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Standard Guide for Schedule Performance Index, Schedule Beta (β_s)[1]

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INTRODUCTION

The schedule performance index, schedule beta (β_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 (β_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 (β_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 (β_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 (β_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 (β_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 (β_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 (β_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:

Covariance (R_i, R_m)	=	$[(R_i - \bar{R}_i) \cdot (R_m - \bar{R}_m)]$,
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
β_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 (β_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* (β_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:

Covariance (D_i, D_m) = $[(d_j - \bar{d}_i) \cdot (d_n - \bar{d}_m)$,
Variance (D_m) = $(d_n - \bar{d}_m)^2$,
β_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.

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 irrespective of any specified period of time—inclusive of the entire population of projects.

3.3.11 *schedule beta upside (β_{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 when limited to performance on construction projects for which the *as-built schedule duration is less than the as-planned schedule duration*. That is, the construction project finished ahead of the as-planned duration: The project took less time to finish than originally established.

3.3.12 *schedule beta downside (β_{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 when limited to performance on construction projects for which the *as-built schedule duration is greater than the as-planned schedule duration*. That is, the construction project finished behind the as-planned duration: The project took more time to finish than originally established.

3.3.13 *schedule participant*—the specific owner of an activity and/or collection of activities within a construction project network schedule (critical path method, CPM) system, commonly considered to be a subcontractor; schedule participants typically are responsible for ("own") multiple schedule activities within the network schedule system.

3.3.14 *specified period of time*—the time in calendar years during which completed construction projects will be used to calculate schedule beta (β_s) and its subvariants schedule beta upside and downside.

3.3.15 *variance*—mathematically defined as the square of the standard deviation; [10] specific to the schedule beta (β_s) calculation, variance is defined as sum of the squares of the standard deviation of the array of overall project activity duration deltas.

4. Summary of Guide

4.1 This guide is organized as follows:

4.1.1 *Section 1, Scope*—Identifies the coverage of schedule beta (β_s).

4.1.2 *Section 2, Referenced Documents*—Lists ASTM standards referenced in this guide.

4.1.3 *Section 3, Terminology*—Addresses definitions of terms used in this guide.

4.1.4 *Section 4, Summary of Guide*—Outlines the contents of this guide.

4.1.5 *Section 5, Significance and Use*—Explains the significance and use of the array of schedule beta (β_s) values.

4.1.6 *Section 6, Procedure*—Lists the steps for calculating the array of schedule beta (β_s) values.

4.1.7 *Section 7, Data Sources and Assumptions*—Describes the raw data required, their format, and use in the calculation of the array of schedule beta (βs) values.

4.1.8 *Section 8, Calculation of the Schedule Performance Index, Schedule Beta (β_s)*—Depicts the calculation of the array of schedule beta values—schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}), using data gathered according to Section 7 and with output defined by Section 10.

4.1.9 *Section 9, Applications*—Describes where and how schedule beta (β_s) values can be used.

4.1.10 *Section 10, Report*—Describes the various types of output and reports.

4.1.11 *Section 11, Precision, Bias*—Expected values for the array of schedule beta (β_s) values. Reserved for future development.

4.1.12 *Section 12, Keywords*—Lists related words and phrases related to the schedule beta (β_s) approach.

5. Significance and Use

5.1 The schedule beta (β_s) approach produces informational elements: Overall (or composite) schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-})—representing the quantitative components, and the qualitative insight ("early warning") into the propensity for directional schedule performance for individual schedule participants.

5.1.1 The quantitative component of schedule beta (β_s) (inclusive of the upside and downside subvariants) is an index value that depicts schedule participant's magnitude and direction of movement as compared to the overall project at an assigned value of 1.0, for example, a β_s = +2.5 connotes performance of a schedule participant that moves in the same direction as the collection of completed projects at a rate of 2.5 units (schedule days) for each single unit (schedule day) experienced at the overall project level.

5.1.2 The qualitative component of schedule beta (β_s) (inclusive of the upside and downside subvariants) provides insight as a cautionary and predictive signal depicting the ability for an individual schedule participant to perform in-keeping with the initially-established as-planned schedule duration(s).

5.2 Schedule beta (β_s) also depicts the overall status or health (performing well or not) of a market sector, location and/or trade. Consistent larger schedule beta (β_s) values are indicative of external elements (risks) impacting all participants sharing common attribute(s) (that is, trade, location, market sector, etc.).

5.3 Schedule beta (β_s) measures current schedule participant performance. As a rolling value (for example, calculated for projects completed during the two most recently completed full calendar years), it depicts the schedule performance ability of the schedule participant. See Note 1.

[10] Variance definition from Merriam-Webster website, http://www.merriam-webster.com.

NOTE 1—*Schedule Data Source and Usage*—Schedule beta (β_s) (inclusive of the upside and downside subvariants) utilizes schedule data from any schedule calculation method that depicts individual activity duration versus overall project duration and is updated on a regular basis. Data are used for calculation, comparison, and/or contrasting purposes. They are not created under this guide. Schedule beta (β_s) uses four data points from the external scheduling method: as-planned and as-built durations for both individual activity and the overall construction project in its calculation – see Section 3 for definitions.

5.3.1 *Improving Values*—Schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}) are characterized as improving when their value decreases in magnitude (that is, β_s = +2.5 becomes β_s = +1.75 and β_s = –1.25 becomes β_s = –3.0).

5.3.2 *Deteriorating Values*—Schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}) are characterized as deteriorating when their value increases in magnitude (that is, β_s = +0.5 becomes β_s = +1. 5 and β_s = –2.25 becomes β_s = –1.0).

5.4 Schedule beta (β_s) (inclusive of the upside and downside subvariants) is capable of being calculated any time a project reaches completion and no further activity (no additional days) are recorded within an overall project schedule.

5.4.1 Any schedule participant having completed their work in at least two (2) distinct (mutually exclusive) completed projects may calculate the full array of schedule beta values—schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}).

6. Procedure

6.1 Establish a baseline (as-planned) duration within a network schedule system for work contracted on a project for the collection of activities sufficiently adequate to define the work in its smallest definable components. Baseline schedule shall include a work breakdown structure (WBS) deemed to be sufficiently adequate to represent the collection of individual activities and the overall construction project. See Note 2.

NOTE 2—Work breakdown structure (WBS) is expected to conform to the requirements of Practice E2691.

6.2 Perform work in accordance with the established network schedule system including any adjustments, modifications, changes in scope, etc. required for completion of the overall project, periodically, timely, and consistently updating actual progress (to create the as-built record) through the completion of the project. (See 7.1 for the expectations of network schedule system data accuracy.)

6.3 Collect schedule participant-specific and overall project duration data (as-planned, as-built, final completion date, etc.) for all activities within each project in which the schedule participant performed work. Data collection may result from two (2) methods:

6.3.1 *Hand Tabulation*—Examination of raw schedule data (per 7.2) made available by the overall project schedule owner (general contractor) and determination of the relevant elements for schedule participant-specific inclusion in a computer spreadsheet.

6.3.2 *Computer Program Extraction*—Conversion of formatted schedule data specific to the particular proprietary network schedule system (CPM schedule) into numeric values for direct input and itemization of the relevant elements for schedule participant-specific inclusion in a computer spreadsheet.

6.4 Evaluate project completion date for inclusion within the specified period of time for which any schedule beta (β_s) value is to be calculated.

6.5 Calculate the array of schedule beta (β_s) values—schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}), for all projects for which data have been collected and deemed valid, irrespective of any specified period of time, to establish overall "living" benchmark values.

6.6 Calculate the array of schedule beta (β_s) values—schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}), for the desired specified period of time.

6.7 Compare any or all of the array of schedule beta (β_s) values calculated to the schedule participant-specific benchmarks (for trending purposes) and/or comparison to the values of other schedule participant's schedule betas (βs) based upon trade, location, market sector, etc.

6.8 Identify any and all deviation differential(s) from the schedule participant-specific schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}) benchmark value and/or any benchmark values available based upon trade, location, market sector, etc. and review the attribution to any special causes (see Note 3) impacting the schedule participant-specific schedule beta (β_s) value or values. (See Section 11 for variations in the array of schedule beta (β_s) value differences attributable to special causes).

NOTE 3—As defined by Practice E2587, a special cause (or unassignable cause) is a factor that contributes to variation in a process or product output that is feasible to detect and identify. In the array of schedule beta (β_s) measurement, the factor contributes to variation in as-built duration or deviation from the as-planned benchmark.

7. Data Sources and Assumptions

7.1 The array of schedule beta values—schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}), are predicated upon the following assumptions and/or conditions:

7.1.1 *Unit(s)*—The array of schedule beta values—schedule beta (β_s), schedule beta upside (β_{s+}), and schedule beta downside (β_{s-}), are predicated upon a ubiquitous definition of schedule duration in calendar days. Partial and/or incomplete units (calendar days) are not permissible in the calculation of any schedule beta (β_s) value.

7.1.2 *Completion Status*—Any and all work within and for a project to be used in the calculation of any schedule beta (β_s) value is required to be completed, such that no additional time (days of work activity and/or delay) are recorded in the network schedule system.

7.1.3 *Correctness and Completeness*—Any and all network schedule systems used in the calculation of any schedule beta (β_s) value is required to be accurate (representative of the most current state at any point during execution) and complete (lacking any gaps in content and/or update).