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# Standard Guide for Schedule Performance Index, Schedule Beta ($\beta_s$)[1]

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## INTRODUCTION

The schedule performance index, schedule beta ($\beta_s$), correlates the performance of network schedule participants (critical path method (CPM)) at the activity level to the overall project performance on an ongoing basis. The value of the index is representative of the collection of completed activities within their respective projects over a defined period of time. It identifies the propensity of schedule participants to fulfill their initial schedule durations ("as-planned") by delivering their work on-time, which may be used as an indicator of future performance. Schedule beta ($\beta_s$) enables contractors, project managers, supervisors, and schedulers to include indicative performance when assembling construction project teams, evaluate potential participant appropriateness considering schedule time constraints, and improve schedule accuracy and performance.

## 1. Scope

1.1 This guide covers schedule beta ($\beta_s$), which measures construction project participant schedule performance versus that of the overall completed project and is based on beta (β) from financial portfolio theory for measuring the correlation between individual stock performance and that of the overall stock market.[2] By correlating the delta of actual activity performance ("as-built") minus that originally scheduled ("as-planned") to the delta of as-built minus as-planned for the overall completed project for a participant's collection of projects over a specified period of time, a schedule performance index is established in a similar manner as the aforementioned beta (β) of an individual stock.

1.2 Schedule beta ($\beta_s$) measures, as a unitless index value, schedule participant ("subcontractor's") performance—ahead or behind—as-planned duration as correlated to its respective overall project's schedule performance.

1.3 Schedule beta ($\beta_s$) is measured with input from at least two (2) independent (mutually exclusive) projects that have reached completion, within the defined period of observation.

1.4 Schedule beta ($\beta_s$) is measured across a standard predetermined period of time, in similar fashion to that of the insurance industry's experience modification rate's (EMR) most recent two (2) complete calendar years within the past thirty-six (36) months.

1.5 Schedule beta ($\beta_s$) evaluates schedule participant's ("subcontractor's") most recent performance, not its complete history, such that is it indicative of current performance and contemporary influences—market, geographic, industry trade, etc.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[3]

E631 Terminology of Building Constructions

E833 Terminology of Building Economics

[1] This guide is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.81 on Building Economics.

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[2] The schedule performance index, schedule Beta ($\beta_s$), is based on the Beta (β) factor as found in the Capital Asset Pricing Model (CAPM) of financial portfolio theory, as formalized by Black, Jensen, and Scholes in Jensen, M. C., Black, F., Scholes, M. S., "The Capital Asset Pricing Model: Some Empirical Tests." In *Studies in the Theory of Capital Markets*, ed. M. C. Jensen, Praeger Publishers, Inc., New York, NY, 1972, which received the 1990 Alfred Nobel Memorial Prize in financial economics (Sharpe and Markowitz and Miller).

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E1946 Practice for Measuring Cost Risk of Buildings and Building Systems and Other Constructed Projects
E2166 Practice for Organizing and Managing Building Data
E2587 Practice for Use of Control Charts in Statistical Process Control
E2691 Practice for Job Productivity Measurement

## 3. Terminology

3.1 *Definitions (General)*—For general definitions of terms used in this guide, refer to Terminology E631 and Terminology E833.

3.2 *Definitions (Companion Standard Practices)*—For definitions of terms used in this guide relative to cost risk, refer to Practice E1946. For definitions of terms used in this guide relative to building data, refer to Practice E2166. For definitions of terms used in this guide relative to statistical process control and control charts, refer to Practice E2587. For definitions of terms used in this guide relative to job productivity measurement, refer to Practice E2691.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *as-built duration*—the resulting time an individual activity or the overall construction project actually expended to complete the work.

3.3.1.1 *Discussion*— Individual activity as-built durations may be longer or shorter than the as-planned duration. The overall project as-built duration is the sum of the critical activities (those comprising the critical path) forming the longest uninterrupted sequence of activities in the overall schedule as actually expended. The critical path resulting in the completed project may not be comprised of the same critical activities as initially established in the as-planned schedule due to extensions and/or contractions in actual time expended to complete the work of individual schedule activities.

3.3.2 *as-planned duration*—the amount of time initially established for an individual activity or the overall construction project to be completed.

3.3.2.1 *Discussion*—Individual activity as-planned durations are discrete values assumed independent from other activities within the same construction project. The overall project as-planned duration is the sum of the critical activities (those comprising the critical path) forming the longest uninterrupted sequence of activities in the overall schedule as initially established.

3.3.3 *financial beta*[4]—the mathematical coefficient as found in the CAPM that describes the historic movement of an individual security's (an individual stock's) daily returns to the corresponding daily return of the entire market, as defined by the formula:

$$\text{Beta}(\beta) = \text{Covariance}(R_i, R_m) / \text{Variance}(R_m)$$

where:

$\text{Covariance}(R_i, R_m)$ = $[(R_i - \bar{R}_i) \cdot (R_m - \bar{R}_m)]$,
$\text{Variance}(R_m)$ = $(R_i - \bar{R}_i)^2$,
$i$ = index of individual asset performance,
$m$ = index of market performance,
$\bar{R}_i$ = the asset prior performance benchmark, commonly the previous day's individual stock return, and
$\bar{R}_m$ = the market prior performance benchmark, commonly the previous day's overall market return.

3.3.3.1 *Discussion*—See CAPM definition for $R_i$ and $R_m$.

3.3.4 *capital asset pricing model (CAPM)*[5]—the Capital Asset Pricing Model (CAPM), as developed by Black, Jensen, and Scholes, and represented by the following formula:

$$E(R_i) = r_f + \beta_i \cdot [E(R_m) - r_f]$$

where:

$E(R_i)$ = the expected return of a capital asset (an individual stock),
$E(R_m)$ = the expected return of the overall market,
$E(R_m) - r_f$ = known as the "market premium" or the "risk premium," is the difference between the expected market rate of return and the risk-free rate of return,
$r_f$ = the risk-free rate of return, such as interest arising form government bonds,
$R_i$ = the return of an individual capital asset, typically that of an individual company's stock,
$R_m$ = the return of the overall market, and
$\beta_i$ = beta is the sensitivity of the expected excess asset returns to the expected excess market returns; see financial beta and beta (β) definition for mathematical expression.

3.3.5 *covariance*—mathematically defined as the arithmetic mean of the products of the deviations of the corresponding values of two quantitative variables from their respective arithmetic means.[6]

3.3.5.1 *Discussion*—Specific to the schedule beta ($\beta_s$) calculation, covariance is defined as the arithmetic mean of the product of the deviation of schedule participant activity performance from as-planned to as-built (the "activity duration delta") to its mean value and the mean of the product of the deviation of the overall project schedule performance from as-planned to as-built (the "project duration delta") to its mean value.

3.3.6 *critical chain*—critical chain is a schedule network analysis technique that modifies the project schedule to account for limited resources.

3.3.6.1 *Discussion*—Initially, the project schedule network diagram is built using duration estimates with required dependencies and defined constraints as inputs. The critical path is then calculated. After the critical path is identified, resource availability is entered and the resource-limited schedule result

[4] Beta (β) has been formalized by Black, Jensen, and Scholes (1972).

[5] The Capital Asset Pricing Model (CAPM) of financial portfolio theory has been formalized by Black, Jensen, and Scholes (1972).

[6] Covariance definition from Merriam-Webster website, www.merriam-webster.com.

is determined. The resulting schedule often has an altered critical path. The resource-constrained critical path is known as the critical chain.[7]

3.3.7 *critical path method (CPM)*—the critical path method calculates the theoretical early start and finish dates, and late start and finish dates, for all activities without regard for any resource limitations, by performing a forward and backward pass analysis through the schedule network.[8]

3.3.8 *earned value management (EVM)*—earned value management (EVM) in its various forms is a commonly used method of performance measurement.

3.3.8.1 *Discussion*— It integrates project scope, cost, and schedule measures to help the project management team assess and measure project performance and progress. It is a project management technique that requires the formation of an integrated baseline against which performance can be measured for the duration of the project. The principles of EVM can be applied to all projects, in any industry. EVM develops and monitors three key dimensions for each work package and control account: planned value (PV), earned value (EV), actual cost (AC).[9]

3.3.9 *schedule beta ($\beta_s$)*—the mathematical coefficient (index value) rooted in the CAPM and extended to network schedule systems to describe the historic movement of an individual schedule participant's (an individual subcontractor's) deviation from as-planned to as-built schedule performance versus that of the overall project's deviation from as-planned to as-built schedule performance over a specified period of time, as defined by the formula:

$$\text{Schedule Beta } (\beta) = \text{Covariance}(D_i, D_m) / \text{Variance}(D_m)$$

where:

$\text{Covariance } (D_i, D_m) = [(d_j - \bar{d}_i) \cdot (d_n - \bar{d}_m)]$,

$\text{Variance } (D_m) = (d_n - \bar{d}_m)^2$,

$\beta_s = \sum(d_j - \bar{d}_i) \cdot (d_n - \bar{d}_m) / \sum(d_n - \bar{d}_m)^2$,

$i$ = the index for labeling as-planned activities,

$j$ = the index for labeling as-built activities,

$m$ = the index for labeling as-planned projects,

$n$ = the index for labeling as-built projects,

$D_i$ = the delta of the as-built durations to the as-planned durations of the schedule participant activities for the projects completed during the specified period of time,

$d_j$ = the as-built duration of an individual schedule participant activity within its respective construction project completed during the specified period of time, herein defined as the resulting actual activity duration as presented in the final published version of the construction project schedule,

$d_i$ = the as-planned duration performance benchmark of an individual schedule participant activity within an individual construction project completed during the specified period of time, herein defined as the activity schedule duration as presented in the initial published version of the construction project schedule,

$\bar{d}_i$ = the statistical mean benchmark value of the delta of the as-built durations minus the as-planned durations of the schedule participant activities for the projects completed during the specified period of time,

$D_m$ = the deltas of the as-planned durations minus the as-built durations of the overall construction projects completed during the specified period of time,

$d_n$ = the as-built duration of the overall construction project completed during the specified period of time, herein defined as the project duration as presented in the final published version of the construction project schedule,

$d_m$ = the as-planned duration of the overall construction project completed during the specified period of time, herein defined as the project duration as presented in the initial published version of the construction project schedule, and

$\bar{d}_m$ = the statistical mean benchmark value of the delta of the as-built durations minus the as-planned durations of the overall corresponding individual construction project for the projects completed during the specified period of time, herein defined as the values resulting from total project schedule duration as presented in the initial published version of the construction project schedule.

3.3.10 *schedule beta benchmark ($\beta_{s\text{-}bm}$)*—the collective mathematical coefficient (index value) rooted in the CAPM and extended to network schedule systems to describe the historic

[7] Critical Chain definition from Section 6.5.2.3, Project Management Book of Knowledge (PMBOK) 4th Edition, Project Management Institute (PMI) ANSI/PMI 99–001–2008.

[8] Critical Path Method definition from Section 6.5.2.2, Project Management Book of Knowledge (PMBOK) 4th Edition, Project Management Institute (PMI) ANSI/PMI 99–001–2008.

[9] Earned Value Management (EVM) definition from Section 7.3.2.1, Project Management Book of Knowledge (PMBOK) 4th Edition, Project Management Institute (PMI) ANSI/PMI 99–001–2008.