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This issue of *The Measurable News* has a new topic that was introduced at IPMW this last November – Building Information Modeling (BIM). BIM is a process to create and manage digital representations of the physical and functional characteristics of a physical structure that are built, analyzed, documented and assessed virtually, then revised iteratively until the optimal model results.

There is a story (urban legend perhaps) that is applicable here¹

The automated steam engine is said to have been invented by a young child. In the early days of steam power, steam engines were used to simply push a piston connected to a rocking beam. Due to the simplicity of these machines it was necessary to manually open a valve at the end of each stroke to release the pressure on the piston. Young children were employed to open and close this valve, an occupation called the plug man (Deakins 2008).² As the story goes, one who wanted to play stickball outside with some other children devised a mechanism from scrap steel to do his job. He connected one end of a rod to the rocking beam and the other end to the lever for the valve. As the beam rocked back and forth it opened and closed the valve.

Applying BIM to Defense acquisition, beyond buildings and facilities, is an opportunity to devise a more effective way to assess the performance of projects by connecting the dots between the tree structured WBS, the 3D model of a physical deliverable, the cost and schedule components of that model and its physical manifestation, and information about the interdependencies of the components of both the model and the physical product, and how these interdependencies drive the risk to cost, schedule, and technical performance.

In our current Integrated Program Performance Management world, the WBS and the Earned Value Management processes (IPMR Formats 1 and 3) fail to show these interdependencies and the probabilistic behaviors of cost and schedule that result from these interdependencies. Integrating knowledge about product development with the performance measures of the program developing that product has existed in the construction domain for decades.³ It’s time to start making the links between cost, schedule, technical performance, Measures of Effectiveness, Measures of Performance, Key Performance Parameters, Technical Performance Measures, and Risk.

The object modeling capabilities of BIM provides this circular integration⁴ of the measures needed to increase the probability of program success, interconnected with the program’s technical, cost, and schedule attributes.

BIM is based on the aecXML which is a XML mark-up language using Industry Foundation Classes to create a vendor-neutral means to access data generated by Building Information Modeling. BIM has been developed for use in the architecture, engineering, construction and facility management industries, in conjunction with BIM software (e.g. Autodesk Revit Building), and is trademarked by buildingSMART (the former International Alliance for Interoperability), which is a council of the National Institute of Building Sciences (NISB) (http://www.nibs.org/) NISB a non-profit, non-governmental organization bringing together representatives of government, professions, industry, labor and consumer interests, and regulatory agencies to focus on the identification and resolution of problems and potential problems that hamper the construction of safe, affordable structures for housing, commerce and industry throughout the United States.

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The BIM model is a graphical design and is also a virtual database including technical and management data. The construction manager (CM) can use BIM as a real simulation of the actual project. One question is, “Could this notion of program management be transferred to the management of Defense Programs?”

Let’s start with a framework for BIM – the Product Lifecycle Management paradigm. One place BIM has been established on the DOD side is Ship Building. In the standard BIM domain, the term model is the critical success factor. A BIM solution creates computable building information that enables the model of the building to be understood by a software system as a building. A wall, for example, “knows” what it is and how to react to the rest of the building. As such, it can be scheduled or quantified as a wall: a building assembly made of real materials. Computable building information supports numerous building design and construction activities: structural analysis, MEP (Mechanical, Electrical, Plumbing) system modeling, building energy analysis, and specification management.

Cost estimating of the building process benefits from computable building information as well. Designing a building is done by architects; assessing the cost to build it is done by cost estimators. When preparing cost estimates, estimators begin by digitizing the architect’s paper drawings, or importing their CAD drawings into a cost estimating package, or doing manual material takeoffs from their drawings. These methods introduce the potential for human error and propagate any inaccuracies there may be in the original drawings.

Using the BIM instead of drawings, the material takeoffs, counts, and measurements are generated directly from an underlying model. This information is consistent with the design, and when a change is made in the design – a smaller window size, for example – the change propagates to the related construction documentation and schedules, as well as all material takeoffs, counts, and measurements that are used by the estimator.

One important concept to connect our Defense procurement processes with building design and construction is the recognition that our domain is based on MIL-STD-881-C, where all the components of the product in the Program Performance Management domain are structured as a Tree with formal relationships. This formality is Mutually Exclusive, Collectively Exhaustive, which is a a grouping principle for separating a set of items into subsets that are mutually exclusive (ME) and collectively exhaustive (CE). In this structure, the parent/child relationship of the components of the systems are strictly enforced.

In BIM, the relationships between the components of the systems are networked. In the construction business, there are Five Big Ideas:

1. Collaboration throughout design, planning, and execution
2. Increase readiness among all project participants
3. Projects are networks of commitments
4. Projects are optimized not the pieces of the project
5. Learning is tightly coupled with action

This paradigm of the network is held in the BIM models, to be queried to retrieve information when needed. One important concept with BIM is the JSON (JavaScript Object Notation) data structure for BIM data exchange. JSON has started to enter the Earned Value Management data processes as well. The BIM model is guided by ifcJSON4 (http://openbimstandards.org/).

In the building industry, building data such as objects and processes are described in Industry Foundation Classes (IFC) data model schema to support a neutral data exchange format for the BIM tools to interoperate.

The opportunity to use JSON as the exchange basis between BIM and the EVMS is the next step to be explored in more detail.

Here’s a notional example of the difference between a WBS program structure and a BIM structure: While the BIM structure can include the WBS as a coded field, BIM is a multi-dimensional framework representing the various views of the program, including documents, products, classifications systems, building specification, CAD system models, engineering calculations, facilities management systems, all coded in Industry Foundation Classes (IFC).
In this issue of *The Measurable News*, we’ve included a Bibliography of BIM information. These will further inform you how this powerful modeling can be adapted to DOD acquisition, including Ship Building.

As well, a paper by Gordan Kranz, Earl Carter, Jeff Gravatte, Cathi Hayes, Raul Gomez, and Michael Marcel presents the foundation of BIM and its applicability to Defense acquisition.
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Department of Defense Instruction 7000.2, “Performance Measurement for Selected Acquisitions” was issued on December 22, 1967, marking the widespread adoption of Earned Value Management (EVM) for complex acquisitions. (This policy instruction was my responsibility from 1982 to 1999 as a civil servant.) Its principles remain intact in other forms a half century later – in government-wide acquisition and procurement regulations, in national and international standards, in professional and industrial associations, and in company management procedures. CPM’s professional education and certification programs, workshops and symposia support all these disparate needs and help to advance the state of the art of integrated program performance management using EVM and other techniques.

Rereading the instruction prompts a flood of career memories. My memories as well as those of many others are being captured and organized by CPM Vice President Marty Doucette and his team of volunteers, who are recording interviews, digitizing videotapes, scanning documents and incorporating all into an EVM Timeline that will document thoroughly EVM’s origins and evolution. We are the original professional association dedicated to integrated performance measurement using EVM. As we mark this milestone, it’s a good time to recall first principles and encourage our younger members to bear them in mind as they adapt the vision of our founders to today’s environment.

However, we should indulge a “chicken or egg” question. What came first, BCWS, BCWP and ACWP or their contemporary versions PV, EV and AC? Would it surprise you to learn it was the latter, as documented in a Performance Technology Corporation letter to the Air Force Ballistics Systems Division on March 21, 1965 (except that AC was “Actual Value”)? My point is that usually, simple is better. The letter forwarded drafts of the “Earned Value General Specification and Checklist” in fulfillment of an Air Force contract. These documents would evolve into the Air Force C/SPCS and DoD C/SCSC – and the rest is history.

That history, as with any government policy, has experienced ups and downs. In my experience, the “downs” occurred when overseers lost sight of the first principles. The original objectives of DoD Instruction 7000.2, as listed in the press release accompanying its release, were to:

“... provide an adequate basis for responsible decision-making by both contractor management and DoD components through contractors’ internal management control systems that provide data which (1) indicate work progress, (2) properly relate cost, schedule, and technical performance, (3) are valid, timely, and auditable, and (4) supply DoD managers with a practicable level of summarization.”

Finding the right balance to achieve these objectives follows a cyclical pattern that is influenced by many factors, which will be apparent from the timeline. For example, ratchet-like tightening of regulations in response to contract cost overruns, accompanied by ever more intrusive customer audits, is followed eventually by loosening of regulations – and so the pendulum swings. The danger, of course, is that the swings will be extreme and will compromise the value of earned value.

Criterion-based management using EVM was designed to support essential management needs that remain relevant today. Every manager needs to know how a contract/project/program is performing. And the more complex the organization, the more compelling the need for consistency in management reports. As CPM leads the way into the next half century of management evolution, we all should use these first principles as touchstones, especially as we develop the practitioner and enterprise professional levels of our Integrated Program Performance Management certification.
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ABSTRACT

One of the constant concerns about the acceptance and implementation of Earned Value Management (EVM) is the perception that earned value metrics and trends do not tie well to the schedule and do not reflect the true technical status of a project. We believe that the aerospace and construction industries can learn to manage programs better by using Building Information Modeling (BIM).

In 2012, the U.S. Department of Defense published the Integrated Program Management Report (IPMR) Data Item Description (DID) which emphasized the integration of EVM data with the schedule and facilitates integrated analysis by requiring a common electronic format for the cost and schedule. The use of common tags such as Work Breakdown Structure, Control Account Numbers, Work Package Numbers and Organizational Breakdown Structure allow for electronic correlation and analysis using computers to increase the breadth and depth of the earned value analysis and establishing root cause.

At the center of EVM is the requirement to claim technical progress based on objective criteria. During the development phase of programs, objective criteria for progress claims are sometimes not straightforward. But if the cost and schedule could be electronically tagged to the system design artifacts, as the design matures the technical, cost, and schedule status would be naturally integrated. The vision of BIM is to address this current lack of data integration issue throughout the project lifecycle.

BIM was created as a process and concept in the early 2000s. The concept is to move the construction industry from building complex structures using 2D drawings to designing and building using a 3D interactive BIM approach. BIM is a process with an intelligent model at the core with time and cost and serves as a virtual prototype, a complete model of all building with components of the building as discrete objects.

The IPMW 2017 held a first-ever BIM track to bring both construction experts and performance management experts together to foster collaboration and a working relationship to resolve our common goal to improve cost, schedule, and technical performance across our respective communities.

The BIM track consisted of 5 presentations which are summarized below:

BIM 01 OVERVIEW OF BUILDING INFORMATION MODELING (BIM)
A Wiki definition of Building Information modeling (BIM): A process involving the generation and management of digital representations of physical and functional characteristics of places.

The BIM process allows teams to communicate ideas in a visual prototype manner allowing for collaboration across program management teams to investigate and interrogate a model, like never before, to guide owner decisions by access to accurate evaluation of construction status throughout the design and construction process and even into operations.

The BIM process provides for the integration of intelligent 3D design with schedule (4D) and cost (5D) and eventually to support the business operations and maintenance of the system (building).
**BIM 02 DESIGN AND BIM (3D)**

3D BIM provides a 3D interactive model of the system being designed and built for project stakeholders to communicate. The typical approach in construction today is for architects to manually develop a few alternative designs based on experience to address customer requirements. BIM will allow the ability to use a computer to produce hundreds or thousands of viable design alternatives for customers, architects, and builders to choose from based on a set of desired design outcomes.

The 3D model then continues to mature and gain fidelity as the building or system design matures. Keeping the 3D model up to date facilitates the ability to work through issues found during the design and build process. This is particularly useful since complex buildings are being designed and built concurrently.

**BIM 03 BIM INTEGRATION INTO SCHEDULE (4D)**

4D BIM is the integration of a high-fidelity 3D model over time. Build sequences and dependencies are built into the model allowing the team to visualize the time phased build and design of the system. Being able to visualize the expected maturity of the design in the future can be very powerful in support of identifying potential resource conflicts, building sequence issues, and the ability to iterate on alternate sequences to work around unforeseen issues that arise such as weather or labor strikes.

**BIM 04 BIM INTEGRATION INTO COST (5D)**

Simply stated, 5D BIM means adding the element of cost to models (3D) that have been linked to schedule information (4D). 5D BIM includes the pre-construction planning of costs and performance against budget, while also measuring actual costs and changes against plans for real time project insight.

Bringing together cost, technical, and schedule objects in both cloud and mobile environments enables automatic analysis of key project indicators such as cost performance (CPI), schedule performance (SPI) and earned value (EVM). The reports are highly visual as 3D models are color coded to communicate status, trade and location.

![Figure 1: 5D Performance report (CPI)](image)

**THE IMPORTANCE OF LINKING WITH 5D**

A key concept in 5D BIM is the “intelligent linking” of data. Intelligent linking of data is what makes real-time visibility of project status and performance possible. The key is to embrace the 5D workflow during planning, so the cost, schedule and model structures can be mapped, or linked, to each other with the right level of detail from the beginning of the project. By breaking down siloes of information, empowering workers and reducing risks for owners and contractors, 5D BIM presents a real opportunity for the building construction industry.

**BIM 05 BIM INTEGRATION WITH LIFECYCLE MANAGEMENT (6D)**

Extending the use of BIM into the sustainment phase of a project is where the lasting value can be obtained for the building lifecycle. The cost of operating and maintaining a building is 10 to 15 times the initial cost of the building. As buildings get “smarter” new capabilities can be integrated into the BIM model to provide building operators, users, and maintainers easy access to data allowing for more streamlined and predictable operations.
BIM 06 THE FUTURE OF BIM PANEL DISCUSSION

During the panel discussion, the presenters and members of CPM talked about the common issues we face in evaluating cost, schedule, and technical status throughout the project. The BIM process emphasizes the data integration of all aspects of the project to quickly and accurately evaluate status, evaluate alternatives to resolve issues, forecasting, and planning out future work.

The group agreed that there is synergy in the construction and BIM experts and the CPM performance management experts. Our plan is to continue the collaboration by forming a BIM interest group. The intent of the group will be to continue the collaboration and to look for opportunities to engage in both BIM forums and performance management forums.

Look for the next BIM track at EVM World 2018.

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ABSTRACT

Project management is the art of making the right decisions. Project managers are faced with a huge array of choices. Should a different supplier be used to improve the quality of a product? Should an additional team member be brought in to improve the development performance? Should the work be outsourced or done in-house?

In addition to project management, decision analysis is used in strategic planning, operational management, and other areas of business. Decision analysis helps oil and gas companies determine optimal exploration and production strategies with uncertainties in cost, prices, and exploration prospects. Lawyers use decision analysis to assess complex litigations with uncertain outcomes. Decision analysis helps medical professionals make correct diagnoses and prescribe the most effective treatment.

The most important components of decision analysis can be integrated into project management processes in all knowledge areas. This includes the analysis of potential alternatives as part of each stage of the project and the assessment of uncertainties as part of project risk management. New project management software utilizing quantitative analysis helps project managers make informed decisions. Recent research shows that well-established decision analysis process integrated into an overall project management framework significantly improves organizational performance.

Among the diverse problems that impede accurate decision analysis, those inherent in human mental processes are the most important and most difficult to deal with. Psychologists have discovered a number of patterns in the way people select alternatives, assess probabilities, identify and manage risks, and make decisions. The knowledge of such patterns will help decision-makers avoid potential mental traps and ultimately improve the quality of their decisions.

“3C” PRINCIPLE OF PROJECT DECISION ANALYSIS

The decision-making process is a framework that helps project managers solve a variety of decision-making problems. There are no exact recipes for how decision analysis should be structured. The process can be tailored for different companies, types of projects, and the types of decisions that must be made.

Any decision analysis process is based on three main rules, which we call the 3C Principle (see figure 1):

1. **Consistency**: Standardized decision analysis process for similar kinds of problems and opportunities enables consistent decision making over time.

2. **Comprehensiveness**: Full 360° assessments and analyses of the business situation are vital. Missing or incomplete information can lead to incorrect decisions.

3. **Continuity**: The value of decision analysis will significantly diminish if performed only in discrete situations during the course of a project. Decision analysis is a continuous process of making and refining decisions during the course of a project.
The decision-making process is a framework that helps project managers solve a variety of decision-making problems. There are no exact recipes for how decision analysis should be structured. The process can be tailored for different companies, types of projects, and the types of decisions that must be made. Any decision analysis process is based on three main rules, which we call the 3C Principle (see figure 1):

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**Figure 1. 3C principle of decision analysis**

**STEPS OF DECISION ANALYSIS PROCESS**
To illustrate the process (figure 2), let us analyze a hypothetical example. A software development project is in its final stage, a deadline is looming, and there is a chance the project will not be completed on time. We will examine how the decision analysis process can identify the best solution for the problem.

**Figure 2. Steps of Decision Analysis Process**

1. **DECISION FRAMING**
Decision framing is based chiefly on subjective expert judgment. Experts provide their own beliefs in the form of their answers, which can be biased. There are many forms of biases: cultural, organizational, motivational, cognitive, and others. Motivational and cognitive biases are most common in project management.

   **a. Identifying Potential Problems and Opportunities**
   In some cases, it is difficult to identify the problems and opportunities. For example, what is causing the different projects within the organization to go consistently over budget in relation to the different specific corrective actions that were undertaken? In our software development example, the project will be delayed if certain actions are not taken.

   **b. Assessing Business Situation**
   Before attempting to make a decision, it is important to assess the business environment and define the constraints related to the problem. The assessment may also include an analysis of markets, competition, prices, or anything that is possibly related to the problem or opportunity. In our example, it is the availability of an additional resource.
c. Determining Success Criteria
In our software development example, success is defined by the chance that the project will be completed on time. Very often project managers have to make decisions based on multiple criteria, including project duration, cost, scope, and other parameters.

d. Identifying Uncertainties
Understanding the uncertainties that can affect the project is the key to the decision analysis process. In our example, there are uncertainties in task duration, start and finish times. Potentially, there could be many different types of uncertainties including uncertainties in cost, resource allocation, and others.

e. Generating Alternatives
First, we identify what cannot be changed, or project constraints for making the particular decision analysis. In our software example, it is the deadline. The project scope is a constraint as well. However, there is the possibility of bringing additional resources (software developers) to accelerate the development. As a result, we have three potential project scenarios:
   a. “Do nothing”. In this example, it means that additional project resources will not be added to the project team.
   b. Bring a developer from another team within the organization.
   c. Hire an external contractor.

2. MODELING THE SITUATION
A mathematical model helps the analysis and estimation of future events. During the modeling stage, project managers rely on heuristics or rules of thumb to make estimations and create the model. Under many circumstances, heuristics lead to predictably faulty judgments or cognitive biases.

   a. Creating Models for Each Project Alternative
Project managers constantly create mathematical models of projects, in most cases this is the project schedule. Sometimes, more elaborate models are required. For example, in the analysis of a complete product lifecycle, comprehensive models will include not only product development, but also marketing and sales efforts. In our example, it is possible to create three simple slightly different project schedules associated with each scenario identified at the decision-framing stage: “do nothing”, add a resource from another project team, and hire an external contractor.

   b. Quantifying the Uncertainties
The uncertainties, identified through the decision framing process should be quantified. One of the ways to quantify uncertainties is defining ranges for parameters. For example, define low (optimistic), base (expected), and high (pessimistic) duration estimates for each task.

Another way to define uncertainties is to list all the potential events, that could affect the project schedule and quantify their probabilities and impact. In our software development example, there is a 50% chance that external consultant will not be familiar with the subject area for the software project, which may delay the development by 20%.

3. QUANTITATIVE ANALYSIS
The analysis should give project managers enough data to make an informed decision. Even with most advanced analytical tools and techniques, interpretation of the results of the analysis is the subject of multiple mental traps.

   a. Determining what is Most Important
A model of a project may include a considerable number of variables: large numbers of tasks, resources, risks, and other parameters. For example, certain risks will cause a failure of the project, while others risks will have no noteworthy effect on the project. To determine which project parameter is the most important, project managers can use sensitivity analysis.
In our software development example, the duration required for the training of the external contractor in one of the potential project scenarios can be very uncertain because the experience of the contractor in the particular subject area is unknown.

   b. Quantifying Risks Associated with the Project
Uncertainties associated with input parameters were already quantified during modeling step. Now it is important to analyze how the combination of all these uncertainties might impact the project success. We can apply a number of analytical techniques for this analysis.
In our example, quantitative analysis shows the following probabilities under each scenario that the project will be completed on time:

a. “Do nothing” – 32%
b. “Bring resource from another team” – 95%
c. “Hire external contractor” – 65%

c. Determining the Value of New Information
One of the useful decision analysis techniques is to assess the value of new information. For example, the goal is to select new development tools for the software project based on performance. Tests can be done to determine performance, but could be costly and time consuming. Alternatively, it is possible to select the tools based on specifications, without performing specific tests. The analytical technique helps to establish the value of new information, which in this case would be the testing results, and to determine whether money should be spent on the test.

d. Deciding on a Course of Action
In many situations, selection of alternatives is not so trivial. Sometimes, a decision must be made using multiple criteria, which complicates the selection of the most efficient alternative. In our example, it is clear that, according to our success criterion, we should select alternative (b) “Bring resource from another team”.

4. ACTUAL PROJECT PERFORMANCE TRACKING
Now a decision has been made and a selected course of action is under way. However, in the middle of the project, an unforeseen event occurs that causes the selected plan to derail. For example, because of other commitments, the new software developer cannot move to the project. Luckily, there is a quantitative model of the selected project alternative and the project manager can update the model, perform a new analysis and make a decision. It is very important to constantly track project performance and analyze all potential pitfalls and opportunities.
ABSTRACT

Recent research indicates cost and schedule forecasting from EVM data is improved when the performance factor, PF = 1, is used. This paper uses a small set of real data to examine the research finding, to either confirm or refute. As well, the application of PF = 1 is employed in statistical forecasting; results are tested and compared to the index method. Observations from the research and this study are made referencing historical studies. Further research is encouraged on these topics, but with some precaution when real data is used.

INTRODUCTION

The 2015 paper, “Empirical Evaluation of Earned Value Management Forecasting Accuracy for Time and Cost” authored by Batselier and Vanhoucke, is the inspiration for this article [Batselier et al, 2015]. Their paper is an impressively comprehensive examination of forecasting from the use of Earned Value Management (EVM) data taken from 51 projects, predominantly construction.

In the history of EVM and Earned Schedule (ES) research, covering 25 years for cost and 15 years for schedule, one type of forecasting formula, incredibly, has been ignored. Included in these past studies are several published by Christensen1, Vanhoucke2, Crumrine3, and Lipke4. Uniquely, Batselier and Vanhoucke (B&V) examine several methods of forecasting. B&V demonstrate overwhelmingly in their analysis this ignored formula yields forecasts more often better than the ones most frequently employed by EVM and ES practitioners.

This article, using a smaller set of data than that used by B&V, attempts to corroborate their finding. The primary objective, however, is to implement the improvement shown for deterministic forecasting into statistical forecasting. The focus is to assess whether the improved nominal forecast translates to better statistical forecasts. As well, the investigation may reveal logical reason for the B&V results.

The subsections following, EVM & ES Forecasting, and Statistical Forecasting, provide background for understanding the remainder of the article.

EVM & ES FORECASTING.

EVM and ES forecasting formulas are very similar. They each have the same basic construct; i.e., the forecast is equal to the current value plus the remainder yet to accomplish divided by a selected performance factor.

Before discussing the formulas, the following EVM and ES terminology is introduced in table 1. It is assumed the reader has a fundamental understanding of EVM and ES. If a more complete description is needed, please reference the following: Practice Standard for Earned Value Management [PMI, 2011], and Earned Schedule [Lipke, 2009-2].

1) Christensen et al, 2002(-1,-2), 1995, 1993(-1,-2)).
In the B&V paper several performance factors (PF) are examined for EVM and ES forecasting. For this paper, only four are used. As depicted in table 1, cost applies to 1 and CPI, while schedule uses 1 and SPI(t). The reason only these are studied is to corroborate the B&V finding that use of PF = 1 provides, in most instances, a better forecast of the actual outcome than does the most often used cumulative value for the performance indexes.

For many years, it has generally been conceded that, overall, the performance indexes provide the most reliable of the possible EVM and ES forecasting methods. Some rationale for reliance on the cost index comes from Dr. Chistensen’s conclusion that CPI tends to worsen as the project progresses toward completion [Christensen, 1993]. As well, Christensen determined that forecasts using CPI are optimistic, which he termed the “low bound” [Christensen et al, 2002-1]. His research indicates that the forecast using CPI will be better than PF = 1; i.e., the CPI forecast will be optimistic, but PF = 1 will be even more so. This comparative deduction may be the reason PF = 1 had not been seriously examined prior to the B&V paper.

STATISTICAL FORECASTING.

The use of statistical methods for inferring outcomes is a long-standing proven mathematical approach. The statistical forecasting method for duration has been demonstrated to perform reasonably well [Lipke et al, 2009-3].

The current statistical method of duration forecasting is derived from the ES equation, IEAC(t) = PD / SPI(t), where using the cumulative value of SPI(t) yields the nominal deterministic forecast. The associated high and low Confidence Limits (CL) are computed from the variation of ln SPI(t); i.e., the logarithm of the periodic index values. As well, the statistical forecasting method for duration is equally applicable to cost by using the appropriate indexes.

Because B&V have shown PF = 1 to provide better forecasts, curiosity is raised concerning its use in statistical forecasting. Thus, it is desired to adapt PF = 1 forecasting such that comparison can be made to the present method. The adaptation is not difficult, but does need some explanation.

Let’s begin with the PFs = 1 duration forecasting expression:

\[ \text{IEAC}(t) = AT + PD - ES \]

First, multiply and divide the ES term by AT. Then by arranging terms, the formula is transformed to:

\[ \text{IEAC}(t) = AT + PD - AT \cdot (\text{ES}/AT) = AT + PD - AT \cdot \text{SPI}(t) \]
7) Complete descriptions of the terms “test statistic” and “significance level” are available in mathematics books of statistics [Crowe, et al, 1960].
8) MAPE = $1/n - (\sum |AD - Forecast(i)|/AD)$, where Forecast(i) is one of the n forecasts.

This expression facilitates the statistical use of the cumulative and periodic index values; the identical values used in the current statistical method. Thus, the forecast confidence limits are computed using the index limits in the current method. That is, for example, the high forecast limit becomes:

$$IEAC(t)_H = AT + PD - AT \cdot e^{-CL_L}$$

where $e$ = the base number for natural logarithms
subscript H denotes the high confidence limit for the forecast
subscript L denotes the low confidence limit for the logarithm of the index

Analogously, the $PFC = 1$ formula for $IEAC$ is transformed for statistical forecasting of cost:

$$IEAC = AC + BAC - AC \cdot CPI$$

**METHODOLOGY**

EVM data from 16 projects are included in the study. The project data comes from three sources and is highly varied: two projects are information technology; twelve come from high technology product development; two are construction type projects. The projects range in duration from a few months to several years. There is no indication in the data of reserves for cost or duration. Although it cannot be verified with certainty, it is believed the projects have not undergone re-planning. The use of projects void of re-planning and other anomalies such as stop work and planned down time, enables a cleaner, less encumbered evaluation of the study results. Disturbances such as these impact the computations and the subsequent analysis.

Utilizing the PF = 1 formulas derived for $IEAC(t)$ and $IEAC$, the nominal and confidence limit forecasts are computed for each project. The forecasts are then analyzed utilizing four hypothesis tests, two each for schedule and cost forecasts. The hypothesis test applied is the Sign Test [NIST, 2017]. The test is made for the null hypothesis, identified as $Ho$. When there is insufficient statistical evidence to support $Ho$, the test result is the alternate hypothesis, $Ha$.

The four hypothesis tests for evaluating the forecast confidence limits, expressed in the form of the alternate hypothesis, are defined below:

1. $H_1$: Final Cost is less than $IEACH$
2. $H_2$: Final Cost is greater than $IEACL$
3. $H_3$: Final Duration is less than $IEAC(t)_H$
4. $H_4$: Final Duration is greater than $IEAC(t)_L$

It should be clear from the test definitions that the testing determines the likelihood that the outcome value (final cost or final duration, as appropriate) resides between the computed forecast confidence limits. Should the testing indicate the final value is likely outside of the confidence limits, the statistical forecast is not considered reliable.

For each of the four tests, the test statistic is computed and compared to a significance level ($\alpha$) equal to 0.05. When the test statistic value is less than or equal to 0.05, there is enough evidence to reject the null hypothesis. The test statistic for the Sign Test is computed using the binomial distribution with each trial having a success probability of 0.5.

**RESULTS/ANALYSIS**

To verify that duration forecasting formula $PFS = 1$ produces, generally, better results than $PFS = SPI(t)$, Mean Absolute Percentage Error (MAPE) calculations were made. As observed in table 2, of the 16 projects, the deterministic forecasts using formula $PFS = 1$ had lower error for 12.

Recognizing that the $PFS = 1$ forecast is not always better, a limited investigation was made to see if a combination of the two methods would yield results having less error. For this, attention was shifted to cost forecasting.
To begin, recall Dr. Chistensen’s observation, cited earlier, that CPI generally decreases as the project progresses. If this is true then it follows that, at some point in project completion, index forecasting should converge to the final outcome faster than PF = 1. As well, when CPI or SPI(t) forecasting is used, it is commonly observed that computed results are volatile early in project execution. In fact, many analysts discount the first 15-20 percent of the execution because they believe the EVM and ES indicators are not reliable enough for making management decisions. Thus, it is reasonable to believe PF = 1 forecasting should be superior in the early stages of the project.

With these two thoughts, consideration was given to creating a composite forecast using both forecasting formulas: PF = 1 for the initial two-thirds of project performance, with PF = index for the final third. After several trials, the composite approach did not produce improved forecasts. Although not nearly as comprehensive as the B&V study, the investigation corroborated their finding of PF = 1 performing well in every partition of project completion.

Having established for the 16 projects that PFS = 1 generally provides the superior forecast, it was thought that statistical forecasting may, likewise, show improvement in comparison to the index method. The tabulation of the hypothesis test results for CLs computed at 90 percent confidence level are presented in table 3. To assist with interpreting the results, recall the general meaning of Ho and Ha:

1. Ha indicates the confidence limit encapsulates the final outcome
2. Ho indicates the outcome lies outside of the confidence limit

Examining the table, it is readily seen: the low CL encapsulates the final outcome for both cost and schedule, whereas high CL generally does not. The low CL for cost had the test result Ha for all 16 projects, while for schedule the low CL was observed for 14 projects. For the cost high CL, 15 of the 16 projects indicate the test result Ho. For schedule, 9 of 16 have Ho results.

These results are tabulated as probabilities and shown in table 4. The numbers in the table indicate the probability that the confidence limit encapsulates the final value. The results shown for PF = CPI and SPI(t) come from a previous study [Lipke et al, 2009-3]. As readily seen, statistical forecasting using the indexes produces considerably more reliable CLs.
### Table 4. Comparison of Confidence Limit Probability

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>High CL</td>
<td>0.028</td>
<td>0.613</td>
</tr>
<tr>
<td>Low CL</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Results for CLs computed at 90 percent confidence level are presented in Table 3. To assist with interpreting the results, recall the general meaning of Ho and Ha:

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#### Table 3. Hypothesis Test Results

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In the previous study (PF = index), 98 percent confidence level was examined with the following resulting probabilities: Cost High CL = 0.927, Low CL = 1.000; Schedule High CL = 1.000, Low CL = 0.997 [Lipke et al, 2009-3]. The consistency of the probability values indicates the CLs are very reliable. For the present study (PF = 1), increasing confidence level did not cause appreciable increase in probability. Thus, it is reasoned the PF = 1 statistical forecasting is unreliable.

### Figure 1. Cost Forecast, PF \( \text{C} = \text{CPI} \)

From these results it appears the CLs from PF = 1 forecasting are optimistically biased. Visually, this can be deduced from graphs for cost and schedule, comparing the statistical forecasts from each computation method. Figures 1 and 2 clearly illustrate the optimistic bias of forecasting using PF\( \text{C} = 1 \), as well as showing PF\( \text{C} = \text{CPI} \) forecasting yields more reliable CLs.

### Figure 2. Cost Forecast, PF \( \text{C} = 1 \)
Statistical forecasts from each computation method. Figures 1 and 2 clearly illustrate the optimistic bias of forecasting using $PF_{C} = 1$, as well as showing $PF_{C} = CPI$ forecasting yields more reliable CLs.

Figure 3. Schedule Forecast, $PFS = SPI(t)$

Figure 4. Schedule Forecast, $PFS = 1$

Similar results are obtained for duration forecasting, using the same EVM data as was used for the cost graphs, Figure 3 illustrates $PFS = SPI(t)$ statistical forecasting, while figure 4 shows $PFS = 1$. In general, both graphs have plots portraying optimistic forecasts. However, the high CL for the $PFS = SPI(t)$ does satisfy the hypothesis test and graphically shows a feature seen consistently. There is a graphical component to interpreting the statistical forecasts produced from $PF = index$. It is observed in both the cost and schedule graphs; the most horizontal plot is generally a very good forecast of the actual outcome. For the index graphs, figures 1 and 3, the most horizontal plots are the nominal forecast for cost and high CL for schedule.

**OBSERVATIONS**

Some exploration was made with notional data. The objective was to see if there is something generally true about the two forecasting methods, $PF = 1$ and $PF = index$. If a characteristic could be discovered, then possibly project managers would have information as to when a particular forecasting formula should be applied.

The exploration was not very structured. Nevertheless, it did show that when the index is constant, this method of forecasting is superior to $PF = 1$. However, as the variation in performance increased, $PF = 1$ became the more accurate. Possibly, this is an area for future study. There may be a variation value which demarcates regions for which each forecasting PF produces its best forecasts.

This observation about variation led to reflection on how organizations handle EVM data. Non-recognition of re-plans, stop work, and down time can inflate index variation, thereby causing index forecasting to appear worse than it should.
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<table>
<thead>
<tr>
<th>Table 5. Notional Data</th>
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To illustrate this problem, a notional set of data was created. It is shown in table 5. The PV, EV, and ES data have five highlighted entries. Each of these entries is a repeat of the entry just prior. If all of the highlighted entries were removed, the planned duration would be 10 periods with project completion occurring in period 20. It is fairly easy to deduce with the yellow entries removed that SPI(t) = 0.5 and has no variation. In this circumstance the index forecast of final duration is better than the PF = 1 forecast.

Now, let’s consider what these entries might be. Possibly each is a re-plan. Or, it could be that each of the yellow PV entries is planned down time. Then, when the downtime occurred, conditions were such that it was not possible to accomplish work and, thus, EV did not progress. When EV does not increase, neither does ES. For the remainder of the discussion, let’s assume the entries describe down time and stop work.

In the table, there are three deterministic duration forecasts: PD/SPI(t)c, AT + (PD – ES), and IEAC(t)sp. As each method is discussed it may be helpful to view figure 5. The figure graphically portrays the performance of the three methods.

Figure 5. Notional Data Forecasting Comparison
The PD/SPI(t) forecast is made by simply using the data strings of PV and EV without regard to seeing a need for further review of the highlighted entries. The consequence is the forecast values are erratic, yet the calculation converges to the actual duration.

As well, the forecast method, AT + (PD – ES), does not examine the highlighted entries and uses the ES calculated values to make forecasts. It, too, converges to the actual duration. One observation is these forecasts are consistently optimistic.

Lastly, the IEAC(t)sp forecasts, a modified form of the index method, perfectly align with the final duration. These forecasts are made using the ES Calculator (Special Cases). This calculator takes into account down time and stop work. It filters through the interruptions to make a better forecast. For this example, the special cases calculator provided forecasting perfection; in general, improvement is expected when the conditions of down time and stop work exist, but not perfection.

The take-away from this exercise is that real EVM data used in testing forecasting methods needs close examination. If at all possible, data having re-plans should be avoided. For projects having down time and stop work, the places in the data where they occur need identification so that they can be handled appropriately.

SUMMARY/CONCLUSION
Forecasts of project duration were made using real data from 16 projects. The forecasts using performance factors, SPI(t) and PFS = 1, were compared using MAPE values; 12 of the 16 forecasts made with PFS = 1 were observed to have less error with respect to the final duration. This result is in agreement with the finding stated by B&V [Bastelier et al, 2015]; i.e., forecasts using PFS = 1 are generally better. As well, a very limited examination confirmed the B&V finding that PF = 1 performs well throughout the project.

With confirmation that PF = 1 forecasts generally produce more accurate results, its use in statistical forecasting was explored. The examination revealed that the associated confidence limits are unreliable for both cost and schedule. The CLs are optimistically skewed. Thus, statistical forecasting with PF = 1 is not recommended.

Duration forecasting comparison was made using notional data which included down time and stop work. Three methods were compared; two ignoring the conditions and one recognizing them. The index method, PD/SPI(t), provided highly volatile pessimistic forecasts. The PFS = 1 method was less volatile and consistently optimistic. The method recognizing the conditions, IEAC(t)sp, yielded an accurate forecast. The significant point derived from the exercise is real data needs to be closely examined and used appropriately when performing forecasting studies. Otherwise, the study results are suspect.

SUGGESTED RESEARCH
In the limited investigations of this study it was observed, when the index is reasonably constant, the deterministic forecasts were better than those made with PFS = 1. Thus, there may be a demarcation value for the variation of ln SPI(t) identifying which forecasting method should be applied; i.e., below a specific value of variation the index method is used and above it, PFS = 1 is preferred. It is suggested to researchers that this area be investigated.

At present, the application of Earned Schedule-Longest Path (ES-LP) forecasting has not been sufficiently tested. Possibly, the various forecasting formulas could be used with ES-LP to explore further improvements to forecasting.

9) The Earned Schedule Calculator (Special Cases) is available from the Earned Schedule website (www.earnedschedule.com).
REFERENCES:


About the Author:
Walt Lipke retired in 2005 as deputy chief of the Software Division at Tinker Air Force Base, where he led the organization to the 1999 SEI/IEEE award for Software Process Achievement. He is the creator of the Earned Schedule technique, which extracts schedule information from earned value data.

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- Academic honors - Phi Kappa Phi (ΦΚΦ)
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- PMI Eric Jenett Award (2007)
- EVM Europe Award (2013)
- CPM Driessnack Award (2014)
- Australian Project Governance and Control Symposium established the annual Walt Lipke Project Governance and Control Excellence Award (2017)
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TRUST, BUT VERIFY: AN IMPROVED ESTIMATING TECHNIQUE USING THE INTEGRATED MASTER SCHEDULE (IMS)
By Eric M. Lofgren — Technomics, Inc.

ABSTRACT

“Trust, but verify is a form of advice given which recommends that while a source of information might be considered reliable, one should perform additional research to verify that such information is accurate, or trustworthy. The original Russian proverb is a short rhyme which states, Доверяй, но проверяй (doverai, no proveryai).”

It has long been the wonder of management why the Integrated Master Schedule (IMS) fails to give clear and advanced warning of impending schedule delays. An estimator may follow authoritative guidance in an analysis of schedule health using key metrics, supposing that such checks authenticate schedule realism. Why, then, do practitioners find themselves caught off guard by slips when their IMS appears to be in good health? Answers to the question follow from observing the evolution of the IMS over the course of its submissions. By independently tracing activities across IMS submission, this article will show how an analysis of performance to the original baseline can improve predictions of project end dates.¹

BACKGROUND

The Integrated Master Schedule is more than a tool for managing the time-phasing and resource allocation of project activities. Decision makers find value in an IMS for its ability to evaluate the impacts of schedule risk and provide early warning of schedule slip. For many Major Defense Acquisition Program (MDAP) contracts, the IMS has a questionable history of accurately reflecting schedule risk. In an analysis of eight MDAP contracts,² schedule slips were not apparent until late in the project. It can be seen in the figure below that IMS data often fails to indicate any delay until after half-way through the original schedule duration. In fact, as a project approaches its expected end date, further delays develop resulting in a tail chase.³ The situation gives decision makers minimal leeway for managing trade-offs and implementing well-informed strategies.

Predicted schedule slip reported by IMS submission
Observations from actual IMS data reveal the importance of comparing the most recent IMS submission to its initial. For example, poor schedule performance can be masked by modifying the baseline. Within the sample IMS data, more than a quarter of all activities had changes to their baseline end dates within the first year of execution. Many more were dropped or were otherwise unidentifiable. Those with baseline changes within the first year experienced an average of three months slip. Such “rubber” baselines hinder the schedule’s predictive power. Another way poor schedule performance can be masked is by injecting optimism into future activities. For example, even though actual task completion may have been poor, the schedule can appear on-time if a surge in task completions is forecasted. Sample data suggests this form of optimism is unfounded. The proportion of tasks finishing late generally continues to increase until the project finishes. The sample IMS data shows task performance degrades over the course of a project. A linear approximation indicates that an additional 5% of near-term tasks will finish late to the current baseline for every 10% of project duration that passes. Another way optimism can be injected is using hard constraints. The sample IMS data shows that many schedules constrain more than 5%, and up to 20%, of open activities. Of those activities with constraints, generally between half and all of them are binding. Binding means that the forecast start or end date equals the constraint date. When a constraint binds an activity, it is not driven by its predecessors’ performance and may no longer cause slip to the project schedule.

Maybe the most important concept in schedule construction and maintenance is logic: the idea that every activity must have at least one predecessor and one successor activity. Logic drives the sequencing of activities and interconnects the schedule so that a change to any one given activity ripples across all successors. Not one of the schedules from the sample dataset saw less than 5% of near-term tasks missing logic. Generally, 10% or more of near-term tasks were missing both predecessor and successor logic links. The rate was between 10% and 20% early in the project; half way through many projects were missing upwards of 60% of their logic links, some climbing to 80% by project’s end.

Observations of sample IMS data show that, in general, projects rely on forecasts where expectations of task performance become increasingly detached from actuals. Not only are forecasts biased toward undue optimism, but schedule quality tends to decrease significantly over time leading to schedules with fewer useful interrelationships between activities. Guidance from most authoritative sources does not speak to the trends and patterns in IMS submissions over time. Guidance has focused on gauging the quality of the most recent submission because only the latest IMS incorporates up-to-date information, making the IMS a living document. The inadequacy of status quo metrics stems from the perceived irrelevancy of prior IMS submissions. The metrics are based on a trust that schedules have rigorously maintained a baseline, but little has been said on how to verify that rigor through a cross-IMS analysis.

Without a point of reference to ensure logical evolution, the current IMS can only say so much. It is important to understand, for example, what baseline changes have occurred over time and how actual performance has been measured to near-term plans. While schedules are living documents, the original baseline from the initial IMS stands as the best available point of reference. The original baseline is valid for three major reasons. First, planners tend to know the major activities involved in the execution of a project. All systems can be said to have historical analogies, even those considered revolutionary. Second, contractors generally have well-defined processes for developing these systems. Third, the IMS undergoes an Integrated Baseline Review (IBR) after which both the contractor and client agree to the plan and its efficacy. Thus, the IMS from its outset may be viewed by estimators primarily as a tool for measuring the scheduler’s ability to plan in the near-term.

This article starts from an acceptable assumption—that an activity’s baseline from the first IMS is relevant through subsequent submissions. Planners generally do a good job of laying out major activities, and so early performance on near-term activities should be a good indicator of total schedule realism. Practitioners have often heard anecdotally that early schedule slip cannot be made up despite managerial tactics. This article will explore that notion and whether it finds support in the data. It will be shown that by tracing near-term activities through subsequent IMS submissions and comparing them to their original baseline, as opposed to the current baseline, one may extrapolate a more realistic contract end date far earlier in the project.
THE TECHNIQUE

The preceding section has shown that, in general, schedule quality and performance tend to decrease over the course of a contract. A high number of binding constraints and increasing number of late tasks result in schedule optimism. Numerous baseline changes can conceal poor performance. Fewer logic links indicate a poorly maintained schedule. These generalizations have a negative impact on schedule realism. Even a high quality rating for any given IMS does not mean that it has also evolved in a consistent manner. The relevant question becomes, “Can the IMS data on hand be better utilized to measure schedule risk and extrapolate a realistic end date far earlier in the project?”

The lynchpin of the proposed schedule estimating technique is the baseline in the original IMS submission. The first available IMS, preferably the one immediately following IBR, will be used to independently track activities over subsequent submissions. Activity end dates are traced over time using their designated activity names and/or unique IDs. The updated end dates will then be compared to their original baseline end date and total float (slack days). The process disregards: new activities which get built into the schedule over time; activities which change identifiers; and modifications to activity leads, lags, constraints, and sequencing. While the omissions appear concerning, remember, the primary purpose is to trace performance of the relatively near-term baseline plan. Both contractual parties agreed to the baseline IMS which often takes months to develop. That some activities cannot be traced (for example, a task broken up into three new, smaller tasks) is simply a reality insofar as there is no record of the changes.

To determine schedule slip, the analyst looks across all tasks still identifiable in subsequent IMS submissions and compares them to their original baseline. The activity which has slipped most to that baseline (in terms of business days), with the original days of float factored in, drives the independently predicted end date. That number of days slip is added to the baseline end date for the project’s close-out activity.

\[
\text{Predicted End Date}(t_a) = \text{Baseline End Date}(t_b) + \text{Slip}(t_a)
\]

\[
\text{Slip}(t_a) = \max\{f(x_i) : i = 1, \ldots, k\}
\]

where \( f(x_i) = (\text{Current Finish}_i - \text{Baseline Finish}_i - \text{Baseline Total Float}_i \)

and \( \max\{f(x_i) : i = 1, \ldots, k\} \geq 0 \)

\( \chi_i = \text{observed activity} \)

When the schedule has evolved to the extent that the current activities no longer reflect the original baseline, the predicted end date stabilizes and the estimate is determined. This occurs because the tasks in the baseline IMS have their end dates realized and the planning packages open up into new activities. The rule implemented by the author is to stop the analysis when more than 95% of the activities from the original baseline are either finished or no longer appear in the current schedule. The final prediction for project end is then set. An example will illustrate this methodology.

The first IMS sets the baseline for future activities. All activity end dates will be evaluated for each subsequent IMS and compared to their baseline. In the case of IMS #2, several activities have experienced slips to their forecast end dates. For example, “Frame first floor walls” has slipped 4 business days while it only had 3 days of float available. This means that the task will affect the start of all its successor tasks and push out the milestone “Framing complete” by 1 day, all else equal. In IMS #3, “Install roof decking” has slipped 7 days to baseline, and factoring in its original 3 business days of float, should now affect “Framing complete” by 4 days.

A simplified example of an evolving IMS
How has “Framing complete” been able to stay on track? In the example above, the forecasted tasks have had their durations squeezed to make up time. In the sample from actual IMS data, forecasted discrete tasks do not regularly show shorter durations than past tasks. A plausible reason is that the long-term future is represented by planning packages which incorporate many tasks. When opened, the resulting tasks are given realistic durations and distribute the implicit duration squeeze onto planning packages still further out. Although evidence cannot be concretely pulled from the data, it has been shown that forecasted performance is optimistic and there are numerous binding constraints. Such behavior is sufficient to maintain a fixed near-term schedule, even if it is unrealistic in the long-term. The total schedule might be saved because of the future’s vagueness. As time progresses, the pool of undetailed tasks dwindles and increasingly focuses implicit duration compression. By the time the schedule’s unrealism is noted—possibly by pure reckoning—it would be relatively late in the project.

RESULTS

The proposed technique disregards over-optimism by relying on early task performance to the original baseline. Because major activities are reasonably phased from the start, the total schedule receives a one-for-one slip with the worst performer to the original baseline. The idea becomes increasingly attractive when considering the fact that schedules tend to lose an alarming number of logic links over time, perhaps implying higher reliability of the networking imparted on the original baseline. The estimation technique is not intended to forecast exact dates, but should be viewed as a rough order of magnitude for would-be schedule slips. Below, one may see that from the contractor’s point of view (blue), the IMS predicted less than a 10% schedule slip up until near 70% of the total duration had passed. Then significant delays were belatedly realized; the project eventually slipped by almost 45% to baseline. The independent point of view, representing the technique proposed in this article, quickly registered schedule risk to within about 10% of actual slip. Note that the (red) independent line plateaus shortly after 50% of latest schedule. This is where the current schedule largely reflects new activities; in other words, activities from the original IMS have for the most part been completed or dropped.

The figure below illustrates the new metric’s predictive power across all eight projects. By 50% of the latest schedule duration, the independent metric registered a majority of realized schedule slip. The mean absolute error for the 41-50% of schedule bin is only seven months; compare that to the contractor’s 25 months of error. It equates to a year-and-a-half of schedule slip on average not yet realized by the contractor’s IMS. In fact, the contractor IMS did not reach a mean absolute error of seven months until close to 80% of the total schedule had elapsed. With more than a year of lead time, the improved predictions provides management an early warning indicator that allows them to do advanced planning for cost-schedule-technical tradeoffs. Early recognition of major difficulties also leads to greater flexibility in project termination because of fewer sunk costs. Schedule quality as traditionally calculated largely ignores the quality of the schedule’s evolution.
Using the technique presented above, an analyst may catch a potential schedule slip earlier in the project with relative accuracy. While schedules are a living document and develop over time, planners do a good job at the outset of phasing major milestones and near-term tasks. Though projects change, the deliverable doesn't often transform completely. However, cumulative changes to a schedule tend to deteriorate its realism. As described, schedule performance is best registered early for a variety of reasons including increasingly optimistic forecasts and decreasing quality. It may be concluded that contractors quickly reveal their pace of work and “settle” into a performance; or management strategies such as work-arounds can do little to alleviate ailing projects. Until a culture of improved schedule maintenance takes root, early performance to the original baseline early may serve as the best indicator of realized schedule slip.

The independent metric finds useful application for estimating costs as well. If the metric predicts a one year slip over that reported in the IMS, the analyst may extend the average project cost burn rate out for the same duration. The figure below does just that using one of the real projects analyzed in this article. The red line is the cost of the traditional Independent Estimate At Completion (IEAC) plus the mean actual burn rate multiplied by the number of months slip the independent metric predicts over the current IMS. The new independent cost estimate behaves similar to the schedule estimator and gives a good early indication of realized costs.
DISCUSSION
A year after the development of the estimating technique presented in this article, Shedrick Bridgeforth independently tested it along with various other schedule estimating techniques. He found that for a set of 12 completed defense satellite development efforts, the technique presented in this article, which he called the Independent Duration Estimate (IDE), outperformed all other EVMS-based approaches in predicting the realized schedule. Bridgeforth wrote that “These results suggest Lofgren's approach (IDE) is the most accurate technique.” In particular, the so-called IDE approach provided more realistic estimates far earlier in the development cycle than other techniques. Bridgeforth recommends using the IDE technique for space development contracts when the data are available.

While Bridgeforth's results support the findings in this article, he cautions that “Lofgren’s IDE framework does not consider the critical path; it considers all tasks as equally important. The IDE may struggle to become a best practice because it ignores the CPM [Critical Path Method] and is relatively new.” While the technique is both new and not well recognized in the cost and schedule analysis communities, it is not completely true that the technique ignores the CPM. As explained above, the total float from the original schedule is taken into account, factoring in the logic behind the critical path put into the baseline of the first IMS. Activities in successive schedules that slip more days than they had total float in the first IMS then compete to become schedule drivers on an unofficial critical path. The technique presented here is independent precisely because it ignores changes to tasks and networking relative to the schedule’s original baseline—changes which alter the disposition of what would have otherwise been the critical path.

If the activities and relationships networked in the baseline schedule remained constant over time, the activities driving the IDE technique should be exactly those activities found on the contractor’s critical path in the IMS. What distorts the signal of schedule progress is the cumulative changes to the content and networking of activities. By stripping away such “noise,” which in many cases results from efforts to mitigate realized risks, the technique proposed here focuses on actual performance to baseline plan for near-term tasks. It rejects updated expectations to forecasts of task efficiency, which often has an optimistic bias. While Bridgeforth would be correct to say the technique ignores the current critical path, it does not ignore the critical path as networked into the baseline schedule. In this sense, it creates a counterfactual scenario where the baseline tasks played out as originally planned. The independent estimate is derived from the variance between the current critical path and its counterfactual.

When Bridgeforth wrote that the technique considers all tasks to be equally important, he was completely correct. In some sense, a successful project needs all tasks to come together according to some sequencing—this is the basis of the systems approach. However, actual schedules that are detailed enough for use as a management tool will contain tasks that are in no way critical to the deliverable. Numerous examples of such tasks can be imagined in detailed schedules. A casual use of the technique might result in an inconsequential task, or set of tasks, driving the independent estimate. The point brings up an important issue. The technique presented here is not intended to be a precise. For complex schedules, it is a rather blunt instrument for measuring variance to the counterfactual from baseline assumptions. The analyst must be discerning when evaluating the tasks driving the independent estimate. For example, a best practice is to line the tasks up in rank order of how much they are driving the estimate in the analysis. What content of each task? Did they experience baseline changes to their start or end dates? What activities preceded and succeeded them, and has that network been stable or logical? However, if the IMS is volatile, having dropped and replaced many activities, then seemingly inconsequential tasks may provide some residual signal as to the realized schedule slip of important unseen tasks. The power of the proposed technique more generally is to facilitate project analysis. It is not solely to provide more accurate predictions faster; if that were the goal, then the best rule might be to immediately assume a slip of 40 percent or so. Unlike the presented technique, such a rule does not take individual project circumstances into account and provides no basis for targeting management, or for understanding the impact of changes to project assumptions.
In some cases, there are good reasons for baseline changes, and the fact of the matter is that schedules should continue to be allowed rapid and frequent changes to baseline assumptions, particularly in large or uncertain projects. A recent and important exception to the focus on the current IMS submission is the GAO's “Best Practices for Project Schedules,” which advocates a continuing analysis of the baseline schedule relative to the most recent instantiation of the schedule. It states in the 10th and final best practice: “The baseline schedule is not the same as the current schedule. The current schedule is updated from actual performance data... The baseline schedule represents the program’s commitments to all stakeholders, while the current schedule represents the actual plan to date.” Rigorous maintenance of the original baseline may be too constraining for the schedule to be useful day-to-day and may end up creating unintended consequences. However, referencing the baseline and pointing out the biggest deviations can provide a fruitful starting point from which to ask questions about whether the IMS is providing a realistic assessment of progress. In most cases, variation between the contractor’s end date and the end date from a discerning use of the presented technique should be tolerated within a certain range, reflecting a degree of trust between parties that is crucial to project success. Baseline assumptions can be wrong or non-optimal, especially at the task level, and the contractor must be allowed flexibility to exercise real options that change direction based on updated information, particularly in research and development work. When the production sequence is well-known and repeatable, deviations from an agreed upon baseline should receive less tolerance.

CONCLUSION
As the single source of comprehensive schedule information on most projects, the IMS’s predictive ability rests on its quality. It is preferred that the IMS exhibits high quality such that the analyst can develop actionable plans using its forecast. Currently, analysts spend a great deal of effort trying to tease out the biases in schedules to generate more “realistic” forecasts. The technique presented in this article is no different. It searches for bias by independently tracking baseline activities through subsequent schedules. All such manipulation of native schedule data to support independent predictions is highly speculative. Attention to schedule maintenance is a superior use of scarce resources relative to guessing its inherent biases. Longitudinal checks of the sort described in this article would expose the need to eliminate—or to better understand—the biases that analysts attempt to exploit for the purpose of prediction. Oversight of this sort can go a long way to ensuring high schedule quality from the outset.

Though improving schedule quality is the first-best solution, in today’s scheduling environment there is much to be done using the author’s schedule estimating technique. First and foremost, it is important to scrutinize the tasks that drive the independent technique’s estimate. Put the drivers in rank order and pick out the outliers. The technique is one way to approach the more urgent need of longitudinal schedule analysis. Second is the need for replication studies to test the metric’s robustness. Third, to assess the value of this technique for Indefinite Delivery, Indefinite Quantity (IDIQ) contracts, a more detailed approach is required, such as analysis by task-order. Further assessment is also needed for augmentation to cost estimation. One method (extending mean burn rates) has been presented in this article, but many other approaches are possible. Finally, a large collection of IMSs used for analysis can also provide data-driven generalizations of schedule quality and realism over time. Additional insights into IMS evolution can help practitioners understand how to better manage their schedule, and provides a benchmark for evaluating relative schedule quality.
Endnotes


2) MDAP contract data accessed through the Earned Value Management Central Repository (EVM-CR). This article reflects an analysis of all contract schedules available to the researcher. Data not included: all contracts without data spanning contract start to end and IMSs in PDF or picture format. Eight contract projects are reported. Uniform data extraction methodology used across contract schedules: extracted 19 standard fields for non-summary activities; converted into Microsoft Excel flat-files and used standard template for metrics gathering and analysis. Additional contract insight gained from Defense Acquisition Management Information Retrieval (DAMIR).

Note that the observational findings of the Background section included an additional four Indefinite Delivery, Indefinite Quantity (IDIQ) contracts. The IDIQ contracts remained in the observational findings because conclusions drawn from task hit/miss, logic, constraints, and so forth, are not affected by the IDIQ nature of the contracts. The author did not have detailed data as to which activities went to which task orders to allow for the technique to be applied to IDIQ contracts.


4) Authoritative guidance includes “Earned Value Management System (EVMS) Program Analysis Pamphlet (PAP)” by Defense Contract Management Agency (DCMA), the “GAO Schedule Assessment Guide” by U.S. Government Accountability Office (GAO), and the “Joint Cost and Schedule Risk and Uncertainty Handbook” posted by the Naval Center for Cost Analysis. See additional EVMS guidance from Performance Assessment and Root Cause Analyses (PARCA) including the IMS Data Item Description (DID) and the “IPMR Implementation Guide.” The “Integrated Master Plan and Integrated Master Schedule Preparation and Use Guide” is another useful resource.

5) Total float (also called total slack) is the number of days an activity is allowed to move to the right before any further slips affect the project end date. When an activity has zero days of float, it might find itself on the “critical path,” or a sequence of activities representing the shortest duration between the schedule’s ‘as of’ date and the end of the project.


8) Flexibility in project scheduling is especially important in research and development (R&D) projects where the definition and outcome of tasks cannot be known in advance, leading to reflexive relationships between activities. Rigorous baseline maintenance may not in all cases be optimal when adaptation is required for success. For example, RAND researchers W. Meckling, B. Klein, and E. Mesthene wrote that “Any attempt to schedule an entire R&D program at one time is likely to lead to inefficiency, either because plans for the later stages may have to be scrapped and remade on the basis of information yielded by early tests, or because, in pursuing premature plans, a development program may fail to profit from new information gained along the way. Either case will cause delays, or raise costs, or both.” See “Military Research and Development Policies.” RAND Corp., 4 December 1958, pp. 3.

9) For more information on schedule quality and longitudinal checks, see Lofgren, Eric M. “Putting Schedule Checks to the Test,” ICEAA 2016.
AGILE’S EARNED SCHEDULE BASELINE
By Robert Van De Velde, PhD

ABSTRACT
For managing schedule performance on an Agile project, canonical Agile techniques fall short. Estimates are essential for meeting project time constraints, but Agile’s relative estimates are too “fuzzy” to meet the needs of Sprint planning. Typical Agile Burndown charts focus on Release Point counts that only suggest how well or poorly the schedule is performing. The addition of Earned Value helps, but EVM’s traditional schedule metrics are inadequate. Earned Schedule fills the gaps. It provides a robust baseline to measure past schedule performance and to estimate future impact on delivery date and performance level.

For plan-driven projects, schedule baselines are a given. For Agile projects, baselines are suspect. The difference is evident in the charters of the two approaches.

On one hand, the Project Management Institute states that the schedule baseline is the time-phased plan against which project execution is measured and managed (“PMB”, 2013, p. 549). Without the baseline, there is no basis for measuring and managing schedule performance.

On the other hand, both the Agile Manifesto (Beck et al., 2001a) and Principles (Beck et al., 2001b) omit any reference to baselines. The Manifesto takes the omission a step further by stating that change is valued over following a plan. As the schedule baseline is, by definition, a plan, it is clearly not a high priority for Agile.

The different perspectives are rooted in disparate objectives. Canonical Agile projects seek the early and continuous delivery of the Product Vision. Orthodox plan-driven projects seek the on-time and on-budget delivery of the project objectives.

Schedule and cost constraints make a crucial difference. To deliver on-time and on-budget, you need credible targets for timeline and funding. Baselines embody the targets.

Whether or not Agile projects are ever free of such constraints is debatable. That debate is not the focus here. Instead, the focus is on those projects that use the Agile framework but are also bound by constraints, specifically the time constraint.

DEFINING THE SCHEDULE BASELINE
In Agile projects, a schedule baseline can be derived from velocity. Velocity is the number of Release Points (aka, Story Points) for each Sprint.

How is the velocity set? Again, there are challenges from the canonical Agile view. As the Agile Alliance puts it: “phrases such as ‘setting the velocity’ reveal a basic misunderstanding” (“Velocity”, n.d.). In that view, velocity is a retroactive measurement, something done after the fact. It is not a forward-looking estimate of the future completion rate.

The objection is another consequence of omitting time as a constraint. Without that constraint, you simply measure the number of Release Points completed in each Sprint. At most, that number can be kept in mind as Product Backlog Items are selected for the next Sprint.

In a time-constrained Agile project, the “next Sprint” is not enough. Velocity measures must reach beyond the next Sprint to cover the whole project timeline. Without that scope, you cannot reasonably commit to a delivery date. With that scope, you need an estimate, specifically an estimate that encompasses the whole timeline.
SCRUN ESTIMATES
There are some variants of Agile that advocate forward-looking velocity estimates. For instance, the Scrum framework uses techniques such as T-shirt sizing, Planning Poker, and Fibonacci bucketing to produce estimates (Sil, 2013).

Scrum estimates are for the relative size of Product Backlog Items. The size is determined by comparing items in the Backlog: Item A is larger than Item B which is larger than Item C. But, what dimension is being sized? That is not so clear. Some say it is the amount of complexity; others say it is cost; still others say it is uncertainty.

In the end, Scrum’s relative estimates are viewed as replacements for absolute Work Hour estimates (“Relative Estimation”, n.d.). So, complexity, cost, and uncertainty are just considerations used to size work effort.

Relative estimates often differentiate sizes by assigning numbers from a geometric series or from the Fibonacci sequence. That gives the appearance of quantifying the differences. For instance, an Item assigned an 8 is larger than one assigned a 2.

Many proponents of Agile do not stop there. They say that relative estimates also indicate how much larger one Item is than another (Singh, 2016). For instance, an Item assigned an 8 is four-times larger than one assigned a 2.

We have found that Agile teams often agree on the order between Items. But, we have observed frequent disagreement over how much difference there is between Items. Is an Item labeled with a Fibonacci number of “21” really 7 times larger than one labeled as “3”? Is an Item labeled with a geometric series number “3” really one-third the effort of a “9”?

LIMITS OF RELATIVE ESTIMATES
The disagreements reflect divergent beliefs about size. The situation is similar to one that occurs in social science and marketing research. There, Likert scales measure psychological states such as levels of satisfaction (e.g., with a product or service). The comparative levels are often associated with numbers from 1 to 5, as depicted in Figure 1.

1) Very Dissatisfied
2) Dissatisfied
3) Neutral
4) Satisfied
5) Very Satisfied

Figure 1

Likert scales have been studied extensively (Stevens, 1946; Michell, 1986; Sauro, 2011). The studies have raised questions such as: do the numbers have an objective numerical basis, and are the intervals between levels equal? The upshot is that the scale represents subjective states and that such states cannot be objectively measured. So, we cannot be sure that the difference in assigned numbers is the same as the attribute they represent.

Similarly, Agile team members use numbers to express beliefs about the relative size of work effort. But, what one person believes is twice as much effort may differ from what another person believes is twice the effort. So, although 4 is twice the size of 2, we cannot be sure that everyone on the team means the same thing when they assign “4” to an Item. The most that we can be sure of is that the Item is larger and more-or-less twice the size of a “2”.

WHY “FUZZINESS” MATTERS
Does the “fuzziness” matter? Yes, it matters. The estimates are used in Sprint planning. Sprint planning, in turn, is important for meeting time constraints. Backlog items are selected to fit into a Sprint based in part on the estimated velocity of the team. Without that guide, the Sprint goal might be set too high or too low. Either way, project time commitments would be undermined.

For selecting Items of the right size, relative estimates fall short. Using fuzzy estimates is like driving through a town that has posted its speed limit as “35-ish”. If you are not worried about time—just drive at 15, and you should be OK. Or, if you do not care about safety, drive at 55 but recognize that you might crash.

If time matters, you need to know how fast you can go without breaking the limit but still getting through as quickly and safely as possible. That is what a cardinal estimate tells you. It
goes beyond the subjective state to something that can be objectively measured. It provides a clear baseline for assessing performance on past Sprints and planning future ones. That is why we cannot stop the estimating process with relative estimates. Instead, we need to develop cardinal estimates.

**LIMITS OF RELEASE POINT BASELINES**

Armed with cardinal velocity estimates, the Release Point baseline can be set. It is runs from the Release Point total to zero. The end of each Sprint marks completion of an increment of estimated velocity. For comparison, the number of Release Points actually completed at the end of each Sprint is used to decrement the Release Point total. A burn chart is generally used to illustrate the estimated and actual velocity. Figure 2 illustrates the chart, specifically the Burndown Chart, from a recent project.

Schedule performance is inferred from the relationship between the Actual Burn line and the Planned Burn line. When the Actual Burn line is above the Planned Burn line, it suggests that schedule performance is better than expected. Finally, the size of the gap between the two lines suggests the level of schedule performance efficiency.

It is important to note that the chart only suggests how well the schedule is performing. The data points in the chart are not units of time but are, instead, Release Point counts. There is no quantification of schedule performance efficiency. Finally, there is no estimate of the performance impact on delivery date. The Release Point Baseline and its pictorialization, the burn chart, are good tools for a quick reading on the situation, but they omit key pieces of information.

One reason they fall short is that Release Points do not measure value. On time-constrained projects, we need to know not only the number of Points but also the value of those points. That knowledge enables us to see beyond the completion of low value items that make burn charts look good but are not really moving the project forward.

Note that the term “value” here reflects the efficiency of execution rather than its effectiveness. That is, it is Earned Value rather than Business Value (Alleman, 2011; Alleman, 2009). Earned Value Management (EVM) tells us the budgeted cost of the planned velocity and the amount of that budget earned by the actual velocity. The traditional EVM measure of schedule performance, the Schedule Performance Index (SPI), is the ratio between the cumulative earned value and total planned value.

Unfortunately, traditional EVM measures of schedule performance are inadequate. After a project is about two-thirds complete, the SPI rises inexorably to a perfect 1.0. Even if the project finishes late, the SPI ends at 1.0—a counterintuitive indication of performance. Furthermore, traditional EVM measures do not include an estimate at completion for time (EACt) or an estimate of the schedule performance level required to complete on time (TSPI). Finally, traditional EVM schedule performance measures are framed in terms of dollars, rather than units of time.

Fortunately, Earned Schedule has closed the gaps.

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2) Discussion of techniques for producing cardinal estimates in Agile projects is outside the scope of this paper. Glen Alleman has many instructive posts on the topic in his blog (see Alleman, 2015a; Alleman, 2015b; and Alleman, 2017).

3) There are extensions to traditional EVM that include formulas for EACt (e.g., Anbari, 2001). The extensions are undermined by reliance on SPI.
EARNED SCHEDULE
The amount of time earned on a project is defined as “the time at which the value currently earned should have been earned” (Lipke, 2009, p. 14). The definition neatly ties planned value and earned value into time, framing ES metrics in units of time rather than cost.

The calculation of Earned Schedule is simple. Count the number of Sprints in which the current total of Earned Value is greater than or equal to the cumulative Planned Value.4 Usually, some Earned Value remains after the last full Sprint is counted. The fractional time earned equals the ratio between the left-over Earned Value and the Planned Value for the next Sprint beyond the last full one.

Schedule performance efficiency for time (SPIt) is calculated as the ratio between the amount of schedule earned and the actual time. Based on this efficiency, the EACt is estimated as the ratio between the Planned Duration and SPIt. Finally, the TSPI is the ratio between the Planned Duration less the Earned Schedule and the Planned Duration less the Actual Time.

Studies have repeatedly demonstrated that Earned Schedule metrics are superior to other EVM schedule performance measures (Vanhoucke and Vandevoorde, 2007; Lipke, 2008; Crumrine and Ritschel, 2013). In our own practice, we have used the metrics successfully on many projects—some of which used the Agile framework. We have found ES metrics to be especially useful in managing hybrid project portfolios comprising both plan-driven and Agile projects.

EARNED SCHEDULE BASELINE
The Earned Schedule baseline is framed by the pace of Release Point delivery. Cardinal estimates for the number of planned Release Points and the mean velocity determine the number of Sprints. Given the project start date and number of Sprints, the planned finish date is set. The Earned Schedule baseline fits into that frame as follows: for each elapsed Sprint, one Sprint should be earned.

If all Release Points carry the same value, the mean velocity ensures that the periodic Planned Value is the same for each planned Sprint. It follows that the periodic amount of planned Earned Schedule is the same for each planned Sprint. Expressed as a burn chart, the baseline runs straight from the end of the first Sprint to the end of the last planned Sprint.

It is possible for Release Points to carry different values. For instance, if Release Points express Work Hours, their value might vary depending on the resource responsible for delivering them. In such cases, the baseline is still one earned Sprint for each elapsed Sprint, but there’s a catch.

If Release Points carry different values, a mean Planned Value should be set for all Sprints and used to guide the selection of Items for the next Sprint. A constant Planned Value ensures that the periodic Earned Schedule is the same across all planned Sprints. The ES baseline, therefore, will be isomorphic with the Release Point baseline, providing common ground for comparison.

By contrast, the actual ES burn will usually be non-linear. The amount of schedule earned generally varies from Sprint to Sprint. At the end of each Sprint, the total number of Sprints is decremented by the total amount of schedule earned. So, in a burn chart, the ES burn line typically weaves around the ES baseline.

Figure 3 illustrates the ES Burndown from the same project used for Figure 2. The ES baseline runs straight from the beginning to the planned finish. The ES Burn line runs on or above the baseline. The chart is enhanced with a table displaying additional ES metrics.

4) A Sprint is defined as a time-boxed unit of delivery. All Sprints in a project have the same duration, normally 1 week to 1 month. Calculating ES in terms of Sprints is, therefore, equivalent to calculating ES in units of time.
INTERPRETING THE ES BURNDOWN CHART

The ES Burndown Chart is easy to interpret. If the ES Burn line is above the ES baseline, schedule performance lags the estimate. If the ES Burn line is below the baseline, performance is ahead of the estimate. If it is on the line, schedule performance is exactly on the estimate. Because the data points represent units of time, the chart explicitly shows how time is being used on the project.

In Figure 3, the chart makes it clear that schedule performance is lagging in most Sprints. The performance deficit is clearest when a large gap opens at Sprints 2 through 5. By contrast, Figure 2 suggests that the project is generally running on or slightly behind schedule. (In Sprint 8, it even appears that the project is slightly ahead of schedule.) Given that the project actually finished after the Baseline Finish, the ES Burndown is a more accurate representation of schedule performance.

The project’s backstory helps explain the chart. To build momentum, the project team decided to spend a couple of Sprints working on quick deliverables, even though they were low value and did not align with the mean Planned Value. The quick deliverables preserved Release Point production at the estimated rate but delivered less Earned Value than planned. Hence, the Release Point chart tracked close to plan, and the ES chart did not.

The table included with the chart quantified how time was being used on the project. When the SPIt was below 1.0, schedule performance was lagging. If the SPIt had been over 1.0, schedule performance would have been better than expected. As commonly happens, the SPIt was never exactly equal to 1.0.

Early in the project, as the team built momentum, the SPIt suffered. Eventually, the team returned to the original plan, and the SPIt improved. The improvement did not, however, recover all of the lost time. The SPIt accurately reflected performance throughout the project lifecycle. When the project exceeded the Baseline Finish, the SPIt ended below 1.0.

The EACt and TSPI threw additional light on schedule performance. The Baseline Finish had been set at Sprint 9 with a Committed Finish at Sprint 10. The EACt consistently showed that, given actual performance levels, the Baseline Finish would not be met.

The TSPI re-enforced that view. In several Sprints, the TSPI exceeded the commonly accepted threshold for recoverability (i.e., a value of 1.1 as per Lipke, 2016; Lipke, 2009, pp. 90-91). Unsurprisingly, it was beyond the threshold at Sprint 8, just before the TSPI became undefined.

The most positive signal in the metrics surfaced after Sprint 5. The EACt began to show that the Committed Finish would be met.

In the example, although schedule performance was not uniformly bad, it was never good enough to meet the Baseline Finish. The ES Burndown Chart signalled the potential for delay, and the associated metrics quantified the implications.
CONCLUSION
On time-constrained Agile projects, the Earned Schedule Baseline provides a robust yardstick for measuring schedule performance. Using the ES Baseline entails divergence from both canonical Agile practice and plan-driven methodology. The discrepancies must be acknowledged, but in the end, the value that Earned Schedule brings to Agile projects makes the departures worthwhile.

REFERENCES


ABOUT THE AUTHOR
Robert Van De Velde owns and operates ProjectFlightDeck.com, a company focused on Earned Schedule products and services. As a project manager, Rob has a 30-year track record of delivering IT programs and projects in a variety of domains. He has successfully used ES on both plan-driven and Agile projects. Rob holds a PhD, a PMP, and a Black Belt in MS Project. In 2014, he became a Certified Scrum Master. Rob posts regularly on LinkedIn’s ES group and on his blog, EarnedScheduleExchange.com.

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Building Information Modeling (BIM) is a process that creates and manages information on a construction project across the project lifecycle. A key output of this process is the digital description of every aspect of the built asset. The BIM draws on information assembled collaboratively and updated at key stages of a project. Creating a digital BIM enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset.

The question for the IPPM community is, “How can BIM and the lessons learned from its evolution be used in the ‘built’ environment of aircraft, ships, ground vehicles, and other assets in the Federal Government beyond buildings and facilities?”

Here’s a sample of papers and books on BIM and its connection to DOD acquisition processes. Google will find all these documents.

- “BIM and Cost Estimating,” REVIT® Building Information Modeling, Autodesk – Autodesk has many white papers on the BIM topic.
- “Building Information Management (BIM) Implementation in naval construction,” Raymond Rohena, LSU Master’s Theses, 2011.


• “Traditional Design versus BIM Based Design,” Ireneusz Czmocha and Adam PČkala, *XXIII R-S-P seminar, Theoretical Foundation of Civil Engineering (23RSP) (TFoCE 2014)*, Procedia Engineering, 91, 2014, pp. 210 – 215

• GSA BIM Guides, [https://www.gsa.gov/real-estate/design-construction/3d4d-building-information-modeling/bim-guides](https://www.gsa.gov/real-estate/design-construction/3d4d-building-information-modeling/bim-guides)

• “Linking Knowledge-Based Systems to CAD Design Data with an Object-Oriented Building Product Model,” Kenji Ito, Yasumasa Ueno, Raymond Levitt, and Adnan Darwiche, Center of Integrated Facility Engineering, Stanford University, technical report Number 17, August 1989.
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