EXAMINATION OF THE THRESHOLD FOR THE TO COMPLETE INDEXES

By Walt Lipke, PMI® Oklahoma City Chapter

ABSTRACT

From time to time in the Earned Value Management literature a claim is made that exceeding the To Complete Performance Index (TCPI) value of 1.10 spells doom for the project. That is, when the threshold value of 1.10 is exceeded, the project is out of control and the project manager has little chance of successfully recovering to the desired project cost. An article from a few years ago examined the threshold theoretically, concluding that it appears to have validity. As well, the same article extended its assessment to the comparable Earned Schedule indicator, the To Complete Schedule Performance Index (TSPI). This paper examines the threshold value empirically for both TCPI and TSPI, using real data from 25 projects of differing type and varying sources.

INTRODUCTION

In the application of Earned Value Management (EVM), the To Complete Performance Index (TCPI) is an important cost performance indicator for project managers (PM) [Fleming, et al, 2009]. What does TCPI tell us? The index value describes the cost performance efficiency required for the remainder of the project to achieve the desired final cost. The value of TCPI can have a very powerful influence on how a PM views the need or urgency for intervention and management action.

The indicator is defined as the work remaining to be accomplished divided by the amount of unspent funding [Project Management Institute, 2011]. The indicator is incredibly useful in that it can be evaluated using cost values different from the Budget at Completion. For simplicity in defining the mathematical formula, this "different" cost is termed the total cost desired (TC). Thus, the index formula is defined as follows:

$$TCPI = (BAC - EV) / (TC - AC)$$

where BAC = Budget at Completion
EV = Earned Value
TC = Total Cost
AC = Actual Cost

Historically, the TCPI value of 1.10 is regarded as a threshold to avoid exceeding if at all possible. Although empirical evidence has not been established, it is believed to be the point at which project performance is out of control; i.e., the probability of recovering to the desired total cost is extremely low.

With the development of Earned Schedule (ES), a comparable indicator has been created for schedule performance management, the To Complete Schedule Performance Index (TSPI). The index value yields the schedule performance efficiency required for the remainder of the project to achieve the desired project duration. The TSPI indicator is defined in the time domain, similarly to TCPI. TSPI is equal to the portion of the planned duration remaining completion divided by the time duration available [PMI, 2011]:

$$TSPI = (PD - ES) / (TD - AT)$$

where PD = Planned Duration
ES = Earned Schedule
TD = Total Duration
AT = Actual Time Duration

Applying similar logic as that used for TCPI, the threshold value of 1.10 is the point at which, when exceeded, achieving the desired project duration (TD) becomes virtually impossible.

PREVIOUS RESEARCH

The TCPI has been examined in a theoretical sense as to its behavior when the value approaches and then exceeds the value of 1.10 [Lipke, 2009]. Figure 1 provides a graphical illustration.[1] As the project progresses to completion, with the Cost Performance Index (CPI)[2] constant at the value of 0.85, TCPI begins to increase gradually until its value is 1.10. From that point, TCPI is observed to become markedly larger for small increases in project fraction complete.[3]

The rate of increase (RI) of TCPI with respect to fraction complete was subsequently evaluated for this example using calculus. The RI was evaluated when TCPI = 1.10 and observed to be a moderate value (1.024). Then RI was computed at a fraction complete greater by only 4.4 percent. The RI was alarmingly larger (1.479). The calculations were then repeated, increasing fraction complete by another five percent; RI became much larger (2.500). Certainly, the probability of successfully achieving the desired project cost becomes extremely low when the cost efficiency required is 1.149 and is increasing at the rate of 250 percent.

The conclusion from the research analysis was "...the TCPI value of 1.10 is a reasonable criterion for determining when a project is not recoverable (to its desired cost) and is 'out of control'" [Lipke, 2009]. Because the formulation and behavior of TSPI is analogous to TCPI, it was likewise concluded that exceeding the TSPI value of 1.10 indicates the project most likely cannot achieve its desired duration.

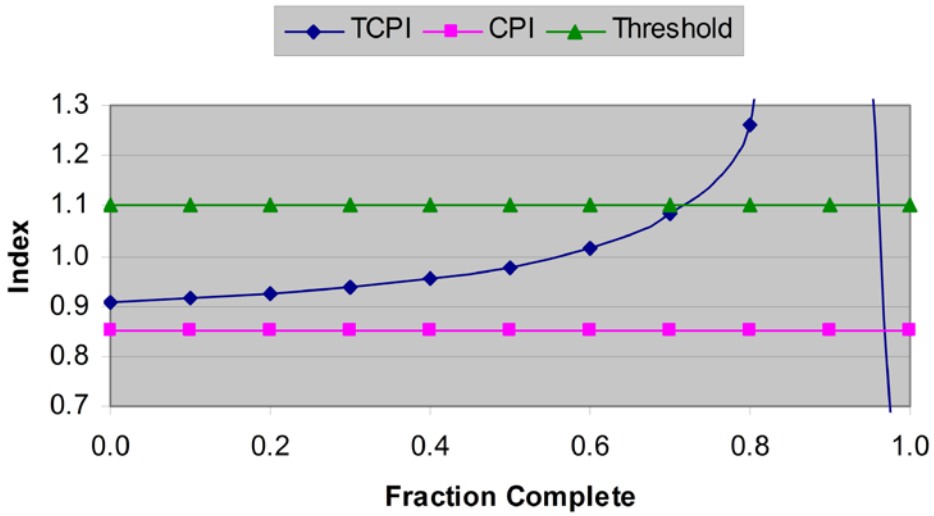

Figure 1. Behavior of the To Complete Performance Index

Beyond establishing the value of 1.10 as a reasonable threshold for TCPI and TSPI, this research described how the "to complete" indexes could be used to determine the period of opportunity for project recovery. As an example, let us assume we are managing the project whose performance is portrayed in figure 1. At 30 percent complete, TCPI equals 0.937 and does not cause management alarm. Yet, from the low value of CPI, we know if the poor cost efficiency continues TCPI is likely to increase and approach the threshold. Using a derived expression, the TCPI formula can be applied to determine the percent complete when the threshold value is reached, assuming no management intervention.[4] For our example, this occurs at 72 percent complete. Thus, with very little effort, it has been determined that we have the next 42 percent of project achievement to effect corrective actions and render a successful outcome, i.e., the period of opportunity.

EVALUATION METHODOLOGY

Data Description. EVM data from twenty five projects was used to evaluate the validity of the TCPI and TSPI threshold value, 1.10. The project data comes from three sources and is highly varied: four projects are information technology; twelve come from high technology product development; nine 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. A significant data characteristic is the projects have not undergone re-planning. The use of projects void of re-planning enables a cleaner, less encumbered evaluation of the study results, by not having to account for the disturbance.

1 - Figure 1 is taken from [Lipke, 2009].
2 - CPI is defined as EV divided by AC [PMI, 2011].
3 - Project fraction complete is equal to EV divided by BAC.
4 - By dividing the numerator and denominator by BAC, TCPI can be expressed in terms of fraction complete and CPI [Lipke, 2009].

TCPI and TSPI Values for Evaluation. For each of the 25 projects, TCPI and TSPI are calculated at each of their respective status points. To evaluate the effect of reserves, the calculations were repeated for reserve amounts of 5, 10, and 15 percent.[5] The project cost and duration outcomes for each reserve scenario are classified as one of three possibilities: over, at, or under in relation to their respective allocations. These outcomes are then used to select TCPI and TSPI values needed for testing by segregating performance into two areas, those that satisfy the completion requirements and those that do not:

1. For projects that do not complete within their cost or duration (to include reserves), the first TCPI or TSPI value exceeding 1.10 was recorded. The condition to identify the "first value" is the first after the project has completed, at minimum, 20 percent of the BAC or PD, as appropriate.

2. For those projects completing at, or within, their cost or duration (including reserves), the largest value for TCPI or TSPI was recorded. Just as for the delinquent projects, the values recorded are identified after the project is at least 20 percent complete.

The rationale for the two groupings is readily explainable. If exceeding the value of 1.10 correlates to a delinquent project, then the first instance is sufficient for the analysis. For the non-delinquent projects, the largest value provides information concerning whether projects can be recovered when the threshold is exceeded.

The recorded values of TCPI and TSPI along with their associated cost and duration outcomes for the 25 projects are then examined through statistical hypothesis testing [Crowe, et al, 1960].

Hypothesis Tests. Four hypothesis tests are performed, two each for TCPI and TSPI. The tests are performed for each of the four reserve percentages (0, 5, 10, 15). Thus, each index is evaluated from the results of eight tests. The hypothesis test method used is the Sign Test [NIST, 2015]. 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 used to evaluate the threshold are defined, as follows:

1. For projects having TCPI ≤ 1.10, identify those over budget
   Ho: Completion within budget is unlikely
   Ha: Completion within budget is likely

2. For projects having TCPI > 1.10, identify those on or under budget
   Ho: Cost recovery is possible
   Ha: Cost recovery is unlikely

3. For projects having TSPI ≤ 1.10, identify those completing late
   Ho: On-time/early delivery is unlikely
   Ha: On-time/early delivery is likely

4. For projects having TSPI > 1.10, identify those completing on-time or early
   Ho: Duration recovery is possible
   Ha: Duration recovery is unlikely

For each of the four tests, the test statistic is computed and compared to a significance level (α) equal to 0.05.[6] 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. The computed value is the probability of a specific number of successes occurring from a number of trials, each having the probability of success equal to 0.5. The number of trials is determined from applying the index condition stated in the test definition; while from the projects identified, the successes counted are those having the stated performance outcome.

ANALYSIS AND TEST RESULTS

The effect of reserves is readily seen in the project outcomes. As reserves are increased, the number of projects meeting or exceeding performance expectations increases. Table 1 is a compilation of the impact of the various reserve amounts.

5 - Reserve amounts are computed in relation to BAC for cost and PD for duration.

6 - A complete description of the terms "test statistic" and "significance level" is available in mathematics books of statistics [Crowe, et al, 1960].

Reserve	Cost Outcomes			Schedule Outcomes		
	Under	At Budget	Over	Early	On Time	Late
0%	6	0	19	3	4	18
5%	9	2*	14	9	2	14
10%	11	0	14	9	3	13
15%	13	0	12	14	1	10

* Projects for which final cost was very close to budget, one within 0.8% and the other 0.3%.

Table 1. Cost and Schedule Outcomes

Of course having reserves increases the likelihood of successful project completion. In addition to this expectation, the table illustrates the impact of reserves on the calculation of the test statistic for hypothesis test evaluation. For example, consider hypothesis test 1. Only those projects meeting the requirement TCPI ≤ 1.10 are subject to the testing (the number of trials). Of those the number completed exceeding the desired cost are counted and used in the calculation (the number of successes). Thus, for the example, it is apparent that the numbers used in the test statistic calculation are less than the total number of projects. The point to be understood from the foregoing discussion is that it is possible the selection process may cause sample size to be very small. When this occurs, the hypothesis test result becomes questionable.

Projects	TSPI	E, O, L	Sign	TSPI	E, O, L	Sign
1	1.250	L	0	1.250	L	-
2	1.118	L	0	1.118	L	-
3	1.601	L	0	1.601	L	-
4	1.134	O	0	1.134	O	+
5	0.905	E	-	0.905	E	0
6	1.118	L	0	1.118	L	-
7	1.200	L	0	1.200	L	-
8	1.006	E	-	1.006	E	0
9	1.156	L	0	1.156	L	-
10	1.129	L	0	1.129	L	-
11	1.115	L	0	1.115	L	-
12	1.115	E	0	1.115	E	+
13	0.928	E	-	0.928	E	0
14	0.782	E	-	0.782	E	0
15	0.893	E	-	0.893	E	0
16	0.833	E	-	0.833	E	0
17	1.066	E	-	1.066	E	0
18	1.137	L	0	1.137	L	-
19	1.000	O	-	1.000	O	0
20	1.587	L	0	1.587	L	-
21	0.947	E	-	0.947	E	0
22	2.000	L	0	2.000	L	-
23	1.120	O	0	1.120	O	+
24	1.439	L	0	1.439	L	-
25	1.169	L	0	1.169	L	-
Calc Values						
R+			0			3
N	Selects the projects having TSPI ≤ 1.10 identifying those that completed Late		25	Selects the projects having TSPI > 1.10 identifying those that completed On-Time or Early		25
n			16			9
S+			0.00195			0.01064
α			0.05			0.05
Test Result						
Ho or Ha	Ho: On-time delivery is unlikely		Ha	Ho: Recovery is possible		Ha
	Ha: On-time delivery is likely			Ha: Recovery is unlikely		
Legend: E = Early O = On Time L = Late						

Table 2. Example of Hypothesis Test

An example of hypothesis tests 3 and 4 is shown in Table 2. Columns 3 and 6 have the heading "E, O, L" and identify the outcome for each project. The legend at the bottom of the table defines the letters: E = Early, O = On-Time, L = Late. The TSPI threshold evaluation is for the scenario with reserve equal to 10 percent. Columns 2, 3, and 4 depict test 3, while columns 5, 6, and 7 are for test 4. Identical data is used for both tests; thus column 2 is the same as column 5, and column 6 replicates column 3. The difference in the two tests is the evaluation made in the two Sign columns.

For test 3 the projects having TSPI ≤ 1.10 are evaluated:
"+" is assigned when "L" is observed
"-" is assigned when "O" or "E" is observed
"0" is assigned for those projects not satisfying TSPI ≤ 1.10

Test 4 evaluates those projects having TSPI > 1.10:
"+" is assigned when "O" or "E" is observed
"-" is assigned when "L" is observed
"0" is assigned for those projects not satisfying TSPI > 1.10

From the assigned symbols (+, -, 0) the test statistic may be calculated:
R+ = the number of projects with "+"
N = total number of projects
n = number of projects with "0"
S+ = test statistic value
α = level of significance

As shown in table 2, the alternate hypothesis, Ha, is the test result for both test 3 and test 4. The test statistic value, S+, is less than the value for α (0.05): test 3, S+ = 0.00195 < 0.05; test 4, S+ = 0.01064 < 0.05. For this circumstance, S+ less than α, there is enough evidence to reject the null hypothesis. Thus, for test 3, Ha indicates on-time delivery is likely when TSPI ≤ 1.10. The Ha result for test 4 indicates that recovery to the desired project duration is unlikely when TSPI > 1.10.

The hypothesis test results for the four reserve scenarios are compiled and provided in tables 3 and 4. Table 3 contains the eight results from testing the TCPI threshold. The result from each of the TCPI hypothesis tests (1 and 2), regardless of scenario, is Ha:

Test 1) When TCPI ≤ 1.10 completion within the desired budget is likely

Test 2) When TCPI > 1.10 recovery to the desired budget is unlikely

Reserve	TCPI ≤ 1.10	At/Under Budget	Test Statistic	α = 0.05 Ho or Ha	TCPI > 1.10	Over Budget	Test Statistic	α = 0.05 Ho or Ha
0%	6	6	0.01563	Ha	19	19	0.00000	Ha
5%	10	10	0.00098	Ha	15	14	0.00049	Ha
10%	12	11	0.00317	Ha	13	13	0.00012	Ha
15%	14	13	0.00092	Ha	11	11	0.00049	Ha

Table 3. TCPI Threshold Hypothesis Test Results

The compiled results for the hypothesis tests (3 and 4) of the TSPI threshold are provided in table 4. As shown, each test result is Ha, with one exception. The one exception is the hypothesis test result for the projects with TSPI ≤ 1.10 and the scenario of zero reserves. For this test, the sample size was only three projects. For those three projects, none finished late; that is, all completed on-time or early. Because the sample size is so small, the test statistic (0.12500) is not truly representative of threshold performance. The observed outcomes from the three project sample indicate that when TSPI is maintained ≤ 1.10, on-time project delivery is an expectation; i.e., in essence the Ha result. Thus, the overall hypothesis test results for TSPI mirrors those for TCPI:

Test 3) When TSPI ≤ 1.10 on-time/early delivery is likely

Test 4) When TSPI > 1.10 recovery to the desired duration is unlikely

Reserve	TSPI ≤ 1.10	On Time / Early	Test Statistic	α = 0.05 Ho or Ha	TSPI > 1.10	Late	Test Statistic	α = 0.05 Ho or Ha
0%	3	3	0.12500	Ho	22	18	0.00217	Ha
5%	8	8	0.00391	Ha	17	14	0.00636	Ha
10%	9	9	0.00195	Ha	16	13	0.01064	Ha
15%	13	13	0.00012	Ha	12	10	0.01929	Ha

Table 4. TSPI Threshold Hypothesis Test Results

SUMMARY

The objective of this paper is to confirm/reject the findings of the previous research through empirical study. The previous research, a mathematical examination of the behavior of TCPI (and TSPI by logical extension), concluded that exceeding the value 1.10 has merit in identifying those projects with low probability of achieving the desired completion (cost/duration). They may be regarded as irrecoverable.

The results of the hypothesis testing for both TCPI and TSPI, using real data from 25 projects, support the conclusion from the research cited. As well, for the four scenarios examined the results in tables 3 and 4 indicate the threshold value provides reliable management information, remaining independent from reserve amounts. Additionally, the parallel behavior of TCPI and TSPI was observed; thereby affirming the assertion made in the earlier research that the two indexes behave equivalently in their respective domains (cost and time).

An unexpected significant finding emerged from the examination:
When the To Complete Index (TCPI or TSPI) does not exceed 1.10 after 20 percent complete, the probability for a successful project is very high; i.e., the project can be expected to meet its desired outcome (cost or duration), including reserves.

CONCLUSION

With this empirical study confirming the previous mathematical study it is reasonably clear the value 1.10 is a reliable threshold for both TCPI and TSPI. When the threshold is exceeded after the project has achieved 20 percent completion, recovery is very unlikely. When the index value is equal to or less than the threshold, a successful project can be expected.

Confirming the threshold value adds credence to the period of opportunity analysis discussed in the previous research paper, and earlier in this paper, as well. Using the method, the project manager (PM) has the capability to identify performance problems early enough to make effective correction. The PM can, with high probability, assure successful project completion by maintaining index values at or below the threshold.

FINAL THOUGHTS

This empirical research has yielded additional confirming evidence for the TCPI and TSPI threshold value of 1.10. However, additional examination is welcomed. The Prediction Analysis Calculator is available from the Earned Schedule website[7] to assist in the analysis. Although it is created for TSPI, the spreadsheet can be very easily adapted to TCPI.

Acknowledgment
Obtaining real data for studies, such as this one, is incredibly difficult. Companies regard their EVM data as proprietary; generally, there is fear that if released the data somehow will provide advantage to competitors. I feel very fortunate to have available the data from 25 projects for this study. I am very appreciative to these gentlemen for generously sharing their data: Dr. Ofer Zwikael, Kym Henderson, and Dr. Mario Vanhoucke. Thank you.

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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.

Credentials & Honors: Master of Science Physics, Licensed Professional Engineer, Graduate of DOD Program Management Course, Physics honor society - Sigma Pi Sigma (ΣΠΣ), Academic honors - Phi Kappa Phi (ΦΚΦ), PMI Metrics SIG Scholar Award (2007), PMI Eric Jenett Award (2007), EVM Europe Award (2013), CPM Driessnack Award (2014)

7 - The Earned Schedule website URL is www.earnedschedule.com.