to be constructed and managed. This will in turn impact how the estimator takes off the project.

Together the project team members can break down the construction into as many or as few work packages as they see fit to accurately evaluate the project. The determination of how many breakdowns to track is often referenced to Pareto's Principle that ***80% of a project's result comes from 20% of the items required for the project.*** Therefore it is important to identify the items with the greatest potential to impact final project manhours and track those.

These more extensive breakdowns provide a contractor with the simplest view into tracking project progress. When utilizing a project control system like that of earned value, the breakdown is of the utmost importance. The more breakdowns there are, the fewer manhours are associated with each breakdown. This can be beneficial if the person tracking the job makes a mistake and is 50% off in a percent complete determination; this error will be negligible when spread out over the entire project. For example, if one breakdown represents 20% of the manhours in a project and the person tracking the project is 50% off in his or her determination of percent complete, this corresponds to a 10% error in the overall project percent complete determination. However, if the breakdown represents only 5% of the total manhours, then a 50% error in percent complete determination for that breakdown would correspond to only a 2.5% error in the project percent complete. For that reason, it is generally suggested, for most cases, that breakdowns at the level used for tracking represent no more than 5 to 10% of the total manhours of a project.

1.2.7 Manpower Loading

Another component of an earned value tracking system is the manpower loading curves. These curves display graphically how the manpower is being expended on a project. The relationship is between time and manpower in hours or number of men. This information can be very telling. A manpower loading curve for a project with a good outcome has a typical shape for mechanical, HVAC, and sheet metal construction. The three stages of manpower loading are the buildup of manpower, the peak, and the rundown. A sample manpower loading diagram is depicted in Figure 1-4, which shows data collected from previous studies indicating the typical manpower loading curve for sheet metal construction, along with the industry average (Hanna & Sullivan, 2004). Mechanical contractors are normally among the last contractors responsible for construction on a project. However, their work is required to be put in place prior to the electrical trades coming in to do their work. Therefore, their buildup phase is a sharply increasing curve at the outset as they ramp up the manpower to reach the manpower peak. Then, when work is approaching overall substantial completion, there is a sharp rundown of project manpower. If a project's manpower is falling below the planned manpower early in the project, it is easy to see that the manpower will need to ramp up later in the project, most likely to a higher level than originally planned, in an effort to finish the project on time. This can have multiple repercussions that can increase costs and lower productivity on the project. Some of these include extensive use of overtime, shift work, adding workers ("over-manning"), and the stacking of trades.

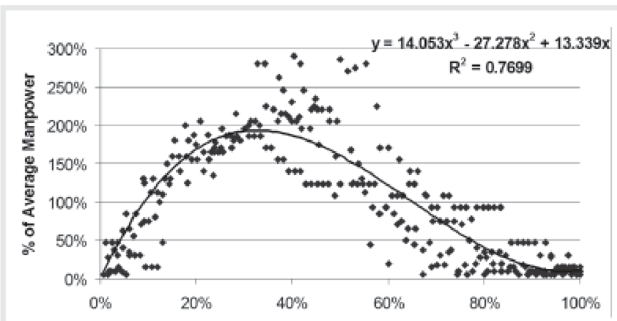

Figure 1-4: *Manpower Loading Curve (Hanna & Sullivan, 2004)*

1.2.8 Measurement Of Output

There are several methods of measuring work output or, stated another way, determining the physical percent complete for an activity or work package. Correctly determining percent complete for activities in a project is of fundamental importance to the accuracy of the Earned Value Tracking System. Measuring the work progress can be easier when using one method over another for certain types of work and situations. The following sections describe four different approaches for measuring output. With each approach to percent complete measurement are guidelines describing situations when it would be advantageous to use each particular method. The four approaches are quantity installed as measured, subjective evaluation, binary approach, and partial complete method.

The projects that were tracked for this research used four methods of project tracking. These four are the quantity installed method, the subjective evaluation or subjective percent complete method, the 0-50-100% complete method, and the 0-100% complete method. Additionally, the partial complete method was integrated into the quantity installed and subjective evaluation methods so that these methods of tracking were as accurate as possible. The accuracy of each of these tracking methods on actual mechanical, HVAC, or sheet metal construction projects is described in detail in Part 2 of this book.

1.2.9 Quantity Installed As Measured

This method is often used with mechanical construction. It can be used with any type of work that is easily measurable and is repetitive in its nature. Percent complete with this method is determined by taking the amount of quantity installed and dividing it by the quantity that is in the estimate or budget (*Quantity Installed/Budgeted Quantity*). This value is then multiplied by the budgeted hours, also from the estimate, to find the earned value for that activity.

Obvious examples in mechanical construction would be ductwork installation, equipment installation, and pipe installation, along with several others. Ductwork installation of various sizes can easily be measured in the field by units of length or measured via invoices and paper records. For example, if 5,000 linear feet of a particular size of ductwork had been delivered on site for a specific task, and 1,000 linear feet of it is currently left, then approximately 80% of it was installed, or the activity is 80% complete. Another possible option would be to physically measure installed quantities in the field. This process has been greatly simplified with the use of laser distance-measuring devices.

The following list summarizes the rules or guidelines when choosing whether to use the quantity installed approach to measure output.

- Use when estimate includes the quantities for each item.
- Use when the work is easily measurable when installed and repetitive in nature.
- Allocate percent complete for each item that is equal to (*Quantity Installed/ Budgeted Quantity*).
- When quantity installed measurement does not seem appropriate, consider subjective evaluation or the partial complete method.

1.2.10 Subjective Evaluation

Subjective evaluation of percent complete is exactly that – subjective. With this approach, management must assign one or more individuals to subjectively place a percent value on the amount of work that has been completed. Typically, the percent complete value for each work package or activity will be out of a full 100% value. This approach requires some guidelines, especially since certain activities may look 90% installed but the last 10% may be the hardest and may take an extended amount of time.

This particular method receives the most criticism because it is subjective. Still, it is one of the easiest to apply, and with well-defined activities or work packages it can be very accurate. One "check" for the system would be to have upper management review the values periodically to make sure more work is not being claimed than is actually occurring.

The following list summarizes the rules or guidelines for the use of subjective evaluation to measure output.

- Establish the WBS to lend itself to subjective evaluation. The WBS needs to be set up with this measurement method in mind so the subjective evaluation is possible and can be evaluated readily.
- Divide the project into at least 20 activities or so the activities represent no more than 5% of the manhours. This should be done so any large error in the subjective evaluation for an activity will have only a small error/impact on the project as a whole.
- Subjectively determine how much of the activity has been completed. Accounting or budget report values should not be used to persuade the subjective values. These values need to be subjectively determined based on the assigned evaluator's visual inspection and experience.
- Subjective values should be between 0% and 100% complete. 0% indicates that no work has been done on the activity and 100% indicates that the activity is fully completed.

- Each person responsible for the subjective evaluation must fully understand what is included in the activity and what represents 100% of the work.
- Subjective evaluations should be conducted by two or more individuals. It is recommended that one of the individuals responsible be the project manager and the other a respected foreman or superintendent on site.

1.2.11 Binary Approach

The binary approach is also sometimes called the "start/finish approach." This is a method of zeros and ones, where zero work is recognized as earned after the activity has started until the project is fully completed, at which time 100% of the work is earned. Many times this approach is expanded to include one or more intermediate points. Most often the system becomes three choices, 0%-50%-100%. With this method, prior to an activity's start, 0% is earned. Upon starting the activity, immediately 50% of the activity's budgeted hours are earned. This overstates the earned work for a period of time, but it then compensates by understating its value because 100% of the work is first earned when the activity has been completed.

This method is primarily used in two cases. The first case for use is when the work breakdowns are so extensive that they all have short enough durations that understating or overstating its percent complete (0% or 100%) by assigning values to the activity's start and completion will not affect the overall percent complete determination of the project. A typical rule of thumb is that the activity size should be between 40 and 80 manhours (Hanna, 2004). The second case for use is when the activities do not have identifiable milestones or junctures where intermediate percentages can be assigned (McConnell, 1985). This is primarily meant for work for which it is difficult to estimate duration.

1.2.12 Partial Complete Method

This method is very similar to the binary approach. The partial complete method, sometimes called the "incremental milestone method," is very useful for sequenced work or when a particular task is completed in a certain fashion every time. It basically takes the 100% value and divides it into subdivisions or milestones as determined by the contractor from experience. This method is beneficial when the subtasks in a task are sequential, or when the task duration is longer than one reporting period (CII, 1988). The long-duration task can be viewed as several milestones that make up the entire task. These milestones are assigned percentages relative to the amount of work they require with respect to the entire task work requirement.

For example, ductwork installation is an instance in which this method can be applied. This activity in its entirety may occur over a long period of time. First, the detailing of the project components and the work is coordinated with other trades and the sheet metal contractor. Then the hangers are installed followed by the ductwork rough-ins. Lastly, the finishes are completed and the work is trimmed to its final component (Streimer, 2007). If the partial complete method for percent complete determination is used, these separate activities, instead of being tracked as separate line items, could be combined if representative intermediate percent complete values were assigned to each activity. A possible percent complete allocation for this example is shown below:

Ductwork Installation	% of Work
Detailing/Coordination	15%
Hanger Installation	15%
Duct Rough-In	50%
Finish and Trim Work	20%

This partial complete method is used for activities that are broken down into phases of work. Again, a good example of this is ductwork installation. This is shown graphically in Figure 1-5.

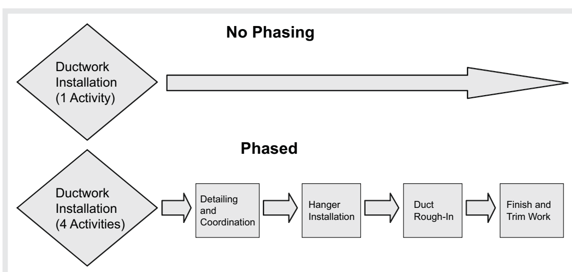

Figure 1-5: *Phased Breakdown*

This method requires extensive effort up front to plan out important intermediate milestones for activities or work packages. Once completed, this method is excellent for companies that do not wish to allow employee subjectivity into their performance measurement system.

The following list summarizes the guidelines for choosing when to use the partial complete method to measure output.

- Use when the WBS has subdivided or combined items for which the work can be separated or linked together in some fashion, usually time or effort, or when the work has identifiable milestones.
- Use when the activity duration is longer than a single reporting period.
- Assign percentage value to each work item that is included in the division shown in the WBS, totaling 100%.
- Allocate the predetermined percent complete to each part of the work task as it is completed.

The methods for output measurement discussed here do not, however, have to be used independently of each other. In some instances, it may better suit a contractor to use a combination of different approaches to better represent the project. If subjective evaluation seems too biased, it may be coordinated with the use of the partial complete method to serve as gates between ranges of percent complete values (Fleming, 2000). Other instances may include using the quantity installed as measured approach only for certain items that are readily measured and one of the other methods for the remainder of the work. As long as the entire work scope is accounted for, the type of work often determines the best choice of approach to output measurement.

1.2.13 Advanced Earned Value Project Tracking

The earned value spreadsheet that was used for this research collected data from four different areas. First, the activities as developed in the WBS and coordinated in the schedule should appear in a systematic order within the spreadsheet. Second, the estimated values are entered into the spreadsheet. Both manhours and quantities associated with each activity are used if both are being tracked. The items in the estimate also correspond to items that appear in the schedule and WBS. The third area of data collection is the actual values of manhours expended, from the field. The final area of data collection is percent complete. These four areas from which the earned value spreadsheet collected data are shown in Figure 1-6. There are several different approaches to determine percent complete values. These methods were described in Section 1.2.8, *Measurement of Output*. What follows in this section is a detailed description of the advanced earned value project tracking spreadsheet that was developed for this research. This section allows contractors to develop a similar earned value project tracking spreadsheet that can be used to accurately and completely track projects. Those not interested in understanding the details of this spreadsheet can skip to Section 1.2.17, *Project Tracking Report*, to continue reading about the findings of this research.

The Earned Value spreadsheet referenced in this book is available for download as an additional resource at **http://www.newhorizonsfoundation.org/proj_tracking/EV_Spreadsheet.xls**

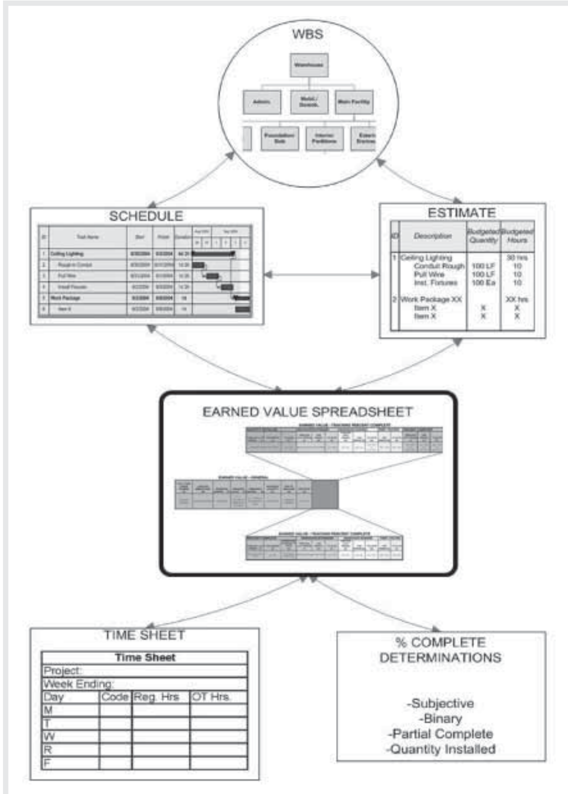

Figure 1-6: *Four Areas of Data Collection for the Earned Value Spreadsheet (Hanna & Kleckner, 2005)*

The four areas of data collection are combined and integrated into one spreadsheet for control. Figure 1-7 is an example spreadsheet. It is depicted in two ways; one would be used if quantity installed as measured were used for percent complete determination, and the other would be used if percent complete were determined subjectively or by a standard method of placing percent complete values for the activities. This example can be expanded or simplified, depending on how the mechanical, HVAC, or sheet metal contractor wishes to track progress. The following information will describe each column and how it was developed.

EARNED VALUE - TRACKING QUANTITY INSTALLED AS MEASURED

QUANTITY INSTALLED			MANHOURS EXPENDED			MANHOURS EARNED			PERF. FACTOR		PERCENT COMPLETE		
(I) THROUGH LAST PERIOD	(J) THIS PERIOD	(K) TO DATE	(L) THROUGH LAST PERIOD	(M) THIS PERIOD	(N) TO DATE	(O) THROUGH LAST PERIOD	(P) THIS PERIOD	(Q) TO DATE	(R) THIS PERIOD	(S) TO DATE	(T) THROUGH LAST PERIOD	(U) THIS PERIOD	(V) TO DATE
Measured Values From Field		(I) + (J)	Measured Values From Field		(L) + (M)	(H) x (I)	(H) x (J)	(O) + (P) or (H) x (K)	(P) ÷ (M)	(Q) ÷ (N)	(I) ÷ (F) or (O) ÷ (C)	(J) ÷ (F) or (P) ÷ (C)	(K) ÷ (F) or (Q) ÷ (C)

EARNED VALUE - GENERAL

(A) COST CODE/ PHASE NUMBER	(B) JOB TASK BREAKDOWN	(C) BUDGETED MANHRS	(D) WEIGHTED VALUE	(E) REMAINING MANHRS	(F) BUDGETED QUANTITY	(G) UNIT OF MEASURE	(H) UNIT RATE
Company Defined	Company Defined	Estimated	(C) ÷ ∑Budgeted Manhrs *all* activities	(C) - Manhrs Expended to Date	Estimated	Company Defined	(C) ÷ (F)

EARNED VALUE - TRACKING PERCENT COMPLETE

PERCENT COMPLETE			MANHOURS EXPENDED			MANHOURS EARNED			PERF. FACTOR	
(i) THROUGH LAST PERIOD	(j) THIS PERIOD	(k) TO DATE	(l) THROUGH LAST PERIOD	(m) THIS PERIOD	(n) TO DATE	(o) THROUGH LAST PERIOD	(p) THIS PERIOD	(q) TO DATE	(r) THIS PERIOD	(s) TO DATE
Measured From Field	(k) - (i)	Measured From Field	Measured Values From Field		(l) + (m)	(C) x (i)	(C) x (j)	(C) x (k)	(p) ÷ (m)	(q) ÷ (n)

Figure 1-7: *Earned Value Spreadsheet (Hanna & Kleckner, 2005)*

1.2.14 General Column Descriptions

Cost Code / Phase Number (Column A): Company-defined numbering system for the organization of activities.

Job Task Breakdown (Column B): Written description of each activity that is tracked.

Budgeted Manhours (Column C): Original estimate of manhours required to complete the job task. This column represents what is planned.

Weighted Value (Column D): Ratio of line item activity size in manhours to budgeted manhours for the entire project. These ratios indicate what proportion of the project the activity constitutes. This is important because it allows management to see quantitatively which cost codes will have the greatest impact on the project.

$$WeightedValue = \frac{BudgetedManhours}{\sum \begin{matrix} BudgetedManhours \\ AllActivities \end{matrix}} \quad \textbf{Or} \quad D = \frac{C}{\sum \begin{matrix} BudgetedManhours \\ AllActivities \end{matrix}}$$

Remaining Manhours (Column E): Remaining manhours left to be used from original estimate.

$$RemainingManhours = BudgetedManhours - ManhoursExpendedtoDate$$

$$\textbf{Or} \quad E = C - N \text{ (for use with QuantityInstalledApproach)}$$

$$\textbf{Or} \quad E = C - n \text{ (for use with Subj\%Complete Approach)}$$

Budgeted Quantity (Column F): Original estimate of material quantity required to complete the job task.

Unit Of Measure (Column G): Unit of measure that will be used to track the installed quantities for a given activity (LF, SF, CY, Ea, etc.).

Unit Rate (Column H): Estimated manhours per unit for the completion of a line item. This is sometimes referred to as the productivity rate.

$$UnitRate = \frac{BudgetedManhours}{BudgetedQuantity} \quad \textbf{Or} \quad H = \frac{C}{F}$$

1.2.15 Tracking Quantity Installed

Quantity Installed – Quantity installed values are derived from the field. This can be accomplished by physically measuring (or counting) installed items or by totaling delivery invoices and subtracting the quantity left uninstalled on site. The latter is fairly accurate if the items are stored together in a designated place on site, whereas physically measuring installed quantities can be difficult, especially for items that are not readily visible. A laser measuring device can help expedite measuring distances such as the linear footage of installed ductwork of a particular size.

Through Last Period (Column I): Value is taken from previous data.

This Period (Column J): Value is measured by contractor.

To Date (Column K): Quantity installed this period added to the quantity installed through last period.

$$QuantityInstalledtoDate = QuantityInstalledThroughLastPeriod + QuantityInstalledThisPeriod$$

Or

$$K = I + J$$

Manhours Expended – Manhours expended are the number of work hours that have been used in the field specifically for completing a particular job task. These values are typically collected from employee time sheets. Employee time sheets should indicate the cost code for which work was conducted along with the hours worked on each cost code, for the respective day in which it took place. An example time sheet is shown in Figure 1-8. The key aspect of collecting these values is making the field labor understand the importance of accurately recording how the number of hours spent on particular activities each day were allocated. This too has an impact on the overall accuracy of the earned value system.

TIME SHEET

Std / OT	Name:				Job:				Week Ending:		
Cost Code	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	Std. Time	OT	Total	Rate
#											
#											
#											
#											

Figure 1-8: *Example Time Sheet*

Through Last Period (Column L): Value is taken from previous data.

This Period (Column M): Value is reported by the contractor through time sheets from field personnel completing the job task.

To Date (Column N): Manhours expended this period added to the manhours expended through last period.

$$ManhoursExpendedtoDate = ManhoursExpendedThroughLastPeriod + ManhoursExpendedThisPeriod$$

Or

$$N = L + M$$

Manhours Earned – Manhours earned is a value that ties the budget to how much work has been physically accomplished for a project. This column corresponds to the work the contractor actually did. Earned hours are the number of hours a task should have taken compared to the budget for a given percentage of work physically completed.

Through Last Period (Column O): Computed by contractor/ spreadsheet.

$$ManhoursEarnedThroughLastPeriod = UnitRate \times QuantityInstalledThroughLastPeriod$$

Or

$$O = H \times I$$

This Period (Column P): Computed by contractor/spreadsheet.

$$ManhoursEarnedThisPeriod = UnitRate \times QuantityInstalledThisPeriod$$

Or

$$P = H \times J$$

To Date (Column Q): Earned hours this period added to the earned hours through last period. Or can be calculated using the following equation:

$$ManhoursEarnedtoDate = UnitRate \times QuantityInstalledtoDate$$

Or $Q = H \times K$ ***Or*** $Q = O + P$

Performance Factors – Performance factors are a measure of productivity or efficiency of the labor force for a task or the entire project. This information can be calculated for the given reporting period or for all work on a project to date. This value is obtained from dividing the earned manhours by the actual manhours spent on a task or on the project as a whole over a reporting period or to date. The performance factor is standardized, therefore a value of 1.0 means that the work efficiency on site is as planned. A value greater than 1.0 indicates that work is progressing at a greater rate than planned productivity; alternatively, a value less than 1.0 indicates productivity on site is less than originally planned.

Through Last Period (Column R): Computed by contractor/spreadsheet.

$$PerformanceFactorThroughLastPeriod = \frac{ManhoursEarnedThroughLastPeriod}{ManhoursExpendedThroughLastPeriod}$$

Or

$$R = \frac{O}{L}$$

This Period (Column S): Computed by contractor/spreadsheet.

$$PerformanceFactorThisPeriod = \frac{ManhoursEarnedThisPeriod}{ManhoursExpendedThisPeriod} \quad \textbf{Or} \quad S = \frac{P}{M}$$

To Date (Column T): Computed by contractor/spreadsheet.

$$PerformanceFactortoDate = \frac{ManhoursEarnedtoDate}{ManhoursExpendedtoDate} \quad \textbf{Or} \quad T = \frac{Q}{N}$$

Percent Complete – Percent complete is the percentage of physical work completed on an activity or on a complete project. This value is completely independent of budget, cost, and schedule. When tracking quantity installed, the percent complete for a given activity is simply the quantity installed divided by the budgeted quantity. The percent complete of a project is calculated by dividing the total project budgeted hours by the total project earned hours. More information about percent complete determinations can be found in Section 1.2.8, *Measurement of Output*.

Through Last Period (Column U): Computed by contractor/ spreadsheet.

$$\%CompleteThroughLastPeriod = \frac{QuantityInstalledThroughLastPeriod}{BudgetedQuantity} \quad \textbf{Or} \quad U = \frac{I}{F}$$

$$\%Complete\,Through\,Last\,Period = \frac{Manhours\,Earned\,Through\,Last\,Period}{Budgeted\,Manhours} \quad \mathbf{Or} \quad U = \frac{O}{C}$$

This Period (Column V): Computed by contractor / spreadsheet.

$$\%Complete\,This\,Period = \frac{Quantity\,Installed\,This\,Period}{Budgeted\,Quantity} \quad \mathbf{Or} \quad V = \frac{J}{F}$$

$$\%Complete\,This\,Period = \frac{Manhours\,Earned\,This\,Period}{Budgeted\,Manhours} \quad \mathbf{Or} \quad V = \frac{P}{C}$$

To Date (Column W): Computed by contractor / spreadsheet.

$$\%Complete\,to\,Date = \frac{Quantity\,Installed\,to\,Date}{Budgeted\,Quantity} \quad \mathbf{Or} \quad W = \frac{K}{F}$$

$$\%Complete\,to\,Date = \frac{Manhours\,Earned\,to\,Date}{Budgeted\,Manhours} \quad \mathbf{Or} \quad W = \frac{Q}{C}$$

1.2.16 Tracking Subjective Percent Complete

This section describes earned value as it relates to project tracking using the subjective percent complete method. This is one of several methods for project tracking that is available to contractors when using earned value.

Percent Complete – In this situation, the subjective percent complete value is input by the contractor.

Through Last Period (Column i): Value is taken from previous data.

This Period (Column j): Value is computed by contractor / spreadsheet.

$$\%Complete\,This\,Period = Subjective\,Average\,to\,Date - \%Complete\,Through\,Last\,Period$$

$$\mathbf{Or}$$

$$j = k - i$$

To Date (Column k): Value is subjectively determined by the contractor.

Manhours Expended – Same description as used previously in Section 1.2.15, *Tracking Quantity Installed*.

Through Last Period (Column l): Value is taken from previous data.

This Period (Column m): Value is reported by the contractor through time sheets from field personnel completing the job task.

To Date (Column n): Manhours expended this period added to the manhours expended through last period.

$$ManhoursExpendedtoDate = ManhoursExpendedThroughLastPeriod + ManhoursExpendedThisPeriod$$

Or

$$n = l + m$$

Manhours Earned – Same description as used previously in Section 1.2.15, *Tracking Quantity Installed*.

Through Last Period (Column o): Computed by contractor/ spreadsheet.

$$ManhoursEarnedThroughLastPeriod = BudgetedManhours \times \%CompleteThroughLastPeriod$$

Or

$$o = C + i$$

This Period (Column p): Computed by contractor/spreadsheet.

$$ManhoursEarnedThisPeriod = BudgetedManhours \times \%CompleteThisPeriod$$

Or

$$p = C + j$$

To Date (Column q): Earned hours this period added to the earned hours through last period. Or can be calculated using the following equation:

$$ManhoursEarnedtoDate = BudgetedManhours \times \%CompletetoDate$$

Or

$$q = C + k$$

Performance Factors – Same description as used previously in Section 1.2.15, *Tracking Quantity Installed*.

Through Last Period (Column r): Computed by contractor/spreadsheet.

$$PerformanceFactorThroughLastPeriod = \frac{ManhoursEarnedThroughLastPeriod}{ManhoursExpendedThroughLastPeriod} \quad \textbf{Or} \quad r = \frac{o}{l}$$

This Period (Column s): Computed by contractor / spreadsheet.

$$PerformanceFactorThisPeriod = \frac{ManhoursEarnedThisPeriod}{ManhoursExpendedThisPeriod} \quad \textbf{Or} \quad s = \frac{p}{m}$$

To Date (Column t): Computed by contractor / spreadsheet.

$$PerformanceFactortoDate = \frac{ManhoursEarnedtoDate}{ManhoursExpendedtoDate} \quad \textbf{Or} \quad s = \frac{q}{n}$$

The previously described concepts and calculations provide the basis for the earned value project tracking spreadsheet from which graphical outputs and at-completion forecasts were then developed.

1.2.17 Project Tracking Report

A project tracking report was sent to the project management staff after every reporting period for the case studies detailed in this book. This report summarized the essential project tracking data derived from the earned value analysis and put it in a concise form for project management and upper management personnel. Each report gave information on the physical project percent complete, percent planned project duration, manpower loading curve comparison, cost variance, schedule variance, cumulative project performance factor, the performance factors of any high manhour activities, forecasted manhours at completion, and the forecasted manhours at completion using linear regression. In addition to reporting these values, an explanation was given of what these values mean for the overall project status. These reports were completed in a very timely fashion – every time new project information was received from the project management staff on site. See Figure 1-9 for a sample report that was given to project management staff for every reporting period.

Project Progress Report #7 Summary		
Percent Physical Project Completion: 67%		
Project Control Technique	**Value**	**Early Warning Explanation**
Percent Planned Project Duration	**78%**	Industry standard (Hanna's control points) indicates that at 78% planned project duration, the project should be around 85% complete. Since this project is currently at 67% complete, it is currently significantly behind schedule. Continued warning sign for schedule overrun.
Manpower Loading Curve Comparison	**Low**	At the current time, the actual manpower expended on site has been lower than what was planned and therefore may be behind schedule. Lower by 551 (4.6% of budget) manhours. This value increased significantly from the last report, which is not a good sign for the project as a whole.
Cost Variance (CV)	**-54**	Representative of 54 more hours expended then earned to date. This is a fairly small number, so no concern to date. Productivity to date on the project has been slightly lower than planned as a whole.
Schedule Variance (SV)	**-605**	This value shows that 605 fewer hours have been earned to date than were budgeted. This means this project is behind schedule by 605 hours. Warning sign for over schedule project.
Cumulative Project Performance Factor (PF)	**0.99**	A value of 1.00 is exact planned productivity. Therefore work to date is exactly equal to planned productivity. However, some work has been done on over-budget activities so, when this is accounted for, the project performance factor is 0.99, which is slightly below planned productivity.
Cumulative East Elevation SF/HR	**10.11**	Represents that to date work in the field is installing 10.11 square feet per manhour on the East Elevation. 8.85 is plan. Productivity increased significantly from last report.
Cumulative West Elevation SF/HR	**11.22**	Represents that to date work in the field is installing 11.22 square feet per manhour on the West Elevation. 12.39 square feet per manhour is plan. Productivity decreased from last report.
Manhours at Completion Forecast (No Trend Regression)	**12,600**	Indicates a likely underrun of 498.6 manhours. This is a very good forecast, especially this late in the project where these forecasts are typically more accurate and reliable. Increased slightly in value from the last report.
Manhours at Completion Forecast (Trend Regression)	**11,496**	Indicates a likely underrun of 1,591.6 manhours. This is a very good forecast, especially this late in the project. Decreased in value from the last report, which is also good.
Overall Project Progress and Outlook: Judging from the values indicated and the descriptions provided, it seems that the project is likely to finish work under budget but with a significant schedule slippage. Current projections estimate it will take a total of 21 weeks to complete the project compared to the 17 contract weeks. Must address this issue or accept the schedule overrun. Work on Interior Panels at Q is at 15.4 SF/HR in the field to date while the budget/estimate is 19.9 SF/HR.		

Figure 1-9: *Sample Project Progress Report*

1.2.18 Progress Reporting

The preceding spreadsheet contains all the information needed for management to analyze and control a mechanical, HVAC, or sheet metal construction project. By updating a similar spreadsheet weekly or every reporting period, various inferences can be made and trends drawn from the data. In order to make meaningful comparisons between the manhours budgeted, expended, and earned, all data should be collected in the same time period (Christensen, 1999). This section will look at and discuss the various graphs, forecasts, and additional indexes that can be used to better demonstrate true project status. The most important aspect of the progress reports is that they must be timely so that management can take the proper action. If the contents of the report are not addressed in an expeditious manner, the goal of monitoring performance is defeated.

1.2.19 Manpower Loading Graphs

As mentioned previously, manpower loading curves display how manpower is being expended on a project. The relationship is between time and manpower (in hours or number of men). The three stages of manpower loading are the buildup of manpower, the peak, and the rundown. Mechanical, HVAC, and sheet metal contractors typically have a steep and quick buildup phase at the outset of a project prior to reaching manpower peak. After the peak, there is a shallow and long rundown of manpower to finish the job. If a project's manpower is falling below the planned manpower early in the project, it is easy to see that the manpower will need to ramp up later in the project, most likely to a higher level than originally planned, in an effort to finish the project on time. A scenario in which this has occurred is displayed in Figure 1-10. This can have multiple repercussions that can increase costs and lower productivity on the project. Some of these include extensive use of overtime, shift work, over-manning, and the stacking of trades. It should be noted that good project management should be able to "catch up" on the project shown in Figure 1-10 from the second month through the twelfth month, and this may avoid over-manning at the end of the project.

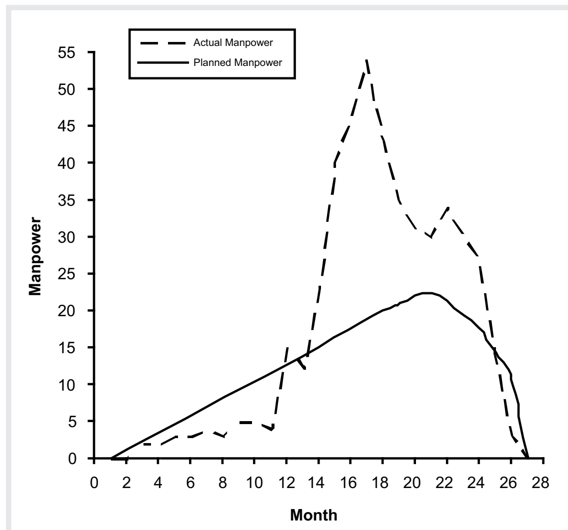

Figure 1-10: *Manpower Loading Curve Example (Hanna, 2004)*

1.2.20 Hanna's Control Points

Manpower loading curves are an effective method of project control, in part due to the previous research on the use of manpower (Hanna, 2004). Throughout a mechanical, HVAC, or sheet metal construction project, at defined intervals, a specific amount of manpower should be used. The previous research found that, on a sheet metal project from 0% to 25% complete, approximately 20% of the total work hours for the project are consumed or 20% of the project should be completed. From 25% to 50% complete, an additional 45% of work hours are consumed; therefore 65% of the project should be complete by this point. Finally, from 50% to 100% complete, the remaining 35% of the work hours are consumed, or the final 35% of the project is completed. These points indicate average manpower consumption, which from a planning perspective should be used to gauge a given project's physical percent complete at any point in time. This, in effect, creates an early warning sign to contractors that, if the project has not progressed enough to nearly reach or surpass these values at defined control points, then the project may be headed for cost overruns and/or schedule slippages.

Hanna's control point method described above is called the trapezoid technique, which is derived from the empirically determined industry average manpower loading curve. It revealed statistically that the greatest amount of risk in a sheet metal project can be found during the 25% to 50% project duration stage when 45% of the work hours are used in a short period of time (Hanna, 2004). The trapezoid technique for sheet metal construction is pictured in Figure 1-11, while the technique for mechanical construction is shown in Figure 1-12. This graphical approach to project control works together with the earned value system to estimate normal project duration, peak workforce level, and the rate of manpower consumption. This method will be used in the case studies presented in Sections 2.1, 2.2, and 2.3.

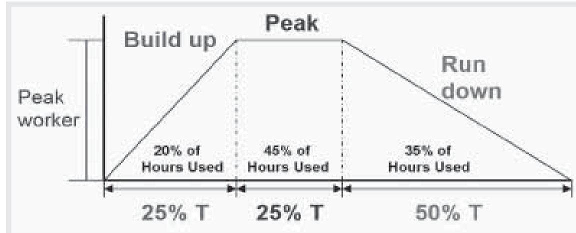

Figure 1-11: *Trapezoid Technique for Sheet Metal Construction (Hanna, 2004)*

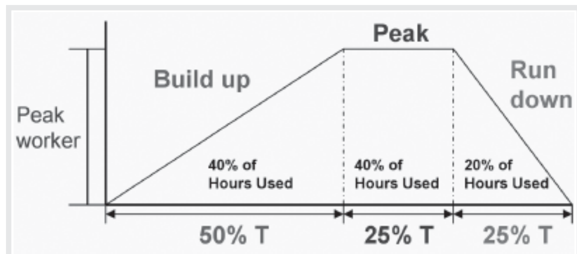

Figure 1-12: *Trapezoid Technique for Mechanical Construction (Hanna, 2004)*

1.2.21 S-Curves

Manpower loading curves are used to develop a graph that shows the cumulative perspective for manpower on the project. Such a graph is called the S-curve, aptly named from its "S" shape. S-curves are strongly related to manpower loading curves. Fundamentally, an S-curve represents the relationship between the project duration and the cumulative project completion, where completion is measured in dollars or manhours. S-curves are built graphically by adding the manhours planned for a project for a period of time (from manpower loading curve) to the cumulative manhours planned prior to that period of time and placing the sum in the current time period. This process forms an S shape culminating in project completion, as seen in Figure 1-13. This figure shows a typical S-curve for sheet metal construction.

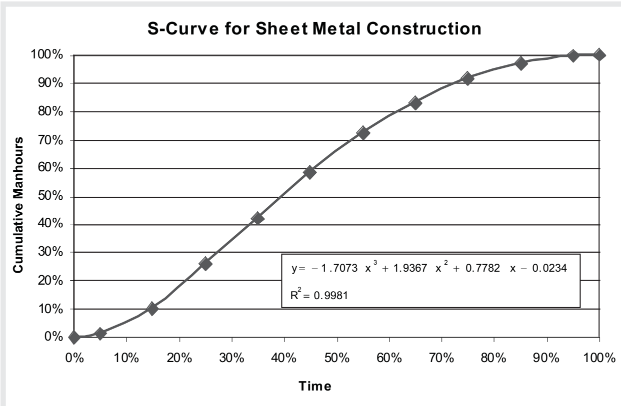

Figure 1-13: *Project S-Curve (Hanna, 2000)*

Originally, S-curves were used to explain half of the story. They compared actual hours (or cost) of the project to the budgeted hours (or cost). These values were shown in relation to time, as seen in Figure 1-14. This comparison did not explain the whole story. With this representation, it is impossible to tell whether the project is ahead or behind schedule or whether it is experiencing labor cost overruns.

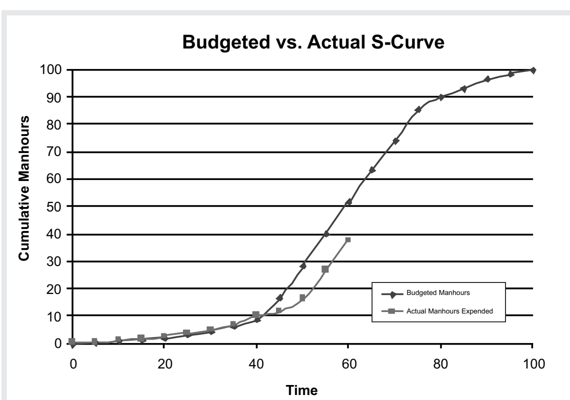

Figure 1-14: *Actual vs. Budgeted S-Curve*

With the use of earned value, S-curves have an added dimension that allows for meaningful project comparisons. S-curves show the relationship between time and percent complete. For instance, a planned S-curve would show the expected level of completed work at each point in the project duration. Deviations in the actual performance of the project will be tracked against the planned percent complete to determine if work is ahead or behind schedule, and also if work is above or below the estimated manhours. In summary, S-curves compare the rate at which manhours were planned, expended, and earned in relation to a time during the project duration. Analysis of an S-curve can be a telling tool as to project progression as well as to a falling off of a project.

As seen in Figure 1-15, an S-curve is made up of three curves: the planned or budgeted S-curve, the expended S-curve, and the earned S-curve. From these three curves, the cost and schedule performance of the project can be observed. Below is a sample S-curve from previous earned value research. At a designated point in time, contractors can analyze their progress in relation to their own baseline plan, and to the industry standard S-curve, as defined using Hanna's control points from the trapezoid technique for manpower loading.

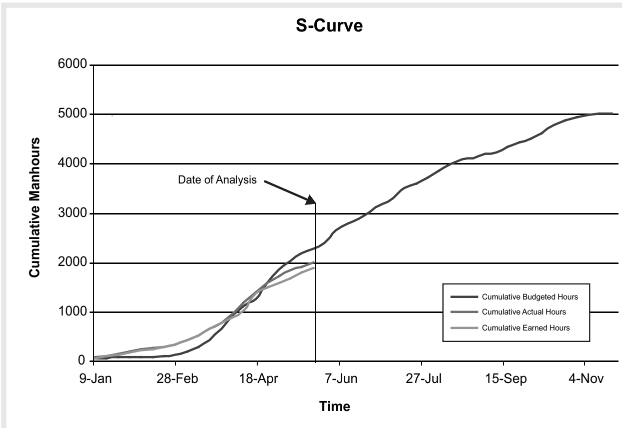

Figure 1-15: *Earned Value S-Curve (Hanna and Kleckner, 2005)*

This is done by looking at variances from the planned S-curve. These variances are very similar to those used in previous literature, except previously they were used to develop indexes to measure progress. The primary purpose of these variances is to indicate how the project is progressing graphically. It is the management's responsibility to recognize impending problems perceived from the graph and respond to them.

The first variance, which has traditionally been called the cost variance (CV), shows the manhour position of the project. But cost would imply use of a cost basis for this determination when really labor hours are being used. Therefore, a better nomenclature may actually be labor hour variance. In any case, the nomenclature that stuck with the industry has been cost variance. The cost variance is the difference between earned hours and actual hours, as seen in Figure 1-16. A positive value is favorable because it means that the project has earned more hours than have been spent, indicating a productivity or performance factor greater than planned. Inversely, a negative value indicates the project has spent more hours than were earned at this point in time and there is a worse than planned rate of productivity. The cost variance is an important value because it is rarely recovered throughout the remainder of the project. In past DoD projects, a database was formed containing data from over 700 projects. The results showed that, when a project was at least 15% complete, the labor overrun at completion will not be improved from the labor overrun to date, and the percent overrun at completion will be greater than the percent overrun to date (Fleming, 2000).

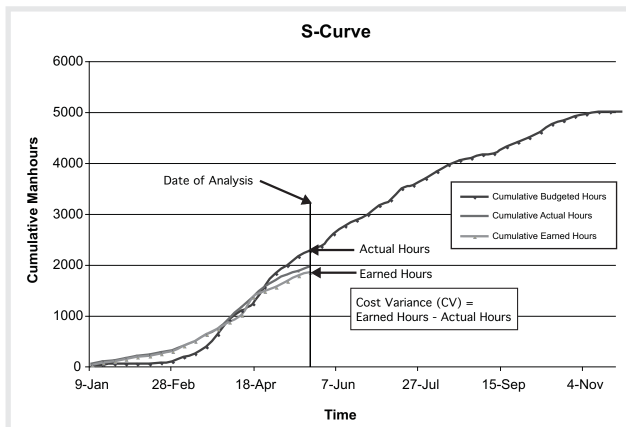

Figure 1-16: *Determination of Cost Variance* (Hanna and Kleckner, 2005)

The other variance, schedule variance (SV), indicates the schedule position of the project. The schedule variance is the difference between earned manhours and the number of manhours budgeted at that point in time, as seen in Figure 1-17. If the value is positive, the variance is indicating that more hours were earned to date than what were planned. In turn, if negative, it implies that the schedule is falling behind. This is a useful indicator of schedule position, but it is important to note that the progression of the schedule is best shown with critical path methodology scheduling. If the activities that have a poor schedule variance have any amount of float time, they are of less importance than the activities that are near or on the critical path and have a poor schedule variance. These are the activities that require some action, whereas the ones with float indicate that the schedule is behind the initial plan for that activity (Fleming, 2002). A consistently poor schedule variance value often results in higher manning levels to compensate for the underperformance. This better ensures that the target completion date will still be met if that is required (Zink, 1980). Another thing to keep in mind when looking at the schedule variance is the mathematical expression it is based on: *Earned Hours – Budgeted Hours to Date*. Whether the project is experiencing positive or negative variances, the equation will eventually equal zero when the project is complete. Therefore it is important to understand that the decreasing magnitude of the schedule variance may not mean that the project is not as far ahead or behind schedule anymore; rather it may mean that the project is at a point where the remaining hours left in the project are less than the magnitude of the schedule variance itself.

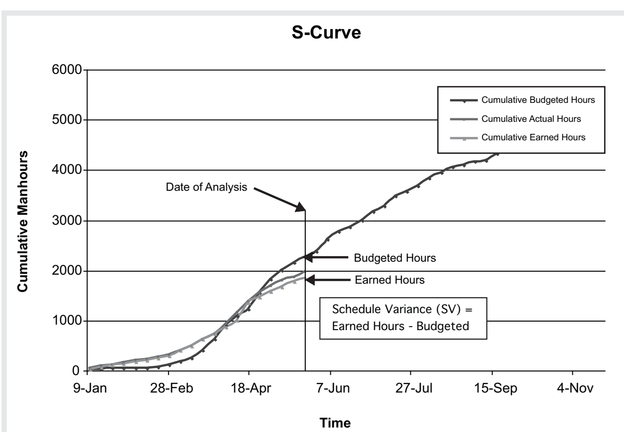

Figure 1-17: *Determination of Schedule Variance (Hanna and Kleckner, 2005)*

Small variations from positive to negative or vice versa for either cost variance or schedule variance are not of great concern. Rather, if one or the other variance is consistently well below zero, a warning flag should go up for the project manager. This points toward possible manhours overruns and/or schedule slippages and should be responded to accordingly. This scenario is shown in Figure 1-18, which takes the same project that has been used to show how to determine the variances. Upon completion, this project overran both its budgeted manhours and planned completion date.

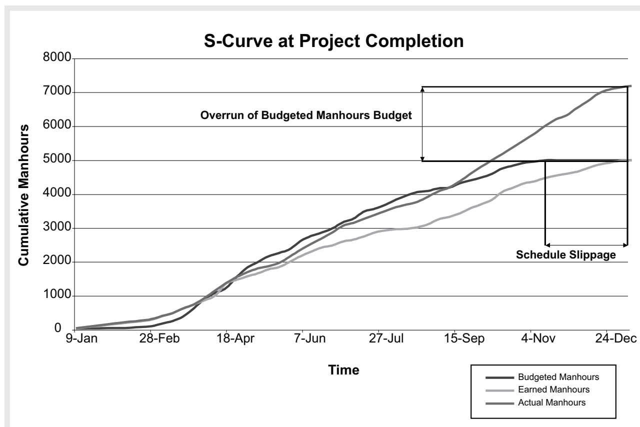

Figure 1-18: *S-Curve at Project Completion (Hanna and Kleckner, 2005)*

For contractors who do a large amount of work on similar projects, the S-curve can also be used to check the project plan to determine whether it seems realistic or too aggressive. This can be accomplished by collecting data from historical projects which the contractor has completed, determining whether the specific type of work seems to have a standard S-curve shape, and comparing those S-curves to the plan developed for the new project.

1.2.22 Performance Factor Profiles

Performance factors or cost performance indices (CPI) are established every reporting period along with a cumulative performance factor, which shows the labor efficiency over the duration of the project. The equation used for performance factors takes the earned hours and divides them by the actual hours expended either per period or to date. Ideally, the performance factor throughout the project would then be at or above a value of 1, because it would be the contractor's goal to meet or exceed planned rates. This is usually not the case when looking at performance factors on a per period basis – a very staggered graph is typical. During one period, the contractor may have seen great work efficiency and found that the performance factor was 1.5. In the following period, the contractor may have seen a performance factor of 0.5. Although this is below a value of 1 and seems bad, it is common. Project management should recognize this as a period that needs to be improved upon. Still, the cumulative performance factor over those two periods, if the same number of hours were expended in each period, is equal to 1, which is a desirable value. Only when the performance factor continues to be low or declining should management view this as a warning sign of potential project problems. If a downward trend is occurring, planned manning levels may need to be increased to balance the poor performance (Zink, 1980, 1986).

Although a performance factor appears to be a productivity value, only when in the end the actual quantities of work are equal to those budgeted are the values true productivity values (CII, 1987). The ending quantities of work are not always equal; therefore, when analyzing the performance of an activity, it is important to realize that a poor performance factor can be the result of several problems. The problem could, in fact, be low productivity, but it also could be estimate inaccuracy, extreme over-manning, or possibly the crew mix, which is pushing the performance factor down (CII, 1987). When the performance factor is consistently low, but management believes work has been efficient in the field, a logical next step is to then look into the possibility that one or more of these other problems are at the root of the issue.

Performance factors can be displayed graphically by looking at the relationship between percent complete and performance factors. The project percent complete on the x-axis and the cumulative performance factor on the y-axis can be seen in Figure 1-19, a typical performance factor profile.

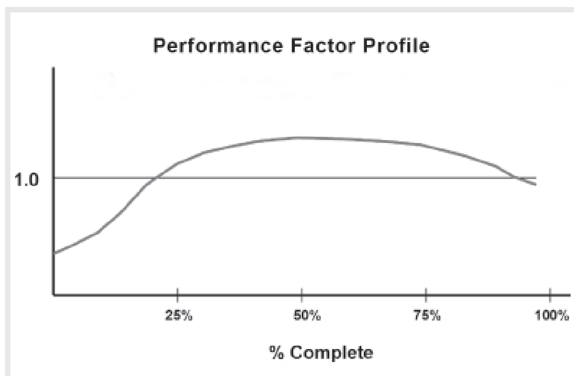

Figure 1-19: *Performance Factor Profile (Hanna, 2004)*

The performance factor to date graph, however, should be a smooth line that resembles a shallow hump, in which the performance factor increases to a point then decreases slightly. At the project outset, productivity is typically below the index line of one. This can be attributed to having a crew that is not wholly familiar with the project or fully staffed. Characteristically, the performance factors increase and peak near the halfway point of a project, and then decline as the project nears closeout. This increase is justified by the workers hitting their stride with the work required along with becoming more familiar with the specific project. Different contractors may have different shapes to their performance factor graphs. These shapes can be determined from records of past projects and then analyzed to determine if a given project is at the performance factor typically experienced or whether it is below and in need of corrective action. Still, this shallow hump that was mentioned may be very shallow or not appear at all, especially if the project is experiencing problems. In either case, two statistics from past research are important to understand when analyzing performance factor profiles. Restated, they are

1. Performance factors have been shown to stabilize by the 15 to 20% completion point of a project, which will show a trend for the remainder of the project (Fleming, 1995, 2002).

2. Research on completed defense contracts show that the cumulative performance factor does not change by more that 10% from its value at the 20 to 30% completion point, and in most cases it only worsens (Christensen and Heise, 1993).

1.2.23 Manhour At Completion Forecasts

There are techniques that allow contractors to predict a value for the total number of manhours that will be required for the project, early in the project. The goal of the forecast is to accurately predict how many total manhours are going to be required to complete the project.

This book focuses on the theory that the cumulative performance factor, once established for a project, is difficult to alter significantly in the positive direction. That said, the forecast takes into account the performance factor to date and uses the rate at which work will continue for the remainder of the project. Since the performance factor tends to stabilize by the 20 to 30% complete mark, the manpower forecast at completion should begin to be predictable around 30% complete (Christensen and Heise, 1993). The forecast may level out or at least show some sort of trend that can be extrapolated. This can be seen in Figure 1-20, which uses project data from this research and is plotted with project percent complete on the x-axis against the forecasted manhours at completion on the y-axis. The formula for the forecasted manhours at completion is shown below. Previous research on DoD contracts has suggested that this formula provides a low value or floor to the final manhours required (Christensen, 1999). Still, using this technique provides better, more realistic results than assuming the rest of the project will advance as originally planned.

$$\begin{array}{l} ForecastedManhours \\ AtCompletion \end{array} = \frac{*TotalManhoursExpended}{Project\%Complete}$$

Or

$$\frac{TotalBudgetedHours}{CumulativePerformanceFactor}$$

*(Both equations provide the same result)

It is important to note that these equations can be calculated at the project level or at the activity level. If possible, the calculations should be made at the activity level because it is a much more accurate way to forecast. The reason for this is because every activity is different in nature, and specific manhour forecasts for every individual activity take into account this variability. All the case studies in this research use manhour forecasts by activity, which are then summed to obtain a total manhours at completion value for the project as a whole.

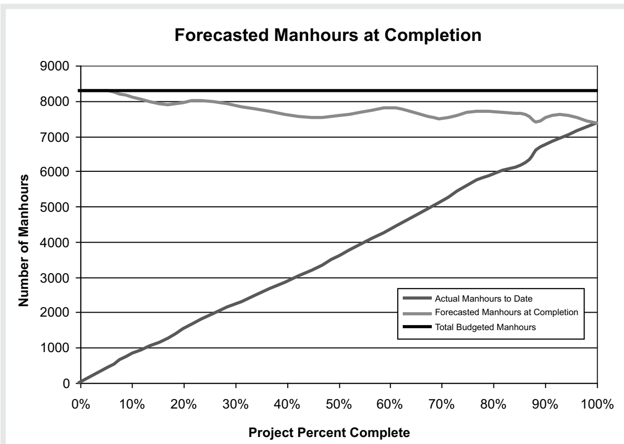

Figure 1-20: *Forecasted Manhours at Completion*

Knowing that performance factors tend to stabilize around the 20 to 30% complete mark of a project is important, considering that many contractors continue to hold out hope that the performance will considerably improve late in the project and will bring up a poor cumulative performance factor. In Figure 1-21, three scenarios are depicted. One shows what the forecast would look like if the performance factor were equal to 1 for the entire project. The second scenario depicts what industry has shown in the past as a typical performance factor profile, in which the performance factor starts out below 1, increases to a peak around the halfway point, and decreases slightly to project closeout and the corresponding forecast. The final scenario shows a performance factor that starts out at the planned or indexed value of 1 and decreases to 0.9 at the 20% complete mark then continues to decrease but only by 10% of the 0.9 value, throughout the remainder of the project, and its matching forecast. The figure shows the direct relationship between the performance factor and its corresponding manhour forecast at completion.

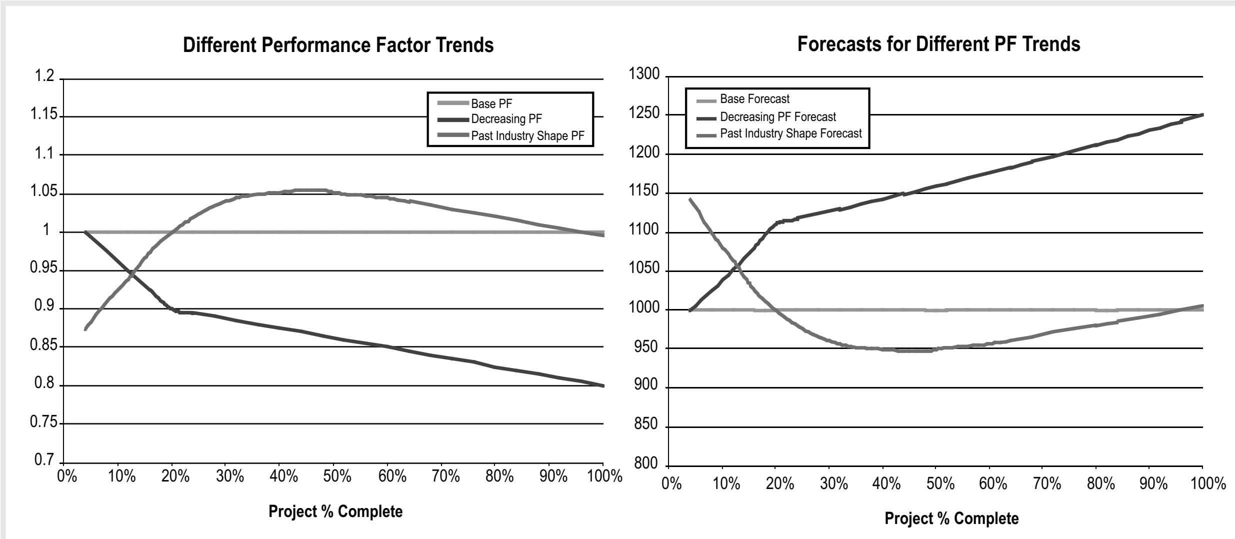

Figure 1-21: *Three Performance Factor Scenarios and Resultant Forecasts*

Using these forecasted values, a simple additional step can be taken to determine the number of weeks required to complete the project at predetermined manning levels. If the project is thought to exceed the original scheduled completion date, this can be helpful when determining how long a time extension should be requested or how much to increase the manpower level in order to complete the project by a specific deadline. This procedure can be conducted in both directions, depending on whether the goal is to determine how many weeks are left at the selected manpower level or how many hours need to be expended each week to finish the project in a selected number of weeks. The steps to determine the number of weeks left on a project are outlined below.

Procedure for Calculating Remaining Duration

1. Select an average level of manpower for the remainder of the project.

$$= \frac{\textit{Average Actual Hours}}{\textit{Week}}$$

2. Multiply the selected manpower per week by the cumulative performance factor for the project to date, which will result in a value of earned hours per week.

$$= \frac{\textit{Average Actual Hours}}{\textit{Week}} \times \begin{matrix}\textit{Cumulative}\\ \textit{Performance}\\ \textit{Factors}\end{matrix} = \frac{\textit{Earned Hours}}{\textit{Week}}$$

3. Subtract the number of earned hours to date from the current number of budgeted hours for the project, which equals the remaining hours that need to be earned on the project.

$$= BudgetedManhours - EarnedHours = RemainingHours$$

4. Divide the previously determined remaining hours by the earned hours per week, which provides the number of weeks left to complete the project, at the selected manpower level.

$$= \frac{RemainingHours}{EarnedHoursWeek} = \begin{matrix} NumberofWeeks \\ toComplete \end{matrix}$$

5. The total estimated weeks to complete the work can then be obtained by adding the elapsed weeks to date to the expected number of weeks to complete.

$$= TotalEstimatedWeekstoComplete = ElapsedWeeks + NumberofWeekstoComplete$$

A shortcut to this procedure can be used when manhour forecasts have already been done. The procedure outlined above is the same as simply taking the forecasted manhours at completion and subtracting the actual hours expended to date to arrive at the remaining hours for the project. That value is then divided by the selected manpower level for the remaining duration to get the number of weeks remaining. This procedure can also be done in reverse to find the level of manpower required to complete the project in a selected number of weeks. Another variation to this method is to take the average earned hours per week to date in the project as the denominator in the number of weeks to complete equation. This variation does not require a prediction for the average level of manpower for the remainder of the project in either number of workers or number of hours per week.

2 CASE STUDIES AND CONCLUSION

2.1 CASE STUDY #1

2.1.1 Introduction

Earned value project control has been used on government defense and acquisition projects and general civil projects of all sizes. However, no in-depth research has ever recorded any data for analysis using earned value project tracking on mechanical, HVAC, and sheet metal construction projects.

With the cooperation of several mechanical, HVAC, and sheet metal contractors, the research team has been able to track the progress of one mechanical construction project and two sheet metal projects from start to completion. Tracking the case study projects has allowed for an in-depth investigation into the applicability of earned value analysis in mechanical, HVAC, and sheet metal construction and similar labor-intensive trades, the accuracy of predicting project outcome using subjective evaluation, the binary system versus actual field measurement, and the accuracy and applicability of Hanna's control points for project progress benchmarking. The precision of using performance factors as a prediction tool for forecasting project outcome was also investigated.

The intent was to track several projects ranging in size, complexity, and type. The limitations were that the project must fit into this study's timeline, and the contractor had to be willing to send periodic updates with the information required for the tracking to occur. With that in mind, it is important to note that each case study was tracked slightly differently to best accommodate the contractors' usual practices. The end results of the research efforts were three very distinct projects varying in project type, size, and complexity from various geographic areas. These projects include a dormitory retrofit in the lower Midwest, a paper mill in the western United States, and a university building expansion in the upper Midwest. The following sections will describe how each project employed earned value project control along with the results attained from each project.

There are three main parts to each case study: a description of the project, the methodology for the implementation of earned value, and the prediction compared to the actual results. The earned value system is based on several variables: the forecasted manhours at completion, percent complete determination, performance factors, total estimated weeks to complete, and cost and schedule variances. These categories will be analyzed at different points throughout the project duration. At these selected junctures, the accuracy of the prediction will be determined and a comparison to previously defined control points will be conducted. Three case studies are included in their full form within this publication.

This research was conducted with the intent of keeping participating contractor and project information confidential. For that reason, all company and project identification has been removed.

2.1.2 Project Description: Dormitory Retrofit Project

This project in the Midwest consisted of retrofitting two college dormitory buildings during the summer of 2007, adding air conditioning to the rooms/buildings, and remodeling the existing bathrooms and common areas. The scope of work for this project was mainly plumbing and mechanical work with a little sheet metal work as well. Work on this project was completed in approximately 220 rooms from mid-May until mid-August. The work for this project was design-build, meaning that the contractor also completed the full design and drawings for the project. This was one reason why there was a very limited amount of change order work for this project. The job featured extensive use of prefabrication, using PVC, Pex, copper, and cast materials. The manhour budget for the project was 14,102 manhours, and the initial contract weeks for the project were 15. On average for this project, 1 general foreman, 1 foreman, 12 journeymen, 8 apprentices, and 3 helpers/pre-apprentices were working on site.

2.1.3 Methods

The contractor already had a labor feedback system in place prior to participation in this research, which made it easier to provide the necessary information for this research. The contractor's system primarily relied on capturing data such as actual hours and hourly rates for activities. Project management was allowed to selectively report percent complete on activities. However, prior to this research quantities installed were not reported; the contractor had to make an adjustment in order to provide the necessary information for this research. For this project, the work was broken down into condensate drain, chilled water, domestic water, equipment, demolition, fixtures, sanitary, and waste and vent work, along with a few other miscellaneous activities. Each of these work components for each of the five floors and two buildings was tracked as a separate activity.

In this particular project, the contractor WBS consisted of 79 cost codes for which the field workers allocated their hours. The time sheet on which the workers recorded their hours is depicted in Figure 2-1.

TIME REPORT

COMPANY NAME — PROJECT LOCATION

EMPLOYEE NAME | LOCAL UNION NO. | EMPLOYEE I.D. NO. | WEEK ENDING | APPROVED BY

MON.			TUES.			WED.			THUR.			FRI			SAT.		SUN.	TOTALS				JOB #	OP CODE	RATE
ST	TH	DT	ST	TH	DT	ST	TH	DT	ST	TH	DT	ST	TH	DT	TH	DT	DT	ST	TH	DT	TOTAL			
																		0.0	0.0	0.0	0.0			
																		0.0	0.0	0.0	0.0			
																		0.0	0.0	0.0	0.0			
																		0.0	0.0	0.0	0.0			
																		0.0	0.0	0.0	0.0			
																		0.0	0.0	0.0	0.0			
																		0.0	0.0	0.0	0.0			
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																		0.0	0.0	0.0	0.0			
																		0.0	0.0	0.0	0.0			
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	TOTAL		

Figure 2-1: *Time Sheets Used for Case Study #1*

2.1.4 Quantity Installed Project Tracking Results

Determining what happened to a project after it is complete is not the difficult part. The challenge is to be able to show accurate project progress in real time and to predict likely project outcomes early in the project duration. The following statistical analysis of the data collected throughout this project's duration attempts to do just that. It will explain the data at different junctures of the project duration in terms of project status, prediction accuracy, and potential early warning signs of project distress.

The entire project had only 56 change order hours, which brought the total budgeted manhours at project completion to 14,158, up from 14,102 budgeted manhours at project start. The reason for the minimal number of change order hours is that the contractor and the designer of the work were the same, a single entity of responsibility from the owner's perspective. Additionally, there was early involvement from the construction arm of the design-build entity, which also assisted in minimizing change orders. At project completion, the contractor had used 13,731 manhours to complete the work, 427 manhours under the final labor budget. This represents a 3.0% underrun from the final budgeted hours for the project. The project ended up taking 17 weeks to complete the work, 2 weeks over the 15 contract weeks that were allotted for the work to be completed. Therefore, this project finished under budget from a labor perspective but with a schedule overrun of 2 weeks. The work scope for this project was broken down into 79 activities with the largest activity representing 6.8% of the labor budget. One other activity represented 5.7% of the labor budget, but the rest of the activities comprised less than 5% of the budget individually. Overall, the project was well broken down with the exception of these two activities that represented 12.5% of the project labor budget.

The results detailed in this section are from the quantity installed method of project tracking. Overall, the final installed quantities exceeded the initial budgeted quantities at the project level by 6.4%. This means that the initial budgeted quantities for numerous activities were slightly low. These errors seemed to be localized around 5 to 10 activities on the project. This information can be used in future projects to correct these estimate errors.

2.1.4.1 Hanna's Control Points

Based on previous research conducted by Dr. Awad Hanna (Hanna, 2004), a system of control points has been developed based on projects compiled by Hanna, provided by 31 participating contractors from around the nation. Hanna's control points identify a minimum amount of manpower that should be consumed in relation to a percent of project duration. This amount of manpower is tied to a minimum project percent complete that should be completed at different points of the planned project duration. This comparison is a tool to show whether the project is performing at a level that will accommodate project completion for the planned date. Table 2-1 provides the comparison between the dormitory retrofit project and industry values for mechanical construction.

% Planned Project Duration		**35%**	**50%**	**65%**	**75%**	**85%**	**100%**
Hanna's Control Points	% Complete	30% or more	40% or more	62% or more	80% or more	90% or more	100%
Actual Project	% Complete	43%	62%	69%	**76%**	**84%**	**94%**

Table 2-1: *Comparison Between Hanna's Control Points and Project % Complete, Case Study #1*

The table above is noteworthy because, judging from the comparison between Hanna's control points and this project's percent complete, it appears that, for the first 65% of the planned project duration, the project is meeting the minimum progress requirements. Only later in the project (75%) is the lack of project progress realized. This table does not, however, indicate the actual number of manhours expended in order to realize each percent complete value. The manhours that were expended on this project in relation to the percent of project completion were misaligned, in that fewer hours were being expended to do the work than what had been planned. It is for that reason that this tool alone cannot definitively show project progress.

2.1.4.2 S-Curves

The manpower loading curve comparison leads right into project S-curve development. By plotting cumulative values for the planned and actual manpower along with the addition of an earned manhour curve, a project S-curve is developed. The S-curve then allows variances to be shown, indicating the cost and schedule position of the project. The S-curve for this project is displayed in Figure 2-2. As described in Section 1.2, *Earned Value Analysis*, the cost variance and schedule variance values can be obtained from the earned, expended, and budgeted manhours that are shown in this figure.

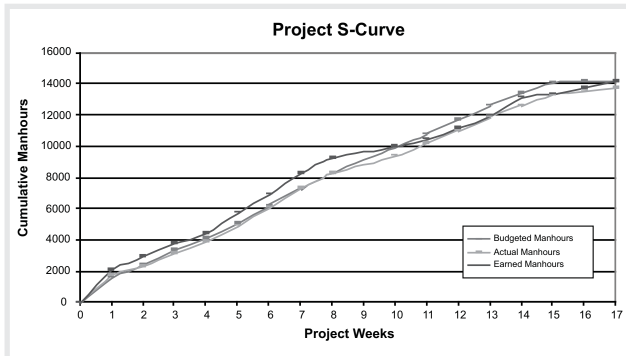

Figure 2-2: *S-Curve for Case Study #1*

When the cost or schedule variance values are consistently negative, or negative and increasing in magnitude, a red flag is triggered and management needs to devise a way to combat the potential overruns in labor and slippage in schedule. Table 2-2 shows how the cost and schedule variance for the project are changing at defined project junctures.

% Planned Project Duration		35%	50%	65%	75%	85%	100%	
Hanna's Control Points	% Complete	30% or more	40% or more	62% or more	80% or more	90% or more	100%	
Actual Project	% Complete	43%	62%	69%	**76%**	**84%**	**94%**	**100%**
	Cost Variance (Mhrs)	860	963	618	223	139	118	427
	Schedule Variance (Mhrs)	650	738	89	**-395**	**-594**	**-742**	**0**

Table 2-2: *Cost and Schedule Variances for Duration of Project, Case Study #1*

This table provides a more detailed story as to the progress of the project. It shows that, throughout the project, labor usage was not the issue, since at every stage in the project the earned hours were greater than the expended hours (positive cost variance). On the other hand, it can be seen that, at 75% complete, Hanna's control points indicated the first serious warning of a schedule overrun and, at that same juncture, the schedule variance indicated another serious warning of a schedule overrun. In addition to these warnings, the schedule variance significantly decreased from 62% complete to 69% complete, which provided an early warning that the schedule variance was very soon going to turn negative. Therefore, the main issue that was affecting this project was that not enough hours were being expended each week. These values are not very serious if management is able to respond to them in a timely fashion and correct the problems. This project was not able to correct the schedule issues since the project ended up finishing over schedule and since the schedule variance continued to worsen even after these warning signs were evident to project management. Project management on the project decided to allow the schedule to overrun since no overtime, shift work, or manpower were added after a schedule slippage was imminent.

It is important to realize that the ***schedule variance will always end up zeroing out*** because of its mathematical equation: *Schedule Variance = Earned Hours – Budgeted Hours*; and eventually at project completion the number of hours earned on the project will equal that which was budgeted. This is an important issue to understand, especially when viewing the schedule variance value toward the end of any project. As mentioned earlier in the text, in order for the schedule variance to be understood properly, its relation to the critical path schedule for the project must be understood. The negative schedule variances simply mean that less work was accomplished than was planned to date; but if this makes sense with what the critical path schedule is showing, and the activities which are causing the poor schedule variance have float available, then maybe it is not of great concern. It also is common to have a situation in which something occurred that delayed work, and the mechanical/sheet metal contractor was not at fault for the delay. Here the schedule variance demonstrates part of its value to the Earned Value Tracking System. The project control system has indicated a slippage in schedule for the entire project even though it is analyzing only the mechanical/sheet metal construction labor force. This can prove valuable later in projects when it becomes necessary to request project extensions as a result of delays that impacted mechanical/sheet metal construction.

2.1.4.3 Performance Factors

Performance factors are another way to understand project performance. Unless there is an estimate problem that causes the budgets for items to be considerably wide of the mark, the performance factor is a measure of construction productivity, or efficiency. Performance factors are found by using the following equations:

$$PF = \frac{Earned}{Actual}$$

$$ActivityLevelPF = \frac{EarnedHours}{ActualHours}$$

$$ProjectPF = \frac{\Sigma\ EarnedHourstoDate}{\Sigma\ ActualHourstoDate}$$

Performance factors can be looked at for each activity being tracked or over a project as a whole. Performance factors can also be looked at on a period-by-period basis or cumulatively throughout the project duration. Figure 2-3 displays the performance factors each period and cumulatively for the overall project. The performance factors shown are the exact project performance factors obtained from the quantity installed method of project tracking. Also, the performance factors by activity (per report and cumulative) were also made available so it could be determined which activities were underperforming or overperforming to date.

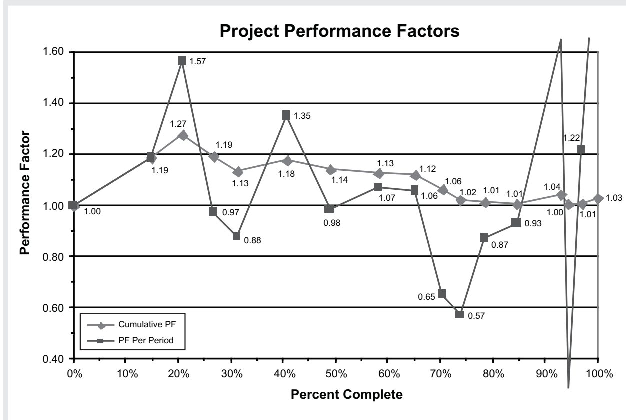

Figure 2-3: *Project Performance Factor Profiles, Case Study #1*

The profile in Figure 2-3 clearly shows a trend in which the performance of the project overall is in good shape throughout the project and there is never any sign for the project management staff to be concerned. Later in the project, the individual report performance factors are below 1.0 for some time period but not long enough to bring the cumulative performance factor below the planned productivity value of 1.0. Referring back to research completed on defense contracts, Christensen and Heise stated, "The cumulative PF does not change by more than 10% from its value at the 20-30% completion point, and in most cases only worsens." When this statement is put to test on this project, which had a performance factor of 1.13 at 30% complete and 1.03 at 100% complete, this statement holds up since the performance factor change was only 9.7% over that duration. Additionally, the performance factor was also not improved upon in the long run since it decreased from the 30% complete mark until project completion.

If a project's performance factor is below planned productivity, the next step is to look at the individual activities that are causing the performance factor to be less than desirable. On this project, the demolition and core drilling work was well under a performance factor value of 1.0 because the crews were jumping from floor to floor in the beginning couple of weeks of the project in order to keep the crews busy while getting as much work done as possible. As will be shown in Section 2.1.7, *Project Crew Mix*, the project crew mix for the duration of the project also impacted the cumulative project performance factor.

2.1.5 Manhour Forecasts By Tracking Method

The four methods of project tracking that were simultaneously tracked for every project for this research are the quantity installed, subjective evaluation, 0-50-100%, and 0-100% methods. The quantity installed method is universally known to be the actual and exact status of a project at any point in time. The other methods were simultaneously tracked for this research to investigate how simplifying the tracking system impacted accuracy. These other tracking methods typically require significantly less labor to complete. Therefore, if one or two methods can be determined to be equally as accurate as the quantity installed method, then they can become power tools for project management on site while minimizing the time needed to obtain the essential project tracking information.

A direct relationship exists between the cumulative performance factor and the forecasted manhours at completion.

The forecasted manhours at completion value can be calculated using the following equations:

Forecasted Manhours at Completion =
Budgeted Hours/Performance Factor
Or
= Manhours Expended/Percent Complete

The forecasted manhours at completion value can be calculated at the activity level and then summed to obtain a total project number. On the other hand, it can be calculated at the project level if that is the only information available. Therefore, the next step in reporting progress with the Earned Value Tracking System is to predict the final number of manhours that will be required to finish the project. This forecast acts as an indicator of how much the project will save in hours or by how many hours the project will exceed the budget. Figure 2-4 shows the forecasted manhours for the four tracking methods throughout the duration of the project.

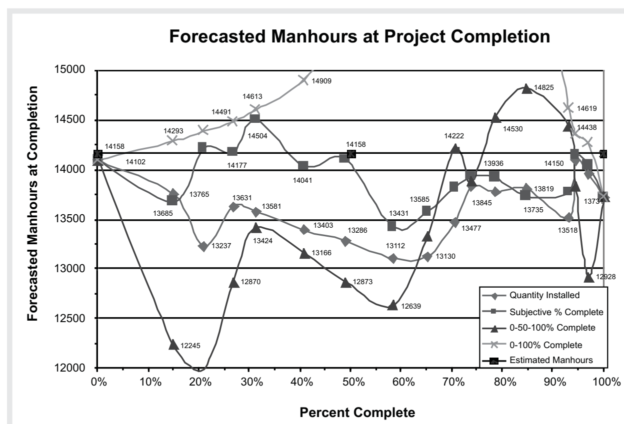

Figure 2-4: *Forecasted Manhours for Four Tracking Methods, Case Study #1*

Again, the actual hours used to complete the project were 13,731. It is important to note that, for the majority of the project duration the quantity installed, subjective evaluation, and 0-50-100% complete methods correctly predicted the overall manhour underrun that actually occurred on the project. The 0-100% complete method was very inaccurate for this project as well as for all the other projects that were tracked for this research. Therefore, after the discussion for this project, the 0-100% complete method will no longer be discussed in this paper.

It is important, however, to understand the nature of the 0-100% tracking method and why in most cases its prediction is much higher than the actual hours. In the 0-100% complete method, an activity's hours are not earned until the activity is 100% complete. It is for this reason that, throughout most of the project this tracking method is showing only hours being used up rather than hours being earned. This, in turn, gives the project and each activity a poor performance factor value. This method is especially poor when the activities that are tracked are relatively large because an activity might have 1,000 budgeted hours and might not finish work until the project is 95% complete. This activity will have an inaccurate and high forecasted manhours at completion value up until the activity is completed, when the earned hours are given to equal the budgeted hours for that activity. Additionally, this method of tracking is also poor when most of the activities will be completed mostly at the end of the work, because no hours will be earned for the project until the end of the project. This will result in extraordinarily high forecasted manhours at completion for the project duration and up until the majority of activities are being completed where the true picture of the project status becomes evident. Therefore, for the 0-100% complete method to be useful, the scope of work must be broken down into very small activities (40 manhours per activity), and the work schedule must be one where activities will be completed throughout the duration of the project.

The manhour forecast error for each of the four tracking methods is shown in Figure 2-5. The predictions at every point in the project for each method were compared against the final actual manhours to complete work (13,731) in order to come up with this forecast error.

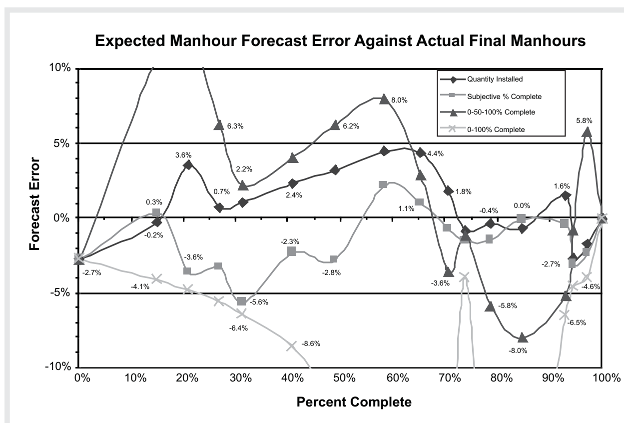

Figure 2-5: *Manhour Forecast Error for Four Tracking Methods, Case Study #1*

Project % Complete	20%	35%	50%	65%	75%	85%	100%
Correctly Forecasting Underrun	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Forecasted Manhours at Completion	13,237	13,500	13,250	13,134	13,812	13,821	13,731
Forecast Error	-3.6%	-1.7%	-3.5%	-4.4%	0.6%	0.6%	0.0%

Table 2-3: *Percent Error of Manhour Forecast, Case Study #1*

Using the predicted manhour value found at each reporting period, the quantity installed forecast shown above is fairly accurate for the entire project duration since its error never exceeds 4.5%. This manhour forecast also improves its accuracy as the project progresses. This improvement becomes very evident from 70% complete until the end of the project where the forecast never exceeds 2.7%. This improving accuracy as time passes is important for the project management staff to know since every ensuing forecast has a greater accuracy than the previous forecast. The accuracy for defined points in time for the quantity installed method is shown in Table 2-3.

From this table it is important to note that the forecasted manhours at completion successfully predicted the manhour underrun at every defined percent complete. This is important to project management staff since throughout the project it can be seen that the project will come in under budget. For this project there was never a warning sign for a labor overrun at any stage of the project.

The forecast error graph for the subjective evaluation method shown in Figure 2-5 shows that the subjective evaluation method is also an accurate way to track this project since its forecast error is never greater than 5.6%. Additionally, this error decreases significantly as the project progresses. This is a very good trend from the research team's perspective as well as from the project management's perspective. From 40% complete onward, the subjective evaluation error is never greater than 2.8%. This is extraordinary accuracy, which shows the true power and capabilities of earned value project tracking. The subjective evaluation error differs slightly from the quantity installed error rather early in the project when the foreman and project managers are a bit more pessimistic about the progress of the work. However, from 55% complete until the end of the project, errors for these methods nearly mirror each other. The subjective evaluation method is even more accurate than the quantity installed method from 40 to 70% project completion.

The 0-100% complete method has a relatively large forecast error up until the end of the project for reasons discussed in sections above. The 0-50-100% complete method has forecast errors that vary widely throughout the project and for many of the same reasons as the 0-100% complete method. However, the 0-50-100% complete method is much more accurate than the 0-100% complete method because this method includes all the same data as the 0-100% (attributing 100% of the budgeted hours as earned when work is completed on an activity) while adding a midpoint in the analysis to make it much more reflective of the actual project (attributing 50% of the budgeted hours as earned when work starts on an activity). It is important to note that the 0-50-100% complete method requires no additional work or labor to complete its analysis as opposed to the 0-100% complete and therefore should always be preferred over the 0-100% complete method. This is the final reason why the 0-100% complete method analysis and results are shown for this project in the research while removed for the rest of the projects. Lastly, it is interesting to note that the 0-50-100% complete forecast error will typically cross at 0% error somewhere in the middle of the project. In this project that crossing point occurs at 68% project complete.

2.1.5.1 Percent Complete

Another important issue in the construction industry is determining the percent complete of a project at any point in time. This determination is of fundamental importance to the accuracy of the earned value system. Generally, the quantity installed method is viewed as the actual project percent complete. For this reason the other tracking methods' percent complete deviation from the actual percent complete should be graphed. This information is shown in Figure 2-6.

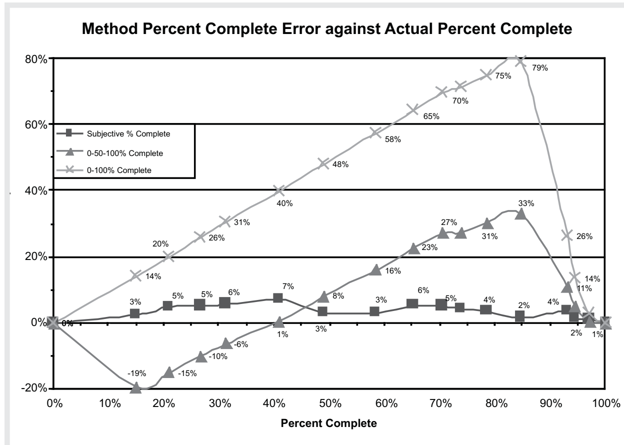

Figure 2-6: *Method Percent Complete Error against Actual, Case Study #1*

Certain trends from previous figures are also shown on this graph. It can be seen that the 0-100% complete method severely understates the actual project percent complete for the duration of the project. Only at the end of the project when the majority of activities are being completed does it get close to the actual percent complete. The subjective evaluation method never deviates significantly from the quantity installed method, but it does consistently understate the actual percent complete on the project. This is due to the foreman and project manager being on the cautious side of coming up with the subjective percent completes. The difference between these methods also seems to decrease as the project progresses. The 0-50-100% complete method, on the other hand, overstates the project percent complete early in the project as activities are starting and half of the budgeted hours for each started activity become earned. Then, around the 50% complete mark, this trend reverses and the 0-50-100% complete method understates the project percent complete before a significant number of activities are completed.

One goal of this research was to determine which tracking method most closely correlated with the quantity installed method of project tracking. For the manhour forecasts, the subjective evaluation method had about three times less variance than the 0-50-100% complete method and approximately 17 times less variance than the 0-100% complete method. The 0-50-100% complete method had seven times less variance than the 0-100% complete method. Therefore, the subjective evaluation method most closely correlates to the quantity installed method by a rather significant margin over the other two methods, while the 0-50-100% complete method is distinctly better than the 0-100% complete method.

2.1.5.2 Performance Factors

The cumulative performance factors for all four tracking methods are shown in Figure 2-7, which also shows the general trends that often occur for the four tracking methods. The performance factor value for the subjective evaluation method at 30% complete is 0.94, while it ended up being 1.03 at project completion. This represents an 8.7% change, which is less than a 10% change over this time span and is similar to the quantity installed method. The other two project tracking methods do not exhibit this trait.

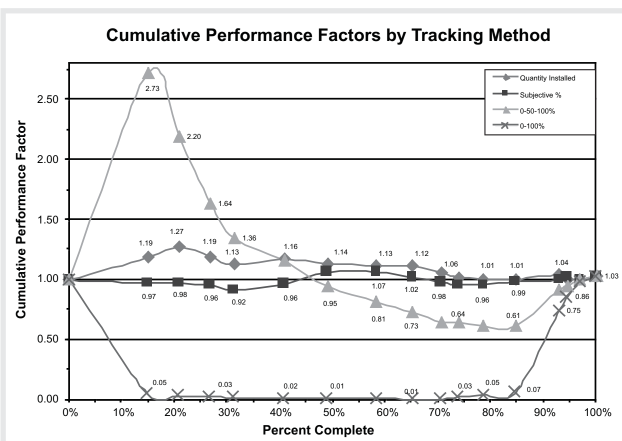

Figure 2-7: *Cumulative Performance Factors for Four Tracking Methods, Case Study #1*

2.1.6 Project Schedule Analysis

In the sections above only the manhour forecasts as an early warning sign for project cost overruns were discussed. Another key aspect of any project tracking system is the project schedule analysis. Analyzing the project schedule and obtaining an early warning of a schedule overrun can be very beneficial to the project management staff. Often, if a project schedule is overrun, the contractor or subcontractor can be charged significant sums of liquidated damages. Many times, when it is determined that a project schedule will be overrun in the future, a contractor must employ acceleration techniques that are labor related in order to finish work on schedule. These include over-manning the project, working overtime, and doing shift work. All these techniques add significant cost. These added costs can be the result of paying extra wages for overtime work or for the loss of productivity associated with over-manning a project. The earlier a schedule overrun or underrun can be determined in a project, the better the overrun can be mitigated and the better the underrun can be used to decrease project costs.

Calculating the total estimated weeks to complete a project is one crucial schedule analysis tool available for contractors. Project management staff can look at the total estimated weeks to complete forecast at any stage in a project to gauge how many weeks it will take to complete the work if the work productivity to date continues until the end of the project. Figure 2-8 shows the total estimated weeks to complete the work for this project. The contract weeks for the project were 15, while it actually took 17 weeks to complete the work. Early in this project, work was progressing at a fast pace. This is evident from the initial points in Figure 2-8, where the project was expected to finish ahead of schedule. At around 75% project complete, the total estimated weeks to complete began to predict a schedule overrun, just as Hanna's control points, schedule variance, and the S-curve did around 65% to 75% complete.

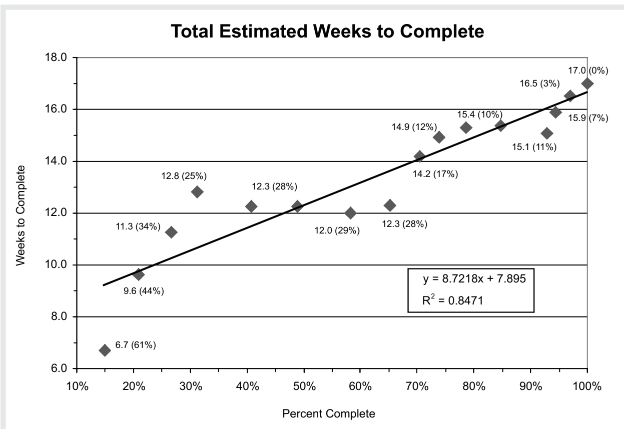

Figure 2-8: *Total Estimated Weeks to Complete, Case Study #1*

However, the trend of the total estimated weeks to complete graph shows that, for almost every successive report, the total estimated weeks to complete value increased. Therefore, the project was progressing at an increasingly slower rate. This sort of situation lends itself to a linear regression. The linear trend evident in Figure 2-8 is statistically a rather good fit since the R^2 value, which is a measure of variability between the model and the data, is 0.85. The R^2 can also be thought of as how well the model fits the data with a perfect fit being a value of 1.0. The linear regressed total weeks to complete accurately predicted the final weeks to complete but for the purpose of simplicity that analysis has not been included in this book.

This forecast showing a schedule underrun also affected the project management's crew mix decisions. This will be discussed more fully in Section 2.1.7, *Project Crew Mix*. The amount of management on site was decreased significantly and a larger proportion of work was being completed by sub-journeymen rather than journeymen as the project went along. Lastly, the crew size on site was decreased throughout the job in order to limit the number of labor inefficient hours. All three of these alterations were a factor in the expected weeks to complete predictions increasing throughout the project as well as the project coming in under budget.

These total estimated weeks to complete values can be compared against the actual weeks needed to complete the project, which was 17 weeks for this project, in order to obtain a forecast error. This prediction error is shown in parentheses in Figure 2-8. It can be seen that the total expected weeks to complete prediction error starts out rather large but continually and sharply decreases throughout the project. Again, the trend in the forecast is evident as the data closely correlates to a linear trend. This trend, along with project management's knowledge of the work that remained, provided a key tool for analyzing the project schedule in real time.

2.1.7 Project Crew Mix

The crew mix on a project goes a long way toward determining project productivity. Certain crew mixes lend themselves to better productivity rates because of the job tasks that each labor type does. A foreman is a field supervisor who is in charge of a group of workers. A journeyman is a craft or skilled worker who has completed apprenticeship training and has been admitted to full membership in his or her craft. An apprentice (sub-journeyman) is a person who is engaged in learning a trade through employment under the supervision of a certified journeyman and by attending apprenticeship training. Generally, a higher foreman-to-apprentice ratio results in better job management and higher project productivity. The same can be said that a higher journeyman-to-apprentice ratio typically results in higher productivity because the more journeymen there are, the more skilled and knowledgeable the labor force, and therefore more work will get done. Sub-journeymen are still learning the trade and often need hands-on guidance for some of the work they complete. The breakdown of labor hours by foreman, journeyman, and sub-journeyman (apprentice) per month on the project is shown in Figure 2-9.

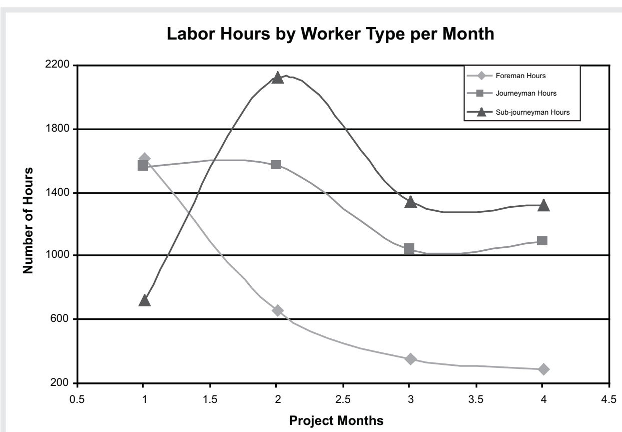

Figure 2-9: *Project Labor Hours by Worker Type per Month, Case Study #1*

It can be seen in Figure 2-9 that the foreman hours on site continually decreased throughout the project, while the journeyman hours followed the same trend but to a lesser degree. The sub-journeyman hours started out low then increased to a maximum and then finished the project out at a medium level. This graph, along with the project performance factor graph shown in Figure 2-3, can lead to some final conclusions about crew mix. From that graph, the cumulative performance factor for the first month of the project was around 1.20. After the first month this cumulative performance factor on the project steadily declined until the final performance factor value of 1.03 was reached at project completion. This is interesting because, as the cumulative performance factor is decreasing throughout the project, so are the foreman-to-journeyman and the journeyman-to-sub-journeyman ratios. This trend follows the general trends for crew mix ratios. For this project, the time period with the highest project performance factor is when the foreman-to-journeyman ratio was approximately one and the journeyman-to-sub-journeyman ratio was approximately two.

2.1.8 Case Study #1 Summary

The tracking for this project resulted in numerous findings that can be helpful to the entire contracting industry. Of course it is understood that this section presents the findings of only one project. There are four essential project tracking tools when it comes to looking at the project schedule for early warning signs of a schedule overrun or underrun. First, it was determined that Hanna's control points can be an accurate predictor of a schedule overrun when a schedule overrun was predicted for this project at 75% project complete. Second, the S-curve accurately predicted a schedule overrun at 55% project complete and is another tool useful to project management when analyzing the project schedule. Third, the schedule variance predicted a schedule overrun at 75% project complete. Fourth, the total expected weeks to complete value predicted a schedule underrun early in the project, like many other of these tracking methods, when work was progressing rapidly, but then accurately predicted a schedule overrun at 75% project complete. All these tracking methods should be used in conjunction with one another to help in determining early project warning signs. If it can be determined, for example, at 65% project complete that all the variables/values are predicting a schedule overrun, there is still a good portion of the project left in which to make project changes to prevent this. This can save the project a lot of money and headaches in the long run.

A few conclusions were also drawn from the project performance factors. This information is summarized in Table 2-4. For the quantity installed method of project tracking it was determined that that performance factor value at 30% complete (1.13) did not vary by more than 10% (actually 9.7%) at project completion (1.03). Additionally, it only worsened, as many previous research sources stated that it does. Also, the same was true for the subjective evaluation method of project tracking, since the performance factor value at 30% complete (0.94) did not vary by more than 10% (actually 8.9%) at project completion (1.03). However, this performance factor actually increased as the project progressed.

The expected manhours at completion for the quantity installed method had a forecast error of less than 4.5% for the duration of the project, and in most cases it was significantly less. The subjective evaluation expected manhours at completion forecasts were also fairly accurate for the project. The error for this method was less than 5.6% for the entire project duration and less than 2.8% after 30% project complete. Additionally, this project tracking method most closely correlated with the quantity installed method of project tracking. Lastly, both of these methods correctly predicted the manhour underrun throughout the project.

The forecasts, trends, project values, and their accuracies for this project show how useful an effective Earned Value Tracking System can be to the project management staff. This tracking system can effectively and accurately determine early warning signs of

Tracking Method	PF at 30% Complete	PF at 100% Complete	Percent Change	Predicted Eventual Labor Hours Underrun
Quantity Installed	1.13	1.03	-9.7%	Yes
Subjective Evaluation	0.94	1.03	8.9%	No
0-50-100% Complete	1.36	1.03	-32.0%	Yes

Table 2-4: *Project Performance Factor Summary, Case Study #1*

a labor and schedule overrun or underrun. This information can assist management in making important sequencing, crew mix, and manpower decisions for the remainder of the project.

2.2 CASE STUDY #2

2.2.1 Introduction

Tracking the case study projects has allowed for an in-depth investigation into the applicability of earned value analysis in mechanical, HVAC, and sheet metal construction and similar labor-intensive trades, the accuracy of predicting project outcome using subjective evaluation, the binary system versus actual field measurement, and the accuracy and applicability of Hanna's control points for project progress benchmarking. The precision of using performance factors as a prediction tool for forecasting project outcome was also investigated.

Three main parts to the case study are presented in this chapter: a description of the project, methodology for the implementation of earned value, and the accuracy of the results. There are a few values on which the earned value system is based: the forecasted manhours at completion, percent complete determination, performance factors, total estimated weeks to complete, and the cost and schedule variances. These categories will be analyzed at selected points throughout the project. At these selected junctures, the accuracy of the prediction will be determined and a comparison to previously defined control points will be conducted.

2.2.2 Project Description: Paper Mill Project

This project in the western United States consisted of architectural sheet metal work. The scope of work for this project consisted of reconstructing the exterior sheet metal for a paper mill. Work on this project was undertaken from the end of June until the end of December. Because this project was design-bid-build, where the design was completed by another company, there was a large amount of change order work for this project. The original manhour budget for the project was 13,099 manhours and the initial contract weeks for the project were 17. The significant amount of change order work for this project totaled 1,010 manhours of work and represented a 7.7% change on the project. Additionally, starting at the 40% project complete mark, the contractor started working 50-hour weeks because the owner wanted to have the work dried in early and was willing to pay extra for this overtime. To complete the work, the contractor took 29 weeks and used 15,268 manhours, over the labor budget and over schedule. On average for this project, one foreman, eight journeymen, one arch journeyman, and three apprentices were working on site.

2.2.3 Methods

The contractor already had a labor feedback system in place prior to participation in this research, which made it easier to provide the necessary information for this research. The contractor's system primarily relied on capturing the manhours expended by cost code and comparing them to the manhour estimate. An example of the contractor's labor tracking report is shown in Figure

2-10. This allows project management to see manhour overrun by cost code but only after the cost code has already overrun the budget. This research used a much more effective project tracking system. Prior to this research the contractor did not report quantity installed; the contractor had to make an adjustment in order to provide the research team with the necessary information for this research. For this project, the work was broken down into bridge elevations, interior panels, north elevation, south elevation, east elevation, west elevation, and roof panels, along with a few other miscellaneous activities. In this particular project, the contractor WBS consisted of 18 cost codes to which the field workers allocated their hours.

2.2.4 Quantity Installed Project Tracking Results

The entire project had 1,010 change order hours, which brought the total budgeted manhours at project completion to 14,109, up from 13,099 budgeted manhours at the start of the project. At project completion the contractor had used 15,268 manhours to complete the work, which was 1,159 manhours over the final labor budget. This represents an 8.2% overrun from the final budgeted hours for the project. The project ended up taking 29 weeks to complete the work, 12 weeks over the initial 17 contract weeks that were allotted for the work to be completed and 5 weeks over the 24 final contract weeks, which included the time

	HOURS		
	Estimate	Actual	Variance
004-999-999 Administration Labor		7.78	7.78-
004-999-999 Shop Labor - Detailing		.67	.67-
004-999-999 Shop Labor	81.90	26.12	55.78
004-999-999 Shop Labor (Indirect)	5.70		5.70
004-999-999 Delivery Labor		2.51	2.51-
004-999-999 Job Labor	1,801.88	628.50	1,173.38
Total Labor	1,889.48	665.58	1,223.90
004-999-999 Contractor Owned Rental			
Total Material	.00	.00	.00
Total for North Elevation	3,113.80	1,270.11	1,843.69
005-001-999 Administration Labor		26.05	26.05-
005-001-999 Shop Labor		1.04	1.04-
005-001-999 Job Labor	2,094.00	2,128.00	34.00-
005-001-999 Job Labor (Indirect)			
Total Labor	2,094.00	2,155.09	61.09-
005-999-999 Administration Labor		12.89	12.89-
005-999-999 Shop Labor - Detailing		1.00	1.00-
005-999-999 Shop Labor	66.90	86.85	19.95-
005-999-999 Shop Labor (Indirect)	4.70		4.70
005-999-999 Delivery Labor		13.00	13.00-
005-999-999 Job Labor	878.00	1,048.50	170.50-

Figure 2-10: *Contractor Labor Tracking Printout, Case Study #2*

extension given as a result of the change orders. Therefore, this project finished over budget from a labor perspective and over schedule with a schedule overrun of 5 weeks. The work scope for this project was broken down into 18 activities, with the largest activity representing 14.7% of the labor budget. One other activity represented 13.0% of the labor budget, but the rest of the activities each comprised less than 10% of the budget on their own. Overall, the project was well broken down, with the exception of the two activities that represented 27.7% of the project labor budget. These two activities were closely monitored so that they did not disproportionately affect the project forecasts.

The results detailed in this section are from the quantity installed method of project tracking. Overall, the final installed quantities exceeded the initial budgeted quantities at the project level by 8.2%. This means that the initial budgeted quantities for numerous activities were too low. The majority of these increases were a result of the project change orders, since at project completion the quantities installed exceeded the final project budgeted quantities by only 0.5%. The information for which activities significantly installed more quantities than originally budgeted can be used in future project estimating.

2.2.4.1 Hanna's Control Points

As described in previous sections, Hanna's control points identify a minimum amount of manpower that should be consumed in relation to a percent of project duration. This amount of manpower is tied to a minimum project percent complete that should be completed at different points of the planned project duration. This comparison is a tool to show whether the project is performing at a level that will accommodate project completion for the planned date. Table 2-5 provides the comparison between the paper mill project and industry values for sheet metal construction.

The table below is noteworthy because, judging from the comparison between Hanna's control points and this project's percent complete, it is evident that, throughout its duration, the project is not meeting the minimum progress requirements. This is one early warning sign of a significant schedule overrun on the project, which is evident from 25% project complete or earlier.

2.2.4.2 S-Curves

The manpower loading curve comparison leads right into project S-curve development. By plotting cumulative values for the planned and actual manpower along with the addition

% Planned Project Duration		**35%**	**50%**	**65%**	**75%**	**85%**	**100%**
Hanna's Control Points	% Complete	38% or more	60% or more	75% or more	85% or more	93% or more	100%
Actual Project	% Complete	**27%**	**40%**	**54%**	**62%**	**68%**	**76%**

Table 2-5: *Comparison Between Hanna's Control Points and Project % Complete, Case Study #2*

of an earned manhour curve, a project S-curve is developed. The S-curve then allows variances to be shown, indicating the cost and schedule position of the project. The S-curve for this project is displayed in Figure 2-11. As described in *Part 1, Earned Value Analysis*, the cost and schedule variance values can be obtained from the earned, expended, and budgeted manhours that are shown in this figure.

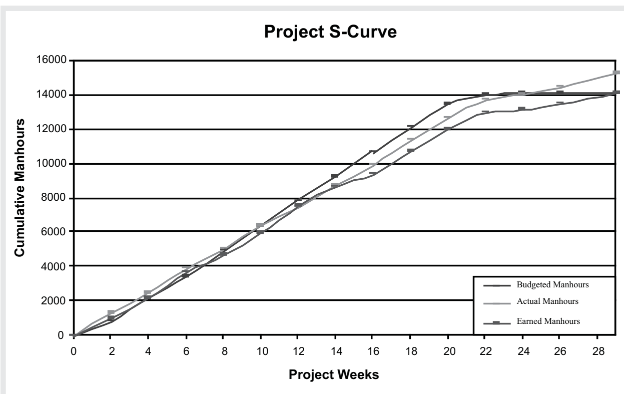

Figure 2-11: *S-Curve for Case Study #2*

It can be observed from the S-curve that the project is headed for a schedule overrun as early as Week 7, when the total budgeted manhours first exceed the earned manhours. Additionally, it can be seen throughout the project duration that the project is headed for a labor overrun since the actual manhours always exceed the earned manhours on the project. Having these early warning signs can be invaluable while there is still time to make project corrections or alterations.

When the cost or schedule variance values are consistently negative, or negative and increasing in magnitude, a red flag is triggered and management needs to devise a way to combat the potential overruns in labor and slippage in schedule. Table 2-6 below shows how the cost and schedule variance for this project changed at defined project junctures.

This table provides a more detailed story as to the progress of the project. It shows that, throughout the project, the labor usage is an issue since at every stage in the project the earned hours are fewer than the expended hours (negative cost variance). Also, it can be seen that, at 27% complete, Hanna's control points indicate a serious warning of a schedule overrun and that, at 40% complete, the schedule variance indicates another serious warning of a schedule overrun. In addition to these early warnings, the schedule variance is significantly decreasing throughout the project duration. These smaller values are not so serious if management is able to respond to them in a timely fashion and correct the

% Planned Project Duration		**35%**	**50%**	**65%**	**75%**	**85%**	**100%**	
Hanna's Control Points	% Complete	30% or more	40% or more	62% or more	80% or more	90% or more	100%	
Actual Project	% Complete	43%	62%	69%	**76%**	**84%**	**94%**	**100%**
	Cost Variance (Mhrs)	860	963	618	223	139	118	427
	Schedule Variance (Mhrs)	650	738	89	**-395**	**-594**	**-742**	**0**

Table 2-6: *Cost and Schedule Variances for Duration of Project, Case Study #2*

problems. Project management was not able to correct the labor or schedule issues, as both variances continued to worsen even after these warning signs were evident. Change orders, overtime labor, and project crew mix all contributed to the final state of the project at completion.

2.2.4.3 Performance Factors

Performance factors can be looked at for each activity being tracked or over a project as a whole, on a period-by-period basis or cumulatively throughout the project. Figure 2-12 displays the performance factors for each period and cumulatively for the entire project duration. The performance factors shown are the exact project performance factors obtained from the quantity installed method of project tracking.

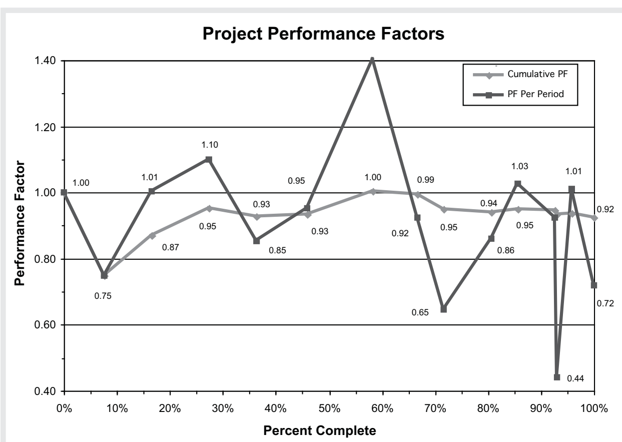

Figure 2-12: *Project Performance Factor Profiles, Case Study #2*

The profile shown in Figure 2-12 clearly shows a trend in which the performance of the project overall is in poor shape throughout the project. Around the middle of the project the cumulative performance factor nears a planned productivity value of 1 for some time period but then sharply declines shortly thereafter. Referring to research completed on defense contracts, Christensen and Heise stated, "The cumulative PF does not change by more than 10% from its value at the 20-30% completion point, and in most cases only worsens." When this statement is put to test on this project, having a performance factor of 0.95 at 30% complete and 0.92 at 100% complete, this statement holds up since the performance factor change was only 3.2% over that duration. Additionally, the performance factor was also not improved upon in the long run since its value at project completion was less than the performance factor value at 30% project complete.

If a project's performance factor is below planned productivity, the next step is to look at the individual activities that are causing the performance factor to be less than desirable. On this project, the south elevation was well under a performance factor value of 1.0 because the owner placed some physical obstacles to work in this region and some change order work was completed on this region. Also, as will be shown in Section 2.2.7, *Project Crew Mix*, the project crew mix for the duration of the project also impacted the project performance factor.

2.2.5 Manhour Forecasts By Tracking Method

The four methods of project tracking that were simultaneously tracked for every project for this research are the quantity installed, subjective evaluation, 0-50-100%, and 0-100% methods. The next step in the reporting process with the earned value system is to predict the final number of manhours that will be required to finish the project. Figure 2-13 shows the forecasted manhours for three tracking methods throughout the duration of the project. The 0-100% method of project tracking has been eliminated from the analysis for this project for reasons explained in Section 2.1.5, *Manhour Forecasts By Tracking Method*.

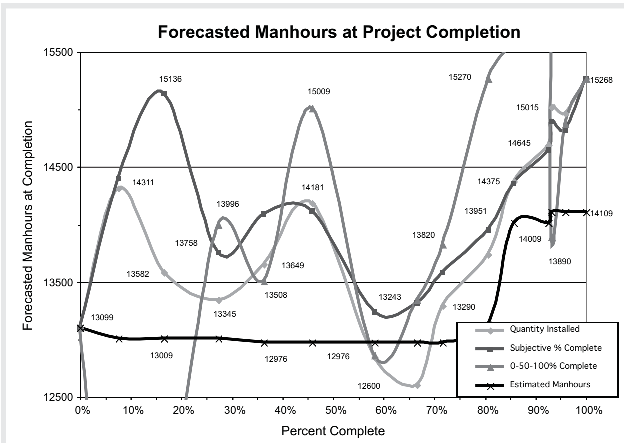

Figure 2-13: *Forecasted Manhours for Three Tracking Methods, Case Study #2*

In this project it can be seen that, from project start until 65% complete, the forecasted manhours at completion for the quantity installed method has a general decreasing trend. From 65% complete until the end of the project, the forecast significantly increased when the majority of change order work was being completed and when extended overtime work began to negatively affect the project performance. It is important to note that the quantity installed manhour forecast successfully predicted a manhour overrun throughout the project duration, with a small exception around the 65% project complete mark. Also, the subjective evaluation method and the 0-50-100% complete method both correctly predicted the overall manhour overrun over the entire project duration. The actual hours used to complete the project were 15,268.

The manhour forecast error for each of the three tracking methods is shown below in Figure 2-14. The forecast error is calculated from the hours used at completion for the given work scope at the given point in time. This is done because, for example, at 20% project complete it was not known that there would be over 1,000 hours of change orders. Therefore, the error should not be based on all the hours needed to complete, but only the hours needed to complete the known work scope at any point in time.

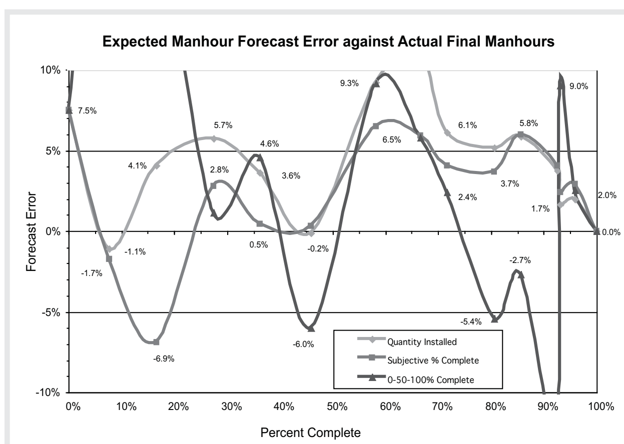

Figure 2-14: *Manhour Forecast Error for Three Tracking Methods, Case Study #2*

Project % Complete	20%	35%	50%	65%	75%	85%	100%
Correctly Forecasting Underrun	Yes	Yes	Yes	No	Yes	Yes	Yes
Forecasted Manhours at Completion	13,431	13,588	13,381	12,694	13,512	14,375	15,268
Forecast Error	-5.1%	-4.0%	-5.5%	-10.3%	-4.6%	-5.8%	0.0%

Table 2-7: *Percent Error of Manhour Forecast, Case Study #2*

Using the predicted manhour value found at each reporting period, the accuracy of the forecast shown for the quantity installed method is fairly accurate for the duration of the project since its error never exceeds 11.0%. Also, the manhour forecast generally improves in accuracy as the project progresses. This steady improvement becomes very evident from 65% complete until the end of the project. This improving accuracy as time passes is important for the project management staff to know since typically every ensuing forecast will have a greater accuracy than the previous one. The prediction accuracy for defined points in the project duration is shown in Table 2-7 above.

From this table it is important to note that the forecasted manhours at completion successfully predicted the manhour overrun at every defined percent complete except at 65% complete, when work was progressing slightly above plan.

The forecast error shown in Figure 2-14 shows that the subjective evaluation method is also an effective and accurate way to track this project, since its forecast error is never greater than 6.9%. Additionally, this error generally decreases as the project progresses. This is a good trend to see from the research team's perspective as well as from the project management's perspective. From 25% to 50% project complete, the subjective evaluation method has an error that is never greater than 2.8%, which provides an impressive and accurate early warning sign for the project labor. The subjective evaluation error differs slightly from the quantity installed error rather early in the project, when the foreman and project managers are a bit more pessimistic about the progress of the work. However, from 45% complete until the end of the project, errors for these methods nearly mirror each other. The subjective evaluation method is as accurate as or even more accurate than the quantity installed method from 25% to 100% project completion.

The 0-50-100% complete method has forecast errors that vary widely throughout the project duration. This is expected based on how this method works. Lastly, it is interesting to note that the 0-50-100% complete forecast error will typically cross at 0% error somewhere in the middle of the project. In this project, two crossing points in the middle of the project occur at 40% and 50% project complete.

2.2.5.1 Percent Complete

Another important issue in the construction industry is determining the percent complete of a project at any point in time. This determination is of fundamental importance to the accuracy of the Earned Value Tracking

System. Generally, the quantity installed method is viewed as the actual project percent complete. For this reason, the percent complete deviation from the actual percent complete should be graphed for the other tracking methods. This information is shown in Figure 2-15.

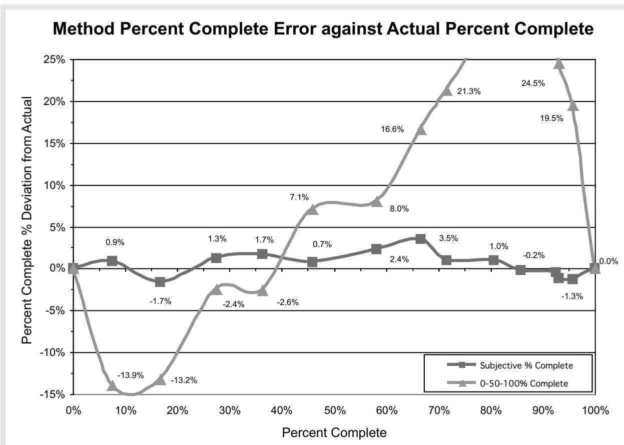

Figure 2-15: *Method Percent Complete Error against Actual, Case Study #2*

Certain trends from previous figures are also shown on this graph. The subjective evaluation method never deviates significantly from the quantity installed, but it does consistently understate the actual percent complete on the project. This is due to the foreman and project manager being on the cautious side of determining the subjective percent complete for work on the project. The difference between these methods seems to stay about the same as the project progresses. The 0-50-100% complete method, on the other hand, overstates the project percent complete early in the project as activities are starting, and half of the budgeted hours for each started activity become earned. At around the 40% complete mark, this trend reverses and the 0-50-100% complete method understates the project percent complete before a significant number of activities are completed.

One goal of this research was to also determine which tracking method most closely correlated with the quantity installed method of project tracking. For the manhour forecasts, the subjective evaluation method for this project had about 2.4 times less variance than the 0-50-100% complete method and approximately 10 times less variance than the 0-100% complete method. The 0-50-100% complete method had about four times less variance than the 0-100% complete method. Therefore, the subjective evaluation method most closely correlates with the quantity installed method over the other two methods, while the 0-50-100% complete method is distinctly better than the 0-100% complete method.

2.2.5.2 Performance Factors

The cumulative performance factors for the three tracking methods are shown in Figure 2-16. This graph also shows the general trends that often occur for these three tracking methods. The performance factor value for the subjective evaluation method at 30% complete is 0.88, and it ended up being 0.92 at project completion. This represents a 4.3% change, which is less than a 10% change over this time span and is similar to the quantity installed method and past research. Additionally, the 0-50-100% complete method has a performance factor value of 1.01 at 30% complete, which represents a 9.8% change at project completion.

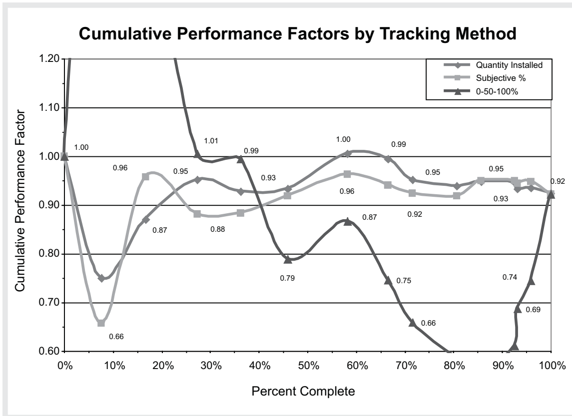

Figure 2-16: *Cumulative Performance Factors for Three Tracking Methods, Case Study #2*

2.2.5.3 Project Issues Summary

Through interviews with participating mechanical, HVAC, and sheet metal contractors, it was determined that, if a project goes poorly from a labor or schedule perspective, it could be the result of one or more of the eight factors listed below:

1. A vendor issue, where a materials/equipment order is delivered incorrectly, incomplete, or with shipping damage;
2. Schedule or coordination issues with the general contractor or other subcontractors that result in lost work hours (Happe, 2008);
3. An unorganized third party within the company that provides assistance to the project. If the third party is late to the project, is missing material/activity sheets, or does not have a clear scope of work, this can result in lost work hours on the project;
4. Shop problems, such as the material delivered to the site is incorrect, is missing items, is of poor quality, or is late;
5. Failure of the project manager to order materials in a timely manner or to communicate information properly (Happe, 2008);
6. The lead technician's inadequate communication of the daily goals to his/her crew or failure to provide the proper materials or equipment;
7. Inefficient, incompetent, or slow crew. The lead technician should monitor this and be able to diagnose this as the problem if it is.
8. The wrong labor mix being used on site (Happe, 2008). The lead technician needs to ensure that the crew on the project meets the net average labor cost of the project.

The issues described above encompass all the possible causes of lost labor time, which in turn hurts the project budget and project schedule. When one or more of these issues arises, it is important to document the issue as completely as possible so that these project records can possibly be used in a cumulative impact claim if the project events warrant such action. Additionally, it is important to have meetings with the interested, affected, and involved parties so that this issue's effects can best be mitigated and future issues can be avoided.

2.2.6 Project Schedule Analysis

In the previous sections manhour forecasts were discussed as an early warning sign for project cost overruns. However, the other key aspect of any project tracking system is the project schedule analysis. Analyzing the project schedule and obtaining an early warning of a schedule overrun can be very beneficial to the project management staff.

Many times, when it is determined that a project schedule will be overrun in the future, a contractor employs acceleration techniques in order to finish work on schedule. These include over-manning the project, working overtime, and doing shift work. All these techniques add significant cost. These added costs can be the result of paying extra wages for overtime work or for the loss of productivity associated with over-manning a project. The earlier a schedule overrun or underrun can be determined on a project, the better the overrun can be mitigated and the better the underrun can be utilized to decrease project costs.

Calculating the total estimated weeks to complete a project is one crucial schedule analysis tool available for contractors. Project management staff can look at the total estimated weeks to complete forecast at any stage in a project to gauge how many weeks it will take to complete the work if the work productivity to date continues until the end of the project. Figure 2-17 shows the total estimated weeks to complete the work for this project. The initial contract weeks for the project were 17, while it actually took 29 weeks to complete the work. The final contract weeks for the project were 24, so the work overran the schedule by 5 weeks. Figure 2-17 shows that the project was expected to finish behind schedule throughout the project duration. The total estimated weeks to complete was not the only schedule analysis factor that showed this. Hanna's control points, the schedule variance, and the project S-curve all were showing a schedule overrun very early in the project.

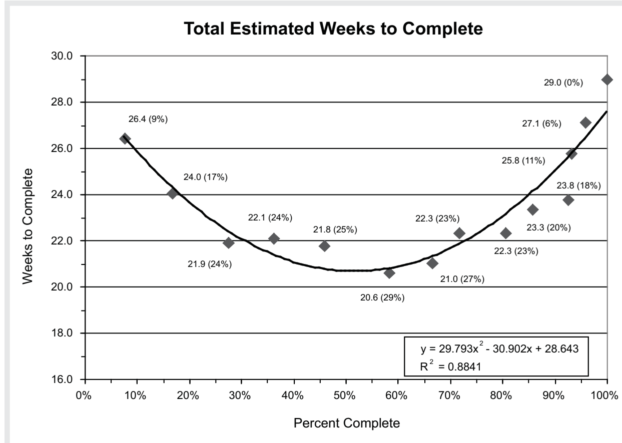

Figure 2-17: *Total Estimated Weeks to Complete, Case Study #2*

However, the trend of the total estimated weeks to complete graph shows that the total estimated weeks to complete decreased until about 50% complete and then increased until the end of the project. This trend lends itself to a best-fit x^2 curve. This x^2 trend evident in Figure 2-17 is statistically a rather good fit since the R^2 value is 0.88. The x^2 regressed total weeks to complete accurately predicted the final weeks to complete, but for the purpose of simplicity this analysis has not been included in this book.

These total estimated weeks to complete values can be compared against the actual weeks needed to complete the project, 29 weeks for this project, in order to obtain a forecast error. The prediction error is shown in parentheses in Figure 2-17. It can be seen that the total expected weeks to complete prediction error starts out small, then increases to a high point and then sharply decreases throughout the rest of the project.

Again, the trend in the forecast is evident as the data closely correlates to an x^2 trend. This trend, along with project management's knowledge of the work that remained, provided a key tool for analyzing the project schedule in real time. It is important to note that, even though these errors appear rather large, the total estimated weeks to complete successfully predicted a schedule overrun throughout the project duration.

2.2.7 Project Crew Mix

The crew mix on a project goes a long way toward determining project productivity on a project. Generally a higher foreman-to-apprentice ratio results in better job management and higher project productivity. The same can be said about a higher journeyman-to-apprentice ratio, which also typically results in higher productivity, because the more journeymen there are, the more skilled and knowledgeable the labor force, and therefore more work will get done. Apprentices are still learning the trade and often need hands-on guidance for some of the work they complete. The correlation on this project between the individual report performance factor and the journeyman-to-apprentice ratio can be seen in Figure 2-18. The foreman-to-journeyman ratios for this project were not analyzed since only one foreman was working for the contractor throughout the entire project duration.

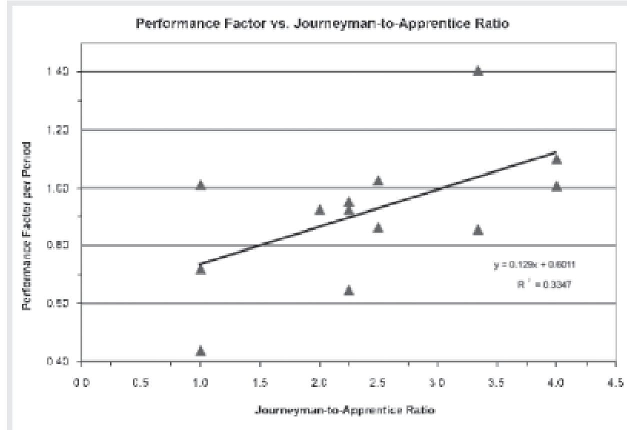

Figure 2-18: *Performance Factor versus Journeyman-to-Apprentice Ratio, Case Study #2*

As expected, it can be seen from Figure 2-18 that there is a slight trend in the project that the higher the journeyman-to-apprentice ratio, the higher the performance factor for that period. This graph, compared with the journeyman-to-apprentice ratio versus the project percent complete shown in Figure 2-19, can lead to some final conclusions about crew mix. Figure 2-19 shows that throughout the project the journeyman-to-apprentice ratio was decreasing, and therefore the general productivity on the project should decrease. However, if the overall project performance factor is studied, this is not the trend observed, since the maximum project performance factor occurred at 60% project complete. However, after this 60% project complete mark, the performance factor value declined continuously until the end of the project. This decrease was determined to be the result of a decreasing journeyman-to-apprentice ratio, the change order work added and completed during this time, and the extended overtime hours that were being worked from the 45% project complete mark until the end of the project.

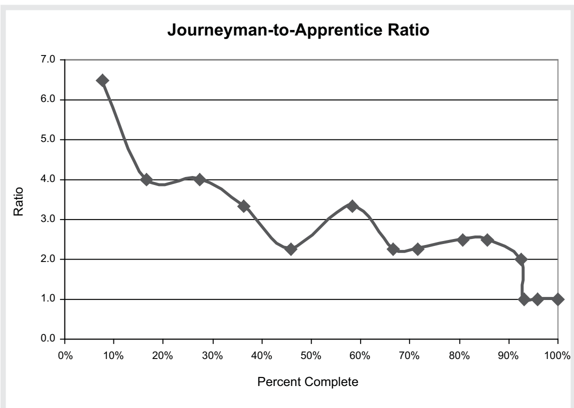

Figure 2-19: *Journeyman-to-Apprentice Ratio, Case Study #2*

2.2.8 Case Study #2 Summary

The tracking for this project resulted in numerous findings that can be helpful to the entire contracting industry. Of course it is understood that what is presented in this chapter are the findings of just one project. There are four essential project tracking tools to use when looking at the project schedule for early warning signs of a schedule overrun or underrun. First, it was determined that Hanna's control points can be an accurate predictor of a schedule overrun when a schedule overrun was predicted for this project at 25% project complete. Also, the S-curve accurately predicted a schedule overrun at 35% project complete and is another tool useful to project management when analyzing the project schedule. The schedule variance predicted a schedule overrun at 35% project complete. The total expected weeks to complete value correctly predicted a schedule overrun for the entire project duration. All these tracking methods should be used in conjunction with one another to help in determining early project warning signs. If it can be determined, for example, at 40% project complete, that all the variables/values are predicting a schedule overrun, there is still a good portion of the project left in which to make project changes to prevent this.

A few conclusions were obtained from the project performance factors. This information is summarized in Table 2-8. For the quantity installed method of project tracking it was determined that the performance factor value at 30% complete (0.95) did not vary by more than 10% (actually 3.2%) at project completion (0.92). Additionally, it only worsened as many previous research sources stated that it does. Also, the same was found for the subjective evaluation method of project tracking since the performance factor value at 30% complete (0.88) did not vary by more than 10% (actually 4.3%) at project completion (0.92). However, this performance factor actually increased as the project went on. Lastly, the same conclusion was reached for the 0-50-100% complete method of project tracking since the performance factor value at 30% complete (1.01) did not vary by more than 10% (actually 9.8%) at project completion (0.92). Again, the value only worsened as the project progressed.

Tracking Method	PF at 30% Complete	PF at 100% Complete	Percent Change	Predicted Eventual Labor Hours Underrun
Quantity Installed	0.95	0.92	-3.2%	Yes
Subjective Evaluation	0.88	0.92	4.3%	Yes
0-50-100% Complete	1.01	0.92	-9.8%	No

Table 2-8: *Project Performance Factor Summary, Case Study #2*

The expected manhours at completion for the quantity installed method had a forecast error of less than 11.0% for the duration of the project and in most cases it was significantly less. This shows that, by using this tracking method, the final manhours for a project can be confidently determined early in a project. The subjective evaluation expected manhours at completion forecasts were also fairly accurate for the project. The error for this method was less than 6.9% for the entire project duration. Both of these methods correctly predicted the manhour overrun throughout the majority of the project duration. Additionally, this project tracking method most closely correlated with the quantity installed method of project tracking. These prediction accuracies show that both of these methods are valuable tools that should be used for project tracking.

The forecasts, trends, project values, and their accuracies shown in this project show how useful an effective Earned Value Tracking System can be to the project management staff. This information can assist management in making important sequencing, crew mix, and manpower decisions for the remainder of the project.

2.3 CASE STUDY #3

2.3.1 Introduction

Tracking the case study projects has allowed for an in-depth investigation into the applicability of earned value analysis in mechanical, HVAC, and sheet metal construction and similar labor-intensive trades, the accuracy of predicting project outcome using subjective evaluation, the binary system versus actual field measurement, and the accuracy and applicability of Hanna's control points for project progress benchmarking. The precision of using performance factors as a prediction tool for forecasting project outcome is also investigated.

Three main parts to the case study are presented here: a description of the project, methodology for the implementation of earned value, and finally, the statistically determined results.

2.3.2 Project Description: University Expansion Project

This project in a Midwestern state consisted of HVAC sheet metal work. The scope of work for this project consisted of constructing the HVAC ductwork systems for an expansion of a large university building. Work on this project was performed from the end of April until mid-January the following year. This project was design-bid-build where the design was completed by another company prior to the start of work. There were no change orders on the entire project. To complete the work, the contractor spent 37 weeks and used 7,344 manhours, which was under the labor budget and ahead of schedule. The crew mix on this project was not tracked by the project management since the number of journeymen and apprentices varied from day to day and were difficult to track. Additionally, this inconsistent crew mix would make it difficult to draw productivity conclusions for every reporting period since there could be as many as five different crew mixes in a given week.

2.3.3 Methods

The contractor already had a project feedback system in place prior to participation in this research, which made it easier to provide the necessary information for this research. The contractor's system primarily relies on capturing the manhours expended and units installed by cost code and comparing them to the original estimate. An example of the contractor's project tracking report is shown in Figure 2-20. This allows project management to see when a manhour or quantity overrun by cost code occurred, but only after the cost code has already overrun the budget. Additionally, there were no columns for the total hours or quantities but only the amount installed and used per week. This research used a much more effective project tracking system. Prior to this research, the contractor did not report the subjective percent complete; an adjustment had to be made in order to provide the research team with the necessary information for this research. In this particular project, the WBS consisted of 76 cost codes. However, the

					WEEK ENDING				
	BUDGET					5/4/2007			5/11/200
CC	DESCRIPTION	UNITS	HRS/EA	HOURS	UNITS	HOURS	% COM	UNITS	HOUR
1-120	M111								
1-121	Rectangular Ductwork & Fittings	501	1.42	709	0	0		0	
1-122	Spiral Ductwork	736.6	0.26	188	0	0		0	
1-123	Diffusers	86	1.07	92					
1-124	Control Dampers	1	3.32	3					
1-125	Fire Dampers	1	1.37	1					
1-130	M112								
1-131	Rectangular Ductwork & Fittings	271	1.29	349	113	175.5	50%		11
1-132	Spiral Ductwork	910.7	0.24	218	15	5.5	25%		12
1-133	Diffusers	101	0.90	91					
1-135	Fire/Smoke Dampers	3	1.33	4					

Figure 2-20: *Contractor Labor Tracking Printout, Case Study #3*

contractor tracked only 26 costs codes for the project, which comprised 82% of the project labor hours. These cost codes were the rectangular ductwork and fittings and the spiral ductwork on the project and were broken down by area. The field workers allocated their hours to these cost codes only. This project shows that portions of a project that will mainly govern the success or failure of the given project can be effectively tracked. This allows the smaller cost codes that can be tedious to track to be eliminated from the tracking, if desired.

2.3.4 Quantity Installed Project Tracking Results

The total budgeted manhours at project start were 8,267 manhours. At project completion the contractor used 7,344 manhours to complete the work, which was 923 manhours under the final labor budget, an 11.2% underrun from the final budgeted hours for the project. The project ended up taking 37 weeks to complete the work, 13 weeks under the 50 contract weeks that were allotted for the work to be completed. Therefore, this project finished under budget from a labor perspective and ahead of schedule with an underrun of 13 weeks. The work scope for this project was broken down into 76 activities with the largest activity representing 8.6% of the labor budget. Seven activities comprised 47.2% of the labor budget, while the rest of the project was broken down very well. These activities were closely monitored so that they did not disproportionately affect the project forecasts.

The results detailed in this section are from the quantity installed method of project tracking. Overall, the final installed quantities were fewer than the initial budgeted quantities at the project level by 16.0%. This means that the initial budgeted quantities for numerous activities were high. The majority of these discrepancies were determined to be variations in the installed quantities or reporting error in the field. The information for which activities installed significantly fewer quantities than originally budgeted can be used to increase the accuracy of future project estimates.

2.3.4.1 Progress Reporting

The analysis conducted for this project, although described in the sections that follow as more of a retrospective of the entire project duration, was completed at regular intervals throughout the project. At each interval, a project progress report was developed with the pertinent values and graphs to allow for a determination of the project status. This report detailed every important project variable and trend in a concise fashion to the project management staff so this information could be used more effectively and efficiently to run the project.

2.3.4.2 Hanna's Control Points

As described in previous sections, Hanna's control points identify a minimum amount of manpower that should be consumed in relation to a percent of project duration. This amount of manpower is tied to a minimum project percent complete that should be completed at different points of the planned project duration. This comparison is a tool to show whether the project is performing at a level that will accommodate project completion for the planned date. Table 2-9 provides the comparison between the university expansion project and industry values and sheet metal construction.

% Planned Project Duration		**35%**	**50%**	**65%**	**75%**	**85%**	**100%**
Hanna's Control Points	% Complete	38% or more	60% or more	75% or more	85% or more	93% or more	100%
Actual Project	% Complete	**64%**	**86%**	**91%**	**100%**	**100%**	**100%**

Table 2-9: *Comparison between Hanna's Control Points and Project % Complete, Case Study #3*

The table above is noteworthy because, judging from the comparison between Hanna's control points and this project's percent complete, it is evident that throughout the project duration the project is meeting the minimum progress requirements. This shows that the control points do not show any sign of an expected schedule overrun at any point in the project.

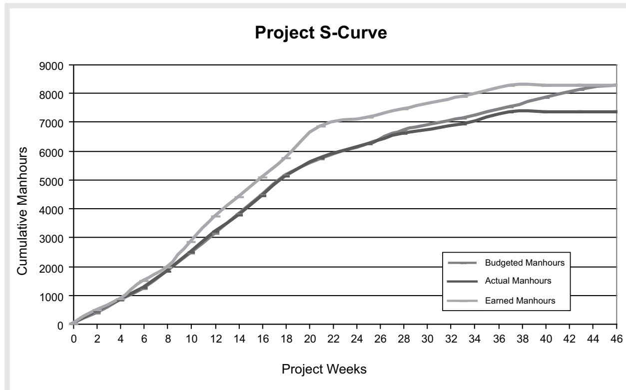

Figure 2-21: *S-Curve for Case Study #3*

2.3.4.3 S-Curves

The manpower loading curve comparison leads right into project S-curve development. By plotting cumulative values for the planned and actual manpower along with the addition of an earned manhour curve, a project S-curve is developed. The S-curve then allows variances to be shown, indicating the cost and schedule position of the project. The S-curve for this project is displayed in Figure 2-21. As described in *Part 1, Earned Value Analysis*, the cost and schedule variance values can be obtained from the earned, expended, and budgeted manhours that are shown in this figure.

It can be observed from the project S-curve that the project is expected to finish ahead of schedule as early as Week 5 when the total earned manhours first clearly exceed the budgeted manhours. Additionally, it can be seen throughout the project duration that the project is headed for a labor underrun since the earned manhours always exceed the actual manhours on the project. These early warning signs can greatly assist the project management staff in making crucial project-related decisions during the reminder of the project.

When the cost or schedule variance values are consistently negative, or negative and increasing in magnitude, a red flag is triggered and management needs to devise a way to combat the potential overruns in labor and slippage in schedule. For this project, the opposite occurred. Table 2-10 shows how the cost and schedule variance for this project changed at defined project junctures.

% Planned Project Duration		35%	50%	65%	75%	85%	100%	
Actual Project	Cost Variance (Mhrs)	342	546	639	621	885	923	923
	Schedule Variance (Mhrs)	389	552	597	628	892	745	0

Table 2-10: *Cost and Schedule Variances for Duration of Project, Case Study #3*

Table 2-10 provides a more detailed story as to the progress of the project. It shows that, throughout the project, labor usage is not an issue because, at every stage in the project, the earned hours are greater than the expended hours (positive cost variance). Additionally, the project is expected to finish ahead of schedule throughout the project duration since the earned hours are always greater than the expended hours (positive schedule variance). The cost and the schedule variances are increasing for every subsequent report, which gives a good indication that the project is continuously headed for good results. The cost and schedule variance predictions made throughout the project accurately predicted the manhour underrun and the schedule underrun that actually occurred on the project.

2.3.4.4 Performance Factors

Performance factors are another way to understand project performance. Unless there is an estimate problem that causes the budgets for items to be considerably wide of the mark, the performance factor is a measure of construction productivity, or efficiency. Figure 2-22 displays the performance factors for each period and cumulatively for the entire project duration. The performance factors shown are the exact project performance factors obtained from the quantity installed method of project tracking for this project. Also, the performance factors by activity (per report and cumulative) were also made available, so it could be determined which activities were underperforming or overperforming to date.

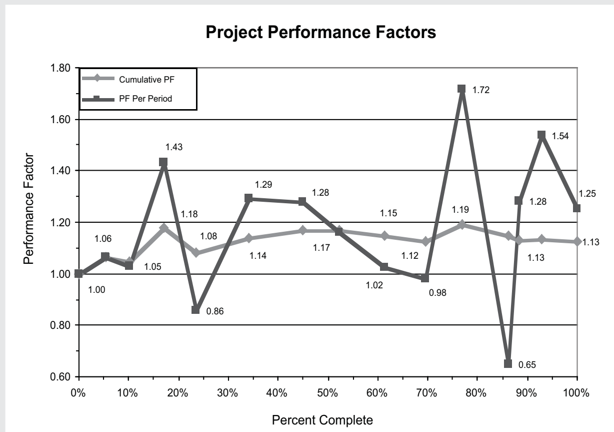

Figure 2-22: *Project Performance Factor Profiles, Case Study #3*

The profile shown in Figure 2-22 clearly shows a trend in which the performance of the project overall is in good shape throughout the project. The cumulative performance factor on the project is always well above a value of 1.0, so there is no reason to be concerned that the project could go over budget. For this project the performance factor was 1.11 at 30% 1.13 at 100% complete, so the performance factor change was only 1.8% over that duration. However, the performance factor did improve slightly from this point until the end of the project.

2.3.5 Manhour Forecasts By Tracking Method

The four methods of project tracking that were simultaneously tracked for every project for this research are the quantity installed, subjective evaluation, 0-50-100%, and 0-100% methods. A direct relationship exists between the cumulative performance factor and the forecasted manhours at completion. The forecasted manhours at completion value can be calculated using the following equations:

$$ForecastedManhoursatCompletion = BudgetedHours / PerformanceFactor$$

Or

$$ManhoursExpended / PercentComplete$$

The forecasted manhours at completion value can be calculated at the activity level and then summed to obtain a total project number. On the other hand, the forecasted manhours at completion value can be calculated at the project level if that is the only available information. Therefore, the next step in reporting progress with the Earned Value Tracking System is to predict the final number of manhours that will be required to finish the project. The 0-100% method of project tracking has been eliminated from the analysis for this project for reasons explained in Section 2.1.5, *Manhour Forecasts By Tracking Method*. Shown below in Figure 2-23 are the forecasted manhours for the three tracking methods throughout the duration of the project.

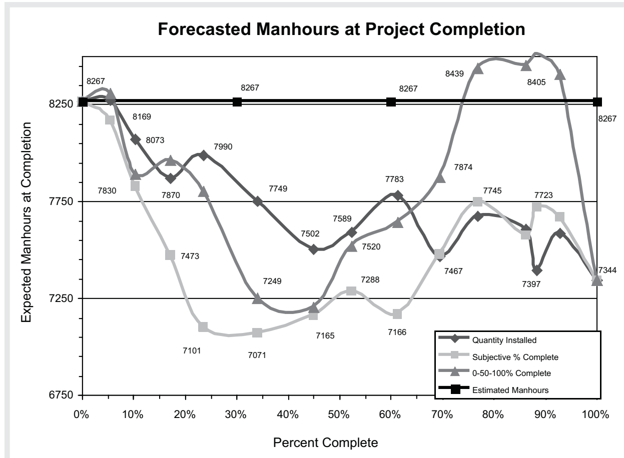

Figure 2-23: *Forecasted Manhours for Three Tracking Methods, Case Study #3*

The actual hours used to complete the project were 7,344. It is important to note that, for most of the project duration, the quantity installed method, the subjective evaluation method, and the 0-50-100% complete method all correctly predicted the overall manhour underrun that actually occurred on the project.

Figure 2-24 shows the manhour forecast error for each of the three tracking methods. The forecast error is calculated from the actual hours used at completion for the project.

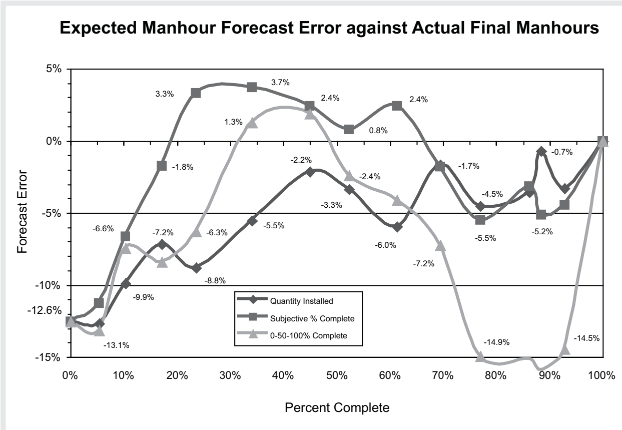

Figure 2-24: *Manhour Forecast Error for Three Tracking Methods, Case Study #3*

Using the predicted manhour value found at each reporting period, the accuracy of the quantity installed forecast shown above is high for the forecasted manhours for the duration of the project since its error never exceeds 12.7%. Also, the quantity installed manhour forecasts generally improve their accuracy as the project progresses. This is evident for the manhour forecast, as the error never exceeds 6.0% from 30% project complete until the end of the project. This improving accuracy as time passes is important for the project management staff to know, because typically every ensuing forecast will have a greater accuracy than the previous one. Table 2-11 shows the prediction accuracy for defined points in the project duration.

From Table 2-11 it is important to note that the forecasted manhours at completion successfully predicted the manhour underrun at every defined percent complete.

The forecast error shown in Figure 2-24 shows that the subjective evaluation method is also an effective and accurate way to track this project since its forecast error is never greater than 6.6% after 10% project complete. Additionally, this error generally decreases as the project progresses. This is a very good trend, from the research team's perspective as well as from the project management's perspective. From 15% to 70% project complete, the subjective evaluation method has an error that is never greater than 3.7%. This provides an essential and accurate early warning sign for the project. The subjective evaluation error differs slightly from the quantity installed error rather early in the project when the foreman and project managers are a bit more optimistic about the progress of the work. However, from 70% complete until the end of the project, errors for these methods nearly mirror each other. The subjective evaluation method is as accurate as or even more accurate than the quantity installed method from 20% to 100% project completion.

Project % Complete	20%	35%	50%	65%	75%	85%	100%
Correctly Forecasting Underrun	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Forecasted Manhours at Completion	7,930	7,757	7,569	7,625	7,621	7,618	7,344
Forecast Error	-8.0%	-5.8%	-3.1%	-3.8%	-3.8%	-3.7%	0.0%

Table 2-11: *Percent Error of Manhour Forecast, Case Study #3*

The 0-50-100% complete method has forecast errors that vary widely throughout the project duration. However, the forecast error was less than 6.3% from 25 to 65% project complete. This shows exceptional accuracy in the middle of the project. Lastly, it is interesting to note that the 0-50-100% complete forecast error will typically cross at 0% error somewhere in the middle of the project. In this project, two crossing points in the middle of the project occurred at 31% and 49% project complete.

2.3.5.1 Percent Complete

Another important issue in the construction industry is determining the percent complete of a project at any point in time. This determination is of fundamental importance to the accuracy of the Earned Value Tracking System. Generally, the quantity installed method is viewed as the actual project percent complete. For this reason the other tracking methods percent complete deviation from the actual percent complete should be graphed. This information is shown in Figure 2-25.

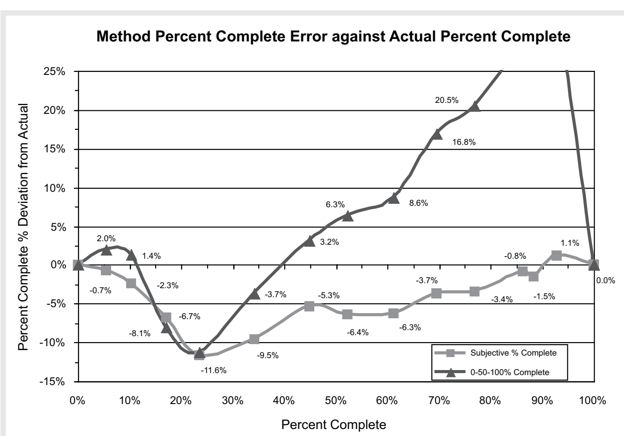

Figure 2-25: *Method Percent Complete Error against Actual, Case Study #3*

Certain trends from previous figures are also shown on this graph. The subjective evaluation method never deviates significantly from the quantity installed, but it does consistently overstate the actual percent complete on the project because the foreman and project manager were a bit optimistic with their subjective percent completes. The difference between these methods decreases as the project progresses. The 0-50-100% complete method, as usual, overstates the project percent complete early in the project as activities are starting and half of the budgeted hours for each started activity become earned. Then, at around the 40% complete mark, this trend reverses and the 0-50-100% complete method understates the project percent complete before a significant number of activities are completed.

One goal of this research was to also determine which tracking method most closely correlated with the quantity installed method of project tracking. For the manhour forecasts, the subjective evaluation method for this project had about the same variance as the 0-50-100% complete method and approximately 2.6 times less variance than the 0-100% complete method. Therefore, the subjective evaluation method and 0-50-100% complete method most closely correlate with the quantity installed method. However, the subjective evaluation method is significantly closer to the quantity installed method from the 50% project complete mark until the end of the project. This method is the most preferable as an alternative to the quantity installed method.

2.3.5.2 Performance Factors

Figure 2-26 shows the cumulative performance factors for the three tracking methods and the general trends that often occur for these three tracking methods. The performance factor value for the subjective evaluation method at 30% complete is 1.52, while it ended up being 1.13 at project completion. This represents a 34.5% change, which is more than the typical 10% change over this time span. This is a result of the project management and the foreman being overly optimistic about what work was already completed when determining the subjective percent complete for each activity early in the project. Additionally, the 0-50-100% complete method has a performance factor value of 1.39 at 30% complete, which represents a 23.0% change at project completion.

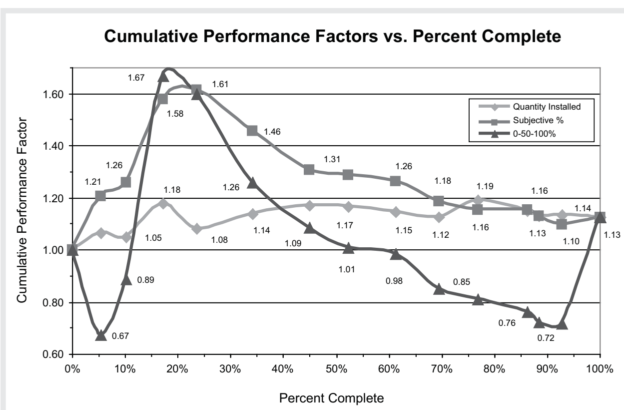

Figure 2-26: *Cumulative Performance Factors for Three Tracking Methods, Case Study #3*

2.3.6 Project Schedule Analysis

The sections above discussed the manhour forecasts as an early warning sign for project cost overruns. However, the other key aspect of any project tracking system is the project schedule analysis. Analyzing the project schedule and obtaining an early warning of a schedule overrun can be very beneficial to the project management staff. Often, when it is determined that a project schedule will be overrun in the future, a contractor employs acceleration techniques in order to finish work on schedule. These include over-manning the project, working overtime, and doing shift work. All these techniques add significant cost. These added costs can be the result of paying extra wages for overtime work or the loss of productivity associated with over-manning a project. The earlier a schedule overrun or underrun can be determined on a project, the better the overrun can be mitigated and the better the underrun can be used to decrease project costs.

Calculating the total estimated weeks to complete a project is one crucial schedule analysis tool available for contractors. Project management staff can look at the total estimated weeks to complete forecast at any stage in a project to gauge how many weeks it will take to complete the work if the work productivity to date continues until the end of the project. Figure 2-27 shows the total estimated weeks to complete the work for this project. The initial and final contract weeks for the project were 50, while it actually took 37 weeks to complete the work. Therefore, the work underran the schedule by 13 weeks. Throughout the project, work was progressing at a very rapid pace. This is evident from Figure 2-27, which shows that, throughout the project duration, the project was expected to finish ahead of schedule. The total estimated weeks to complete was not the only schedule analysis factor that showed this. Hanna's control points, the schedule variance, and the project S-curve all were showing a schedule underrun very early in the project.

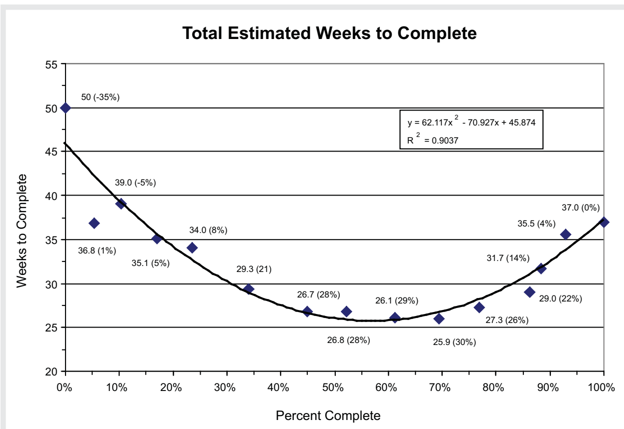

Figure 2-27: *Total Estimated Weeks to Complete, Case Study #3*

Figure 2-27 shows that the total estimated weeks to complete decreased until about 50% complete and then increased until the end of the project. This trend lends itself to a best-fit x^2 curve. This x^2 trend evident in Figure 2-27 is statistically a good fit, since the R^2 value is 0.90. The x^2 regressed total weeks to complete accurately predicted the final weeks to complete, but this analysis has not been included in this book.

These total estimated weeks to complete values can be compared to the actual weeks needed to complete the project (37 weeks for this project) in order to obtain a forecast error. The prediction error is shown in parentheses in Figure 2-27. It can be seen that the total expected weeks to complete prediction error starts out rather small, then increases to a high point, and then sharply decreases throughout the rest of the project. Again, the trend in the forecast is evident as the data closely correlates to an x^2 trend. This trend, along with project management's knowledge of the work that remained, provided a key tool for analyzing the project schedule in real time. It is important to note that, even though these errors appear rather large, the total estimated weeks to complete successfully predicted a schedule underrun throughout the project duration.

2.3.7 Case Study #3 Summary

The tracking for this project resulted in numerous findings that can be helpful to the entire contracting industry. There are four essential project tracking tools for evaluating the project schedule for early warning signs of a schedule overrun or underrun: Hanna's control points, the S-curve, the schedule variance, and the total expected weeks to complete. All these tools successfully predicted a schedule underrun for the duration of the project.

A few conclusions were also drawn from the project performance factors. This information is summarized in Table 2-12. For the quantity installed method of project tracking, it was determined that that performance factor value at 30% complete (1.11) did not vary by more than 10% (actually

1.8%) at project completion (1.13). However, a different conclusion was found for the subjective evaluation method of project tracking since the performance factor value at 30% complete (1.52) did vary by more than 10% (actually 34.5%) at project completion (1.13), because the subjective percent completes were overly optimistic about work that was being completed on site early in the project. The same conclusion was reached for the 0-50-100% complete method of project tracking since the performance factor value at 30% complete (1.39) did vary by more than 10% (actually 23.0%) at project completion (1.13). Also, the value only worsened as the project progressed.

The expected manhours at completion for the quantity installed method had a forecast error of less than 6.0% after 30% project complete. In most cases, this error was significantly less. The subjective evaluation expected manhours at completion forecasts were also fairly accurate for the project. The error for this method was less than 5.5% after 15% project complete. Additionally, this project tracking method most closely correlated with the quantity installed method of project tracking. The 0-50-100% complete method's forecast error was less than 6.3% from 25 to 65% project complete. This shows exceptional accuracy in the middle of the project. These tracking methods can confidently determine the final manhours needed to complete work very early in the project. All these predictions are valuable tools that should be used for project tracking since all the methods correctly predicted the manhour underrun for the majority of the project duration.

The forecasts, trends, project values, and their accuracies shown in this project show how useful an effective Earned Value Tracking System can be to the project management staff.

Tracking Method	PF at 30% Complete	PF at 100% Complete	Percent Change	Predicted Eventual Labor Hours Underrun
Quantity Installed	1.11	1.13	1.8%	Yes
Subjective Evaluation	1.52	1.13	-34.5%	Yes
0-50-100% Complete	1.39	1.13	-23.0%	Yes

Table 2-12: *Project Performance Factor Summary, Case Study #3*

2.4 CONCLUSION

2.4.1 Earned Value Overview

This research was the first to actually implement an Earned Value Tracking System in mechanical, HVAC, and sheet metal construction. The analysis of different tracking methods was also unique to this research. Part 1, *Introduction And Earned Value Analysis*, introduced all the earned value concepts necessary for effectively tracking construction work, including a description of WBS and how they should be constructed to aid the project tracking during construction. Lastly, Sections 2.1, 2.2, and 2.3 presented the research findings obtained from tracking three very different mechanical, HVAC, and sheet metal construction projects.

This research provided many results that can benefit mechanical, HVAC, and sheet metal contractors when implementing earned value project tracking. Some of these results were in the form of guidelines and others were analytically determined from the case studies. Implementing earned value project tracking can be difficult; several key components need to be addressed. Many of these components were stressed by other researchers in the past and are reiterated here with some additions, deletions, and reinterpretations. The following are six essential steps to successfully implementing an Earned Value Tracking System.

1. **Buy in to the Project Control System:** The first step to the implementation of any system is getting everyone, from top management to project engineers to field tradesmen, to buy into the system. If they do not buy into the system, they will not actively analyze progress on the project or the output that the system provides. Therefore, the system will be useless before it even starts.

2. **Conduct Pre-Project Planning:** This is an important stage in determining the success of an earned value system. The scope definition occurs in this stage. The WBS must be developed to account for all the work involved in completing the project. The WBS must include the definitions of what constitutes completion in regards to each breakdown. In addition, it must identify control points and the responsible parties for the work. The engineering and design are being completed during this stage. The goal for every project should be to have the full scope of work determined prior to construction. This is often not possible, but every effort should be made to do so.

3. **Prepare Estimate and Schedule:** The estimate and schedule need to be developed with each other in mind. Accuracy is always the main issue with estimates. Therefore, it is essential to have a continually updated database containing historical unit rates for mechanical, HVAC, and sheet metal construction. The estimator needs to understand the builder's likely coordination of the construction so that the estimate can be prepared with the tracking system in mind. Scheduling the project must correspond to the WBS and the estimate so that there is traceability across each. A full network of activities with dependencies is crucial for the coordination of construction work. The initial schedule then needs to be updated with regularity, but the original needs to be maintained as a project baseline.

4. **Understand Earned Value:** Conceptually, earned value is not difficult to comprehend; however, there are many relationships and equations that need to be understood wholly in order for management to make the most informed decisions. In addition, with several methods available for project tracking, understanding what method is best for different types of construction will benefit the system by increasing its accuracy. The earned value project tracking software that was developed for this research greatly reduces the effort needed to effectively track construction projects.

5. **Report Project Progress:** Periodic reporting of project progress is required to stay atop potential issues that may arise during construction. This allows management to better understand what is causing the system output to change and how those values correspond to the ongoing work. It is possible that the most important part of the progress reports is the ability to easily provide field workers with real-time data as to the status of the project as a whole, their efficiencies in the field, and the likely outcome for the project. This allows the field workers to take ownership in the progress of the project while giving them actual values against which to measure their work, period by period. Since the majority of field employees want to be successful, they accept these challenges to improve. Again, the earned value software assists in real-time project progress reporting.

6. **Update and Maintain Records:** The reason for this step is twofold. First, updating records will aid in future projects by better representing current costs and durations for the construction. Second, in the event a project is not successful or there is a situation where a claim is brought against the contractor, having the earned value results stored on a period-by-period basis provides the necessary documentation that can help in analysis of that claim.

If these steps are followed, contractors can effortlessly and accurately track the labor and schedule positions of a project in real time, thereby allowing for immediate corrective action if an issue arises. Project tracking using earned value also can benefit contractors in developing future estimates and work plans.

2.4.2 Case Study Overview

The quantitative results for this research are based on the mechanical, HVAC, and sheet metal construction projects that are shown in this book. All these case studies were tracked using the quantity installed, the subjective evaluation, the 0-50-100% complete, and the 0-100% complete methods. The overall results for this research center on the predictive accuracy of the Earned Value Tracking System as a whole and the variations between different methods for measuring output. This large number of projects, as well as the variety in project size, type, location, and duration allows the results obtained from this research to be reliable and accurate. The pre-project planning, which has one of the largest impacts on the accuracy of the earned value system, occurred prior to the research team's involvement for the majority of the projects that were tracked. This includes determining how to break down, estimate, and schedule the projects. The summary of each of the three case studies described in this book is shown in Table 2-13.

Project Item	Case Study #1	Case Study #2	Case Study #3
Type of Work	Mechanical	Architectural Sheet Metal	Sheet Metal
Project Size (Manhours)	13,731	15,268	7,344
Project Duration (Weeks)	17	29	37
Project Location	Lower Midwest	Western U.S.	Upper Midwest
Final Labor Status	Under by 371 hrs	Over by 1,159 hrs	Under by 923 hrs
Final Schedule Status	Behind by 2 wks	Behind by 12 wks	Ahead by 13 wks

Table 2-13: *Summary of Case Studies*

Each project was tracked slightly differently due to project size, construction type, location, contractor preference, etc. All these variables have an impact and therefore somewhat limit the predictive accuracy of the tracking system. At the same time, this variety also increases the applicability of the project results. For example, the outcomes of the three projects described in this research vary in that one finished under budget and behind schedule, another finished over budget and behind schedule, and the third finished under budget and ahead of schedule. This shows that the Earned Value Tracking System results obtained from this research can be applied to any project regardless of the final schedule or labor outcome. The same can be confidently said for the type of work, project size, project duration, and project location.

2.4.3 Performance Factor Conclusions

A performance factor on a project can be an accurate determinant of project status. A value of 1.0 means that work is progressing at planned productivity levels; a value above 1.0 means that work is progressing faster than planned productivity; and vice versa for if it is below 1.0. It is also a useful value since it can easily be seen how well or badly a project is progressing. For example, a performance factor value of 1.13 means that work is progressing 13% better or faster than planned productivity. Previous research has shown that the performance factor value stabilizes at some point early in construction projects. No studies have ever been conducted to determine this value for mechanical, HVAC, and sheet metal construction. This research has shown that the performance factor value at 30% project complete will not vary by more than 10% from the 30% complete point until the end of the project. This percent change information for every case study and for each project tracking method can be seen in Table 2-14. The 0-100% complete method has not been included since the case studies did not have the work broken down enough to allow this tracking method to be useful.

Project Tracking Method	Case Study #1	Case Study #2	Case Study #3
Quantity Installed	-9.7%	-3.2%	1.8%
Subjective Evaluation	8.9%	4.3%	-34.5%
0-50-100% Complete	-32.0%	-9.8%	-23.0%
Quantity Installed Correct Labor Prediction at 30% Complete	Yes	Yes	Yes
Subjective Evaluation Correct Labor Prediction at 30% Complete	No	Yes	Yes
0-50-100% Correct Labor Prediction at 30% Complete	Yes	No	Yes

Table 2-14: *Performance Factor Percent Change from 30% to 100% Project Complete*

The performance factor percent change for the quantity installed method was always less than 10%. Two out of three projects had a percent change of less than 10% for the subjective evaluation method. The other project had a higher than usual percent change because the project management staff was overly optimistic regarding the work that was completed at the 30% complete mark. The 0-50-100% complete method fit this conclusion for one of the three projects. Still, even more important than the percent change of the performance factor is whether or not the performance factor at 30% complete correctly predicted the final labor situation of the project. This information for every case study is shown in Table 2-14. All the tracking methods were successful in doing this, which illustrates another benefit of computing the project performance factor on a project.

2.4.4 Manhour Forecast Conclusions

The ability to accurately forecast the final manhours needed to complete a project is another powerful tool that earned value brings to project tracking. With these predictions comes the ability to identify early in a project whether or not the project will experience a labor overrun or underrun so that an expected labor overrun can be best mitigated and an expected underrun can be used to reduce overall project cost. Overall, these early warning signs assist the project management staff in making crucial project-related decisions throughout the remainder of the project. This research has shown that, throughout the project, the manhour forecasts of each method, along with their linearly regressed manhours forecasts, can accurately predict the final manhours needed to complete the project. The average forecasting error by method is shown in Table 2-15, which shows that average forecasting error for every method and every project are at acceptable levels.

Project Tracking Method	Case Study #1	Case Study #2	Case Study #3
Quantity Installed	2.1%	4.7%	3.8%
Subjective Evaluation	1.9%	3.4%	2.3%
0-50-100% Complete	4.6%	4.2%	6.9%

Table 2-15: *Average Forecasting Error by Method for Duration of Project*

In most cases, the manhour predictions exhibit extraordinary accuracy and provide a crucial early warning sign of an expected manhour overrun or underrun on the project. The quantity installed method has an average forecasting error that is never greater than 4.7%. The subjective evaluation method has an average forecasting error that is never greater than 3.8% and is even more accurate than the quantity installed method in some circumstances. In Table 2-15, it appears that the subjective evaluation method is more accurate than the quantity installed method, which is true in some situations, but this table fails to take into account which method was more accurate later in the project duration. Therefore, for a detailed breakdown of the forecasting error by method, see the respective section in each case study.

The forecast error is one crucial element to consider when deciding which forecasting methods are worth using. The other element to consider is when in the project duration the given forecasting method correctly predicts the final manhour situation of a project. This final situation can be either a manhour overrun or a manhour underrun. Table 2-16 shows the project duration range for which each forecasting method correctly predicted the final manhour situation for each case study project.

Clearly, the accurate prediction of the manhour situation of a project varies from project to project, which can be seen in Table 2-16. However, every forecasting method shows consistent success in correctly predicting the eventual manhour situation of a project throughout the project duration. For example, the quantity installed method and the subjective evaluation method correctly predicted the eventual labor overrun or underrun for nearly the entire project duration for all three case studies. This information can be just as helpful to the project management staff as the exact quantity of the labor overrun or underrun. Overall, these

Project Tracking Method	Case Study #1	Case Study #2	Case Study #3
Quantity Installed	0-100%	0-56%; 68-100%	0-100%
Subjective Evaluation	0-20%; 35-100%	0-100%	0-100%
0-50-100% Complete	0-75%; 95-100%	22-56%; 65-100%	0-75%; 95-100%

Table 2-16: *Project Range of Correct Prediction of Final Labor Outcome*

forecasting methods have shown that they are effective and accurate early warning signs for the labor situation on all mechanical, HVAC, and sheet metal projects.

2.4.5 Schedule Forecast Conclusions

Being able to determine an expected schedule overrun or underrun early in a project can also be useful to the project management staff in making project-related decisions throughout the remainder of the project. Being able to accurately determine this numerically is another benefit of using an Earned Value Tracking System. The case studies shown in this research have proven this point. However, even more important than the actual percent error of the schedule prediction is the correct prediction of whether or not the project will be completed on time. The project duration range for which each schedule forecasting method correctly predicted the eventual schedule outcome is shown in Table 2-17.

Table 2-17 shows that Hanna's control points, the S-curve, the schedule variance, and the weeks to complete all provide an accurate indicator of the schedule situation on mechanical, HVAC, and sheet metal construction projects. Even though it took until around 50% to 75% complete for these factors to correctly predict the schedule situation for Case Study #1, it was a result of work in the beginning of the project progressing at a rate such that it was expected that there would be a schedule underrun. However, as work went on, it progressed at a slower rate, and eventually a schedule overrun was predicted. For the other two case studies, these factors predicted the schedule situation of the project very early in the project.

2.4.6 Recommendations

The results of the research generated several recommendations to mechanical, HVAC, and sheet metal contractors. Contractors who wish to employ an in-depth project tracking system first need to heed one piece of advice: it starts with the field workers. The success of a project control system is wholly dependent on field workers adhering to the rules set by management. For that to happen, one change needs to occur in the minds of many construction workers. Budgets are not bank accounts; one cannot draw from another account once one account is depleted. The accuracy of the earned value system depends on this not occurring. If workers charge their time to whatever account has manhours remaining, there will be no accuracy within the system. In addition, when it comes to change orders, if they are tracked separately,

Project Tracking Method	Case Study #1	Case Study #2	Case Study #3
Hanna's Control Points	75-100%	25-100%	0-100%
S-Curve	55-100%	35-100%	0-100%
Schedule Variance	75-100%	35-100%	0-100%
Weeks to Complete	75-100%	0-100%	0-100%

Table 2-17: *Project Range of Correct Prediction of Final Schedule Outcome*

often workers will not use a different cost code designated by the change, because the original cost code is so familiar to them. In that case, there will be no way of tracking change order hours. If a contractor can commit a labor force to adapting to a new system, the potential for success greatly improves.

Throughout the research process, many contractors that employed some sort of tracking system were contacted to get their view of the Earned Value Tracking System. On numerous occasions, they would state that the biggest benefit to implementing and using an earned value system, or any tracking system for that matter, is getting the field crew to buy into the process and utilize its reports to improve their work and productivity. They continuously responded that it enabled management to provide feedback to the crews responsible for the work on site. This allowed the workers to set a baseline for what constituted productive work. This benchmark would often motivate the crew to improve upon that efficiency. Upon setting a new improved benchmark, management realized a lower bid cost and an improved margin on future projects.

For the most accurate and complete earned value picture, change order work on a project should be tracked separately. This is the best method when possible. This way, the changes can have their own cost codes associated with them so performance can be measured and it will not affect the values for the performance already achieved on the original scope of work. In addition, change orders tracked separately have the ability to sum up several work tasks into one code identified by the change order. This simplifies the process for field workers so they are not confused when allocating their time. When it is not conducive to track every change order separately, and the hours are added to the original budget, it is essential to update the budget when the change order work is approved. This may cause a time delay between when the change order work is underway and when it is approved, if the direction in the field was to start the work. This is a better practice then carrying pending change orders in an open cost code that may or may not already be accounted for in the evaluations within the original cost codes for the type of work designated in the change order.

Using earned value principles for cost and schedule forecasts has been proven to be effective at predicting cost and/or schedule overruns or underruns right from the project start. Additionally, the linearly regressed forecasts have been proven to be accurate after as little as 20% project complete and should be calculated and used after this point in the project. The project performance factor at 30% project complete has also been shown to vary by less than 10% from 30% project complete until the end of the project. This is an essential project number that all contractors can easily and quickly determine to assist the project management's decision making. Lastly, the subjective evaluation method has been proven to be a useful and accurate alternative to the quantity installed method of project tracking. At the very least, all projects should be tracked using this method.

2.4.7 Summary

The goal of this research was to determine how the Earned Value Tracking System can best be used in mechanical, HVAC, and sheet metal construction, to provide guidelines for the effective implementation of the system by mechanical, HVAC, and sheet metal contractors, and to determine the accuracy of different tracking methods. The research goals were accomplished through the compilation of extensive literature that has been published on the topic and the tracking of numerous case studies of which three are described in detail in this book. It is expected that the resulting earned value analysis tools and case study samples will assist mechanical, HVAC, and sheet metal contractors in their efforts to implement and effectively use the Earned Value Tracking System. This tracking system gives contractors an early warning sign of a labor overrun or underrun and of a schedule overrun or underrun. Lastly, this project tracking system and earned value techniques should be employed by contractors of all work types to give them an accurate view of the labor and schedule position of projects.

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APPENDIX A: DESCRIPTIONS AND DEFINITIONS

The concept of earned value has been used in industry for several years, although many times, it was not referred to as earned value. For that reason and in order to present this research in an organized fashion, descriptions and definitions of the terms used throughout this research are provided below. These terms will also be defined the first time they appear in the text.

0-100% Complete Method: Binary method of project tracking that assigns 100% of an activity's budgeted hours as earned when work finishes on that activity.

0-50-100% Complete Method: Method of project tracking that assigns 50% of an activity's budgeted hours as earned when work starts on that activity. The final 50% of the hours are assigned when work finished on a project.

Activity: A task performed by an individual or multiple persons that is required for the completion of a work package and project as a whole.

Actual Cost of Work Performed (ACWP): This value represents the actual hours used on site to complete an activity. This value is compared with the earned hours (BCWP) to obtain the labor status of the project/activity. This definition can be very confusing to new users and should be avoided. This book refers to ACWP as the actual hours, which is more user friendly.

Actual Hours: Manhours that are taken directly from a contractor's time sheets. In a project control system that relies on accurate values for actual manhours expended, it is crucial that each member of the contractor's labor force fill out a time sheet. Each time sheet should include the code or phase worked along with the corresponding hours spent on each code, each day.

Budgeted Cost of Work Performed (BCWP): This is another name for the earned hours or earned value on the project. This name is less than intuitive and can needlessly create confusion. The terms earned hours or earned value should be used instead.

Budgeted Cost of Work Scheduled (BCWS): This value represents the budgeted hours used on site to complete an activity. This value is compared with the earned hours (BCWP) to obtain the schedule status of the project/activity. This definition is overly confusing and should be avoided in all circumstances. This book refers to BCWP as the budgeted hours, which is more user friendly.

Change Order: Owner-approved changes are changes in the scope of work required on a project. They can be additive or deductive. Usually they affect both the original budget and schedule.

Cost Coding/Phase Numbering: Company-defined numbering system for the organization of projects and project tasks. There are many ways to approach numbering a job. Several options include using predefined mechanical/sheet metal task numbers, like MasterFormat from the Construction Specifications Institute (CSI), the Uniform Construction Index (UCI), or other mechanical/sheet metal organizations. In addition, some contractors will choose to develop their own numbering system.

Cost Variance: The cost variance is an essential earned value tool that is used to analyze the labor (cost) situation of a project at any point in time. It is calculated by subtracting the actual hours from the earned hours. A positive cost variance is preferable.

Critical Path Method (CPM) Schedule: A project management technique for scheduling that displays a network of the activities that constitute the project schedule. The "critical path" indicates the chain of activities that have the least amount of scheduling flexibility, or float. The durations for each activity that falls on the critical path, when totaled, establishes project duration.

Earned Value: Earned value is a measurement of the amount of work that was accomplished versus what work was planned while considering the amount of resources (manhours) used to complete that amount of work.

Forecasted Manhours at Completion: This value indicates the anticipated number of manhours that will be expended at the conclusion of the project. It is determined by dividing the manhours expended to date by the percent complete to date of the project.

Manpower Loading (Curves): Manpower loading is the distribution of manhours that a contractor uses to complete a project. Manpower loading curves display the relationship between time and manpower (in hours or number of workers).

Percent Complete: Percent (%) complete is the percentage of physical work completed of a task or of a complete project. This value is completely independent of budget, cost, and schedule. For example, if, at a moment in time a project has used 80% of its budgeted hours but has completed only 50% of the contracted work, the project is 50% complete, not 80%.

Performance Factor: This value is a measure of productivity of the labor force for a task or the entire project over the reporting period or to date. This value is obtained from dividing the earned manhours by the actual manhours spent on a task or on the project as a whole over a reporting period or to date.

Project Control: Project control is any system that is put in place for a construction project that allows management the ability to see the current project condition from a standpoint of budget, cost, and schedule. This enables the contractor to see how the project is progressing and to forecast likely project outcomes in time to allow for corrective actions to be taken.

Quantity Installed Method: Method of project tracking that is based on measuring the quantities installed for every activity for every period. This method of project tracking is accepted as the exact status of a project, because there is nothing more accurate than keeping tabs on the exact amounts completed.

R^2 Value: The coefficient of determination, which is a measure of the percent variability explained by a regression. A high R^2 indicates that the model represents the collected data relatively well, whereas a low R^2 indicates that a model does not represent the collected data well.

S-Curve: S-curves show the relationship between time and percent complete or percent complete and cumulative manhours. For instance, a scheduled S-curve would show the expected level of completed work at each point in the project duration.

Schedule Variance: The schedule variance is an essential earned value tool that is used to analyze the project schedule at any point in time. It is calculated by taking the earned hours and subtracting the budgeted hours. A positive schedule variance is preferable.

Subjective Evaluation Method: Method of project tracking that is based on a subjective percent complete for every activity for every period. This method can be more accurate if more than one person on a project completes the subjective percent completes. Also, this method takes into account activity mobilization and setup time.

Total Estimated Weeks to Complete: The estimated weeks that it is expected to take to finish all work components on a project. This value is obtained by adding the forecasted number of weeks yet to complete the work plus the number of weeks that have elapsed. This value is then compared against the budgeted or contract weeks to determine if the project is expected to finish earlier or later than planned.

Work Breakdown Structure (WBS): A hierarchical system that subdivides larger elements of the project into smaller elements called work packages. The scope of work in each work package should be defined to avoid overlaps and omissions between work packages. The scope of each work package should be manageable, independent, and measurable in terms of progress (Hanna). A WBS will define what constitutes a given project.

Work Package: A portion of a project that has a defined scope of work. It can vary in size and complexity. There are four main guidelines to the development of a work package. It must be manageable, independent, measurable, and integrateable (Kerzner, page 553).