

IS THE CUMULATIVE SCI-BASED EAC AN UPPER BOUND TO THE FINAL COST OF POST-A12 DEFENSE CONTRACTS?¹

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ABSTRACT

Christensen (1999) describes several methods to evaluate the predicted final cost of a defense acquisition contract, termed the “Estimate at Completion” (EAC). One of the methods uses the EAC derived from the cumulative Schedule-Cost Index (SCI) as a potential upper bound to the final cost of a defense contract. The method was derived from Department of Defense (DOD) experience on hundreds of defense contracts completed in the 1970s and 1980s, and used by Beach (1990) to evaluate the reasonableness of contractor and government estimates of the final cost of the A12 program. This study tests the validity of the rule on 120 contracts completed after the A-12 cancellation in 1991. Results show that the average cumulative SCI-based EAC is significantly *lower* than the average final cost of defense contracts in the early and middle stages of completion. Using it as a lower bound may result in more realistic estimates of final cost.

BACKGROUND

The A12 and the Beach Report

The cancellation of the Navy’s A12 program in 1991 was a powerful catalyst for change in the defense acquisition community. When Secretary of Defense Cheney cancelled the A12 program he complained that no one could tell him the program’s final cost (Morrison 1991). Although more realistic estimates were available, a Navy investigation lead by Chester P. Beach (1990) reported that estimates supported by the contractor and government program offices were too low, and that more realistic estimates prepared by a senior cost analyst on the A12 program were suppressed. Beach concluded that similar problems were likely on other defense programs because of an “abiding cultural problem” that suppressed realistic estimates.

In support of the conclusion that contractor estimates of the final cost of the A12 program were too low, Beach cited DOD experience on hundreds of completed defense programs, wherein the EAC derived from the cumulative cost performance index (CPI) was a reasonable lower bound to final cost. As shown in Figure 1 (Beach 1990), the estimates supported by the A12 contractor and the government program office were lower than cumulative CPI-based EAC.

Using large samples of defense contracts completed from 1980 to 2000 researchers have validated the rule (Christensen 1994b, Christensen and Rees 2002), and demonstrated that understating the EAC was a DOD-wide epidemic (Christensen 1994a, 1996). To avoid another possible A12 cancellation and to encourage cost realism, the DOD modified its policy documents to require that any EAC lower than the cumulative CPI-based EAC be specifically justified (DOD 2001). In addition, the cost management report submitted by the contractor was modified to include a range of EACs (high, most-likely, low), rather than a single point estimate.²

The Beach report (1990) also created interest in the SCI-based EAC as a possible upper-bound to final cost. As shown in Figure 1, the SCI-based EAC was significantly larger than the other index-based estimates. The purpose of this research is to test this possibility using a sample of contracts completed since 1991.

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² The policy was implemented shortly after the A12 cancellation was announced. It requires the government program manager (PM) to specify a range of estimates at completion, reflecting current, best, and worst cases, in the Defense Acquisition Executive Summary (DAES) report, and to “justify the PM’s best estimate if the contract is at least 15 percent complete and the estimate is lower than that calculated using the cumulative cost performance index” (DOD 2001, 7.15.3g(1)). In addition, the policy requires the servicing cost analysis organization to provide an explanation if the estimate reflecting its best professional judgment is lower than that calculated using the cumulative cost performance index (DOD 2001, 7.15.3g(2)).

Earned Value Management and index-based EAC formulas

Earned Value Management (EVM) is a widely-recognized project management tool that has been used for many years. For a complete description of the analysis techniques and the internal controls designed to assure the reliability of EVM data, see DOD (1997), Fleming and Koppelman (2000), and *Guide to the Project Management Body of Knowledge* (PMI 2004). The foregoing description of EVM terminology and analysis techniques is summarized from Christensen (1996, 1999), and focuses on index-based EAC formulas.

The cost management report includes performance data using the framework of a product-oriented work breakdown structure. Key data elements include planned value, earned value, and actual cost. Each of these terms has other names and rather awkward acronyms. Planned value is also known as the "budgeted cost of work scheduled" (BCWS). Earned value is also known as the "budgeted cost of work performed" (BCWP). Actual cost is known as "actual cost of work performed (ACWP). On defense acquisition contracts, each of these is typically reported as a monthly and cumulative amount on the *Cost Performance Report* prepared by the defense contractor.

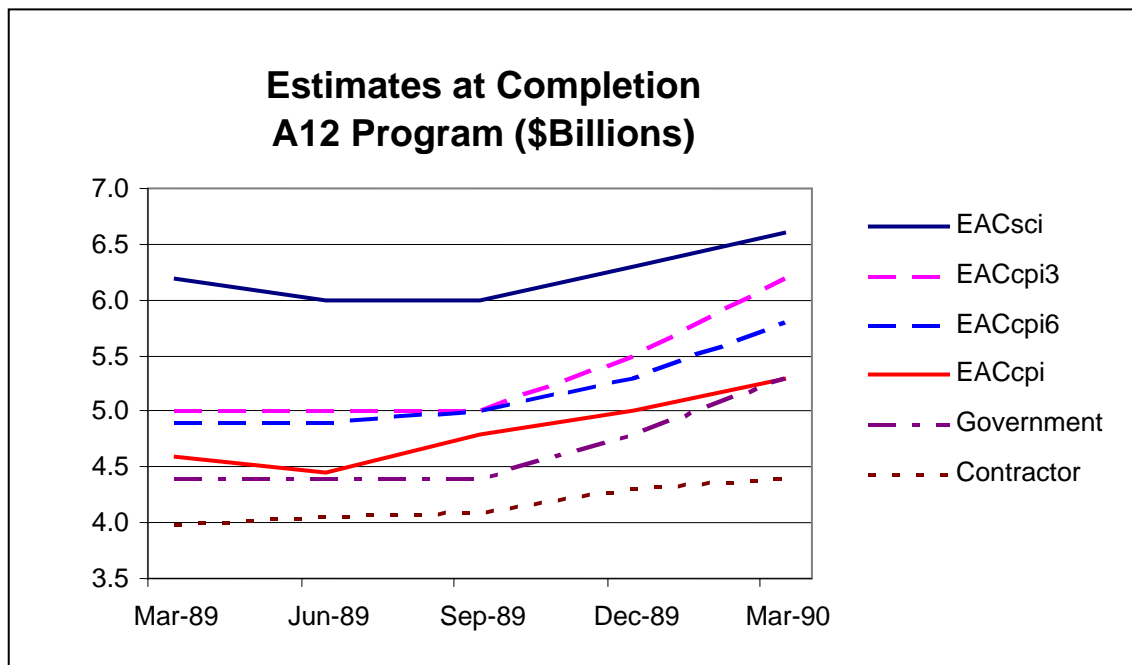


Figure 1. Estimates at Completion on the A12 Program.

As shown in Figure 2, planned value is the time-phased budget for increments of work on the project. When cumulative planned value is graphed, it forms a characteristic s-shaped curve, known as the performance measurement baseline. The end-point of the baseline, termed the "budget at completion" (BAC), represents the total budget for all the identified work on the contract. The EAC is the actual cost of the completed work (cumulative ACWP) plus the estimated cost of the remaining work. When the EAC exceeds the BAC, an adverse "variance at completion" (VAC) is identified.

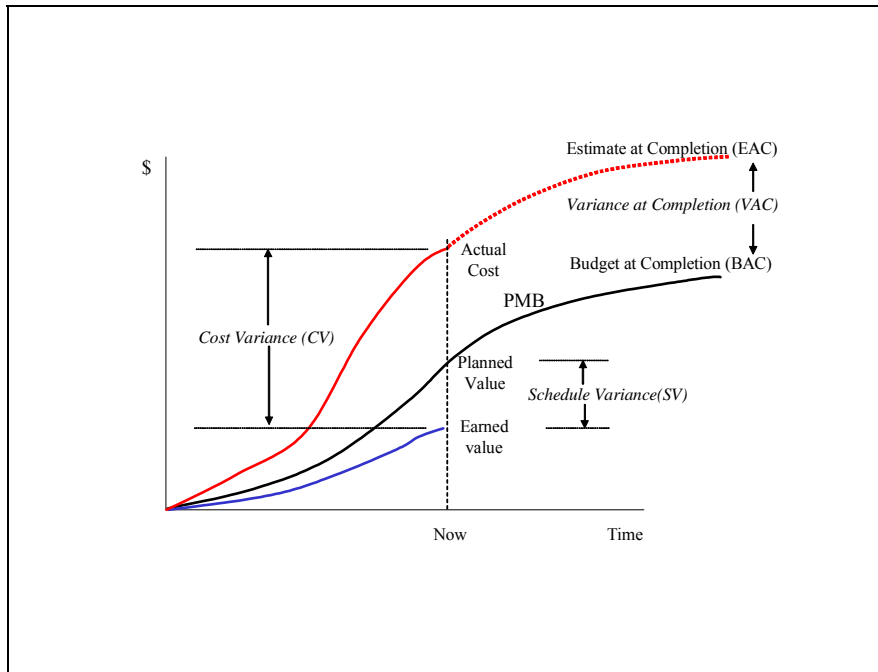


Figure 2. Earned Value Management Data and Variances.

Two other variances are also identified on the report. When earned value is less than planned value, less work has been accomplished than was planned to be accomplished, and an adverse "schedule variance" (SV) is identified. When actual cost exceeds earned value, the cost of the work has exceeded its budget, and an adverse "cost variance" (CV) is identified. Figure 2 thus illustrates the typical condition of a defense contract: behind schedule, over-budget.

When these variances are judged to be significant, the contractor will investigate, document the causes, and develop a corrective-active plan. The intent of variance reporting is not to find fault but to identify and correct problems before they worsen.

The variance analysis may also indicate that the projected final cost of the project (EAC) needs to be adjusted. Equation 1 shows the generic formula for the EAC.

$$EAC = \text{Cumulative Actual Cost} + (\text{BAC} - \text{Earned Value}) / \text{Performance Index} \quad (1)$$

This formula is often used by the government to develop independent EACs. The independent EACs are used by the government to evaluate the reasonableness of the contractor's estimate. Contractors may also use this formula to evaluate the reasonableness of their own "grass roots" estimates that were developed by other methods. Internal controls on defense contracts, termed EVMS criteria, require that contractors develop comprehensive EACs at least annually. The comprehensive EAC is then updated, as required, in the monthly report to the government. As such, the monthly EAC, also termed the "Latest Revised Estimate," may reflect the influence of an index-based EAC.

As indicated in Equation 1, the EAC is equal to the cost of the completed work plus an estimate of the cost to complete the remaining work on the project. Because the budget for the remaining work (BAC - BCWP) is typically understated, a performance index is used to adjust the budget upward.

There are four kinds of performance indices:

$$\text{Cost Performance Index (CPI)} = \text{Earned Value} / \text{Actual Cost} \quad (2)$$

$$\begin{aligned} \text{Schedule Performance Index (SPI)} &= \text{Earned Value} / \text{Planned Value} & (3) \\ \text{Composite Index} &= W1 \times \text{SPI} + W2 \times \text{CPI} & (4) \\ \text{Schedule Cost Index (SCI)} &= \text{SPI} \times \text{CPI} & (5) \end{aligned}$$

The CPI compares performance to actual cost. When the CPI is less than one, the cost of the completed work has exceeded its budget. The SPI compares actual performance to planned performance. When it is less than one, the work may be behind schedule.³ The other two indices combine the SPI and the CPI. The composite index is the weighted sum of the two indices, where the weights (W1 and W2) add to one. The SCI is the product of the SPI and the CPI.

Clearly, there are many possible EACs. The performance index may be derived from monthly, cumulative, or averaged data. In addition, the weights chosen for the composite index are often systematically changed, with the SPI receiving greater weight in the early stages of a project. Accordingly, determining a "most likely" EAC, or even a range of likely EACs is a problem. Research has shed light on this issue.

There have been dozens of EAC studies over the past thirty years. The usual procedure in an EAC study is to compute a variety of EACs from a sample of completed contracts. The EACs are then compared to the final costs of the completed contracts to determine the relative accuracy of the formulas. Based on a review of 25 EAC studies, no single EAC formula is always the most accurate (Christensen et al. 1995). The predictive accuracy of the formula depends on project-specific factors, such as program phase, type of contract, the type of weapon system, and the military service that managed the project.

However, it has been possible to establish that the EAC derived from the cumulative CPI is a lower bound to the final cost of a contract. Based on a review of 21 completed or nearly completed Navy contracts in 1982, Haydon and Reither (1982) reported that a range of EACs bounded each contract's final cost sixty-four percent of the time. In most cases the final costs were greater than the EACs derived from the cumulative CPI. In addition, when the contractor's EAC was smaller than the CPI-based EAC, the CPI-based EAC was more accurate seventy-nine percent of the time.

More recent research has explained why the cumulative CPI may be used to establish a floor for the EAC. Based on an analysis of 155 completed defense contracts in 1991, Christensen and Heise (1993) demonstrated that once a project is twenty percent completed, the cumulative CPI does not change by more than ten percent; in fact, in most cases it only worsens. Because cost overruns are rarely reversed, the EAC computed using a cumulative CPI usually represents a floor to the other EACs and the contract's final cost.

The A12 program is illustrative. Figure 1 shows EACs reported by the contractor and the government on the A12 program (Beach 1990). All the other EACs on the graphs were computed using performance indices, and are generally consistent with the theory explained above. The EAC computed using the cumulative SCI was the largest in the range. The EAC computed using the cumulative CPI was the smallest of the index-based estimates. The other EACs shown in the figure were derived from CPIs averaged over three month periods (CPI3) and six month periods (CPI6). As explained by Beach, estimates computed using performance indices averaged over shorter periods will likely be higher, especially when the newly-completed work is experiencing large adverse cost variances (Beach 1990). The SCI-based EAC is often the largest because the SCI is the product of the CPI and the SPI, each of which is usually less than one.

An analysis of index-based EAC formulas further explains the relative order of the EACs. First, if the CPI is less than the SPI, then the EAC derived from the CPI (EAC_{cpi}) will be larger than the EAC derived from the SPI (EAC_{spi}). The reverse is also true; if the CPI is greater than the SPI, then the EAC_{cpi} will be less than EAC_{spi}. Second, if the CPI is not equal to the SPI, then the EAC derived from the weighted sum of the SPI and the CPI (EAC_w) will always be between the EAC_{cpi} and the EAC_{spi}. Third, if the CPI and the SPI are each less than one, then the EAC derived from the SCI (EAC_{sci}) will be greater than either the EAC_{cpi} or the EAC_{spi}. The reverse is

³ The SPI should be used with other schedule information, such as critical path indicators, before concluding that the work is behind schedule, on-schedule, or ahead-of schedule (Fleming and Koppelman 2000: 42).

also true; if the CPI and SPI are each greater than one, then the EACsci will be less than either the EACcpi or the EACcpi. When considered together, the following inequality equations are apparent:

<u>Contract Status</u>	<u>EAC relationships</u>	
CPI < SPI < 1	EACsci > EACcpi > EACw > EACspi	(6)
SPI < CPI < 1	EACsci > EACspi > EACw > EACcpi	(7)
CPI > SPI > 1	EACsci < EACcpi < EACw < EACspi	(8)
SPI > CPI > 1	EACsci < EACspi < EACw < EACcpi	(9)

Because the usual condition of a defense contract is behind schedule and over-budget, the SPI and the CPI are each less than one by definition. Therefore, the relative order of the EACs derived from performance indices on defense contracts will usually be as described in Equations 6 or 7. Furthermore, because the SPI is forced to unity as a contract proceeds to completion, the relative order of EACs computed in the late stages of a contract will usually be as described in Equation 6, where the EACsci is the largest and the EACspi is the smallest. In the early to middle stages of a contract, the relative order of the EACs will usually be as expressed in Equation 7, where the EACsci is the largest and the EACcpi is the smallest. Of the four equations, Equation 7 is probably the most important because it reflects the relative positions of these common index-based EACs at stages in the contract when accurate estimates are most valuable.

Christensen (1994b, 2002) has verified that the cumulative CPI-based EAC is reasonable floor. To date, no one has explicitly tested the possibility that the SCI-based EAC is an upper-bound to final cost on a large sample of completed contracts, the purpose of this study. Widely-recognized EVMS experts have occasionally suggested that the SCI-based EAC is a ceiling or “worst-case” estimate of final cost (e.g., Fleming and Koppelman 2000; Humphreys and Associates 2002). In an analysis of 8 Ballistic Missile Defense Organization (BMDO) development contracts, Bachman (2001:15) reported that the SCI-based EAC was slightly higher than final cost in the late stage of contract completion (70-90 percent complete), and lower than final cost in earlier stages (10-60 percent complete). A description of the methodology and results follow.

METHODOLOGY

Hypotheses

Null and alternative hypotheses for the cumulative SCI-based EAC appear below. If the null hypothesis is rejected, the SCI-based EAC is an upper-bound to final cost.

- Ho: Cumulative SCI-based EAC \leq Final Cost
 Ha: Cumulative SCI-based EAC $>$ Final Cost

The cumulative SCI at the 20%, 50%, and 70% completion points was computed for each contract in the sample. Percent complete was defined as cumulative earned value divided by the total budget for the planned work on the contract, termed the Budget at Completion (BAC). The 20% completion point was chosen because earlier performance data are often either not available or considered unreliable. For example, it has sometimes taken over one year for a contractor to be found compliant to the earned value management systems (EVMS) criteria, or to establish a performance measurement baseline (Fleming 1992). Until each is accomplished, performance measurement data are of dubious value.

The Database

Contract performance data were collected from the Defense Acquisition Executive Summary (DAES) database, maintained by the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD (AT&L)). The database contains cost and schedule performance data on more than 500 completed and on-going contracts from as early as 1971. A contractor prepares a monthly cost performance report (CPR) that summarizes cost and schedule performance, and sends it to the government program office for analysis. The program office summarizes the CPR data into a DAES report that is sent to OUSD (AT&L) for analysis and storage in the DAES database.

The reliability of the data is controlled by a DOD requirement for contractors to comply with Earned Value Management Systems (EVMS) criteria (DOD 1997). The criteria are internal controls intended to encourage adequate planning and control. When the contractor's management control systems are compliant to the EVMS criteria, the government assumes that the performance data are reasonably reliable. In general, contractors that submit the CPR are required to be EVMS criteria-compliant.

The Sample

We identified 120 post-A12 contracts with the necessary data to test the hypothesis. All contracts with the necessary data were included in the sample. The necessary data included values for cumulative earned value, cumulative actual cost, and BAC at the 20% (early), 50% (middle), 70% (late) completion points, and after the 80% completion point. Contracts with unstable budgetary baselines were excluded because the validity of cost performance data on such contracts is seriously impaired.⁴ For the early, middle, and late stages, any contract within plus or minus 5% of that stage was selected. Because many contractors discontinue CPR reporting after the 80% completion point, final cost was defined as the cumulative actual cost from the last available CPR for each contract. The contract was included if the percent complete exceeded 80% and could be matched with the same contract at the other stages.

Hypothesis Testing

The hypothesis was tested on the entire sample and on various categories within the sample using the one-sided t test.⁵ To adjust for differences in contract size, the EAC for each contract was normalized into deviation from the final cost (DAC). The average DAC was computed for the entire sample and for various categories of the sample, including contract phase (development, production), contract type (cost-reimbursable, fixed price), and the military service managing the contract (army, air force, navy). The hypothesis was evaluated at the 0.05 level of significance.

$$\text{DAC} = (\text{EAC} - \text{Final Cost}) / \text{Final Cost} \quad (10)$$

RESULTS

The average cumulative SCI-based EAC is not an upper-bound to the EAC; it's a lower bound. As shown in Table 1, the average cumulative SCI-based EAC was significantly lower than the average final cost of the 120 defense acquisition contracts in the early and middle stages of contract completion. In the early stage (20 percent complete), the average SCI-based EAC was 18.1% below average final cost. Likewise, in the middle stage (50 percent complete), the average SCI-based EAC was 8.2 percent below average final cost. The t-test and the Wilcoxon signed rank test showed that each of these deviations was highly significant ($p < 0.000$). In the late stage (70 percent complete), the average SCI-based EAC was 2.1 percent below final cost, but not statistically significant.

Table 1 also shows that the results were sensitive to the category of contract. In the early stage, the average DACs of all categories except Air Force contracts were significantly less than zero. In middle stage, the average DACs of all categories except Fixed Price and Army categories were significantly less than zero. In the late stage, only Development, Cost-Reimbursable, and AF contracts were significantly less than zero. However, the sensitivity analysis on these categories should be interpreted with caution because of the small sample sizes.

DISCUSSION

After the A12 program was cancelled, DOD policy was changed to encourage more realistic estimates of final cost. In part, this was accomplished by establishing the cumulative CPI-based EAC as a lower bound in a range of estimates appearing on the Cost Performance Report. The results of this study suggest that the cumulative SCI-based

⁴ When re-planning of the budget baseline results in a total allocated budget that is greater than the budget for all of the authorized work, the contract is in an "over-target-baseline" (OTB) condition. When this happens, cumulative cost and schedule variances may be eliminated.

⁵ The assumption of normality required by the t-test was evaluated using the Kolmogorov-Smirnov test for normality. The null hypothesis that the sample of DACs is normally distributed could not be rejected at an alpha of 0.05 (Sheshkin 1996).

EAC is also a reasonable floor to final cost for most defense contracts. Because it is usually larger than the other cumulative index-based estimates, using it as a floor may encourage even more realistic estimates of final cost. Bachman (2001:16) reported that a BMDO policy decision to standardize EAC calculations on the SCI-based EAC “stabilized BMDO EAC calculations and increased them an average of 2% to 7%.” It seems likely that a DOD-wide policy would have a similar effect.

The cancellation of the A12 was a catalyst that helped change a DOD-wide systematic bias toward underestimation (Drezner et al. 1993). Since the A12 cancellation, contractor and government estimates of final cost have been much more realistic. As asserted by Beach (1990) and confirmed by researchers (Drezner et al. 1993, Christensen (1994a, 1996), the estimated final costs of virtually all defense contracts were too optimistic before the A12, with averages often less than the cumulative CPI-based EAC. As shown in Table 2, contractor and government estimates of final cost are now greater than cumulative CPI and SCI-based estimates. We interpret these results as a signal that the “abiding cultural problem” of suppressing bad news about the cost variances on defense contracts is disappearing.

CONCLUSION

The cumulative SCI-based EAC is a reasonable floor to final cost on the early and middle stages of contract completion. The cumulative CPI-based EAC has been used as a reasonable lower bound to final cost since the A12 cancellation, resulting in more cost realism. It seems likely that even more realistic estimates of final cost may be achieved by using the cumulative SCI-based EAC as a lower bound.

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TABLE 1
DEVIATION FROM FINAL COST
(SCI-based EAC – Actual Cost) / Actual Cost

Contract Category	n	df	Early stage (20% complete)				Middle stage (50% complete)				Late stage (70% complete)			
			Mean	St.dev.	t	p	Mean	St.dev.	t	p	Mean	St.dev.	t	p
All	120	119	-0.181	0.258	-7.65	0.000	-0.082	0.184	-4.86	0.000	-0.021	-0.133	-1.73	0.086
Development	59	58	-0.211	0.250	-6.49	0.000	-0.110	0.202	-4.18	0.000	-0.047	-0.157	-2.291	0.026
Production	60	59	-0.154	0.269	-4.46	0.000	-0.056	0.162	-2.76	0.008	0.002	0.098	0.117	0.907
Cost Reimbursable	76	75	-0.211	0.247	-7.42	0.000	-0.107	0.190	-4.912	0.000	-0.036	0.146	-2.120	0.037
Fixed Price	43	42	-0.128	0.275	-3.07	0.004	-0.041	0.167	-1.623	0.112	0.006	0.103	0.391	0.698
Army	23	22	-0.140	0.269	-2.49	0.021	-0.037	0.214	-0.826	0.418	-0.001	0.160	-0.036	0.972
AF	34	33	-0.245	0.289	-1.98	0.142	-0.127	0.201	-3.683	0.001	-0.481	0.150	-1.186	0.071
Navy	59	58	-0.156	0.235	-4.984	0.000	-0.662	0.158	-3.226	0.002	-0.017	0.109	-1.165	0.249

Note: the t-statistics and corresponding significance values (p) are two-tailed.

TABLE 2
A COMPARISON OF DEVIATIONS FROM FINAL COST
(120 Contracts, 1992 to 2003)

Descriptive Statistics	CPI-based EAC			SCI-based EAC			Contactor EAC			Government EAC		
	Early	Middle	Late	Early	Middle	Late	Early	Middle	Late	Early	Middle	Late
Mean	-0.211	-0.105	-0.032	-0.181	-0.082	-0.021	-0.164	-0.058	0.008	-0.163	-0.028	0.026
Standard Error	0.022	0.016	0.012	0.024	0.017	0.012	0.026	0.019	0.014	0.028	0.021	0.017
Median	-0.176	-0.080	-0.008	-0.167	-0.052	-0.001	-0.114	-0.043	0.013	-0.111	-0.024	0.040
Standard Deviation	0.245	0.180	0.133	0.258	0.184	0.133	0.280	0.207	0.153	0.303	0.235	0.182
Sample Variance	0.060	0.033	0.018	0.067	0.034	0.018	0.078	0.043	0.023	0.092	0.055	0.033
Kurtosis	0.299	1.276	1.043	0.218	1.365	1.179	0.844	0.717	0.607	1.086	4.784	8.298
Skewness	-0.705	-0.668	-0.864	-0.533	-0.722	-0.919	-0.801	-0.414	-0.111	-1.082	-0.210	-1.450
Range	1.261	1.133	0.659	1.274	1.140	0.676	1.424	1.145	0.832	1.390	2.003	1.555
Minimum	-0.919	-0.735	-0.432	-0.882	-0.731	-0.432	-1.000	-0.720	-0.433	-1.000	-1.000	-1.000
Maximum	0.342	0.397	0.226	0.391	0.408	0.244	0.424	0.425	0.399	0.390	1.003	0.555