



**COMPARING THE PREDICTIVE CAPABILITIES OF LEVEL THREE EVM
COST DATA WITH LEVEL FIVE EVM COST DATA**

THESIS

Joshua D Johnson, Captain, USA

AFIT-ENC-14-M-04

**DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY**

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government. This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

AFIT-ENC-14-M-04

**COMPARING THE PREDICTIVE CAPABILITIES OF LEVEL THREE EVM
COST DATA WITH LEVEL FIVE EVM COST DATA**

THESIS

Presented to the Faculty

Department of Mathematics and Statistics

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Cost Analysis

Joshua D Johnson, BS

Captain, USA

March 2014

DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

**COMPARING THE PREDICTIVE CAPABILITIES OF LEVEL THREE EVM
COST DATA WITH LEVEL FIVE EVM COST DATA**

Joshua D Johnson, BS

Captain, USA

Approved:

//signed//
Edward D. White, PhD (Chairman)

28 February 2014
Date

//signed//
Lt Col Jonathan D. Ritschel (Member)

28 February 2014
Date

//signed//
William Stockman, PhD (Member)

28 February 2014
Date

Abstract

Contract cost growth has been a concern for the Department of Defense (DoD) for decades. Earned value management is a tool used by the DoD to assist in identifying cost overruns before they occur. Current DoD regulations require contracts to report their earned value management (EVM) data down to level three of the work breakdown structure (WBS). Previous research has shown level three EVM data can predict contract cost growth earlier than using level one EVM data. This research examines if level five EVM data would better predict cost growth than level three. The results indicate that level five is not a better predictor of cost growth than level three. Thus, the results do not support the DoD requiring contractors to provide level five EVM data.

Acknowledgments

I thank my family for their continuous support throughout this thesis process as well as in all phases of my life. I also express my sincere appreciation to my faculty advisors, Dr. Edward White and Lt Col Dan Ritschel, for their guidance throughout the course of this thesis effort. I certainly appreciated their insight and experience.

Joshua D Johnson

Table of Contents

Abstract.....	v
List of Figures.....	ix
List of Tables	xi
Chapter 1 – Introduction	1
Background.....	1
Purpose of Research	3
Research Objective	5
Research Questions #1	6
Research Questions #2	6
Methodology.....	7
Assumptions	8
Overview of Thesis Chapters	8
Chapter 2 - Literature Review	9
Purpose	9
Define Work Breakdown Structure	9
Earned Value	11
Relevant Research Completed.....	21
Conclusion.....	24
Chapter 3 – Data Collection and Methodology	26
Chapter Overview.....	26
Defense Cost and Resource Center (DCARC).....	26
Data Collection.....	28
Overview of Data	30
Methodology.....	37

Conclusion.....	44
Chapter 4 – Analysis and Results	45
Chapter Overview.....	45
Evaluating the EAC	45
Evaluating the LRE	62
Comparing Level Three EVM Data with Level Five EVM Data	71
Summary of Findings	75
Chapter 5: Conclusions	77
Introduction	77
Review Purpose of research	77
Limitations in our Research.....	78
Assumptions in our Research	78
Briefly Review Results.....	79
Follow-on Research.....	80
Appendix A - Acronyms	81
Appendix B: Contracts Used in Analysis	82
Appendix C: List of Independent Variables used in Model.....	88
Appendix D - JMP® Output Screens for Explanatory Variable #1.....	90
Appendix E - JMP® Output Screens for Explanatory Variable #2.....	110
Appendix F – JMP® Output Screens for Explanatory Variable #3	129
Appendix G – JMP® Output Screens for Explanatory Variable #4.....	153
Appendix H – Relationship between Level Three and Level Five Data (Using Contractor’s EAC or LRE	175
Appendix I – Relationship between Level Three and Level Five Data (Using Recalculated EAC).....	195
Works Cited.....	215

List of Figures

	Page
Figure 1- Contract Price Diagram	4
Figure 2 - CWBS and OBS Intersection	5
Figure 3 - Simple PWBS.....	10
Figure 4 - Relationship between EVM elements	13
Figure 5 - Relationship between EVM elements	14
Figure 6 - Earned Value Analysis	16
Figure 7 - Estimate at Complete	18
Figure 8 - EAC Growth Definitions.....	38
Figure 9 - Level three and Five Explanatory Variables	39
Figure 10 - Distribution of Percent Change of Level 1 EAC	46
Figure 11 - Distribution of Percent Change of level 1 EAC (excluding two extreme outliers)	47
Figure 12 - Distribution of Percent Change of level 1 EAC (excluding three additional outliers)	47
Figure 13 - Distribution of Percent Change of level 1 EAC (excluding all outliers)	48
Figure 14 - H1 Upgrade	50
Figure 15 - FBCB2.....	50
Figure 16 - VTUAV (N00019-12-C-0059).....	51
Figure 17 - V-22 - Osprey Joint Advanced Vertical Aircraft (N00421-10-D-0012).....	52
Figure 18 - V-22 - Osprey Joint Advanced Vertical Aircraft (N61340-11-C-0004).....	52

Figure 19 - ISPAN (FA8722-04-C-0009).....	53
Figure 20 - Regression Equation for Growth Definitions #1 and #2.....	54
Figure 21 - Regression Equation for Growth Definitions #3 and #4.....	54
Figure 22 - Number of Contracts by Bin	55
Figure 23 – Cost Growth Definition #3 Independent Variables by Percent Complete	59
Figure 24 - Distribution of Percent Change of Level 1 LRE	62
Figure 25 - Distribution of Percent Change of Level 1 LRE (Excluding two extreme outliers)	63
Figure 26 - Distribution of Percent Change of Level 1 LRE (Excluding three additional outliers)	63
Figure 27 - H1 Upgrade LRE growth	65
Figure 28 - VTUAV LRE Growth	66
Figure 29 - Comparing Level three and Level five LRE at 45% complete	71
Figure 30 - Comparing Level three and Level five EAC at 45% complete.....	72
Figure 31 - LRE Slope by Percent Complete.....	74
Figure 32 - EAC Slopes by Percent Complete.....	74

List of Tables

	Page
Table 1 - Five Basic Elements for Earned Value.....	13
Table 2 - Percent Complete Formulas	19
Table 3 - EVM-CR Program Breakdown	28
Table 4 - Data Overview by Criteria.....	31
Table 5 - Data by Phase	31
Table 6 - Data by ACAT.....	32
Table 7 - Data by Contract Type.....	32
Table 8 - Data by type of WBS.....	33
Table 9 - Total number of level 5 Elements	34
Table 10 – Notional Example #1 of Contract Errors	35
Table 11 – Notional Example #2 of Contract Error.....	35
Table 12 - Number of Errors per Contract.....	36
Table 13 – Cost Growth Definition #1 Example	40
Table 14 – Cost Growth Definition #3 Example	40
Table 15 – EAC Contract Outliers.....	49
Table 16 – Cost Growth Definition #1 JMP® Results	57
Table 17 – Cost Growth Definition #1 Influential Contracts	58
Table 18 – Cost Growth Definition #3 JMP® Results	60
Table 19 – Cost Growth Definition #3 Influential Contracts	61
Table 20 - LRE Contract Outliers	64
Table 21 – Cost Growth Definition #2 JMP® Results	67

Table 22 – Cost Growth Definition #2 Influential Contracts	68
Table 23 – Cost Growth Definition #4 JMP® Results	69
Table 24 – Cost Growth Definition #4 Influential Contracts	70
Table 25 - Comparing Slopes between Level Three and Five with Regards to the response of EAC and LRE	73

COMPARING THE PREDICTIVE CAPABILITIES OF LEVEL THREE EVM COST DATA WITH LEVEL FIVE EVM COST DATA

Chapter 1 – Introduction

Background

The Department of Defense (DoD) outsources most major acquisitions projects to different private companies; so it is imperative for the DoD to have effective oversight of these projects. Earned value is the method the DoD has decided to use in order to achieve this oversight. In 1967, the DoD created the Cost/Schedule Control Systems Criteria (C/SCSC). The C/SCSC used thirty-five different formulas to assist program managers and commanders in determining if a project was on budget and on schedule. The Earned Value Management System (EVMS) replaced C/SCSC in 1997.

Earned value management has been successful in assisting program managers and commanders with oversight of programs for over fifteen years. As in any profession, the evaluation and rewards of contracts depend upon the contractor's performance. However, there are some concerns with EVMS as well. Some contractors learn how to beat, or at least go around, the system. Some project managers learn how to manipulate their earned value numbers in order to have their programs appear on time and budget, when in reality, the program manager is aware the program is not (CIO Insight, 2005). For example, if a project manager says a task is 80% complete, EVMS might allege the project is on time and on budget. However, what proof is there that the task is 80% complete, not just 40% complete? Slight changes in the completion percentage can make

a large impact on the actual status of a project (CIO Insight, 2005). This issue of intentional misrepresentation will always be a concern for the DoD.

Another concern for the DoD with EVMS, not involving intentional misrepresentation, is what level to report cost data using EVMS formulas. There are currently three techniques to evaluate cost data: a top level showing the total project cost, a bottom level breaking the cost down to the lowest level (control account), or the third option of somewhere in between. Each of these three techniques has positive and negative aspects, respectively.

Using top-level cost data (Work Breakdown Structure (WBS) level 1), the project manager is able to obtain a quick picture of the overall status of a project. The negative aspects of this approach are that the overall project might currently be on budget and schedule, even if there is a lower level element that is falling behind schedule or over budget. This could cause the entire project to fall behind or go over budget. Because the purpose of EVMS is to predict future problems, top level cost data would show only the current state of the project with limited predicative capabilities.

Using bottom level cost data (control accounts) is a practice widely used by companies in the private sector who use EVMS (DAU Website, 2013). Using this level of cost data allows the project manager to see exactly what area(s) have the greatest risk of going over budget or falling behind schedule. The disadvantages of using these cost data is that the project manager now has to track many different data points, and it drives up the management cost due to the extra accounting work and man-hours to prepare the data.

Currently, the DoD uses the third method. The current requirements are for contractors to report cost down to work breakdown structure level three. However, there are some exceptions to this rule. High-risk or high-cost elements in a project require a lower collection of cost data. The reason for requiring this level is that the government “does not want to constrain the contractor’s ability to define or manage the program and resources” (MIL-STD-881C, 2011).

Purpose of Research

The purpose of this research is to determine the predictive nature of EVM when the government has visibility of cost data down to level five of the WBS. Currently, the government requires its contractors to provide cost data only at level three of the WBS. Knowing there are additional costs associated with obtaining additional information from the contractor, is it beneficial for the government to pay the additional cost?

The cost of any DoD contract can be broken down into two main areas, the Total Allocated Budget (TAB) and profits and fees. The TAB is the sum of all budgeted costs for a contract. The dollar value of the TAB can fluctuate throughout the contract life and on contracts. The Budget at Complete (BAC) and the TAB can be interchangeable on contracts (DAU Gold Card, 2013). Figure 1 displays the relationship between the contract price and its components. Found in Appendix A, are a complete list of EVM acronyms.

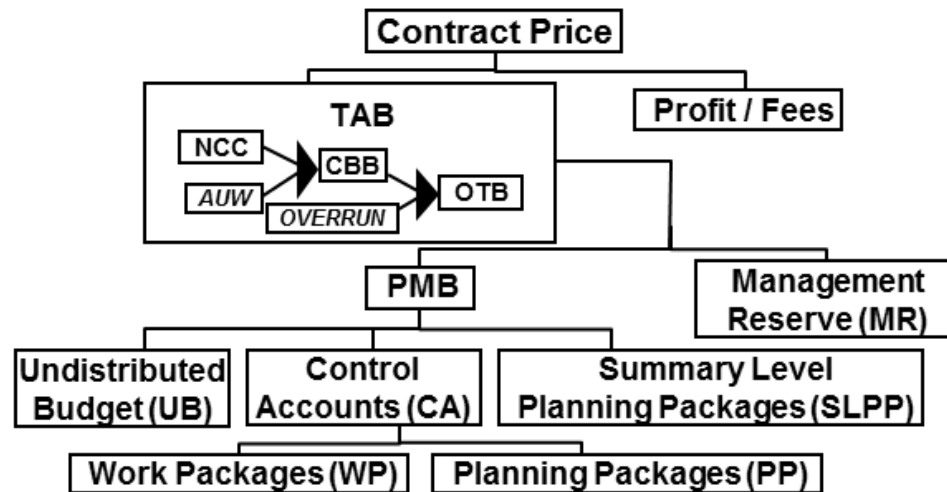


Figure 1- Contract Price Diagram

The work breakdown structure (WBS) divides all government projects (MIL-STD-881C, 2011). The WBS divides the overall project into multiple layers of smaller sub components, which allows the government to monitor and track what tasks, or parts, are required to complete the project. However, contractors also use an organizational breakdown structure (OBS). The OBS, like the WBS, divides the different parts of a project, but instead of breaking the different parts down by product, the OBS breaks the parts down by which department of the organization will actually work on the part. The control account is where the WBS and OBS meet. Figure 2 illustrates a generic relationship between the WBS and the OBS. However, the figure gives the impression that the control account is located at level five of the WBS, which might not be true. Every program will have different levels in its WBS. The DoD has attempted to standardize only the first three levels of the program WBS.

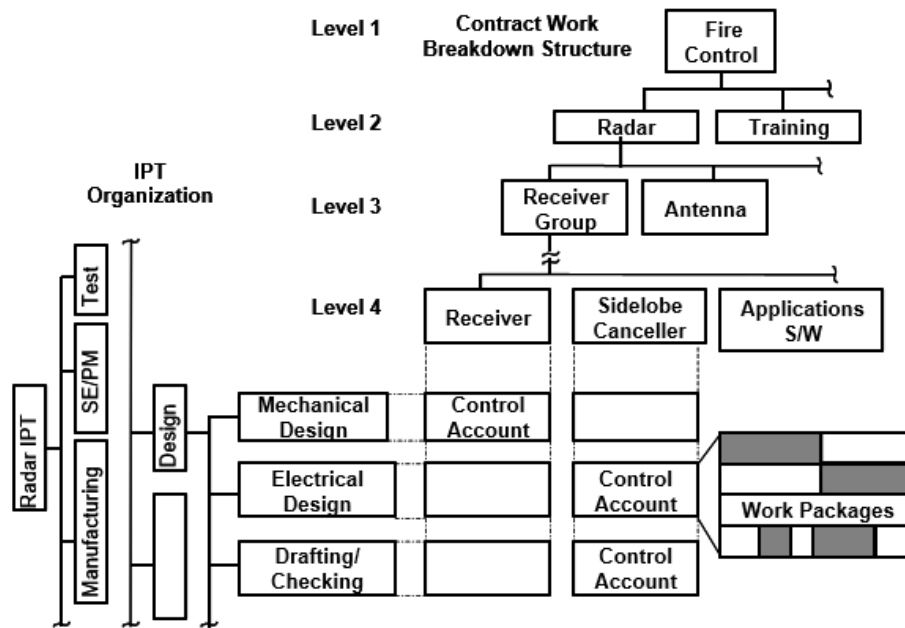


Figure 2 - CWBS and OBS Intersection

This research looks into the comparison of earned value management at level five compared to the current reporting standard of level three of the WBS. Currently, when a contractor reports the status of a project to the government, the contractor is required to show the project's cost information down to the third level of the contract WBS. Program managers and analysts use cost information to predict if the project is on schedule and budget in various EVM formulas. This research investigates if it would be more beneficial for the government if the contractors would provide cost information down to level five.

Research Objective

The main objective of this research is to determine if level five EVM data will predict overall cost growth earlier and more accurately than level three EVM data. Then if level five is more predictive, how much extra would it cost the DoD to obtain this data

and is the extra cost worth any additional value level five data has? Previous research has proven the benefits of using level three EVM data compared to level one EVM data (Rosado, 2011). However, due to inconsistencies in the data available, Rosado was unable to research below level three.

Research Questions #1

The primary question is if level five EVM data is more predictive than level three EVM data at predicting overall contract cost growth. If level five data is not more predictive, the government should not invest additional money into the contract. To answer this research question we evaluated the following three investigation questions:

Investigation Question #1.1

Which EVM metric should we use to predict cost growth? Rosado used the EAC provided by the contractor to compare cost growth while Keaton also included the cost performance index (CPI) and schedule performance index (SPI).

Investigation Question #1.2

Our last investigating question for research question #1 is can we build a statistical model using levels three and five EVM data to predict overall contract performance?

Research Questions #2

The next research question is what is the additional cost associated with requiring contractors to provide level five EVM data? In addition, should we have the contractor include all level five elements or just a certain percentage based on the size of each level five element compared to the overall size of the contract?

Methodology

We plan to use a regression-based approach to determine the relationship between our level three and five EVM data and the overall contract cost growth. Regression-based models have been widely used in previous research to predict cost growth (Rosado, 2011; Trahan, 2009; Thickstun, 2010). However, Trahan and Thickstun both looked at top-level EVM data while Rosado examined level three EVM data. We believe we will be able to look down to level five due to an improvement in EVM reporting.

The Office of Performance Assessments and Root Cause Analyses (PARCA) is the organization that oversees earned value management within the Department of Defense (DoD) (PARCA Website). PARCA is continually attempting to improve the implementation of EVM data.

PARCA's goal is to increase earned value's constructive attributes for the DoD firms managing acquisition programs by reducing the economic burden of inefficient implementation of EVM. PARCA is dedicated to the concept that EVM is a management tool, not merely a contractually required report (PARCA Website)

Using the Earned Value Management – Central Repository (EVM-CR), we have access to approximately “30,000 Contractor Cost Data Reports (CCDR), Software Resources Data Reports (SRDR) and associated documents (DCARC Website, 2013).” In addition, from talking with an analyst at PARCA, he estimated there are approximately 177 contracts within the EVM-CR that contain level five EVM data (Pflieger, 2013).

After we run our regression models, we need to clarify we are not attempting to show causality between overall contract growth and our independent variables. We are attempting to show that the relationship between our independent variables and EAC

growth act as predictors. Our goal is to create a regression model that will provide an early warning to project managers and analysts of possible cost growth within a contract. We ultimately want to identify if level five EVM data can predict that growth earlier and more accurately than level three data.

Assumptions

For our research, we made two key assumptions about the EVM data available. The first assumption we have to make is the contracts with level five EVM data are not biased. As we stated earlier in this chapter, contractors are required to report below level three for contracts that are considered high risk or high cost. The risk we are assuming is that not all of the available contracts with level five EVM data are just either high risk or high cost. Another assumption we made was that the WBS data available was contract WBS not program WBS. What this means to our research is that we will not attempt to prove a program's overall cost growth. Instead, we will be looking at individual contract's cost growth.

Overview of Thesis Chapters

In the following chapter, we will fully explain the origins of earned value and discuss previous research completed on relevant topics. In Chapter Three, we will explain how we obtained our data and how we selected the data points we will use in our model. Then, we will continue to explain our methodology on how we will analyze and evaluate our data. In Chapter Four, we will show the results of our statistical model. During the final chapter, we will give a conclusion and some possible follow-on research problems.

Chapter 2 - Literature Review

Purpose

The purpose of this chapter is to review relevant literature dealing with earned value management system (EVMS). In this chapter, we will define the major parts as well as look at the history of earned value and why it is important. We will then discuss research dealing with problems of the effectiveness of the DoD's earned value system operations. In addition, we will provide some information on completed relevant research.

Define Work Breakdown Structure

Understanding the parts of a problem is the best way to understanding the problem. The first area we are going to explain is a work breakdown structure and its intended uses. Segmentation occurs with the WBS into two types of WBSs. The first type is a Program Work Breakdown Structure (PWBS). The other type of WBS is the Contract Work Breakdown structure (CWBS). Both types of WBS break down the elements of a project into logical levels (MIL–STD 881, 2011).

The Program WBS shows the entire program at a summary level. The program WBS will consist of at least three levels (Albert, 2008). The DoD standardizes these three levels. Contractors use PWBSs to report the status of their projects to the DoD. Only the top three levels of the WBS are required because requiring additional lower levels could affect a contractor's methods and cause delays in processes due to the additional reporting requirements (Albert, 2008). Level one of the WBS ascertains the entire item usually identified as a major program or a project within an aggregated

program. Levels two and three recognize the elements of the parent level broken down to their next logical steps. Figure 3, from MIL STD 881C, displays a simple relationship between the first five levels of the WBS (MIL STD 881C, 2011).

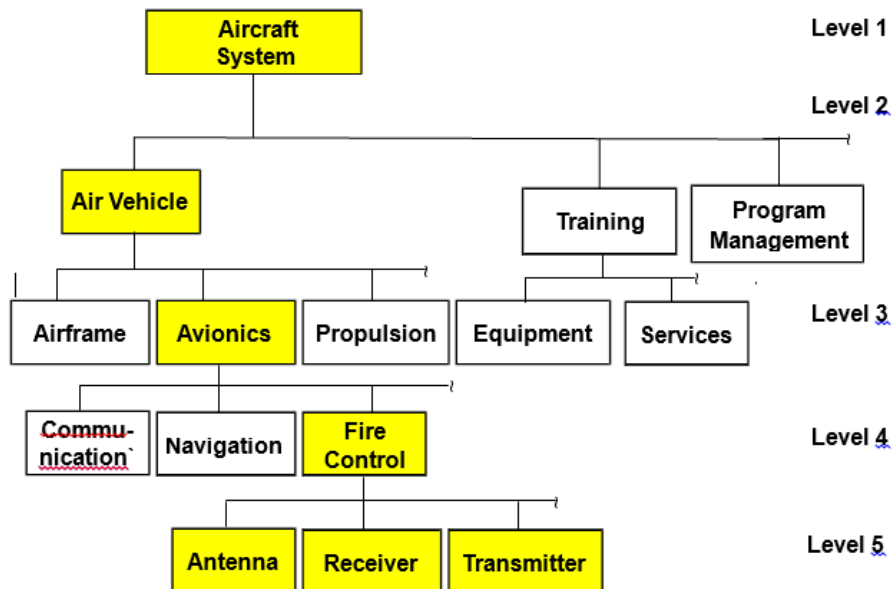


Figure 3 - Simple PWBS

The contractor uses the other type of WBS, the CWBS. The CWBS will normally start where the PWBS stops and continues down to at least one level below the negotiated DoD reporting level. In most cases, the contractors will have their CWBS going all the way down to the control account level. The benefits of the CWBS for the contractor are that the CWBS allows the contractor to break the work down into manageable size elements. By breaking the work down to a manageable level, the contractor can track the individual people working on a project and determine exact cost and schedule data for each element. The lowest level of the WBS is the control account. The control account is where the WBS intercepts the organizational breakdown structure (OBS).

The main difference between the PWBS and the CWBS is standardization. The DoD has developed twelve different standardized PWBS. MIL-STD 88c contains a breakdown of each WBS structure. The reason for twelve different WBS is the differences between types of project. These standardizations assist the DoD when evaluating similar projects, indicating one will have the ability to find the same elements in levels one through three for a C-130 or an F-35. In contrast, in a contract WBS, the elements can vary by how the contractor decides to break down each element. The standardization reason for the PWBS, while the CWBS is not, is because the DoD is responsible for developing and maintaining the PWBS, while the individual contractor is responsible for the CWBS (Albert, 2008).

Earned Value

In this section, we will explain what earned value is and explain some earned value terms and definitions. We will also go into the need for earned value and its purpose within the DoD.

Terms and Definitions

Analysts often use the following terms interchangeably; earned value analysis, earned value management, and earned value management system. However, there is a distinctive difference between each of these terms (Lukas, 2008). The following definitions are from Lukas's article "Earned Value Analysis-Why it Doesn't Work":

- Earned Value Analysis (EVA) - a quantitative project management technique for evaluating project performance and predicting final project results, based on

comparing the progress and budget of work packages to planned work and actual costs.

- Earned Value Management (EVM) – a project management methodology for controlling a project, which relies on measuring the performance of work using a Work Breakdown Structure (WBS) and includes an integrated schedule and budget based on the project WBS.
- Earned Value Management System (EVMS) – the process, procedures, tools and templates used by an organization to do earned value management.

As one can see from these definitions, each of these terms is different. However, each is dependent on the other.

For earned value to work properly within any organization there must be five basic data elements. They are as follows; Budgeted Cost of Work Scheduled (BCWS) or Planned Value (PV), Budgeted Cost of Work Performed (BCWP) or Earned Value (EV), Actual Cost of Work Performed (ACWP) or Actual Cost (AC), Budget at Complete (BAC) or Planned Cost, and Estimate at Complete (EAC) or Forecasted Cost. Table 1 displays the five core elements used with earned value in the DoD (Air Force Cost Analysis Handbook, 2007).

Table 1 - Five Basic Elements for Earned Value

Element	Title	Common Terminology
BCWS	Budgeted Cost of Work Scheduled	Planned Value (PV), Performance Measurement Baseline (PMB), plan, baseline
BCWP	Budgeted Cost of Work Performed	Earned Value (EV)
ACWP	Actual Cost of Work Performed	Actual Cost (AC), actuals
BAC	Budget at Complete	Planned Cost
EAC / LRE	Estimate at Complete / Latest Revised Estimate	Forecasted Cost

Figure 4 illustrates the basic relationship between the cumulative values of the five basic elements of EVM (DAU Gold Card, 2013).

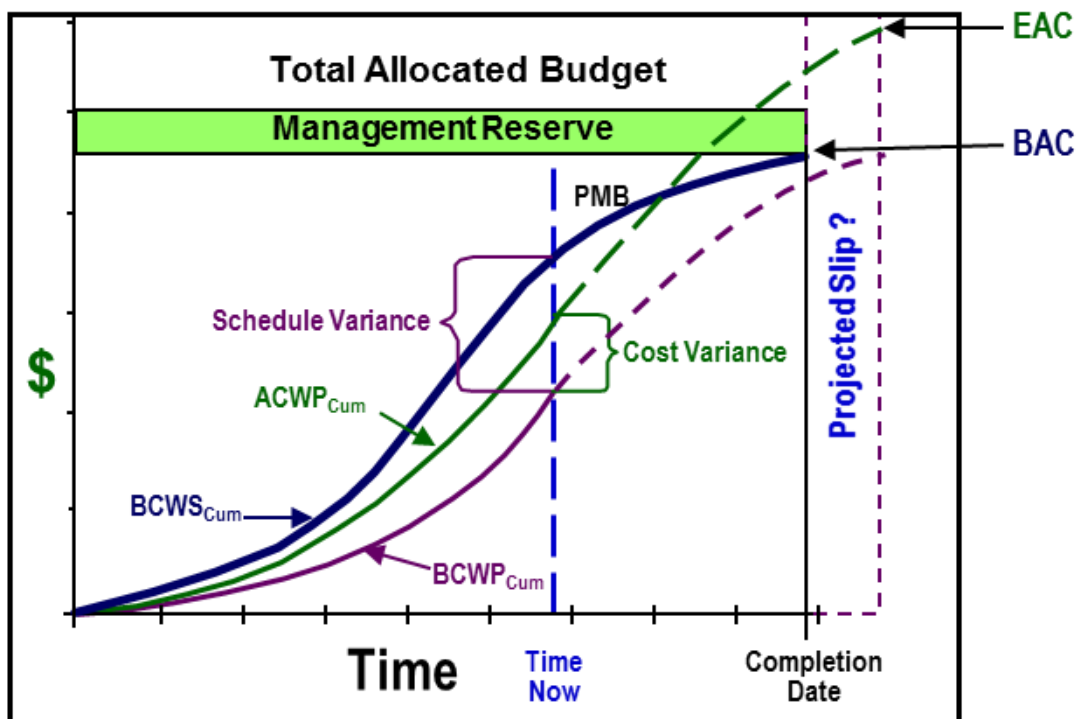


Figure 4 - Relationship between EVM elements

As Figure 4 indicates, the ACWP will equal the EAC at the end of the contract and the BCWS and BCWP should both equal the BAC at the end.

Figure 5 displays the relationship between PV, AC and EV (Lukas, 2008):

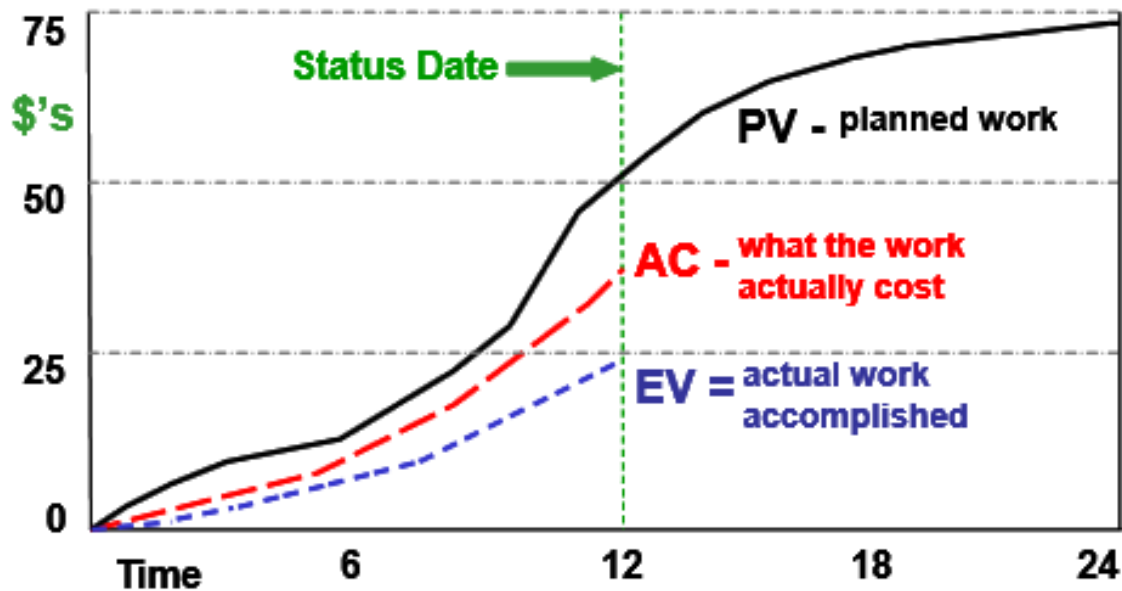


Figure 5 - Relationship between EVM elements

Figure 5 illustrates the status at the time the project was budgeted to have spent \$50 but actually spent only about \$35. At first glance, this looks positive until earned value is also considered. At the time of the status date, the project actually earned only \$25 worth of value. With these three data points, a project manager can immediately calculate the cost variance (CV), schedule variance (SV), cost performance index (CPI), and schedule performance variance (SPI).

The cost variance indicates the difference between the earned value and the actual cost. If the CV is less than zero, it means costs are higher than the value earned to date.

If the CV is greater than zero, it demonstrates costs are lower than the value earned to date (Lukas, 2008).

$$CV = EV - AC$$

The schedule variance shows the difference between the earned value and the planned or budgeted value. If the SV is less than zero, it demonstrates less work accomplished than one planned to date. If the SV is greater than zero, it demonstrates more work accomplished than one planned to date (Lukas, 2008).

$$SV = EV - PV$$

The cost performance index shows a ratio comparing the earned value with the actual value. The CPI determines the value of every dollar spent on a project. The CPI shows the percentage of value gained for every dollar invested. The CPI demonstrates less money earned on the project than invested if it is less than one (not getting a full dollar's worth of work). The CPI demonstrates more money earned on the project than invested if it is more than one (Air Force Cost Analysis Handbook, 2007).

$$CPI = EV / AC$$

The schedule performance index shows a ratio comparing the earned value with the planned value. The SPI shows the efficiency of the work accomplishments. If the SPI is less than one, it shows less work has been done than planned, while if it is greater than one it shows more work has been done than planned (Air Force Cost Analysis Handbook, 2007).

$$SPI = EV / PV$$

Figure 6 displays how the CV, SV, CPI, and SPI relate with the PV, AC, and EV.

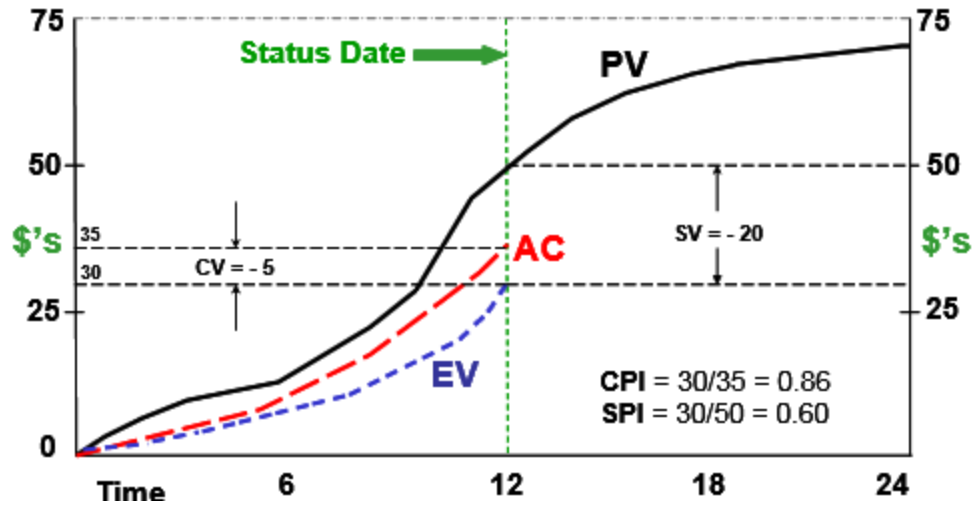


Figure 6 - Earned Value Analysis

The earned value calculations in Figure 6 convey to us the current state of the project. While this information is important, one of the main purposes of EVMS is to predict the estimate at complete (EAC) or final cost of a project from the information we have now. According to Joseph Lukas, there are three different ways for calculating the EAC.

EAC_1 assumes the CPI will remain 1.0 for the rest of the project. This method assumes that even if the project has been running behind schedule it will automatically correct itself for the remainder of the contract. This formula produces the most optimistic outcome for a project.

$$EAC_1 = AC + (BAC - EV)$$

EAC_2 is entitled the CPI forecast. This formula assumes past cost performance is the only indicator for future performance. It assumes the CPI will remain constant during the rest of the project.

$$EAC_2 = BAC/CPI$$

EAC₃ is entitled the CPI * SPI Forecast. Considered the most pessimistic or worst case, this formula assumes past cost and schedule performance are indicators for future performance (Lukas, 2008).

$$EAC_3 = BAC / (CPI \times SPI)$$

The Defense Acquisitions University Earned Value Management Gold Card gives two different ways to calculate the EAC, the EAC_{CPI} and the EAC_{Composite}. The formula below, demonstrates how the EAC_{CPI} is calculated (DAU Gold Card, 2013):

$$EAC_{CPI} = ACWP + [BAC - BCWP] / CPI$$

or

$$EAC_{CPI} = AC + [BAC - EV] / CPI \text{ shows}$$

The EAC_{Composite} is similar to Lukas's EAC₃. The below formula demonstrates how the EAC_{Composite} is calculated.

$$EAC_{Composite} = ACWP + [BAC - BCWP] / [CPI * SPI]$$

or

$$EAC_{Composite} = AC + [BAC - EV] / [CPI * SPI]$$

Figure 7 displays how the EAC is calculated.

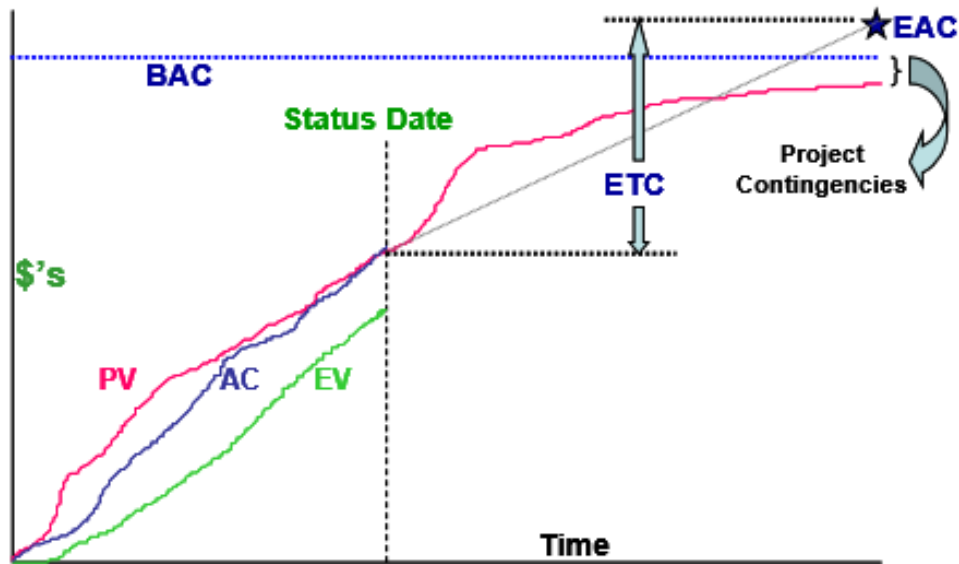


Figure 7 - Estimate at Complete

The EAC at complete is the summation of the ACWP, or AC, and the Estimate to complete (ETC).

Another formula that is widely used, when analyzing EVM data, is percent complete. The final budgeted amount compared to where the project is demonstrates the percent complete. However, the literature shows percent complete calculated two different ways. The most commonly used formula is by dividing the BCWP by the BAC (Thickstun, 2010; DAU, 2013; Christensen and Templin, 2002). The other method we have seen percent complete calculated is by dividing ACWP by the BAC (Trahan, 2009). Table 2 illustrates the two different formulas and the definition for each acronym.

Table 2 - Percent Complete Formulas

$\% \text{ Complete} = \frac{\text{BCWP}}{\text{BAC}}$	ACWP: Actual Cost of Worked Performed
$\% \text{ Complete} = \frac{\text{ACWP}}{\text{BAC}}$	BCWP: Budgeted Cost of Worked Performed
	BAC: Budget at Completion

History of Earned Value in the DoD

Earned value has four major evolutions within the DoD over the past six decades. The DoD first started to use a form of earned value back in 1957 with the Navy's Polaris missile project, entitled program evaluation and review technique (PERT). The original purpose of PERT was to help management create a network model showing the logical steps to complete a project while focusing on time and the probability of success of the project. In less than five years, this method needed replacing (Fleming and Koppelman, 1998).

In 1962, the U.S. Air Force expanded on the original PERT by adding resources to the network model, entitling the new technique PERT/Cost. The evaluation of changes in a project was the most important achievement of PERT/Cost. Until this time, the evaluation process was comparing cost plans with the actual cost for each project. With PERT/Cost, project managers compared the value of the work to the actual cost. Today, we look at this as a simple idea, but in the 1960s, this changed the process of project evaluations. Similar to PERT, PERT/Cost lasted only three years (Fleming and Koppelman, 1998).

Even though the DoD decided to stop using PERT/Cost, it still believed earned value concept had merit and decided to retain earned value as a tool to evaluate a project.

In 1967, the DoD formally implemented earned value with Cost/Schedule Control System Criteria (C/SCSC). Based on the best practices from private industry since the early 1900s, C/SCSC required defense contractors to provide a minimum standard for reporting program performance, as well as requiring contractors to integrate their cost, schedule and effort into a single master plan. C/SCSC was a major improvement with earned value. Managers finally had the resources to predict the final total cost and project length more accurately (GAO-09-3SP, 2009).

Cost/Schedule control system criteria were DoD's first major use of earned value to evaluate projects. However, there were many problems with the system. One of the biggest problems was the rigid requirements. This issue caused some contractors to maintain two sets of data for a project. One set would be the company's working data used to manage the project. To meet the DoD's requirements, contractors maintained a second set of data (GAO, 2009). Another issue contractors had with C/SCSC was the contractor thought that C/SCSC did not add value to their projects by requiring them to complete all the requirements for the DoD (Fleming and Koppelman, 1998).

At the end of 1996, the DoD decided to discontinue C/SCSC due to the problems C/SCSC was causing with the contractors. To create an improved earned value system, the DoD, along with private industry, created the Earned Value Management System (EVMS). When the DoD implemented EVMS, in 1997, the DoD stated, "they brought EVM back to its intended purpose of integrating cost, schedule, and technical effort for managers and providing reliable data to decision makers" (GAO-09-3SP, 2009).

Problems with Earned Value Management System in the DoD

Even with the evolution of earned value over the past six decades, the lingering question of the best way to evaluate data still exists. Solomon has written multiple times about his concern on the proper way companies report their EVM data. He states that in the current DoD system, a contractor could report 100% complete for EVM; however, the project fails to meet the technical requirements (Solomon, 2006; Solomon, 2013).

Lukas also expresses concerns with how earned value is calculated. He suggests there needs to be a quantitative method to assess the project, not a qualitative approach. Stating a qualitative approach could lead to team biases (Lukas, 2008).

Etxegoien expresses concerns about risk in incorporated EVM values. Stating that risk, which is initially added to the contract, is “locked in time with the EVMS baseline while the actual risk is measured and track separately (Etxegoien, 2002).”

Bushey and Etxegoien both also state that the current EVMS is too restrictive for program managers. In both of their researches, they mention program managers need for more freedom to choose what level to report elements. They also mention the current negative connotation of rebase lining hinders program managers from admitting a program might be going over budget. They mention this fear could lead program managers to misrepresent the actual status of a program (Bushey, 2007; Etxegoien, 2002).

Relevant Research Completed

Quantitative research about cost growth into lower level EVM data is very limited. Most research using EVM data looks only at level one. We are attempting to

determine the most beneficial level for the DoD to calculate its EVM data. We have found only one study that used quantitative data to evaluate lower level EVM data. The limited amount of research in this area is because there is not a lot of EVM data that goes down that low. However, we did find multiple qualitative studies supporting lower level EVM data is more predictive and should be used (DAU Website, 2013). However, for the DoD, we require that the contractor only report EVM data at level three of the WBS (MIL-STD-881C, 2011).

Rosado (2011) conducted the only quantitative study on lower level EVM data found in our literature review. Rosado had two main goals for his research. The usage as an early warning for cost growth within a contract was the first intention in the creation of a regression model using lower level WBS EVM data. His second intent was to determine which specific program element contributed the most to overall cost growth.

Rosado, however, used only level three WBS elements in his models. The reason he did not go deeper down the WBS tree was due to lack of commonality of program elements. He wanted to be able to compare like elements in the different programs to see how they predict the overall cost growth. Since there is no standardization below level three, Rosado was unable to use lower level elements. He concluded his research by finding a strong relationship between level three DT&E elements and the overall program EAC growth (Rosado, 2011).

While Rosado conducted the only quantitative research, Bushey (2007) and Etxegoien (2002) both conducted qualitative research on the subject. Etxegoien looked at how program managers can better use EVM data. The current standardized requirements constrain the program manager's ability to track and forecast cost growth. At whatever

level is necessary to give clarity to the program manager, he recommends collecting EVM data. He also recommends collecting EVM data to the lowest level possible on elements that fall within the critical path of the program. Etxegoien does not use any quantitative models to support his argument. His logical argument gave a large basis for his recommendations (Etxegoien, 2002).

Bushey, like Etxegoien, looks at how program managers can best use EVM data. In his research, he says the best way to detect a problem early is to have visibility of the EV data at the smallest level. He states that by drilling down to the lower levels, a program manager can easier identify root causes for cost growth or schedule slippage. He also states that the ability to view the lower level (control account) EVM data allows the program manager to be able to talk directly with the control account manager (CAM). By speaking directly to the CAM, the program manager will also be able to receive even further insight of any possible issues with the program.

He uses an analogy of a car: “if our car would not start, we would focus on repairs at the lower-level starter system and not on analysis at the overall car level or unrelated lower-level areas such as paint, tires, or structure” (Bushey, 2007). However, in his research, he states the benefits of lower level data, but fails to show a quantitative supporting argument for his statement.

Fonnesbeck and Lee conducted a study in 1987. In their research, the authors were looking at the WBS from a cost estimator’s perspective. They wanted to be able to deliver the best cost estimate with the cost data available. One of the problems they stated was the lack of standardization of cost data below level three. The main reason they state this requirement will not change is:

the Office of Management and Budget (OMB) has established guidelines requiring OSD to minimize the reporting requirements placed on the contractors by the CCDR system. This seems to concur with the administration policy to reduce the volume of bureaucratic paperwork.

The authors interviewed different DoD contractors while conducting this study. The authors' intent was to determine if the contractors could provide cost data lower than level three of the WBS. They found most contractors had cost data at least one level below the PWBS and some had data as low as levels eight and nine. Fonnesbeck and Lee gave two suggestions on how to improve cost report, even if we cannot change the requirement for contractors to only report down to level three. One of their suggestions dealt with creating a time-phased data reporting system and a data base system to store EVM data. The other suggestion, however, is to remove some level three elements and replace them with their level four sub-elements. This sounds simple, but the authors found in many projects that the level four element could account for more than 40% of the level two element above it. By not being able to track the level four element closely, it makes reporting where a problem is more difficult, if not impossible (Fonnesbeck and Lee, 1987).

Conclusion

In the chapter, we provided a brief look into how a WBS works and the relationships between the CWBS and the PWBS. We also explained the definition of earned value with some basic formulas and definitions. Then, we went over the history and evolution of earned value in the DoD. Through our research, we have not seen any research looking into the exact problem we are researching. However, Rosado, Etxegoien, Bushey, Fonnesbeck and Lee demonstrate there have been some studies

completed on this topic, but these authors lacked the ability to obtain cost data down to the control account level. In the next chapter, we will explain our data collection process and methodology for evaluating our cost data in detail.

Chapter 3 – Data Collection and Methodology

Chapter Overview

This chapter describes our data collection and methodology in our research. The objective of this chapter is to make clear the steps we performed in our analysis and data collection and give the reason behind our choices. We also briefly explain other techniques we attempted, as well as the analysis and the reason we chose not to use them. By the end of this chapter, we will have shown you how we collected our data and how we limited it. We will also have shown our criteria for evaluating our research question and the steps we took to obtain our results.

Defense Cost and Resource Center (DCARC)

History and Intent

Established in 1998, DCARC's primary role is to collect past and present Major Defense Acquisition Programs in one central location. DCARC has four main objectives. The first is to allow one location to collect contractor's cost and software data reports. The second allows authorized users access to this cost data for analysis for future projects. The third objective is to maintain the integrity and accuracy of the data collected from contractors. The final object is to improve the quality of data reported by industry. The overall goal of DCARC is to provide senior leaders with accurate and timely cost estimates in order to provide the war fighter the weapons and equipment needed to win (DCARC, 2007).

Earned Value Management Central Repository

We collected the data for our research from the Earned Value Management Central Repository (EVM-CR) found on the Defense Cost and Resource Center (DCARC) portal. Designating a single place where contractors can submit their Contract Performance Reports (CPRs), Contract Funds Status Reports (CFSRs), and Integrated Master Schedules (IMSs) is the function of the EVM-CR (Office of the Secretary of Defense Central Repository for Earned Value Management (EVM) Data Manual, 2008). Performance Assessments and Root Cause Analysis (PARCA) directly oversees EVM-CR.

A contractor must submit seven different CPRs. Contractors have used the first five formats for years. However, in 2012, formats six and seven were established (PARCA Memo, 2012). The intent of these two new formats is to better integrate cost and schedule reporting. Format six contains the contract's Integrated Master Schedule (IMS) and format seven contains an electronic history and forecast file. The format we will focus on in our research is format seven.

The EVM-CR sorts all of the programs into five different organizations. The five organizations are Army, Air Force, Navy, Department of Defense, and Missile Defense Agency (MDA). There are currently 143 different programs and 422 contracts found on the EVM-CR. Table 3 displays the breakdown by organization.

Table 3 - EVM-CR Program Breakdown

	# of Programs	# of Contracts
Army	34	74
Air Force	40	93
Navy	46	181
DOD	12	50
MDA	11	24
Total	143	422

Data Collection

In this section, we will explain the process and steps required to create our data set and subsequently use in our evaluation of our research questions. The first step implemented was to request access to the EVM-CR database through PARCA for approval. Initially, we only had access granted to the Army's EVM data. This restriction was due to policies at PARCA limiting access only to the service of the requesters. In order to gain access to the Navy's and the Air Forces' EVM data, we had to submit an exception to the policy and then each branch's representative had to approve our request. Ultimately, the Army, Air Force and Navy cost data were the only agencies we had permission to access. Both the Missile Defense Agency and DoD projects did not grant access. However, we felt the three services we had would provide sufficient data to conduct our research.

Selecting Contract Data

Once we had access to the EVM data, we determined the criteria we needed in order to answer our research questions. We looked through every contract (to date) for

the Army, Air Force and Navy. The first and most important requirement was that the contract had to have EVM data down to at least level five of the WBS. We also needed to ensure that the level five EVM data was different from the level three data. In many of the contracts, we found level three and five data identical. In these cases, we removed those elements from our analysis.

Our second criterion was that each contract has at least twelve consecutive periods of EVM data. The reason for the requirement was to allow us to analyze our explanatory variable over a length of time. We determined any contract with less than twelve periods of EVM data would limit the predictive capabilities of our model.

Our final criterion was that the data was complete and relevant. The system was able to tell us if the contractor had lower level data and if the contract was over twelve months, however, the system could not tell us if the data was complete or if all the months had EVM data. In our screening of these criteria, we found that many elements reported by the contractor failed to have complete EVM data. Many times contractors would only report their Latest Revised Estimate (LRE). We also found in some contracts, the contractor left multiple months of EVM data empty.

Contract Selection Criteria

After we determined the criteria for our data, we needed to create requirements for the individual contract in the EVM-CR. The EVM-CR database organizes its EVM data into six different types of files. They are Integrated Program Management Report (IPMR) Cost, Formatted Cost, IPMR Schedule, Native Schedule, Contract Fund Status Report (CFSR), and History files (Format 7). However, we found the best way to obtain our data was by looking only for history files. The history file presented each of the

WBS elements and their cumulative changes over the length of the project. Contracts are required to upload a new history file to the EVM-CR at least annually. In cases where there were more than one history file with a contract, we only downloaded the most recent published history file.

In order to view and sort the history files we downloaded, we used the CPR File Viewer software provided from the DCARC website. This software allowed us to quickly sort and evaluate the different contracts. Once we sorted the contracts, we used the software to download the files into Microsoft Excel format. We then used these Excel files to define our explanatory variables to use in our statistical analysis.

Overview of Data

After applying our data and contract criteria, we narrowed the number of contracts from 422 to 40. Appendix B contains a list of the forty contracts. Table 4 illustrates the breakdown by criteria. Column 1 and 2 indicate the number of programs and contracts in each service. The following four columns are the criteria for limiting data. The numbers in Table 4 are dependent on the number to the left. An example, the Army had thirty contracts with at least level five data and only twenty-five of them were greater than twelve months. The final column calculates the percentage of contracts with usable data.

Table 4 - Data Overview by Criteria

	# of Programs	# of Contracts	# with History Files	Lvl 5 or greater WBS	>12 Months	Complete Data	% Complete
Army	34	74	52	30	25	9	12.16%
Air Force	40	93	54	24	18	4	4.30%
Navy	46	181	111	44	30	27	14.92%
DOD	12	50	21	ACCESS NOT GRANTED			
MDA	11	24	6				
Total	143	422	244	98	73	40	9.48%

From looking at Table 4, we can identify the breakdown of the forty contracts by department. We also see a majority of the contracts came from Navy contracts.

Furthermore, Table 4 makes evident the Air Force has the smallest percentage of usable contracts.

Observing just the forty contracts used in our analysis, we broke the contracts down by which phase the contract was in (RDT&E, Production, Other or Unknown), ACAT level (IAC, IAM, IC, ID, II, III or Unknown), contract type (CPAF, CPFF, CPIF, FFP, or IDIQ) and type of WBS (Aircraft, Electronic/Automated Software, Missile, Ordnance, Ship, Space, UAV or Other). Table 5 illustrates the breakdown by phase of contract.

Table 5 - Data by Phase

	# of Programs	# of Contracts	# with History Files	SDD	Prod	Other	Service	Unknown
Army	34	74	46	5	3	0	0	1
Air Force	40	93	49	3	1	0	0	0
Navy	46	181	104	14	9	1	0	3
DOD	12	50	16	ACCESS NOT GRANTED				
MDA	11	24	3					
Total	143	422	218	22	13	1	0	4

As Table 5 displays, all but five of the contracts are either RDT&E or Productions contracts.

Table 6 illustrates the breakdown by ACAT.

Table 6 - Data by ACAT

	# of Programs	# of Contracts	Complete Data	IAC	IAM	IC	ID	II	III	Unknown
Army	34	74	9	0	0	3	5	0	0	1
Air Force	40	93	4	1	1	0	1	0	1	0
Navy	46	181	27	0	0	12	15	0	0	0
DOD	12	50	ACCESS NOT GRANTED							
MDA	11	24								
Total	143	422	40	1	1	15	21	0	1	1

Table 7 indicates the breakdown by contract type

Table 7 - Data by Contract Type

	# of Programs	# of Contracts	Complete Data	CPAF	CPFF	CPIF	FFP	FPIF	IDIQ
Army	34	74	9	1	1	4	2	1	0
Air Force	40	93	4	1	1	0	1	0	1
Navy	46	181	27	11	5	6	0	4	1
DOD	12	50	ACCESS NOT GRANTED						
MDA	11	24							
Total	143	422	40	13	7	10	3	5	2

Table 8 illustrates the data by type of WBS.

Table 8 - Data by type of WBS

	# of Programs	# of Contracts	Complete Data	Aircraft	ELECTRONIC/ AUTOMATED SOFTWARE	Missile	Ordnance	Ship	Space	UAV	Other
Army	34	74	9	0	4	1	2	0	0	0	2
Air Force	40	93	4	1	2	0	0	0	1	0	0
Navy	46	181	27	10	5	4	0	5	0	3	0
DOD	12	50		ACCESS NOT GRANTED							
MDA	11	24									
Total	143	422	40	11	11	5	2	5	1	3	2

Table 9 lists each of the forty contracts and the total number of level five elements in the contract. Table 9 also breaks down the size of the level five elements as a percentage of the level one EAC.

Table 9 - Total number of level 5 Elements

	Total # of lvl 5	# lvl 5 w/ EVM data	>.25%	>.50%	>1%
B2 MOP - Massive Ordnance Penetrator (F33657-99-D-0028)	126	66	17	9	7
Chem Demil - CMA (DAAA09-97-C-0025)	2494	1520	63	19	9
Chem Demil - CMA (DACA87-89-C-0076)	441	293	41	30	20
Excalibur (DAAE30-98-C-1032)	23	21	20	18	15
Excalibur (W15QKN-08-C-0530)	22	20	20	20	16
FBCB2 (W15P7T-04-D-G205)	443	300	96	53	18
IAMD (W31P4Q-08-C-0418)	495	345	83	48	19
ISPAN (FA8722-04-C-0009)	141	104	65	40	29
JAGM (W31P4Q-08-C-A123)	34	33	25	23	21
JTRS (DAAB07-02-C-C403)	29	24	7	4	1
MPS - SEIC (FA8720-05-C-0005)	54	28	25	23	15
NAVSTAR GPS (FA8807-06-C-0001)	302	160	31	14	10
WGS (FA8808-06-C-0001)	54	21	20	20	15
WIN-T INC3 (DAAB07-02-C-F404)	75	68	37	31	15
AAG - Advanced Arresting Gear Program (N68335-03-C-0205)	608	419	101	60	19
AGM-88E (Advanced Anti-Radiation Guided Missile (N00019-03-C-0353)	96	78	39	27	17
AIM-9X Block II (N00019-12-C-2002)	48	25	22	16	14
AMDR - Air & Missile Defense Radar (N00024-10-C-5359)	33	17	13	13	10
CEC - Cooperative Engagement Capability (N00024-05-C-5100)	104	73	45	33	22
DDG 1000 - Zumwalt Class Destroyer (N00024-05-C-5346)	3820	2746	69	31	7
DDG51 - Arleigh Burke Class Guided Missile Destroyer (N00024-02-C-2304)	27	21	16	15	12
EA-18G - Airborne Electronic Attack variant (N00019-04-C-0005)	10	7	3	3	2
H1 Upgrades (N00019-06-G-0001)	28	23	12	12	6
JPALS - Joint Precision Approach and Landing System (N00019-08-C-0034)	178	109	36	28	15
JPALS - Joint Precision Approach and Landing System (N00019-08-C-0034) (2)	49	41	32	21	15
JSOW (N00019-05-G-008-DO)	12	12	10	10	9
LCS - Littoral Combat Ship (N00024-03-C-2310)	1729	524	38	28	21
LCS - Littoral Combat Ship (N00024-11-C-2301)	87	32	18	17	15
LPD 17 - San Antonip Class (N00024-04-C-2204)	2193	308	47	27	14
MH-60R (N00019-04-C-0130)	50	47	33	28	22
MH-60R (N00019-08-C-0005)	53	48	32	27	23
MH-60R (N00019-09-C-0059)	24	18	12	12	10
MH-60S (N00019-03-C-0003)	101	80	43	33	17
MQ-4C Triton (N00019-08-C-0023)	772	523	51	24	11
P-8A Poseidon Program (N00019-04-C-3146)	38	24	14	12	9
SM-6 Standard Millile 6 (N00024-04-C-5344)	104	100	61	37	22
SM-6 Standard Millile 6 (N00024-09-C-5305)	81	77	37	24	18
V-22 - Osprey Joint Advanced Vertical Aircraft (N00421-10-D-0012)	4	4	4	4	3
V-22 - Osprey Joint Advanced Vertical Aircraft (N61339-08-D-0004)	36	23	10	7	5
V-22 - Osprey Joint Advanced Vertical Aircraft (N61340-11-C-0004)	17	11	9	8	7
VTUAV (N00019-00-C-0277)	204	157	52	29	16
VTUAV (N00019-12-C-0059)	725	429	58	25	10
Number of Level 5 elements	15964	8979	1467	963	581
Percent of total # level 5		56.25%	9.19%	6.03%	3.64%

Table 9 reveals that 56.25% of all the level five elements actually had EVM data. In addition, we can see that less than 10% of all the level five elements are larger than 0.25% of the total contract.

Contract Error

While going through the forty contracts, we found numerous errors within the contracts. Although these errors did not seem intentional, we needed to address the errors the best we could. We either removed the WBS element from the calculations or attempted to reconstruct the intended value. Some examples of attempting to reconstruct the intended value are when the WBS element is on a constant growth and then a month is blank. After which, the WBS element continues to grow at the previous growth rate. Table 10 notionally demonstrates this error.

Table 10 – Notional Example #1 of Contract Errors

	Time					
	1	2	3	4	5	6
WBS Element	\$5	\$10	\$15		\$25	\$30

In this instance, we would extrapolate the EVM values for the missing month. In this example, we would have inserted \$20 in the fourth month. Table 11 illustrates another common error we encountered. In this type of error, a contractor inserted a monthly change instead of the cumulative change for a WBS element.

Table 11 – Notional Example #2 of Contract Error

	Time					
	1	2	3	4	5	6
WBS Element	\$10	\$20	\$30	\$10	\$50	\$60

In this insistence, we would add the monthly change value to the last reported cumulative value. In this example, we would have inserted \$40 in the fourth month. ACWP, BCWP, and BCWS were common places we found this type of error because of the constant growth of these elements. We found 212 errors in twenty of our forty contracts. Table 12 details the twenty contracts with errors and the number of errors in each contract.

Table 12 - Number of Errors per Contract

Service	Project Name	Prime Contract Number	# of errors within contract Level 3	# of errors within contract Level 5
Air Force	B-2 MOP - Massive Ordnance Penetrator	F33657-99-D-0028	0	1
Navy	CEC – Cooperative Engagement Capability	N00024-05-C-5100	1	50
Army	Chem Demil - CMA	DACA87-89-C-0076	0	1
Army	Chem Demil - CMA	DAAA09-97-C-0025	1	2
Navy	DDG 1000 - ZUMWALT CLASS Destroyer	N00024-05-C-5346	0	1
Army	IAMD - Integrated Air & Missile Defense	W31P4Q-08-C-0418	0	2
Navy	LCS - Littoral Combat Ship	N00024-11-C-2301	20	0
Navy	LPD 17 - SAN ANTONIO CLASS Amphibious Transport Dock Ship	N00024-04-C-2204	0	6
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-09-C-0059	0	3
Navy	MH-60S - Multi-Mission Combat Support Helicopter	N00019-03-G-0003	0	10
Navy	MQ-4C Triton (Formerly BAMS)	N00019-08-C-0023	0	12
Navy	P-8A - Poseidon Program	N00019-04-C-3146	0	11
Navy	SM-6 – Standard Missile-6	N00024-04-C-5344	0	5
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N00421-10-D-0012	0	1
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61340-11-C-0004	0	7
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61339-08-D-0004	1	1
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-00-C-0277	0	46
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-12-C-0059	0	26
Air Force	WGS – Wideband Global SATCOM Program	FA8808-06-C-0001	0	3
Army	WIN-T Inc. 3 - Warfighter Information Network Tactical Increment 3	DAAB07-02-C-F404	0	1

Table 12 indicates 89% of the errors we detected were in level five elements.

Methodology

EAC Growth

We decided to use the EAC growth as our predictive variable. The main reason we decided to use EAC as our predictive variable is because EAC allows us to project where the contract's final cost is heading. The issue we found with using the EAC is what value do we use? For each element, the contractor provides an EAC. However, the usage of the formulas stated in Chapter Two cannot calculate the contractor's EAC. In most cases, contractors provide their latest revised estimate (LRE) as the EAC instead of using an established formula. The contractor's LRE is their estimation of future cost for the element. It can include factors outside of EVM data. This caused an issue with our research in determining the predictive capabilities of the lower level earned value data. In the next section, we will discuss the way we decided to calculate the EAC. As stated in Chapter Two, there are many different ways EAC can be calculated using earned value data.

Defining Percent EAC Growth

First, we had to determine how we would calculate our EAC. As stated earlier, the EAC provided by the contractor in the EVM data was actually the contractor's LRE. However, the LRE is very subjective and we decided not to only use this value for our EAC. We decided to also use the composite EAC as discussed in Chapter Two. The reason we chose this formula is that it is the most conservative formula for the EAC. Below is the formula for the $EAC_{\text{composite}}$:

$$EAC_{Composite} = AC + [BAC - EV] / [CPI * SPI]$$

We were able to calculate the EAC composite using the EVM data provided by the contractor from the EVM-CR. We then recalculated all the monthly EACs for each element at level one, three and five.

Defining Lower Level EAC Growth

We evaluated two different techniques to measure levels three and five cost growth. The first method examined only the cost growth of the individual elements within each level. Definitions #1 and #2 used this technique. The second technique examines the overall cost growth within a level. We used this technique with definitions #3 and #4. Additionally, the second technique is the method Rosado used in his research. Figure 8 displays each of the four definitions and if it used the EAC or LRE and which cost growth technique was used. The next section explains each of these definitions further.

EAC Cum Change Definition #3	EAC Element Change Definition #1
LRE Cum Change Definition #4	LRE Element Change Definition #2

Figure 8 - EAC Growth Definitions

Explanatory Variables

Once we recalculated our predictive variable, EAC growth, we created our level three and five explanatory variables to use in our different statistical models. We used

the four definitions in Figure 8 for both our level three and five variables. Figure 9 illustrates each definition. In all four instances, we created a ratio by dividing the monthly change of our predictive variable by the last reported level one EAC. By creating a ratio, in respects to the final level one EAC, it allowed us to normalize our data.

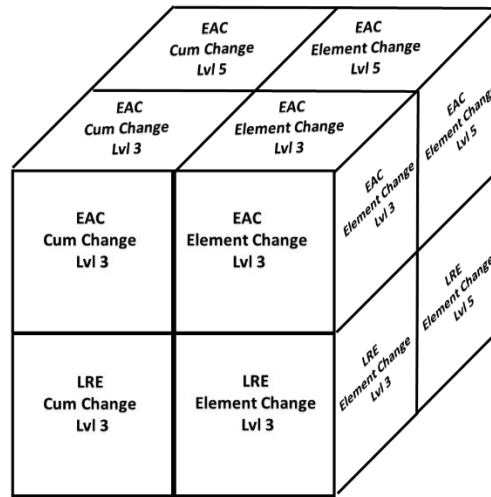


Figure 9 - Level three and Five Explanatory Variables

Cost Growth Definition #1

In most cases, not all level three or five elements start at the beginning of the contract. Our first definition looked only at the cumulative change in each level's EAC. This method excluded the initial cost of an element. Table 13 displays this example. This method allowed us to compare only the cost growth of lower level elements.

Table 13 – Cost Growth Definition #1 Example

		Time				
		1	2	3	4	5
Element	1	\$10	\$15	\$20	\$25	\$30
	2		\$10	\$10	\$10	\$15
	3				\$50	\$100
Monthly Change		\$0	\$5	\$5	\$5	\$60
Cum Change		\$0	\$5	\$10	\$15	\$75

Cost Growth Definition #2

With the exception of the usage of the contractor's EAC provided in the contract, the calculated variable used the same technique as definition #1. This allowed us to evaluate if there was a difference using the contractor's EAC or recalculating the EAC using an established formula.

Cost Growth Definition #3

Similar to the first definition, this looked at our recalculated EAC. Definition #3 differs from the first by including the cost of new elements into our calculations of the monthly cumulative change. Table 14 illustrates this example.

Table 14 – Cost Growth Definition #3 Example

		Time				
		1	2	3	4	5
Element	1	\$10	\$15	\$20	\$25	\$30
	2		\$10	\$10	\$10	\$15
	3				\$50	\$60
Monthly Change		\$10	\$15	\$5	\$55	\$60
Cum Change		\$10	\$25	\$30	\$85	\$145

Cost Growth Definition # 4

Definition #4 is another test variable using the same technique as definition #3, except the contractors EAC. Again, for this definition, we created it to compare a recalculated EAC with the contractor's provided EAC (LRE).

Normalizing Cost Growth

Our contracts ranged in value from \$19 million to over five billion dollars. In order to compare the wide range of data, we created a cost growth ratio for each of our eight explanatory variables. Our ratio compares the cumulative change divided by the final level one EAC.

$$\text{Cost Growth Ratio} = \frac{\text{Level 3 or 5 Cum Change}}{\text{Final Level 1 EAC (or LRE)}}$$

Normalizing Contract Length

Our contracts ranged from twelve months to over eighty months. In order to compare this wide range of data, we calculated the percent complete of level one for each month of the contract. The formula we used to calculate the percent complete was (Tracy, 2005):

$$\text{Percent Complete} = \text{CumBCWS/BAC}$$

Upon completion of the percent complete calculation for each month, we created bins for every 5% complete. A bin would contain any month falling within plus or minus 2.5% of the bin value. For example, the 40% complete bin would contain any month with a percent complete greater than or equal to 37.5% and less than 42.5%. In cases where more than one month fell into a bin, we used only the last month that fall within the bin.

Multiple Regression

The technique we used in our analysis was Ordinary Least Squared (OLS) multiple regression. We used OLS multiple regression to create and analyze our four different definitions of cost growth. There were three main reasons why we chose this method. The first reason for choosing OLS multiple regression was to evaluate the overall model using the F-test. We then compared the F-test value to our alpha (.05). The model failed if the F-test's p-value was greater than the alpha. The second reason we chose this method was that it provided a T-test. The T-test evaluates each individual independent variable. We used Bonferroni correction to determine if each independent variable was significant. Bonferroni correction compares the independent variable's p-value to our alpha (.05) divided by the number of independent variables in the model. An example using Bonferroni correction is if there are five independent variables then for the variable to be significant, its p-value needs to be less than 0.01 (0.05 divided by five). The final analysis this method provided was a variance inflation factor (VIF) score. The VIF score quantifies the magnitude of multicollinearity of the independent variables in the regression model. In order to determine if two or more independent variables correlated, we ensured that each variables VIF score was less than five. Any value over five meant that the particular variable had a higher than acceptable amount of correlation with at least one other variable.

We also used stepwise regression to determine which independent variables were included in our models. Stepwise regression is an automatic process conducted by our statistical software. The software adds or removes variables attempting to create the most predictive model available with the independent variables available. We used stepwise

regression to determine our variables because in each of our models we had our level three and five explanatory variables along with over fifty independent variables.

Appendix C contains a list of all the independent variables used in our models. Since we were not sure which variables would be the most predictive, we used stepwise regression to determine which ones to add.

The final tool we used with our multiple regression was Cook's Distance or Cook's D. Cook's D allowed us to determine if a certain contract was overly influential in our regression output. We defined a contract as being overly influential if its Cook's D score was greater than 0.5.

Fit Y by X

We also evaluated the relationship between our level three and five EVM data. We used a fit Y by X to examine this relationship. The fit Y by X compares the relationship between one independent variable and the response variable. We identified our level three variable as the response variable and the level five variable as our explanatory variable. This technique allowed us to compare our level three and our level five data to detect any correlation between the level three and five variables. We used this technique for definitions #3 and #4 at each 5% complete bin. This technique allowed us to compare the slope of the fit line to determine the relationship between level three and five. A slope of one would indicate there is perfect correlation between level three and level five data.

The software package we used in our analysis was JMP® 11.0. There were two reasons we chose this software. First, JMP® was able to perform all the different types of analysis we required and could handle the amount of variables we needed to include. The

other reason we chose JMP® was our familiarity with the software. Key elements for choosing the software were due to prior knowledge of the software, wide availability and its capabilities.

Conclusion

In this chapter, we described our data collection methods. We also created criteria for the contracts, as well as for the data within the contracts. We described our data set and explained our methodology to answer our research questions. In the next chapter, we review the results of our data in the different statistical models described.

Chapter 4 – Analysis and Results

Chapter Overview

We created a regression model, which would determine if level five EVM data was more predictive than level three EVM data. We anticipated the ability to indicate level five data, compared to level three data, was a better predictor for overall cost growth.

We measured overall cost growth by calculating the growth of level one's EAC from the first reported period to the final period. Given our data set, our regression model includes service, program type, contractor and length of contract. In order to compare the contractor's provided EAC with an EVM calculated EAC, we divided Chapter Four into two sections. For the purpose of the rest of this chapter, we will refer to the contractor's EAC as an LRE and the recalculated EAC as the EAC.

The first section evaluates the EAC, while the second section will evaluate the LRE. Each of these sections has the same structure. First they will examine the distribution of our response variable (percent increase in level one EAC (or LRE)) and identify any outlier contracts. Then, they both display the multiple regression results. The results also display any contracts excluded either because it was an extreme outlier or was overly influential in the model.

Evaluating the EAC

In the following sections, we examine the results using the EAC.

Distribution of Response Variable

While conducting our analysis, we detected two extreme outlier contracts based upon level one recalculated EAC growth. Contract N00019-06-G-0001 and W15P7T-04-D-G205 grew 11,606% and 1,405% respectively. Figure 10 displays the distribution of the percent change in level one's EAC.

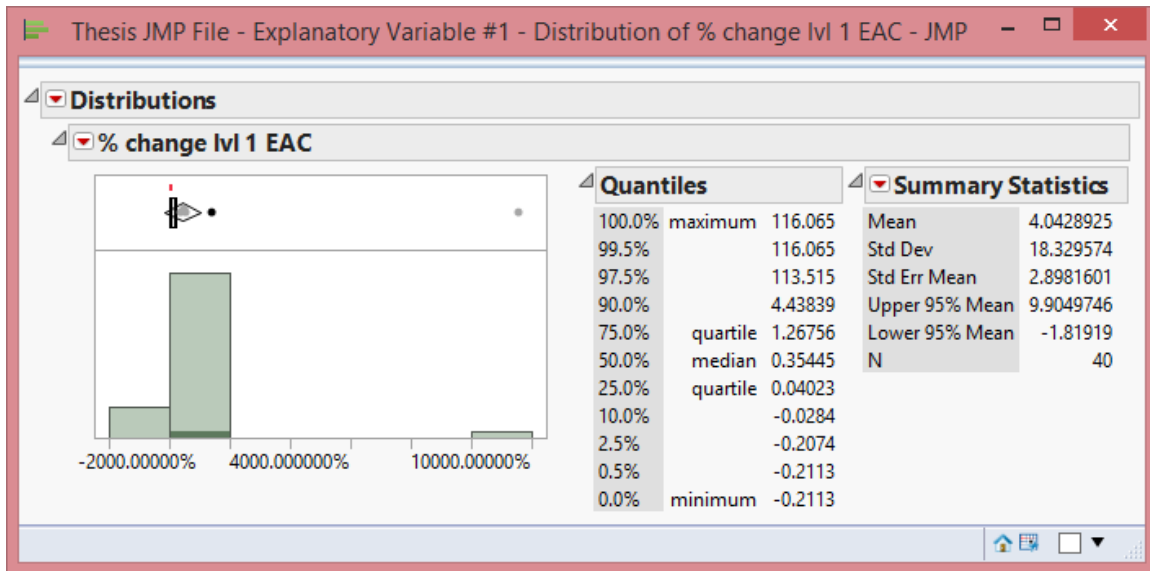


Figure 10 - Distribution of Percent Change of Level 1 EAC

We removed these two contracts from our data set. This lowered our total number of contracts for our analysis down to thirty-nine. Figure 11 represents the distribution excluding the two contracts.

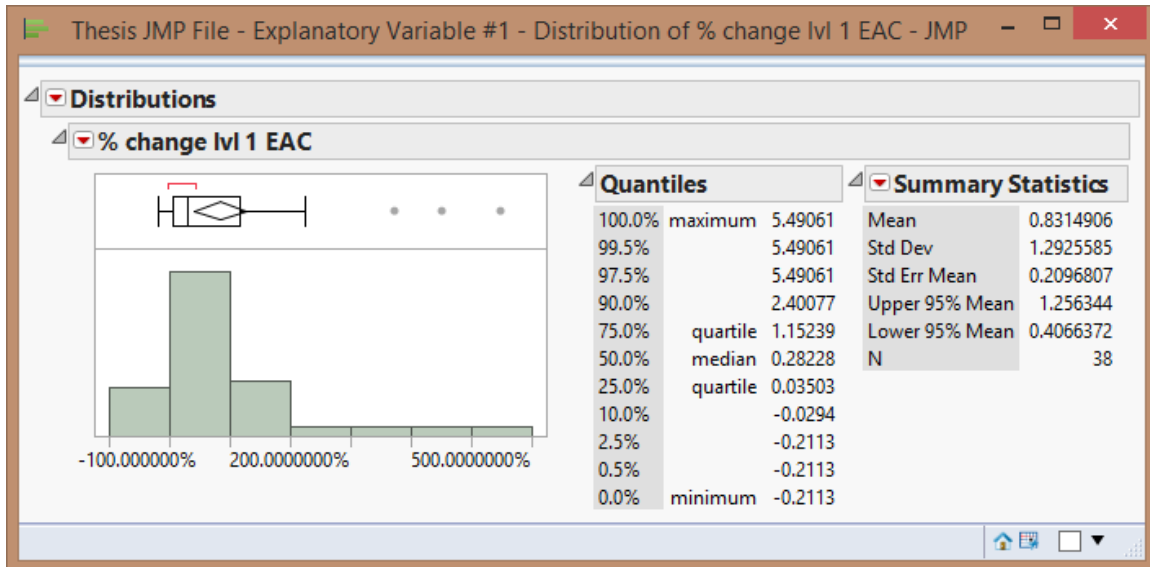


Figure 11 - Distribution of Percent Change of level 1 EAC (excluding two extreme outliers)

After removing the two extreme outliers, three additional contracts became outliers.

Figure 12 displays our distribution removing these additional three outlier contracts.

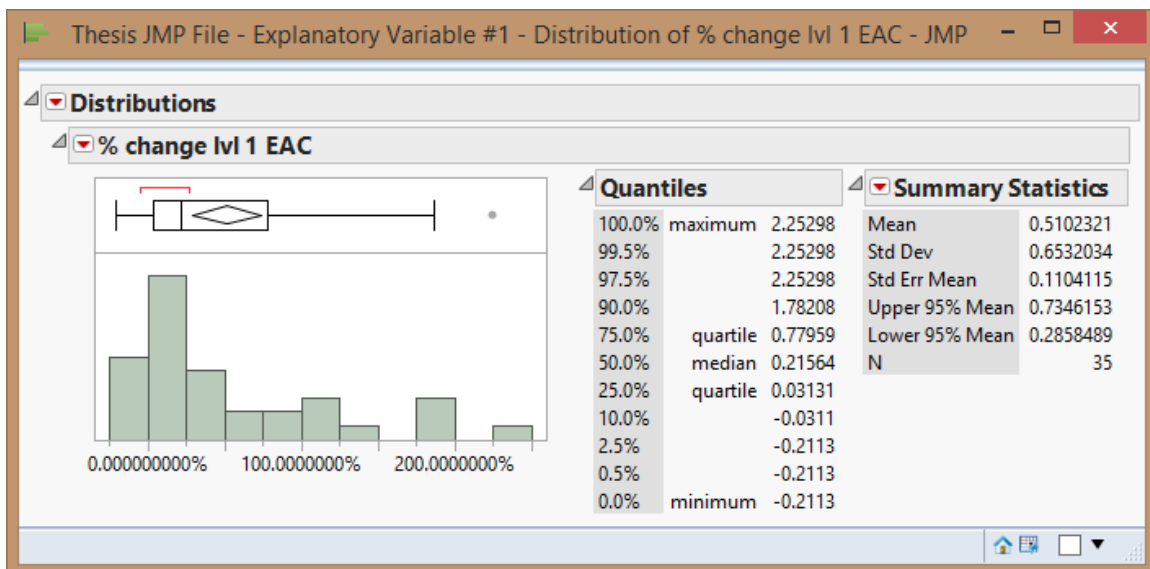


Figure 12 - Distribution of Percent Change of level 1 EAC (excluding three additional outliers)

After removing the three additional outliers, one additional outlier was recognized and removed.

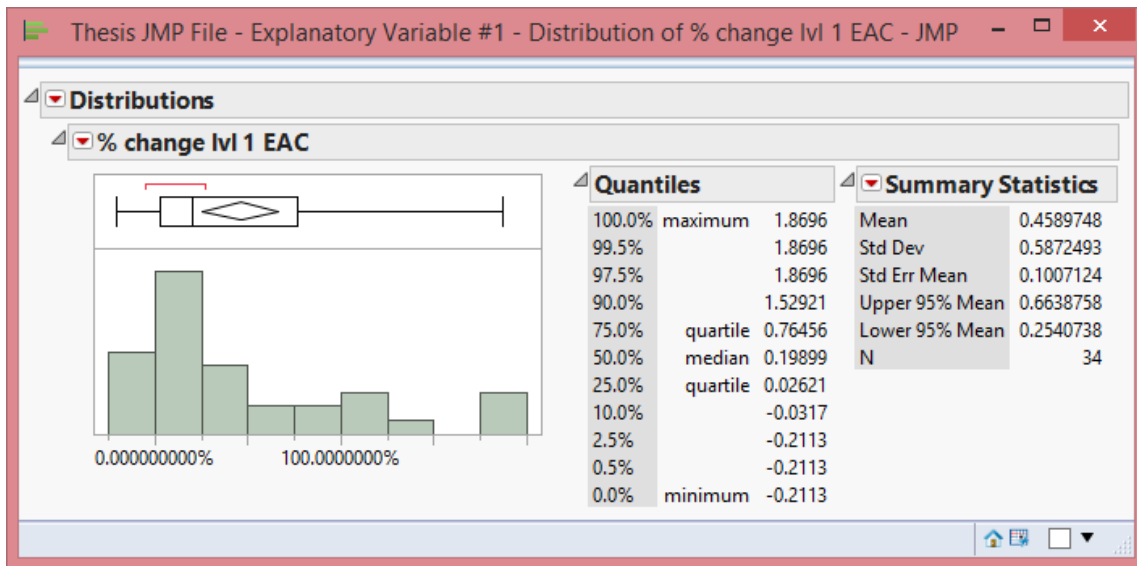


Figure 13 - Distribution of Percent Change of level 1 EAC (excluding all outliers)

Figure 13 displays the distribution of the response variable excluding all outliers. By excluding these six contracts, it lowered our mean EAC growth from 404% to 46% and lowered the standard deviation from 1832% to 59%. We identified six outliers, however, within our models we initially only excluded the two extreme outliers. Table 15 details the six outlier contracts and the percent change in level one EAC.

Table 15 – EAC Contract Outliers

% change lvl 1 EAC	Service	Project Name	Prime Contract Number
11606.53%	Navy	H-1 UPGRADES (4BW/4BN) - United States Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter	N00019-06-G-0001
1405.37%	Army	FBCB2 - Force XXI Battle Command Brigade and Below Program	W15P7T-04-D-G205
549.06%	Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-12-C-0059
451.70%	Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N00421-10-D-0012
373.09%	Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61340-11-C-0004
225.30%	Air Force	ISPAN - Integrated Strategic Planning and Analysis Network - Block 1	FA8722-04-C-0009

The first two contracts in Table 15 are the two extreme outliers, while the next four were the subsequent outliers. Next, we briefly explain each outlier.

The H1 upgrade was the most extreme outlier in our data set. Figure 14 displays the contract's EAC along with the BAC. There are two reasons for the large percent increase in level one EAC. The first reason was because its first EAC and BAC were extremely low. The initial EAC was \$702,478 and the initial BAC was \$1,375,089. Two months later, both of these figures increased to \$27,591,793 and \$19,151,617 respectively. Figure 14 also identifies a change in scope in October 2009, which is another cause for the increase in cost.

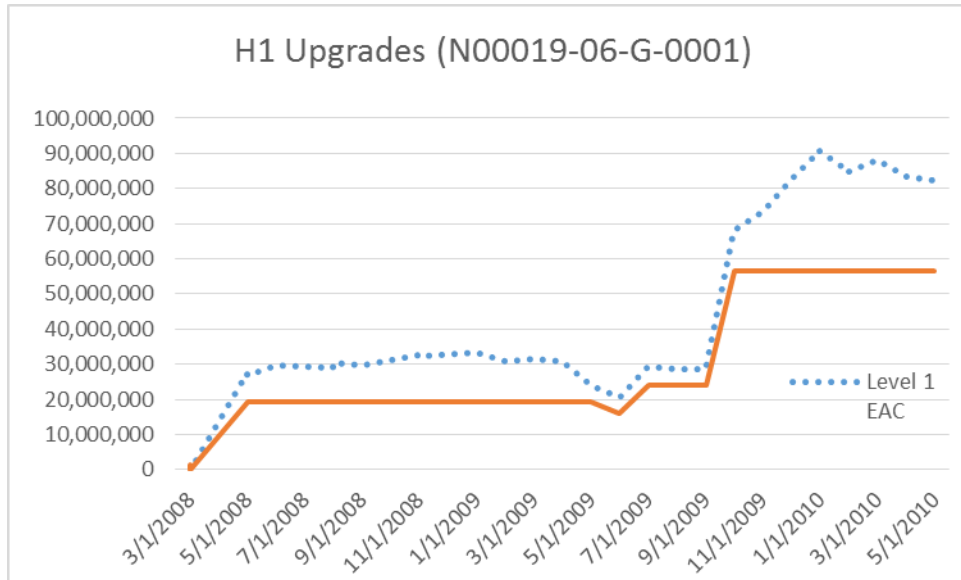


Figure 14 - H1 Upgrade

The next contract excluded was the FBCB2. Figure 15 displays both the EAC and BAC for this contract. Unlike the H1 upgrade, a constant change in quantity ordered caused this contract's cost growth. This contract's cost has been increasing at a constant rate since it began.

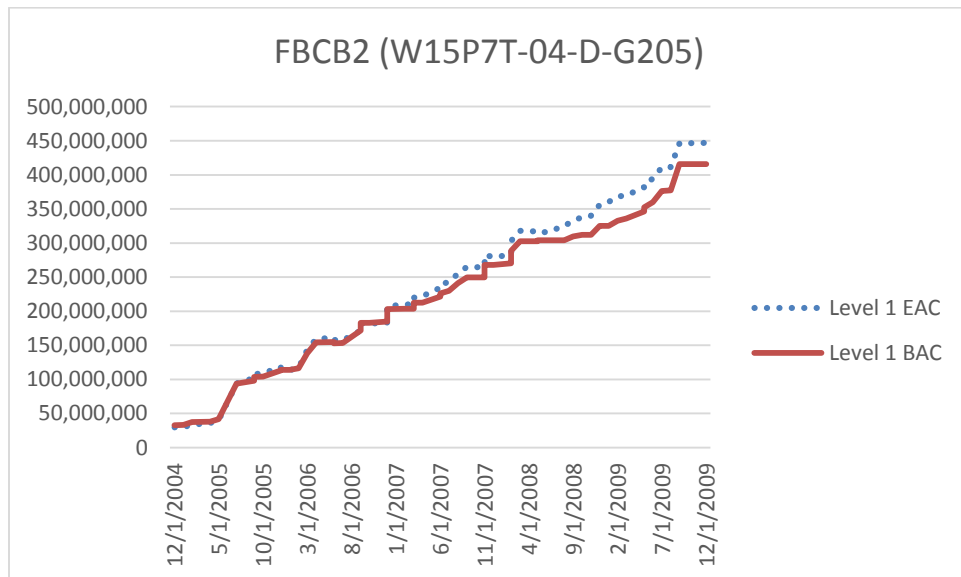


Figure 15 - FBCB2

Excluding one of the Navy's VTUAV contracts, Figure 16 displays both the EAC and BAC. An early change in scope and/or additional requirements explains the reason for the cost growth in this contract.

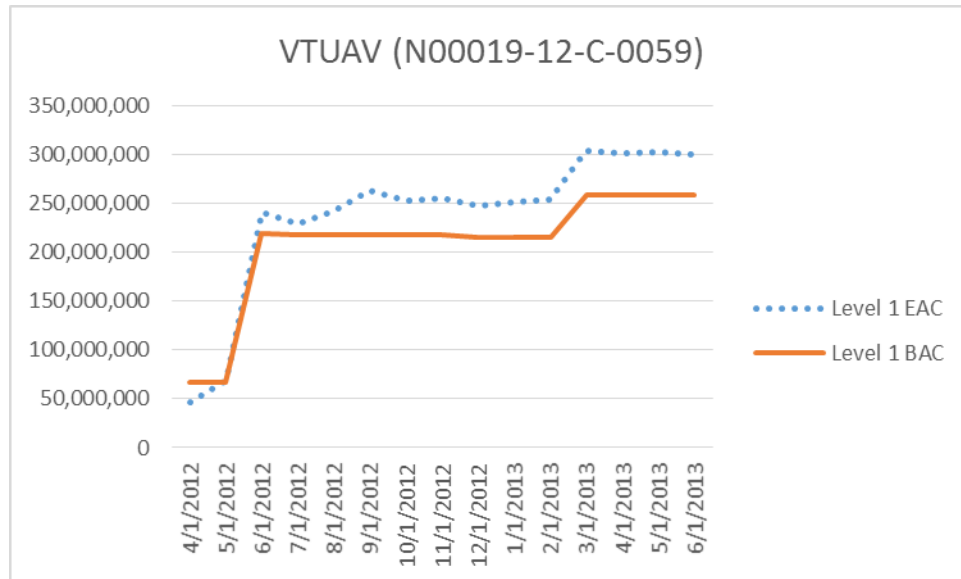


Figure 16 - VTUAV (N00019-12-C-0059)

The next two contracts excluded came from the V-22 OSPREY program. The first V-22 contract appears to have had cost overruns since the contract began.

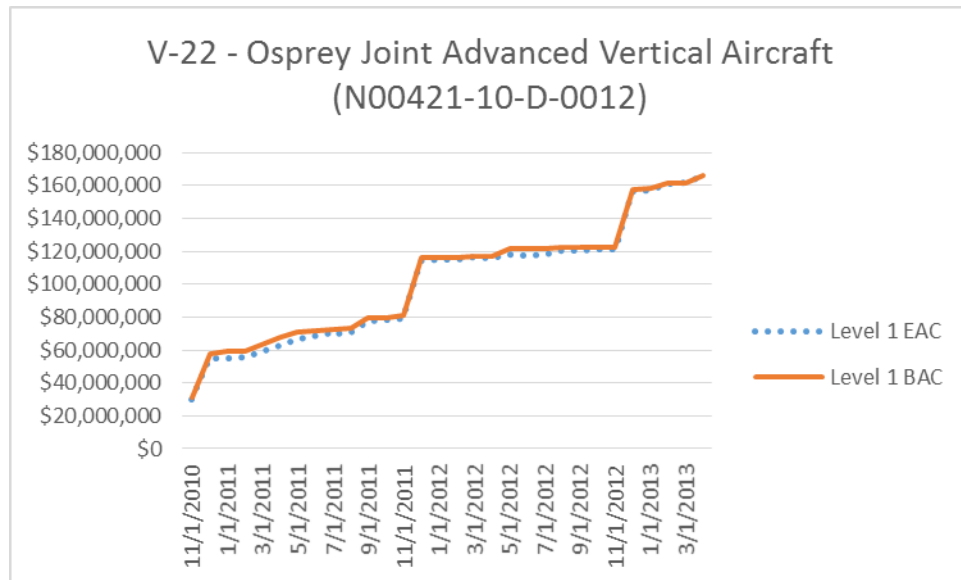


Figure 17 - V-22 - Osprey Joint Advanced Vertical Aircraft (N00421-10-D-0012)

The second V-22 contract shows a large growth in EAC due to the EVM data inputted the first month. However, we did not remove the first month's data because we wanted to compare the EVM data.

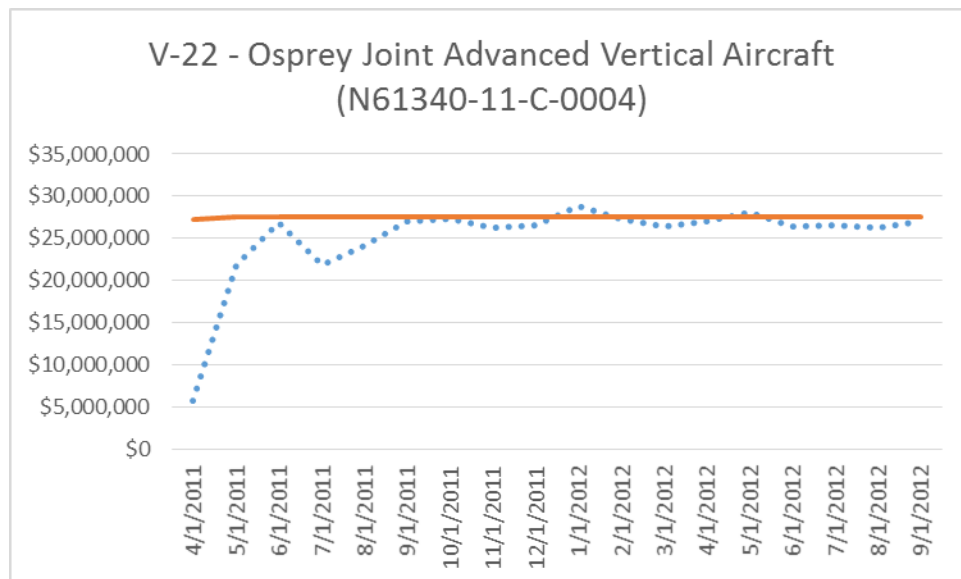


Figure 18 - V-22 - Osprey Joint Advanced Vertical Aircraft (N61340-11-C-0004)

The final contract excluded was the ISPAN contract. This contract, similar to the FBCB2 contract, has had a constant cost growth since the beginning of the contract.

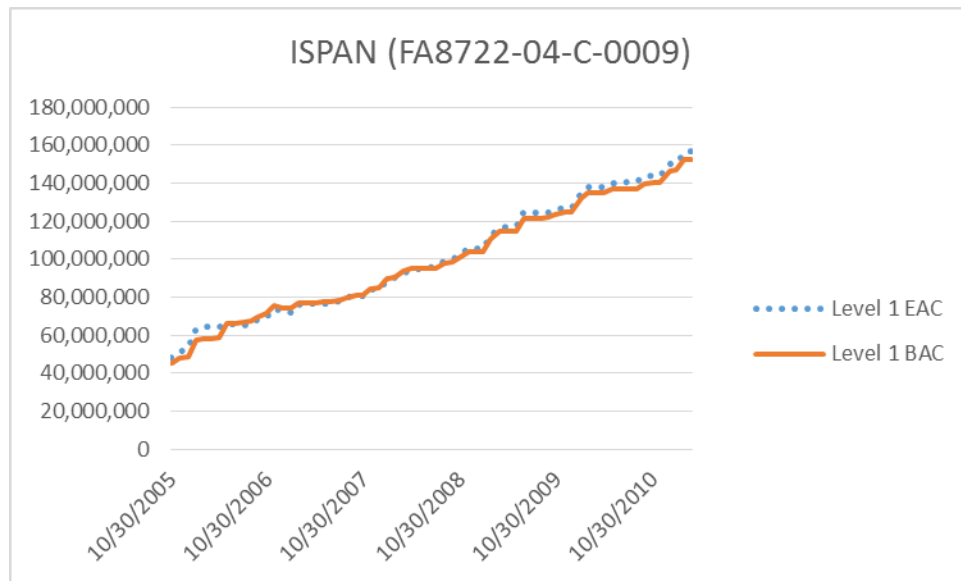


Figure 19 - ISPAN (FA8722-04-C-0009)

Multiple Regression Results using EAC

For each definition, we created a twenty multiple regression models, one for every 5% complete, starting at 5% and ending at 100%. Figure 20 displays the regression equation for growth definitions #1 and #2. Figure 21 displays the regression equation for growth definitions #3 and #4. Figure 22, illustrates how many contracts had cost data in each percent complete bin.

$E(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2$	
<u>Definition #1</u>	<u>Definition #2</u>
<i>Y = Level 1 EAC Change</i>	<i>Y = Level 1 LRE Change</i>
<i>X₁ = Level 3 Explanatory Variable</i>	<i>X₁ = Level 3 Explanatory Variable</i>
<i>X₂ = Level 5 Explanatory Variable</i>	<i>X₂ = Level 5 Explanatory Variable</i>

Figure 20 - Regression Equation for Growth Definitions #1 and #2

$E(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \dots + \beta_{55} X_{55}$	
<u>Definition #3</u>	<u>Definition #4</u>
<i>Y = Level 1 EAC Change</i>	<i>Y = Level 1 LRE Change</i>
<i>X₁ = Level 3 Explanatory Variable</i>	<i>X₁ = Level 3 Explanatory Variable</i>
<i>X₂ = Level 5 Explanatory Variable</i>	<i>X₂ = Level 5 Explanatory Variable</i>
$\sum_{n=3}^{55} X_n = \text{Independent Variables listed in Appendix C}$	$\sum_{n=3}^{55} X_n = \text{Independent Variables listed in Appendix C}$

Figure 21 - Regression Equation for Growth Definitions #3 and #4

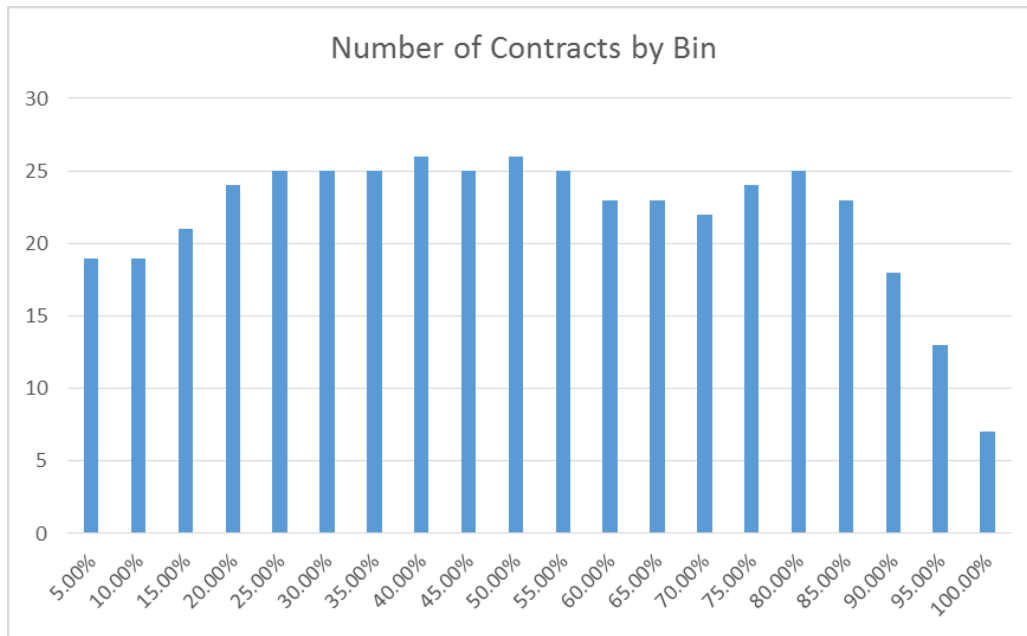


Figure 22 - Number of Contracts by Bin

For each of our explanatory variables, we ran twenty different multiple regression models, one model for each percent complete bin.

Since this is an early attempt into examining EVM data below level three, we were not sure which elements were significant. We used stepwise regression for all of our models in order to determine which independent variables to include. Each model had the potential to include our level three and five variable and fifty additional independent variables. Appendix C contains a list of the additional independent variables. However, upon running stepwise regression for definitions #1 and #2, the stepwise regression did not include our level three and five explanatory variables. After we learned of this, we only included the level three and five explanatory variables for our model using definition #1 and #2. In the following sections, we will reveal the results for each definition of cost growth.

Cost Growth Definition #1 Results

Table 16 details the results of the twenty multiple regression models ran using definition #1. The second column represents the number of iterations conducted for each percent complete. Multiple iterations were run if Cook's D detected at least one contract that was overly influential. An overly influential contract is defined as a contract with a Cook's D greater than 0.5. We excluded overly influential contracts and repeated the model. Once complete with the model, any overly influential contracts would then be included for the next percent complete model.

The sixth column represents the number of observations within model. An observation represents one contract. The final column displays the number of independent variables used in the model. For definition #1, this value will not be larger than two because all the models were limited to level three and five explanatory variables. At the 95% percent complete bin, we used only one independent variable because the cumulative change for level three and five had a high level of multicollinearity. Appendix D has the complete JMP® output and Cook's D for each of the models.

Table 16 – Cost Growth Definition #1 JMP® Results

Percent Complete	Number of Iterations	R ²	Adjusted R ²	Prob > F	Number of Observations	#IV
5%	1	0.008234	-0.10844	0.9321	20	2
10%	2	0.025397	-0.09643	0.814	19	2
15%	2	0.031998	-0.07556	0.7463	21	2
20%	3	0.094713	-0.00587	0.4084	21	2
25%	3	0.018638	-0.0795	0.8285	23	2
30%	3	0.032951	-0.05915	0.7034	24	2
35%	3	0.058247	-0.03144	0.5325	24	2
40%	2	0.159495	0.089453	0.1243	27	2
45%	1	0.097554	0.02235	0.2918	27	2
50%	4	0.00382	-0.08674	0.9588	25	2
55%	1	0.064663	-0.01328	0.4483	27	2
60%	2	0.023485	-0.06952	0.7792	24	2
65%	1	0.018631	-0.07058	0.8131	25	2
70%	2	0.034704	-0.06183	0.7024	23	2
75%	2	0.152431	0.07171	0.1761	24	2
80%	2	0.33358	-0.0507	0.6769	26	2
85%	1	0.179567	0.101431	0.1252	24	2
90%	1	0.034002	-0.08675	0.7582	19	2
95%	2	0.19763	0.117393	0.1476	12	1
100%	4	1	1		3	2

Table 17 lists all the contracts removed while examining definition #1. The fourth column displays the total number of times a contract exclusion occurred and the final column displays the excluded bins for each contract.

Table 17 – Cost Growth Definition #1 Influential Contracts

Service	Program	Contract Number	Total	Excluded Bins			
Navy	AGM-88E AARGM - AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) Program	N00019-03-C-0353	1	100%			
Navy	CEC – Cooperative Engagement Capability	N00024-05-C-5100	1	100%			
Army	Chem Demil - CMA	DACA87-89-C-0076	1	95%			
Navy	DDG 1000 - ZUMWALT CLASS Destroyer	N00024-05-C-5346	1	75%			
Navy	DDG 51- ARLEIGH BURKE CLASS Guided Missile Destroyer	N00024-02-C-2304	2	70%	75%		
Army	EXCALIBUR - Family of Precision, 155mm Projectiles	DAAE30-98-C-1032	1	20%			
Army	FBCB2 - Force XXI Battle Command Brigade and Below Program	W15P7T-04-D-G205	20	ALL			
Navy	H-1 UPGRADES (4BW/4BN) - United States Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter	N00019-06-G-0001	20	ALL			
Navy	LCS - Littoral Combat Ship	N00024-03-C-2310	3	20%	25%	100%	
Navy	LCS - Littoral Combat Ship	N00024-11-C-2301	4	15%	20%	25%	30%
Navy	LPD 17 - SAN ANTONIO CLASS Amphibious Transport Dock Ship	N00024-04-C-2204	1	60%			
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-04-C-0130	2	20%	50%		
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N00421-10-D-0012	2	10%	35%		
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61340-11-C-0004	4	30%	35%	40%	50%
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-00-C-0277	3	80%	95%	100%	
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-12-C-0059	7	10% - 35%	50%		
Air Force	WGS – Wideband Global SATCOM Program	FA8808-06-C-0001	2	100%			

Due to the high p-value for the F test, definition #1 provided no useful models for our research.

Cost Growth Definition #3 Results

Method to Select Independent Variables

For definition #3, we ran a stepwise regression for each model to determine which variables were significant at each percent complete bin. The only exception was at 70% complete. Stepwise regression was not able to create a model at 70%. Therefore, we manually created the model by using our level three explanatory variable and the square of our level three explanatory variable. Figure 23 illustrates the number of variables each model used, as well as the number of variables found significant in each percentage complete bin.

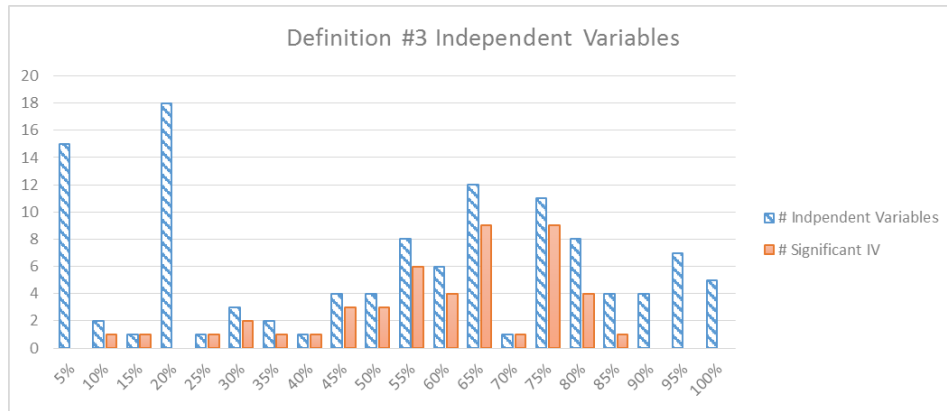


Figure 23 – Cost Growth Definition #3 Independent Variables by Percent Complete

Table 18 displays the results of the twenty multiple regression models ran using definition #3. The first seven columns are structured the same as the first seven columns of Table 16. The three additional columns contain the number of significant variables found in each model and if the model contained either of our level three or level five explanatory variable. Appendix F has the complete JMP[®] output for each of the models.

Table 18 – Cost Growth Definition #3 JMP® Results

Percent Complete	Number of Interations	R ²	Adjusted R ²	Prob > F	Number of Observations	#IV	# Significant IV	Include Level 3 variable (Y/N)	Include Level 5 variable (Y/N)
5%	4	0.500839	0.084872	0.3498	34	15	0	N	N
10%	3	0.225539	0.178602	0.0147	36	2	1	N	N
15%	3	0.167795	0.144018	0.0118	37	1	1	N	N
20%	6	0.747205	0.397181	0.0841	32	18	0	N	N
25%	3	0.178451	0.15563	0.0082	38	1	1	N	N
30%	7	0.515625	0.463728	0.0001	32	3	2	N	N
35%	3	0.308683	0.248569	0.0143	26	2	1	Y	N
40%	3	0.178451	0.15563	0.0082	38	1	1	N	N
45%	9	0.993052	0.988421	0.0001	11	4	3	Y	N
50%	10	0.991076	0.982151	0.0002	9	4	3	Y	N
55%	7	0.996923	0.993406	0.0001	16	8	6	Y	N
60%	6	0.906008	0.843347	0.0004	16	6	4	N	Y
65%	2	0.993305	0.984379	0.0001	22	12	9	Y	N
70%	**	0.752003	0.725898	0.0001	22	2	1	Y	N
75%	3	0.994692	0.988853	0.0001	22	11	9	Y	N
80%	3	0.968438	0.950402	0.0001	23	8	4	Y	N
85%	2	0.257657	0.147681	0.0802	32	4	1	N	N
90%	2	0.046627	-0.08049	0.8303	35	4	0	N	N
95%	2	0.145953	-0.0602	0.6654	37	7	0	N	N
100%	1	0.034283	-0.11661	0.948	38	5	0	N	N

Table 19 lists all the contracts removed while examining definition #3. The fourth column displays the total number of times a contract exclusion occurred and the final column displays the excluded bins for each contract.

Table 19 – Cost Growth Definition #3 Influential Contracts

Service	Program	Contract Number	Total	Excluded Bins			
Navy	AAG - Advanced Arresting Gear Program	N68335-03-C-0205	4	45%	50%	60%	65%
Navy	AMDR - Air & Missile Defense Radar	N00024-10-C-5359	1	70%			
Air Force	B-2 MOP - Massive Ordnance Penetrator	F33657-99-D-0028	5	45% - 60%	70%		
Army	Chem Demil - CMA	DACA87-89-C-0076	2	50%	70%		
Army	Chem Demil - CMA	DAAA09-97-C-0025	3	55%	70%	85%	
Navy	DDG 1000 - ZUMWALT CLASS Destroyer	N00024-05-C-5346	3	45%	55%	70%	
Navy	DDG 51- ARLEIGH BURKE CLASS Guided Missile Destroyer	N00024-02-C-2304	2	50%	70%		
Navy	EA-18G - Airborne Electronic Attack variant of the F/A-18 aircraft	N00019-04-C-0005	2	45%	70%		
Army	EXCALIBUR - Family of Precision, 155mm Projectiles	DAAE30-98-C-1032	2	50%	55%		
Army	EXCALIBUR - Family of Precision, 155mm Projectiles	W15QKN-08-C-0530	2	45%	70%		
Army	FBCB2 - Force XXI Battle Command Brigade and Below Program	W15P7T-04-D-G205	20	All			
Navy	H-1 UPGRADES (4BW/4BN) - United States Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter	N00019-06-G-0001	20	All			
Army	IAMD - Integrated Air & Missile Defense	W31P4Q-08-C-0418	2	50%	70%		
Air Force	ISPAN - Integrated Strategic Planning and Analysis Network - Block 1	FA8722-04-C-0009	3	30%	50%	70%	
Army	JAGM - Joint Air-to-Ground Missile	W31P4Q-08-C-A123	1	70%			
Navy	JPALS - Joint Precision Approach and Landing System	N00019-08-C-0034	1	55%			
Navy	JSOW (BASELINE/UNITARY) - Joint Stand-Off Weapon Baseline Variant and Unitary Warhead Variant	N00019-05-G-0008	2	45%	50%		
Army	JTRS GMR - Joint Tactical Radio System Ground Mobile Radio	DAA807-02-C-C403	10	5% - 20%	50% - 60%	70%	85% - 90%
Navy	LCS - Littoral Combat Ship	N00024-03-C-2310	12	20%	30%	45% - 60%	70% - 95%
Navy	LPD 17 - SAN ANTONIO CLASS Amphibious Transport Dock Ship	N00024-04-C-2204	3	55%	65%	70%	
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-04-C-0130	3	45%	70%	85%	
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-08-C-0005	5	45% - 50%	70% - 75%	85%	
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-09-C-0059	2	10%	65%		
Navy	MH-60S - Multi-Mission Combat Support Helicopter	N00019-03-G-0003	4	30%	55%	70%	80%
Air Force	MPS - Mission Planning System	FA8720-04-D-0005	2	55%	70%		
Navy	MQ-4C Triton (Formerly BAMS)	N00019-08-C-0023	2	45%	50%		
Navy	P-8A - Poseidon Program	N00019-04-C-3146	1	70%			
Navy	SM-6 - Standard Missile-6	N00024-09-C-5305	2	45%	50%		
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N00421-10-D-0012	9	20%	30%	45% - 60%	70% - 80%
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61340-11-C-0004	7	5%	20%	30%	45% - 60%
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61339-08-D-0004	5	5%	20%	55%	70% - 80%
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-00-C-0277	6	45%	50%	60%	70% - 80%
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-12-C-0059	7	5%	20%	30%	45% - 60%
Air Force	WGS - Wideband Global SATCOM Program	FA8808-06-C-0001	5	50%	60% - 70%	90%	

Using definition #3, fourteen of our twenty models had an F-test less than our alpha. In addition, nine of the twenty models contained either our level three or five explanatory variable. Out of the nine models that contained either our level three or five explanatory variable, the level three variable was used in eight different models: 35%, 45%, 50%, 55%, 65%, 70%, 75% and 80%, while our level five explanatory variable was used once at 60%.

Evaluating the LRE

In the following sections, we examine the results using the LRE.

Distribution of Response Variable

While conducting our analysis, we detected two extreme outlier contracts based on level one LRE growth. Contract N00024-09-C-5305 and N00019-06-G-0001 grew 13,374% and 4,346% respectively. Figure 24 displays the distribution of the percent change in level one's LRE.

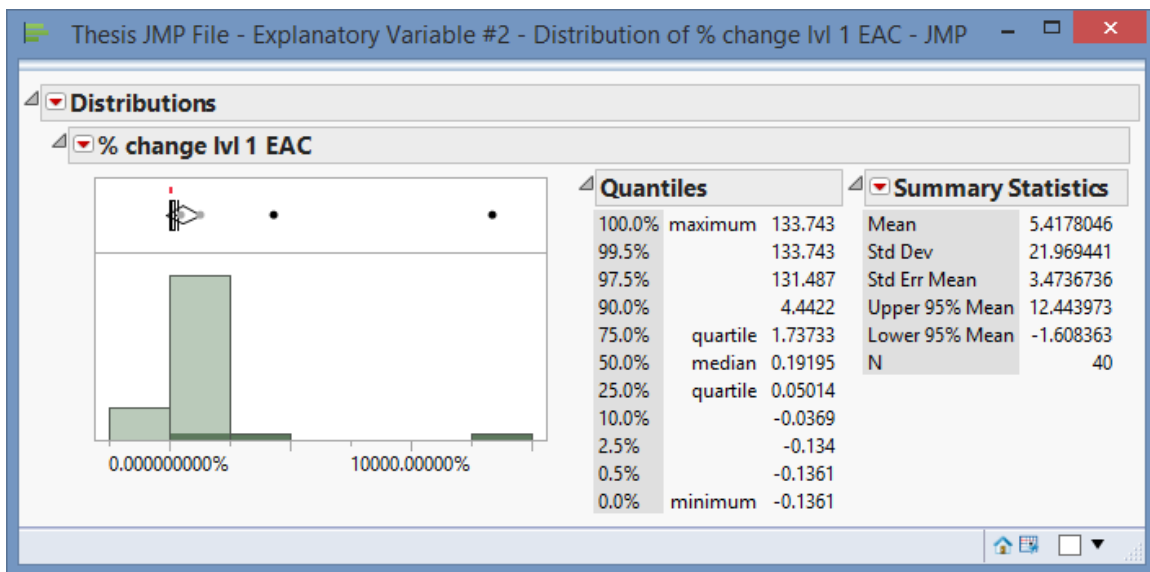


Figure 24 - Distribution of Percent Change of Level 1 LRE

After removing the two extreme outliers, three additional contracts became outliers.

Figure 25 displays the distribution after we removed the two extreme outliers. As Figure 25 indicates, there are now three additional outliers.

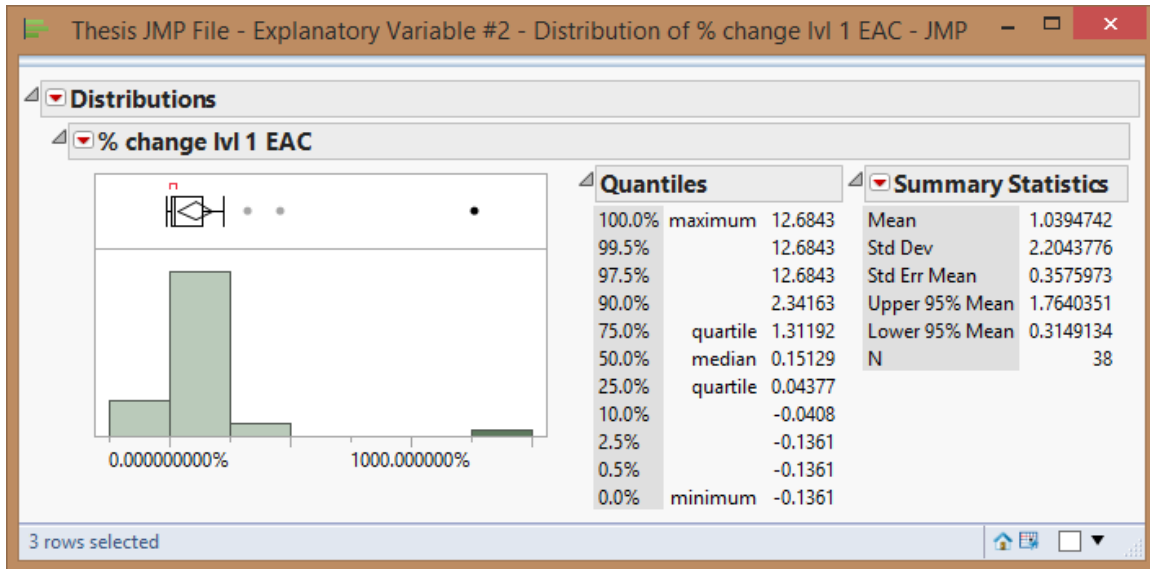


Figure 25 - Distribution of Percent Change of Level 1 LRE (Excluding two extreme outliers)

Figure 26 displays the distribution of the percent change of level one LRE after removing all outliers.

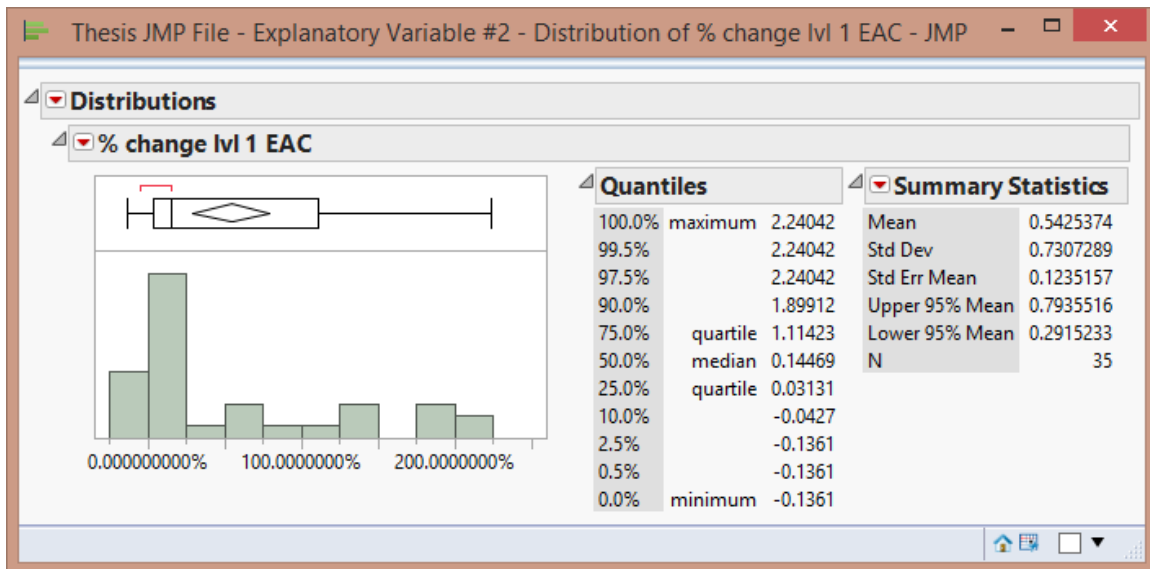


Figure 26 - Distribution of Percent Change of Level 1 LRE (Excluding three additional outliers)

By excluding these five contracts, it lowered our mean LRE growth from 542% to 54% and lowered the standard deviation from 2197% to 73%. We identified five outliers, however, in our models, we initially only excluded the two extreme outliers. Table 20 details the five outlier contracts and the percent change in level one EAC.

Table 20 - LRE Contract Outliers

% change lvl 1 EAC	Service	Project Name	Prime Contract Number
13374.35%	Navy	SM-6 – Standard Missile-6	N00024-09-C-5305
4346.86%	Navy	H-1 UPGRADES (4BW/4BN) - United States Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter	N00019-06-G-0001
1268.43%	Army	FBCB2 - Force XXI Battle Command Brigade and Below Program	W15P7T-04-D-G205
457.44%	Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N00421-10-D-0012
325.25%	Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-12-C-0059

The first two contracts in Table 20 are the two extreme outliers, while the next three were the subsequent outliers. Next, we briefly explain and compare each outlier with the outliers using the EAC.

The most extreme outlier using the LRE was the Navy’s Standard Missile – 6 (N00024-09-C-5305). This contract did not register as an outlier using the EAC. Its level one EAC percent change was 116.04%. Lack of EVM data is the cause of the discrepancy. The contractor reported an LRE of \$2,079,916 in July 2010; however, they did not report any EVM data until September 2010 for \$120,489,469. The difference in the beginning value can explain the drastic difference between the percent growth of the LRE and EAC.

The next extreme outlier was the Navy's H-1 Upgrade (N00019-06-G-0001). This contract grew 11,606.53% using the EAC. Figure 27 displays the level one LRE growth compared to the level one BAC growth. The key differences between the LRE and EAC for this contract are the starting and ending value. The beginning EAC and LRE are \$702,478 and \$1,375,089, respectively. The ending values are \$82,235,822 and \$61,148,373, respectively. In addition, throughout the contract, the EAC was consistently higher.

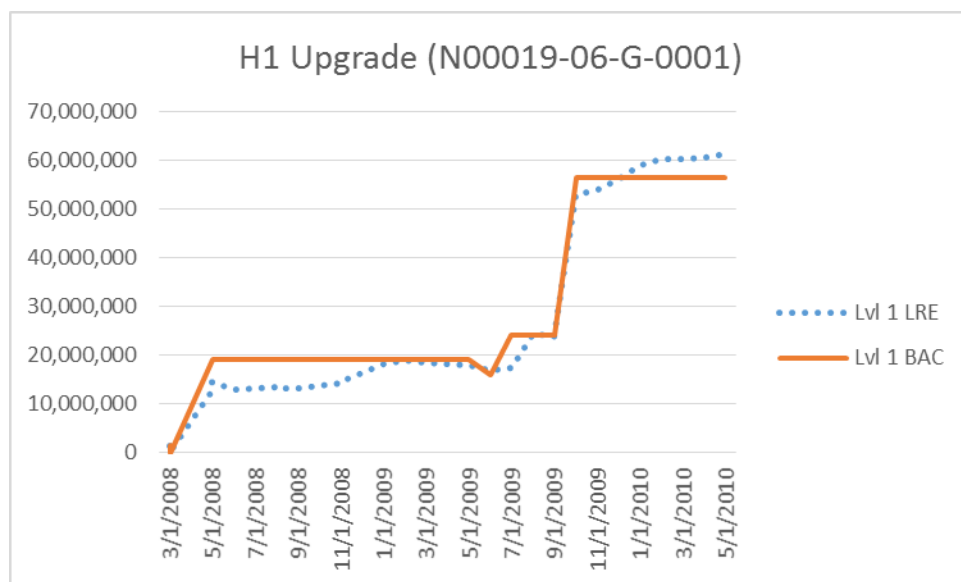


Figure 27 - H1 Upgrade LRE growth

The next outlier contract was the Army's FBCB2 (W15P7T-04-D-G205). The difference in growth between the LRE and EAC is 1405.37% and 1268.43%. Using either the LRE or EAC, the contract had a constant growth since the contract began.

The Navy's V-22 (N00421-10-D-0012) was the next outlier. There was virtually no difference with the percent change of the LRE and the EAC. The EAC grew 451.70% and the LRE grew 457.44%.

The last outlier was the Navy's VTUAV (N00019-12-C-0059). This contract also was an outlier using the percent change in EAC. Its EAC growth was 549.06% compared to 325.25% using the percent change of the LRE. Figure 28 displays the level one LRE and BAC for this contract. As Figure 28 displays, there was a change in scope early within the contract's life.

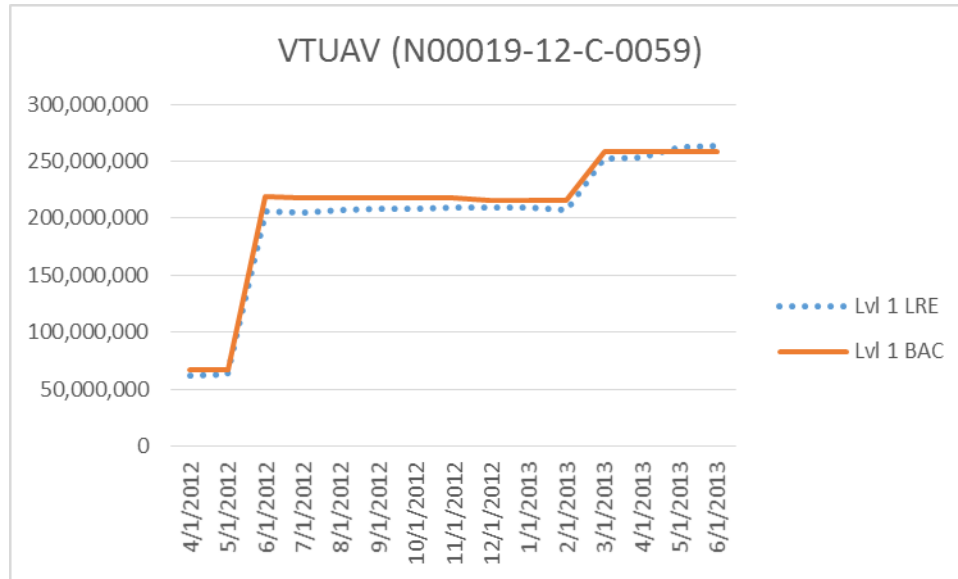


Figure 28 - VTUAV LRE Growth

Multiple Regression Results using LRE

As mentioned earlier in this chapter, we used only the level three and five explanatory variables for definition #2 and we used stepwise regression to determine which variables to add for definition #4.

Cost Growth Definition #2 Results

Table 21 details the results of the twenty multiple regression models ran applying definition #2. Similar to definition #1, we only included the level three and five variables in each model. Appendix E has the complete JMP[®] output for each of the models.

Table 21 – Cost Growth Definition #2 JMP® Results

Percent Complete	Number of Interations	R ²	Adjusted R ²	Prob > F	Number of Observations	#IV
5%	2	0.016459	-0.10648	0.8757	19	2
10%	7	0.271891	0.211215	0.0558	14	1
15%	4	0.072469	0.01449	0.28	18	1
20%	1	0.030431	-0.05388	0.7009	26	2
25%	1	0.005493	-0.03594	0.719	26	1
30%	7	0.105754	0.053151	0.1743	19	1
35%	4	0.029098	-0.01945	0.4479	22	1
40%	3	0.015432	-0.07407	0.8428	25	2
45%	1	0.014753	-0.02466	0.5462	27	1
50%	2	0.049447	0.008119	0.2854	25	1
55%	1	0.043954	-0.03572	0.5831	27	2
60%	1	0.011253	-0.08291	0.888	24	2
65%	1	0.009038	-0.03405	0.6512	25	1
70%	1	0.003963	-0.0909	0.9592	24	2
75%	1	0.080927	0.040967	0.1681	25	1
80%	4	0.002549	-0.04279	0.8148	24	1
85%	1	0.001908	-0.04149	0.8357	25	1
90%	3	0.256683	0.142327	0.1424	16	2
95%	1	0.001877	-0.0813	0.8831	14	1
100%	5	Excluded all contracts			0	0

Table 22 lists all the contracts removed while examining definition #2. The fourth column displays the total number of times a contract exclusion occurred and the final column displays the excluded bins for each contract. Due to the high p-value for the F test, definition #2 provided no useful models for our research.

Table 22 – Cost Growth Definition #2 Influential Contracts

Service	Program	Contract Number	Total	Excluded Bins				
Navy	AGM-88E AARGM - AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) Program	N00019-03-C-0353	1	100%				
Navy	AMDR - Air & Missile Defense Radar	N00024-10-C-5359	1	80%				
Navy	CEC – Cooperative Engagement Capability	N00024-05-C-5100	1	100%				
Army	Chem Demil - CMA	DACA87-89-C-0076	1	30%				
Army	EXCALIBUR - Family of Precision, 155mm Projectiles	W15QKN-08-C-0530	1	30%				
Army	FBCB2 - Force XXI Battle Command Brigade and Below Program	W15P7T-04-D-G205	7	10% - 15%	30% - 35%	50%	80%	90%
Navy	H-1 UPGRADES (4BW/4BN) - United States Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter	N00019-06-G-0001	20	ALL				
Army	JAGM – Joint Air-to-Ground Missile	W31P4Q-08-C-A123	2	15%	90%			
Navy	JPALS - Joint Precision Approach and Landing System	N00019-08-C-0034	2	10%	30%			
Navy	JSOW (BASELINE/UNITARY) - Joint Stand-Off Weapon Baseline Variant and Unitary Warhead Variant	N00019-05-G-0008	2	30%	35%			
Navy	LCS - Littoral Combat Ship	N00024-03-C-2310	1	100%				
Navy	LCS - Littoral Combat Ship	N00024-11-C-2301	2	15%	40%			
Navy	LPD 17 - SAN ANTONIO CLASS Amphibious Transport Dock Ship	N00024-04-C-2204	20	ALL				
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-04-C-0130	1	50%				
Navy	SM-6 – Standard Missile-6	N00024-09-C-5305	20	ALL				
Navy	SM-6 – Standard Missile-6	N00024-04-C-5344	1	100%				
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N00421-10-D-0012	5	10%	30% - 35%	40%	80%	
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61339-08-D-0004	1	100%				
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-00-C-0277	1	100%				
Air Force	WGS – Wideband Global SATCOM Program	FA8808-06-C-0001	1	100%				
Army	WIN-T Inc. 3 - Warfighter Information Network Tactical Increment 3	DAAB07-02-C-F404	1	90%				

Cost Growth Definition #4 Results

Method to Select Independent Variables

For definition #4, we ran a stepwise regression for each model to determine which variables were significant at each percent complete bin. The only exception was at 90% complete. Stepwise regression was not able to create a model at 90%. Therefore, we manually created the model by using our level three explanatory variable and the square of our level three explanatory variable. Table 23 illustrates the results of the twenty multiple regression models ran applying definition #4. Appendix H has the complete JMP® output for each of the models.

Table 23 – Cost Growth Definition #4 JMP® Results

Percent Complete	Number of Iterations	R ²	Adjusted R ²	Prob > F	Number of Observations	#IV	# Significant IV	Include Level 3 variable (Y/N)	Include Level 5 variable (Y/N)
5%	1	0.147679	0.096023	0.0716	36	2	0	N	N
10%	1	0.18978	0.165954	0.0079	36	1	1	N	N
15%	1	0.251717	0.206366	0.0084	36	2	1	N	N
20%	5	0.644684	0.348587	0.1014	23	10	0	N	N
25%	3	0.55403	0.451114	0.001	33	6	1	N	N
30%	1	0.071065	0.014766	0.2963	36	2	0	N	N
35%	2	0.949797	0.698785	0.1026	25	20	0	N	N
40%	6	0.991617	0.984166	0.0001	18	8	6	N	Y
45%	2	0.60629	0.570499	0.0001	25	2	2	Y	N
50%	7	0.955606	0.947535	0.0001	14	2	2	N	Y
55%	4	0.999476	0.998951	0.0001	15	7	6	Y	N
60%	1	0.992805	0.983211	0.0001	22	12	9	Y	N
65%	3	0.880398	0.861998	0.0001	16	2	1	Y	N
70%	9	0.038553	-0.03012	0.4661	16	1	0	N	N
75%	2	0.994196	0.987102	0.0001	21	11	7	Y	N
80%	1	0.924452	0.893344	0.0001	25	7	4	Y	N
85%	4	0.901075	0.89448	0.0001	17	1	1	Y	N
90%	**	0.919212	0.907671	0.0001	17	2	1	Y	N
95%	2	0.857263	0.643157	0.1002	11	6	0	N	N
100%	2	0.099865	0.006748	0.3761	33	3	0	N	N

Table 24 lists all the contracts removed while examining definition #4. The fourth column displays the total number of times a contract exclusion occurred and the final column displays the excluded bins for each contract.

Table 24 – Cost Growth Definition #4 Influential Contracts

Service	Program	Contract Number	Total	Excluded Bins			
Navy	AAG - Advanced Arresting Gear Program	N68335-03-C-0205	5	50%	65%	70%	85% - 90%
Navy	AGM-88E AARGM - AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) Program	N00019-03-C-0353	2	85%	100%		
Navy	AMDR - Air & Missile Defense Radar	N00024-10-C-5359	1	90%			
Air Force	B-2 MOP - Massive Ordnance Penetrator	F33657-99-D-0028	3	50%	65%	85%	
Navy	CEC – Cooperative Engagement Capability	N00024-05-C-5100	2	90%	95%		
Army	Chem Demil - CMA	DACA87-89-C-0076	5	20%	40%	65% - 70%	90%
Army	Chem Demil - CMA	DAAA09-97-C-0025	4	50%	55%	70%	90%
Navy	DDG 1000 - ZUMWALT CLASS Destroyer	N00024-05-C-5346	4	40%	70%	75%	90%
Navy	DDG 51- ARLEIGH BURKE CLASS Guided Missile Destroyer	N00024-02-C-2304	1	70%			
Navy	EA-18G - Airborne Electronic Attack variant of the F/A-18 aircraft	N00019-04-C-0005	4	20%	50%	55%	90%
Army	EXCALIBUR - Family of Precision, 155mm Projectiles	DAAE30-98-C-1032	2	70%	90%		
Army	EXCALIBUR - Family of Precision, 155mm Projectiles	W15QKN-08-C-0530	1	70%			
Army	FBCB2 - Force XXI Battle Command Brigade and Below Program	W15P7T-04-D-G205	20	ALL			
Navy	H-1 UPGRADES (4BW/4BN) - United States Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter	N00019-06-G-0001	20	ALL			
Army	IAMD - Integrated Air & Missile Defense	W31P4Q-08-C-0418	2	20%	70%		
Air Force	ISPAN - Integrated Strategic Planning and Analysis Network - Block 1	FA8722-04-C-0009	6	20%	50% - 70%	85%	
Army	JAGM – Joint Air-to-Ground Missile	W31P4Q-08-C-A123	2	65%	90%		
Navy	JPALS - Joint Precision Approach and Landing System	N00019-08-C-0034	1	40%			
Navy	JPALS - Joint Precision Approach and Landing System	N00019-08-C-0034	2	20%	25%		
Navy	JSOW (BASELINE/UNITARY) - Joint Stand-Off Weapon Baseline Variant and Unitary Warhead Variant	N00019-05-G-0008	4	20%	55%	70%	90%
Army	JTRS GMR – Joint Tactical Radio System Ground Mobile Radio	DAA807-02-C-C403	4	50%	55%	70%	90%
Navy	LCS - Littoral Combat Ship	N00024-03-C-2310	8	20% 40%	50% - 55%	70%	85% - 95%
Navy	LCS - Littoral Combat Ship	N00024-11-C-2301	2	40%	70%		
Navy	LPD 17 - SAN ANTONIO CLASS Amphibious Transport Dock Ship	N00024-04-C-2204	20	ALL			
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-04-C-0130	3	40%	50%	70%	
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-08-C-0005	4	20%	40%	50%	70%
Navy	MH-60R - Multi-Mission Helicopter Upgrade	N00019-09-C-0059	2	20%	55%		
Navy	MH-60S - Multi-Mission Combat Support Helicopter	N00019-03-G-0003	1	50%			
Navy	MQ-4C Triton (Formerly BAMS)	N00019-08-C-0023	1	70%			
Navy	SM-6 – Standard Missile-6	N00024-09-C-5305	20	ALL			
Navy	SM-6 – Standard Missile-6	N00024-04-C-5344	1	90%			
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N00421-10-D-0012	16	20%	25%	35% - 100%	
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61340-11-C-0004	2	20%	55%		
Navy	V-22 - OSPREY Joint Advanced Vertical Lift Aircraft	N61339-08-D-0004	2	65%	75%		
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-00-C-0277	2	70%	90%		
Navy	VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)	N00019-12-C-0059	5	20%	25%	50% - 55%	70%
Air Force	WGS – Wideband Global SATCOM Program	FA8808-06-C-0001	8	20%	50% - 70%	85% - 90%	100%
Army	WIN-T Inc. 3 - Warfighter Information Network Tactical Increment 3	DAA807-02-C-F404	1	90%			

Using definition #4, thirteen of our twenty models had an F-test less than our alpha. In addition, ten of the twenty models contained either our level three or level five explanatory variable. Out of the ten models that contained either our level three or level five explanatory variable, the level three variable was used in eight different models: 45%, 55%, 60%, 65%, 75%, 80%, 85% and 90%, while our level five explanatory variable was used twice at 40% and 50%.

Comparing Level Three EVM Data with Level Five EVM Data

While conducting our analysis of lower level EVM data, we noticed a high correlation between the contractor's level three and five data. In order to verify this, we conducted a Fit Y by X comparing the level three variable to the level five variable. We conducted this test using both the contractor's EAC and the recalculated EAC. Figure 29 displays the results comparing the levels three and five using the LRE. The slope of the fit line for this bin was .9983099, indicating almost perfect correlation between the level three and level five variables.

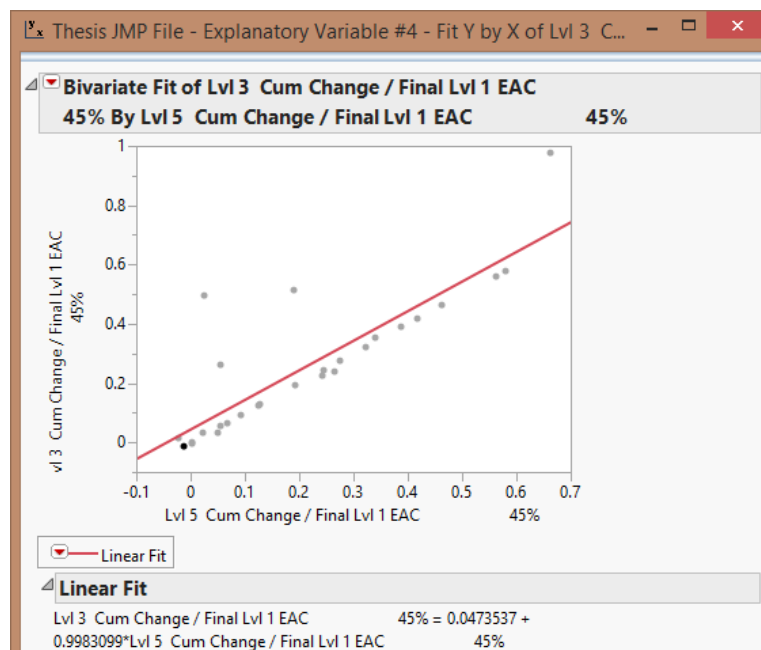


Figure 29 - Comparing Level three and Level five LRE at 45% complete

Figure 30 displays the results comparing the levels three and five using the EAC. The slope of the fit line for this bin was .6470539. In contrast to the LRE's slope at 45%, very little correlation is apparent between the level three and level five variable.

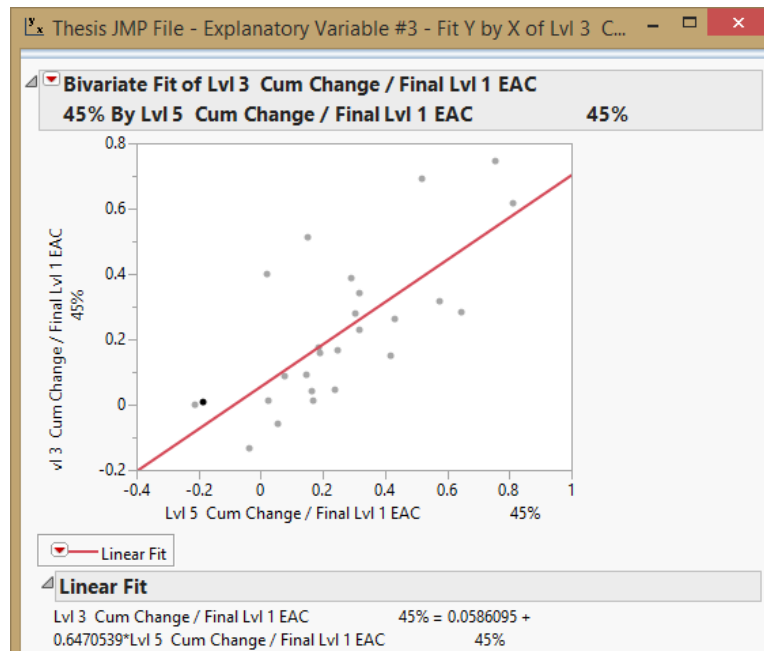


Figure 30 - Comparing Level three and Level five EAC at 45% complete

Appendix I contains the complete results using the contractor's EAC and Appendix J contains the results using the recalculated EAC.

We looked at the slope of the fit line to evaluate the relationship between level three and five. Level three and five variables were identical the closer the slope of the line was to one. Table 25 compares the slope by percent complete for the contractor's EAC and the recalculated EAC. Figure 31 and Figure 32 visually display the slopes. As either the table or figures indicate, the contractor's level three and five variables were almost identical. In addition, Figure 32, illustrates a large increase of the slope in the

100% complete bin. Contract FA8808-06-C-0001 caused this sudden increase at 100%.

If this contract is excluded the slope would decrease to 0.3033184.

Table 25 - Comparing Slopes between Level Three and Five with Regards to the response of EAC and LRE

	LRE	EAC
5%	1.028042	0.020022
10%	0.971286	0.365103
15%	1.111285	0.662947
20%	1.113232	0.085429
25%	1.088484	0.555081
30%	1.071052	0.482034
35%	1.126062	1.052112
40%	1.117613	0.651423
45%	0.99831	0.647054
50%	0.976149	0.610131
55%	0.901014	0.565287
60%	0.886609	0.57314
65%	0.922645	0.561618
70%	0.937097	0.567915
75%	0.969642	0.622586
80%	0.960558	0.528834
85%	0.931023	0.577463
90%	0.933059	0.501941
95%	0.891078	0.554161
100%	1.205188	1.549535
Mean	1.006971	0.586691
Std Dev	0.093836	0.308297

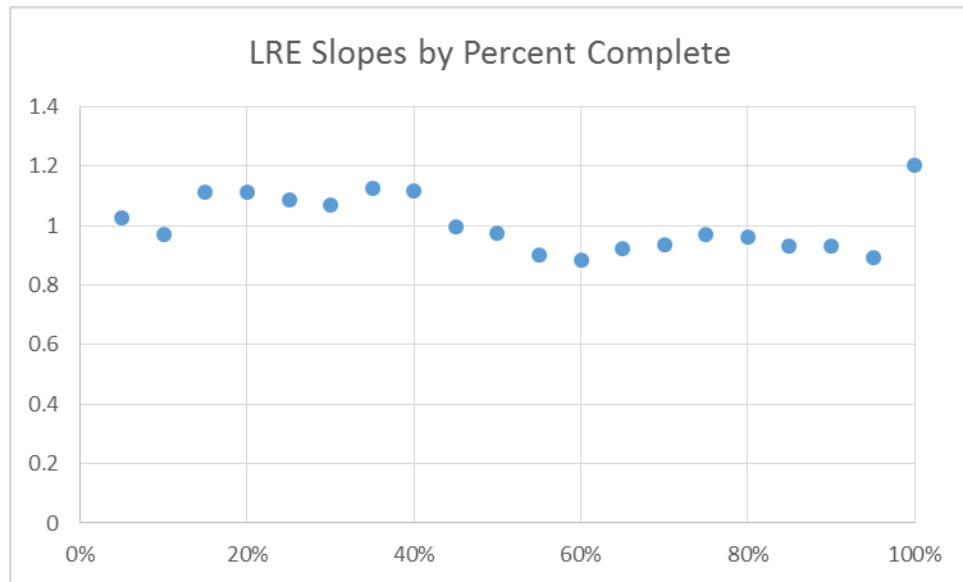


Figure 31 - LRE Slope by Percent Complete

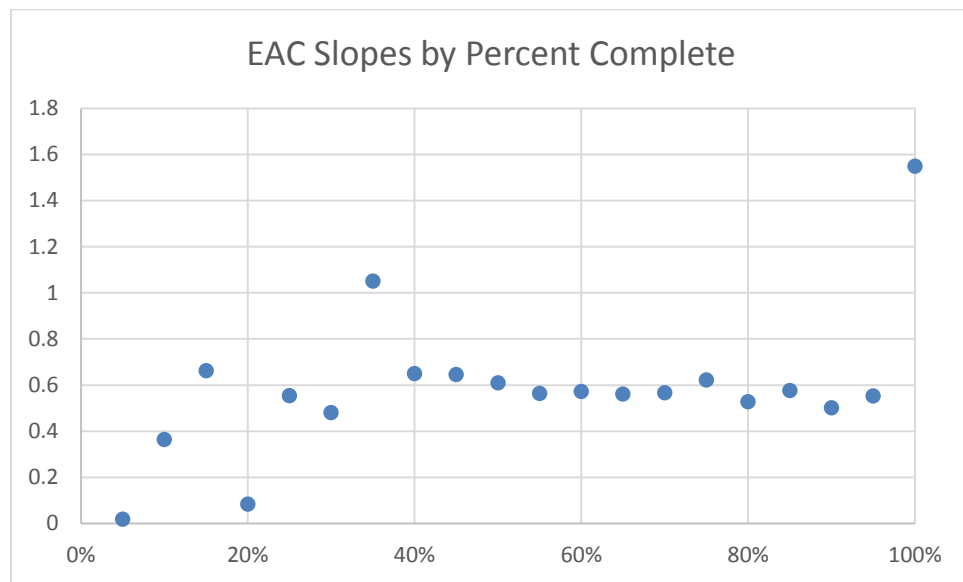


Figure 32 - EAC Slopes by Percent Complete

Summary of Findings

After reviewing the results, we observed definitions #1 and #2 did not provide any useful models. These results indicate that definitions #1 and #2 are not significant to predict overall contract growth. This also indicates the method used to calculate cost growth by definitions #1 and #2 is not effective to predict overall cost growth.

Definitions #3 and #4 had much better results. Definition #3 had fourteen significant models. In addition, it revealed that level three EVM data was predictive of cost growth beginning at 35% with an adjusted R^2 of .248569 and at 45%, the R^2 increased to .988421. Furthermore, none of the models contained both level three and five variables. This may indicate a high level of multicollinearity between the two variables. Stepwise regression selected the level five variable once.

Definition #4 also had promising results. Twelve of the thirteen models were significant and nine of them contained either our level three or level five variable. This model revealed that level five EVM data became predictive of overall cost growth at 40% complete with an adjusted R^2 of .984166. Similar to definition #3 models, none of the models contained both level three and level five variables.

In conclusion, we demonstrated two different techniques to calculate cost growth at lower WBS elements. The first technique, used in definitions #1 and #2, involved only the change in individual lower level elements. This technique proved ineffective to predict overall cost growth and did not provide any significant results. The second technique, used in definitions #3 and #4, evaluated the cumulative change of lower level cost data. This technique did provide significant results as indicated earlier.

Our results also reveal level three and level five EVM data becomes predictive at the 40% complete point of a contract. The results indicate that both the recalculated EAC and the LRE provided by the contractor are predictive at approximately the same point. However, the contractor's level three and level five LRE's were almost identical. Table 25 and Figure 31 identify this correlation.

Our results also indicate level three EVM data is a better predictor of contract cost growth than level five EVM data. As indicated previously, stepwise regression chose level three sixteen times and level five only three times in the forty models between definitions #3 and #4.

Chapter 5: Conclusions

Introduction

In this chapter, we review the purpose of our research and determine if our analysis was able to answer our research questions. We also discuss some limitations and assumptions we had throughout our research. We also briefly review our results and findings from Chapter Four and discuss possible implications on the acquisition community. We conclude this chapter suggesting possible follow-on research ideas.

Review Purpose of research

The purpose of our research was to determine if it would be beneficial for the DoD to require contractors to provide level five EVM data instead of just level three. In this section, we evaluate how our research was able to answer our research purpose. We also look at our research and investigation questions to determine if our research was able to answer them

Our first research question was if level five data is more predictive than level three data. To answer this, we decided to calculate the EAC for each level three and five element. We anticipated from previous research that the EAC would be the best indicator for contract cost growth. We also determined, though limited, sufficient contracts on the DCARC website contained level five EVM data. We were also able to construct a statistical model using stepwise and multiple regression to establish a relationship between WBS level three and five EVM data and cost growth of the overall contract. The answer to our first research question is WBS level five EVM data is not more predictive than level three.

Our second research question became irrelevant due the finding of our first research question. Our second question examined the benefits of level five EVM data compared to the cost to obtain the information. However, we failed to discover what the additional cost would be to obtain this data because we discovered level five EVM data was less predictive.

Limitations in our Research

Our research was limited in two key ways. The first limitation dealt with accessibility to EVM data. Due to the requirements of our research, we were restricted to the EVM-CR database. The main reason for this limitation is the EVM-CR is the most current database of EVM data and the database also contained contracts with lower level EVM data.

Even though there are more than 400 contracts in the EVM-CR, most of them did not meet our requirements. Our screening criteria included, level five EVM data or lower, contract length greater than twelve months and complete EVM cost data. The database contained 98 different contracts with at least level five EVM data. However, many of those contracts were either missing complete EVM data or were not greater than twelve months in length. Our screening criteria limited us to only forty contracts.

Assumptions in our Research

We also made two key assumptions in our research. The first was that the level five EVM data was not biased. This is a concern because the current DoD regulations require contractors to provide level three EVM data unless a contract is determined high

risk or high cost. We assumed these forty contracts represented a random sample of the overall contract population, not just high risk or high cost contracts.

The second assumption necessitated the WBS structures contained in the contracts were CWBS, not PWBS. We made this assumption because WBS level three of a PWBS is equivalent to WBS level one of the CWBS. We assumed that each contract contained the CWBS in order to ensure we were comparing the same level of work across each of the contracts.

There needs to be better clarification of WBS. For example, MIL STD 881C, states a contractor has to report down to WBS level three. Does that mean a contract has to report down to level three for each contract (CWBS) or just that the contractor is required to report down to level three of the project (PWBS). The difference is two additional levels of data. Level three of the CWBS is equivalent to level five of the PWBS.

Briefly Review Results

We were able to establish a relationship between lower level WBS EVM data with the overall contract cost growth. However, our research did not prove WBS level five EVM elements are more predictive than WBS level three EVM elements. Our research proved level three EVM data is a better predictor for overall contract growth than level five EVM data. Based on the data that was available to us, it would not be beneficial for the DoD to require contractors to provide EVM data down to WBS level five.

Follow-on Research

Based on our research, level five is not a better indicator for cost growth than level three. This finding contradicts conventional logic. We created our methodology and statistical models without any bias on the outcome. However, conducting further research using a larger sample size to either confirm or disprove our findings is required.

Our research posed another question referencing the best measurement of an EAC. Should a contractor provide an EAC using EVM data? Two of our statistical models used the contractors EAC and two contained our recalculated EAC. Both the contractor's EAC and the recalculated EAC proved predictive at approximately the same percent complete.

However, when we compared the level three EAC value with the level five EAC values, the contractor's EAC showed very little difference. In contrast, the recalculated EAC for level three and five were completely different. A follow-on research question entails examining the requirements of a contractor to provide the composite EAC.

Appendix A - Acronyms

ACWP (Actual Cost of Work Performed) or **ACTUAL COST** - Cost actually incurred in accomplishing work performed

BAC (Budget At Completion) - Total budget for total contract thru any given level

BCWP (Budgeted Cost for Work Performed) or **EARNED VALUE** - Value of completed work in terms of the work's assigned budget

BCWS (Budgeted Cost for Work Scheduled) or **PLANNED VALUE** - Time-phased Budget Plan for work currently scheduled

CA (Control Account) - Lowest CWBS element assigned to a single focal point to plan & control

EAC (Estimate At Completion) - Estimate of total **Cost** for total contract thru any given level generated

LRE (Latest Revised Estimate) - Contractor's EAC

MR (Management Reserve) - Budget withheld by Contractor PM for unknowns / risk management

PMB (Performance Measurement Baseline) - Contract time-phased budget plan

TAB (Total Allocated Budget) - Sum of all budgets for work on contract = NCC, CBB, or OTB

Appendix B: Contracts Used in Analysis

AAG - Advanced Arresting Gear Program (N68335-03-C-0205)

Contractor: General Atomics Corporation **Contract Type:** CPFF

WBS Type: Electronic / Automated Software

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 6/27/2008 - 5/27/2011

AGM-88E AARGM - AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) Program (N00019-03-C-0353)

Contractor: Alliant Techsystems, Inc. (ATK) **Contract Type:** CPIF

WBS Type: Missile

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 3/31/2007 - 2/22/2009

AMDR - Air & Missile Defense Radar (N00024-10-C-5359)

Contractor: Northrop Grumman Corporation **Contract Type:** FPIF

WBS Type: Electronic / Automated Software

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 11/5/2010 - 9/29/2012

B-2 MOP - Massive Ordnance Penetrator (F33657-99-D-0028)

Contractor: Northrop Grumman Corporation **Contract Type:** CPFF

WBS Type: Aircraft

Service: Air Force **Phase:** RDT&E

Beginning and Ending Contract Dates: 9/25/2009 - 11/5/2010

CEC – Cooperative Engagement Capability (N00024-05-C-5100)

Contractor: General Dynamics Corporation **Contract Type:** CPAF

WBS Type: Electronic / Automated Software

Service: Navy **Phase:** Prod

Beginning and Ending Contract Dates: 3/30/2009 - 7/29/2011

Chem Demil - CMA (DACA87-89-C-0076)

Contractor: EG&G **Contract Type:** CPAF

WBS Type: Other

Service: Army **Phase:** PROD

Beginning and Ending Contract Dates: 1/31/2000 - 5/26/2013

Chem Demil - CMA (DAAA09-97-C-0025)

Contractor: Washington Demil Company **Contract Type:** FFP

WBS Type: Other

Service: Army **Phase:** PROD

Beginning and Ending Contract Dates: 10/1/2004 - 5/24/2013

DDG 1000 - ZUMWALT CLASS Destroyer (N00024-05-C-5346)

Contractor: Raytheon Company

Contract Type: CPAF

WBS Type: Ship

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 11/20/2005 - 3/31/2013

DDG 51- ARLEIGH BURKE CLASS Guided Missile Destroyer (N00024-02-C-2304)

Contractor: Northrop Grumman Corporation

Contract Type: FPIF

WBS Type: Ship

Service: Navy **Phase:** Prod

Beginning and Ending Contract Dates: 6/26/2005 - 5/30/2010

EA-18G - Airborne Electronic Attack variant of the F/A-18 aircraft (N00019-04-C-0005)

Contractor: The Boeing Company

Contract Type: CPAF

WBS Type: Aircraft

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 2/26/2004 - 2/26/2009

EXCALIBUR - Family of Precision, 155mm Projectiles (DAAE30-98-C-1032)

Contractor: Raytheon Company

Contract Type: CPIF

WBS Type: Ordnance

Service: Army **Phase:** PROD

Beginning and Ending Contract Dates: 10/22/2006 - 2/24/2008

EXCALIBUR - Family of Precision, 155mm Projectiles (W15QKN-08-C-0530)

Contractor: Raytheon Company

Contract Type: CPIF

WBS Type: Ordnance

Service: Army **Phase:** RDT&E

Beginning and Ending Contract Dates: 10/2/2011 - 8/26/2012

FBCB2 - Force XXI Battle Command Brigade and Below Program (W15P7T-04-D-G205)

Contractor: Northrop Grumman Corporation

Contract Type: CPAF

WBS Type: Electronic / Automated Software

Service: Army **Phase:** RDT&E

Beginning and Ending Contract Dates: 12/31/2004 - 12/31/2009

H-1 UPGRADES (4BW/4BN) - United States Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter (N00019-06-G-0001)

Contractor: Bell Helicopter Textron, Inc.

Contract Type: CPFF

WBS Type: Aircraft

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 3/1/2008 - 5/8/2010

IAMD - Integrated Air & Missile Defense (W31P4Q-08-C-0418)

Contractor: Northrop Grumman Corporation **Contract Type:** CPIF

WBS Type: Electronic / Automated Software

Service: Army **Phase:** RDT&E

Beginning and Ending Contract Dates: 9/3/2010 - 7/26/2013

ISPAN - Integrated Strategic Planning and Analysis Network - Block 1 (FA8722-04-C-0009)

Contractor: Lockheed Martin Corporation **Contract Type:** CPAF

WBS Type: Electronic / Automated Software

Service: Air Force **Phase:** RDT&E

Beginning and Ending Contract Dates: 10/30/2005 - 3/25/2011

JAGM – Joint Air-to-Ground Missile (W31P4Q-08-C-A123)

Contractor: Lockheed Martin Corporation **Contract Type:** FPIF

WBS Type: Missile

Service: Army **Phase:** RDT&E

Beginning and Ending Contract Dates: 11/30/2008 - 5/30/2010

JPALS - Joint Precision Approach and Landing System (N00019-08-C-0034)

Contractor: Rockwell Collins, Inc. **Contract Type:** Other

WBS Type: Electronic / Automated Software

Service: Navy **Phase:** Other

Beginning and Ending Contract Dates: 12/5/2008 - 7/2/2010

JPALS - Joint Precision Approach and Landing System (N00019-08-C-0034)

Contractor: Raytheon Company **Contract Type:** CPIF

WBS Type: Electronic / Automated Software

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 11/21/2008 - 12/31/2009

JSOW (BASELINE/UNITARY) - Joint Stand-Off Weapon Baseline Variant and Unitary Warhead Variant (N00019-05-G-0008)

Contractor: Raytheon Company **Contract Type:** CPFF

WBS Type: Missile

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 3/25/2007 - 4/1/2012

JTRS GMR – Joint Tactical Radio System Ground Mobile Radio (DAAB07-02-C-C403)

Contractor: The Boeing Company **Contract Type:** Other

WBS Type: Electronic / Automated Software

Service: Army **Phase:** Other

Beginning and Ending Contract Dates: 9/29/2005 - 9/30/2010

LCS - Littoral Combat Ship (N00024-03-C-2310)

Contractor: General Dynamics Corporation **Contract Type:** CPIF

WBS Type: Ship

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 11/27/2005 - 4/4/2010

LCS - Littoral Combat Ship (N00024-11-C-2301)

Contractor: Austal **Contract Type:** FPIF

WBS Type: Ship

Service: Navy **Phase:** Prod

Beginning and Ending Contract Dates: 7/27/2012 - 9/27/2013

LPD 17 - SAN ANTONIO CLASS Amphibious Transport Dock Ship (N00024-04-C-2204)

Contractor: Northrop Grumman Corporation **Contract Type:** CPIF

WBS Type: Ship

Service: Navy **Phase:** PROD

Beginning and Ending Contract Dates: 6/24/2007 - 12/20/2009

MH-60R - Multi-Mission Helicopter Upgrade (N00019-04-C-0130)

Contractor: Harris Corporation **Contract Type:** CPAF

WBS Type: Aircraft

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 1/26/2007 - 4/30/2010

MH-60R - Multi-Mission Helicopter Upgrade (N00019-08-C-0005)

Contractor: Telephonics Corporation **Contract Type:** CPIF

WBS Type: Aircraft

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 9/30/2008 - 4/30/2010

MH-60R - Multi-Mission Helicopter Upgrade (N00019-09-C-0059)

Contractor: L-3 Communications **Contract Type:** FPIF

WBS Type: Aircraft

Service: Navy **Phase:** Prod

Beginning and Ending Contract Dates: 8/21/2009 - 11/26/2010

MH-60S - Multi-Mission Combat Support Helicopter (N00019-03-G-0003)

Contractor: Sikorsky Aircraft Corporation **Contract Type:** CPIF

WBS Type: Aircraft

Service: Navy **Phase:** Unknown

Beginning and Ending Contract Dates: 1/31/2006 - 3/31/2009

MPS – Mission Planning System (FA8720-04-D-0005)

Contractor: The Boeing Company **Contract Type:** CPAF

WBS Type: Electronic / Automated Software

Service: Air Force **Phase:** RDT&E

Beginning and Ending Contract Dates: 3/18/2011 - 10/5/2012

MQ-4C Triton (Formerly BAMS) (N00019-08-C-0023)

Contractor: Northrop Grumman Corporation **Contract Type:** CPAF

WBS Type: UAV

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 10/31/2008 - 5/27/2011

P-8A - Poseidon Program (N00019-04-C-3146)

Contractor: Northrop Grumman Corporation **Contract Type:** CPIF

WBS Type: Aircraft

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 6/26/2009 - 1/28/2011

SM-6 – Standard Missile-6 (N00024-09-C-5305)

Contractor: Raytheon Company **Contract Type:** FPIF

WBS Type: Missile

Service: Navy **Phase:** Prod

Beginning and Ending Contract Dates: 7/25/2010 - 2/24/2013

SM-6 – Standard Missile-6 (N00024-04-C-5344)

Contractor: Raytheon Company **Contract Type:** CPAF

WBS Type: Missile

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 12/31/2008 - 8/28/2011

V-22 - OSPREY Joint Advanced Vertical Lift Aircraft (N00421-10-D-0012)

Contractor: Raytheon Company **Contract Type:** CPAF

WBS Type: Aircraft

Service: Navy **Phase:** Prod

Beginning and Ending Contract Dates: 11/19/2010 - 4/26/2013

V-22 - OSPREY Joint Advanced Vertical Lift Aircraft (N61340-11-C-0004)

Contractor: Bell-Boeing V-22 Program Office **Contract Type:** CPIF

WBS Type: Aircraft

Service: Navy **Phase:** Prod

Beginning and Ending Contract Dates: 5/31/2011 - 10/31/2012

V-22 - OSPREY Joint Advanced Vertical Lift Aircraft (N61339-08-D-0004)

Contractor: Bell-Boeing V-22 Program Office **Contract Type:** CPFF

WBS Type: Aircraft

Service: Navy **Phase:** Prod

Beginning and Ending Contract Dates: 11/30/2009 - 10/31/2010

VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)
(N00019-00-C-0277)

Contractor: Northrop Grumman Corporation **Contract Type:** CPIF

WBS Type: UAV

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 9/1/2006 - 12/31/2010

VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)
(N00019-12-C-0059)

Contractor: Northrop Grumman Corporation **Contract Type:** CPIF

WBS Type: UAV

Service: Navy **Phase:** RDT&E

Beginning and Ending Contract Dates: 4/27/2012 - 6/28/2013

WGS – Wideband Global SATCOM Program (FA8808-06-C-0001)

Contractor: The Boeing Company **Contract Type:** FFP

WBS Type: Space

Service: Air Force **Phase:** PROD

Beginning and Ending Contract Dates: 11/30/2006 - 12/20/2012

WIN-T Inc. 3 - Warfighter Information Network Tactical Increment 3 (DAAB07-02-C-F404)

Contractor: General Dynamics Corporation **Contract Type:** CPAF

WBS Type: Electronic / Automated Software

Service: Army **Phase:** RDT&E

Beginning and Ending Contract Dates: 1/27/2012 - 12/28/2012

Appendix C: List of Independent Variables used in Model

List of Variables used in Statistical Models

1. Total Number of level three elements in contract
2. Total Number of level three elements with EAC data in contract
3. Total Number of level five elements in contract
4. Total Number of level five elements with EAC data in contract

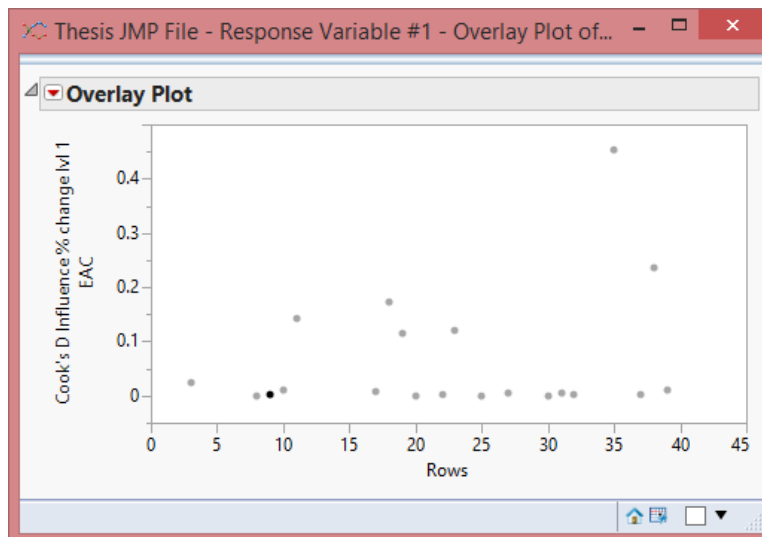
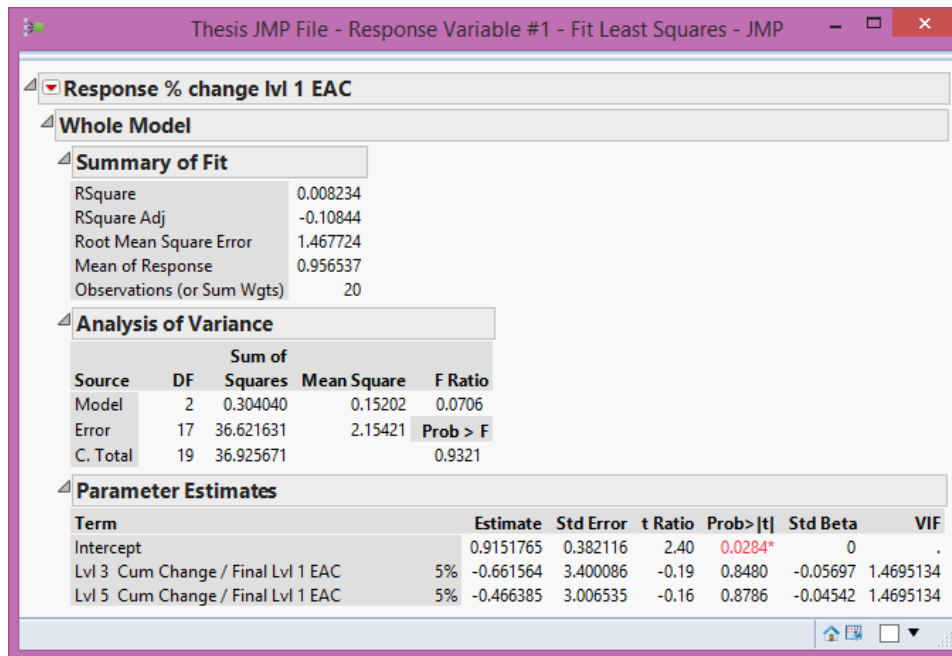
Dummy Variables used in Statistical Models

1. # Lvl 5 elements with EAC data ≤ 30
2. # Lvl 5 elements with EAC data > 30 and < 150
3. # Lvl 5 elements with EAC data ≥ 150
4. RDT&E
5. Production
6. Other Phase
7. Unknown Phase
8. Army
9. Air Force
10. Navy
11. Aircraft
12. Electronic/automated software
13. Missile
14. Ordnance
15. Ship
16. Space
17. UAV
18. Other Handbook
19. CPAF
20. CPFF
21. CPIF
22. FFIP
23. Alliant Techsystems, Inc. (ATK)
24. Austal
25. Bell-Boeing V-22 Program Office
26. Bell Helicopter Textron, Inc.
27. EG&G
28. General Atomics Corporation
29. General Dynamics Corporation
30. Harris Corporation

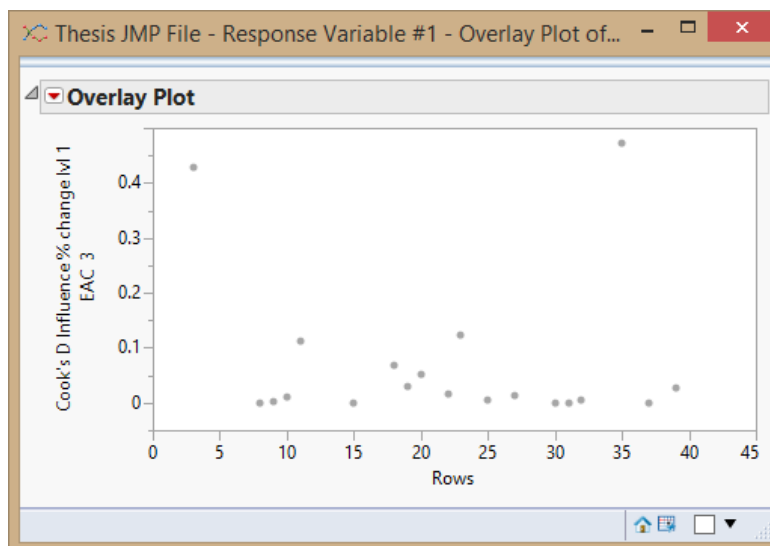
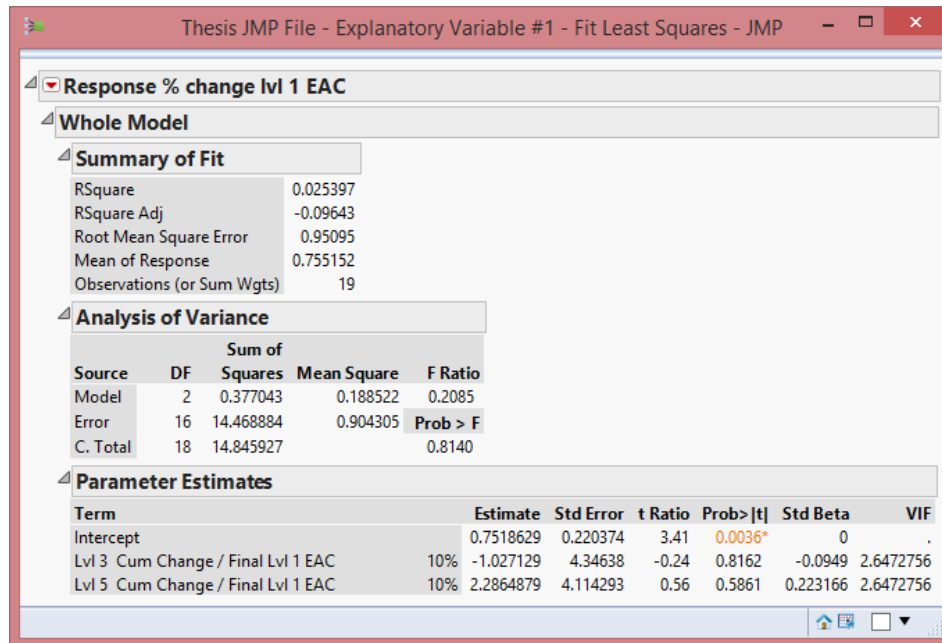
31. L-3 Communications
32. Lockheed Martin Corporation
33. Northrop Grumman Corporation
34. Raytheon Company
35. Rockwell Collins, Inc.
36. Sikorsky Aircraft Corporation
37. Telephonics Corporation
38. The Boeing Company
39. Washington Demil Company
40. Top 3 DoD Contractor
41. Top 5 DoD Contractor
42. Contract length 12-24 Months
43. Contract length 24-36 Months
44. Contract length more than 36 months
45. Percent of program contract covered < 25%
46. Percent of program contract covered 25% - 50%
47. Percent of program contract covered 50% - 75%
48. Percent of program contract covered more than 75%

Appendix D - JMP® Output Screens for Growth Definition #1

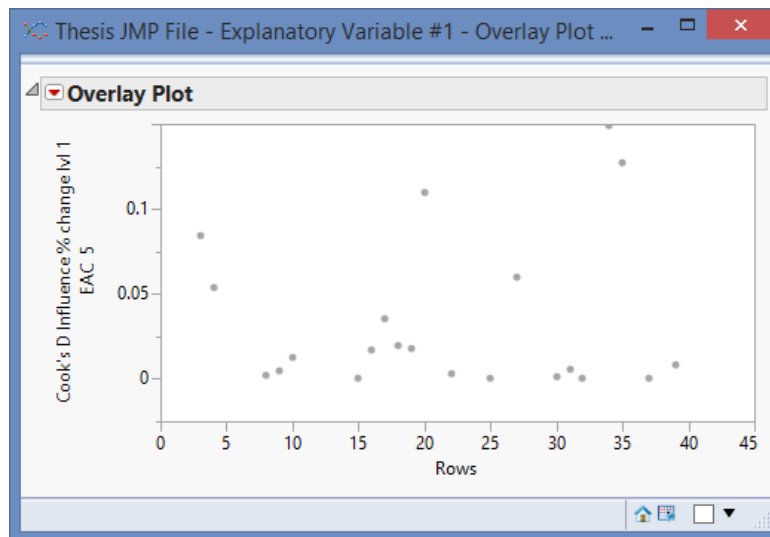
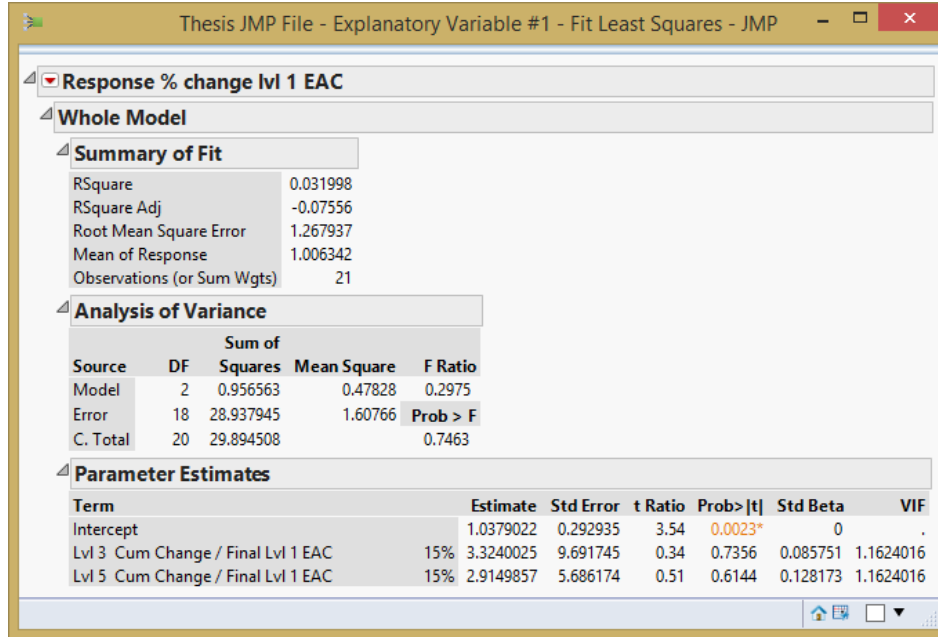
Growth Definition #1 Bin - 5%



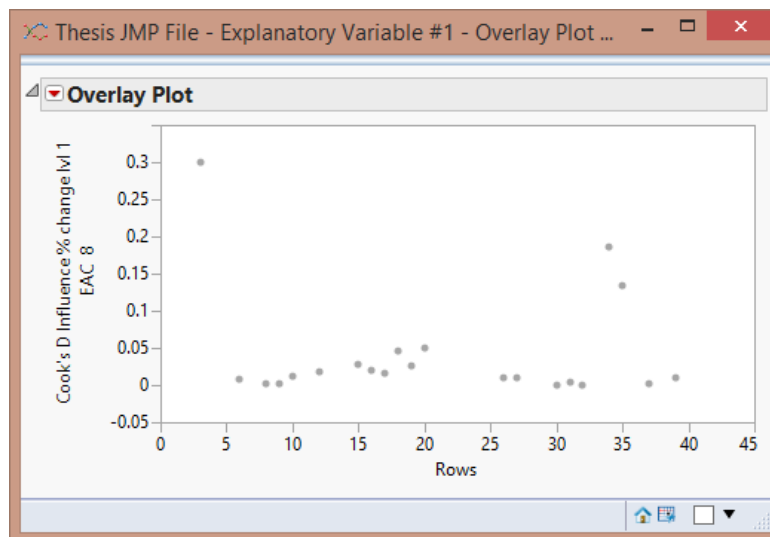
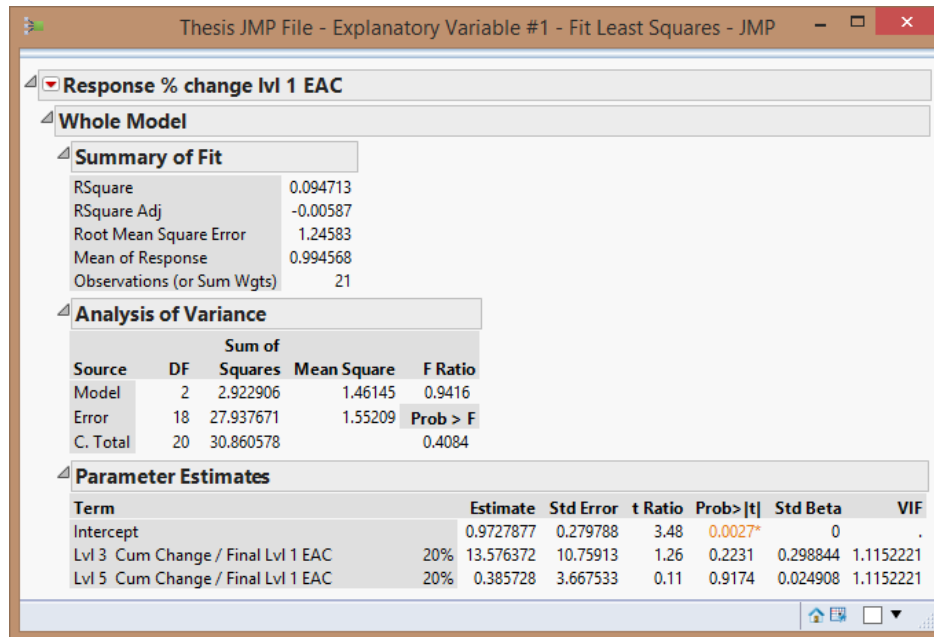
Growth Definition #1 Bin - 10%



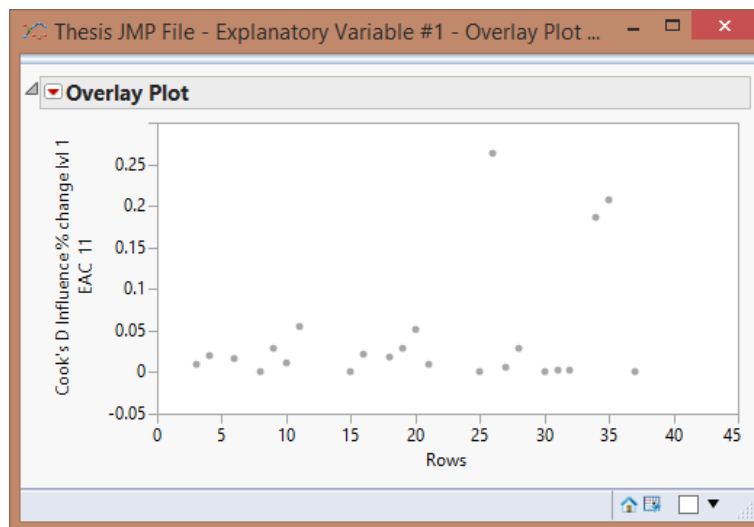
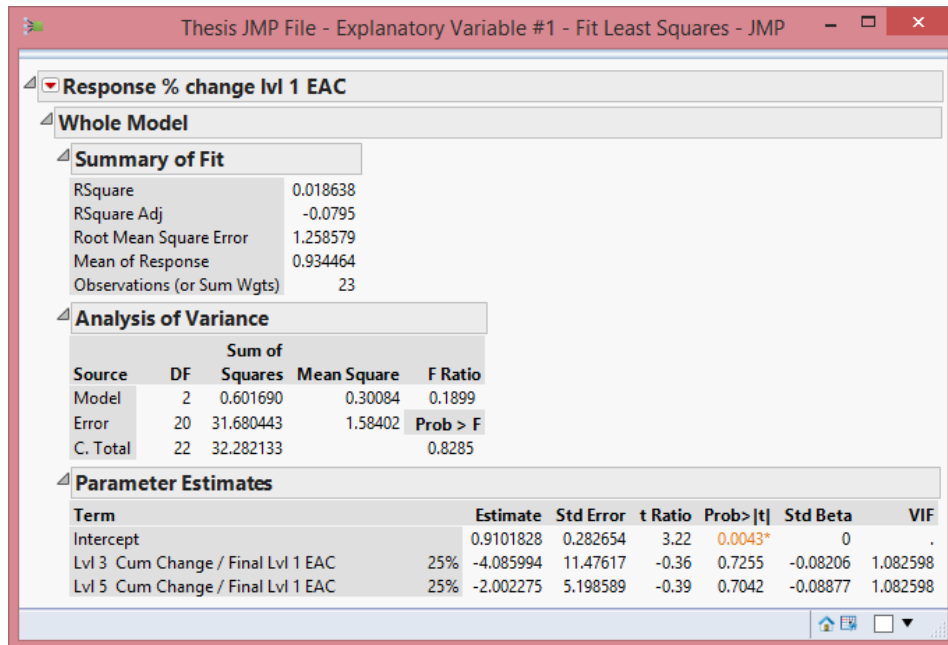
Growth Definition #1 Bin - 15%



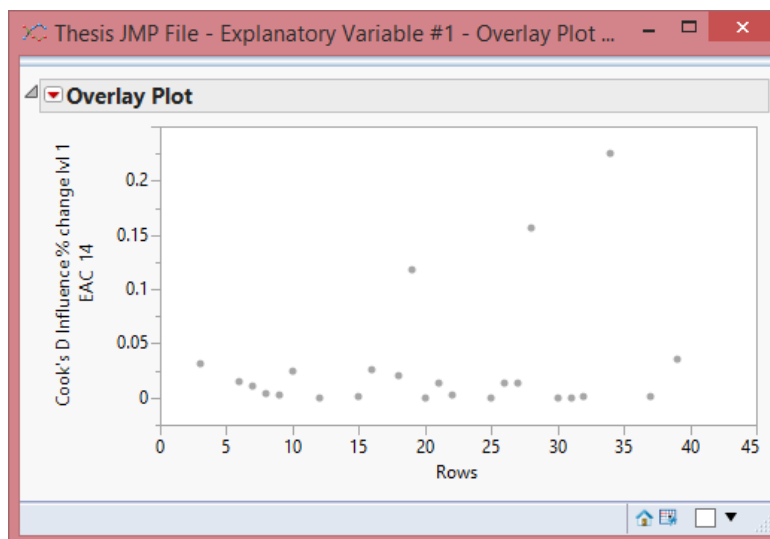
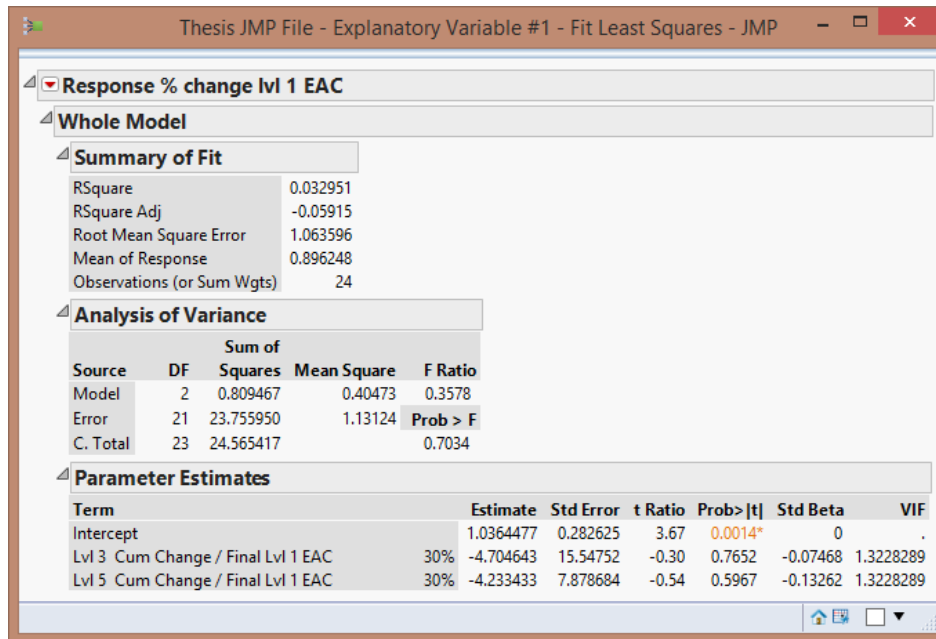
Growth Definition #1 Bin - 20%



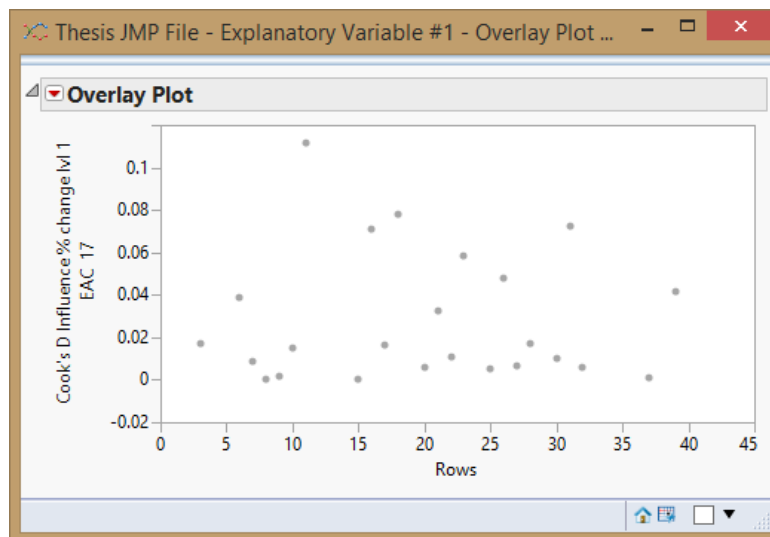
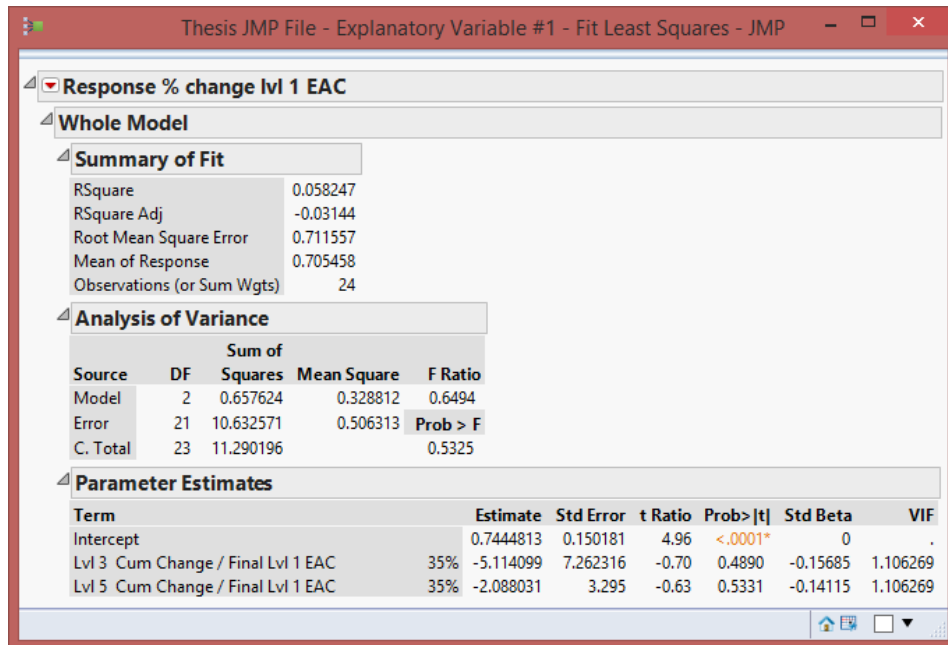
Growth Definition #1 Bin - 25%



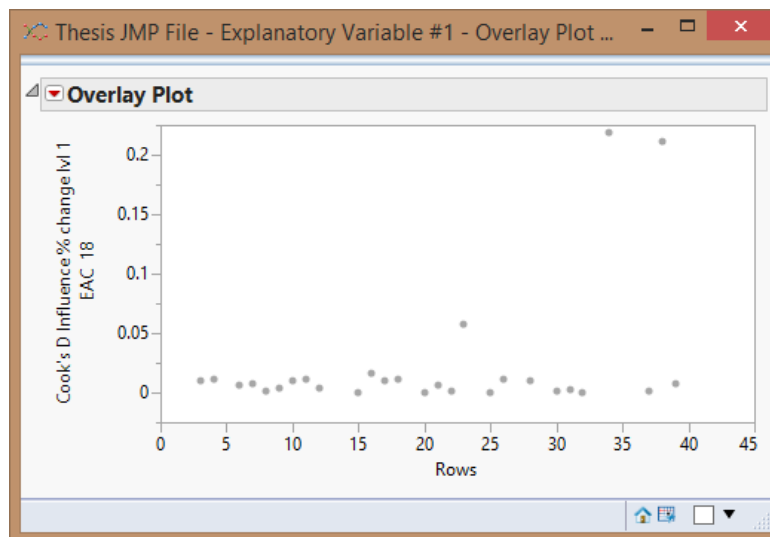
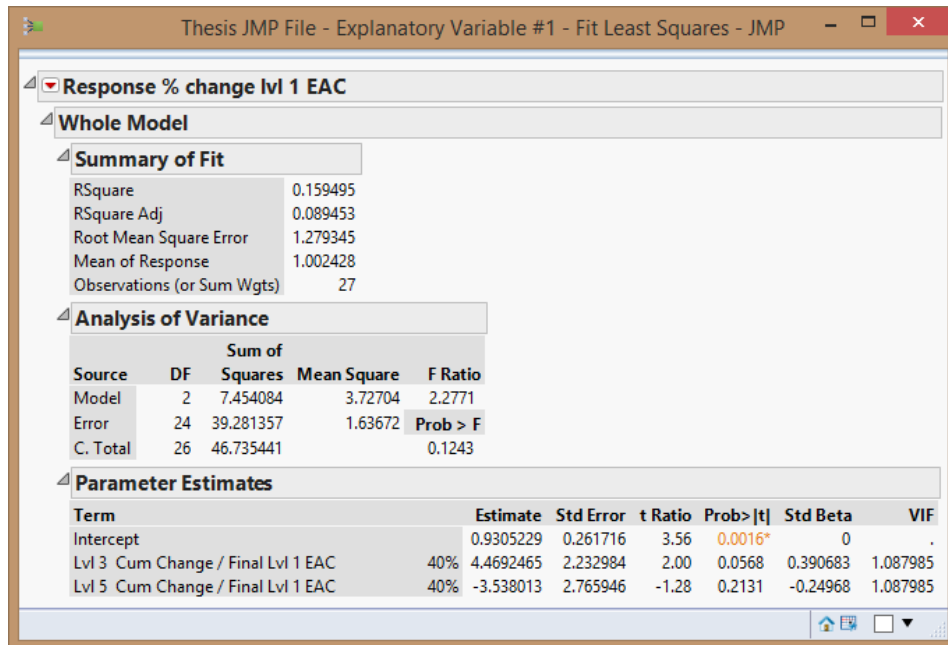
Growth Definition #1 Bin – 30%



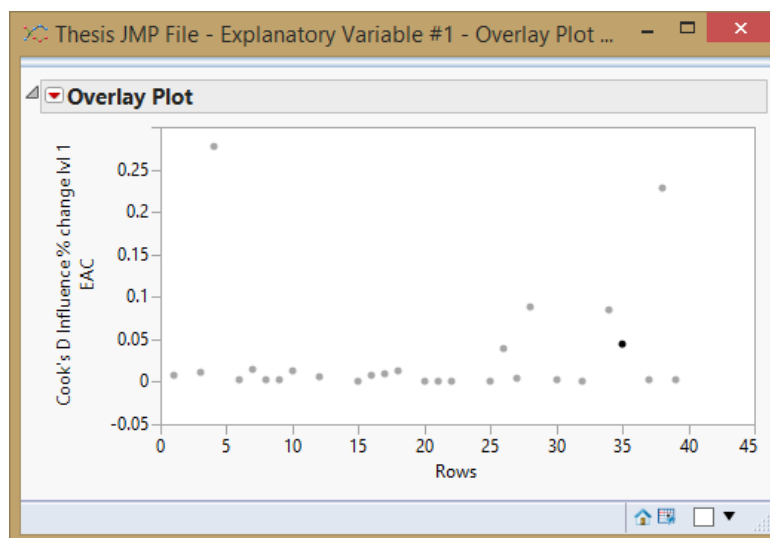
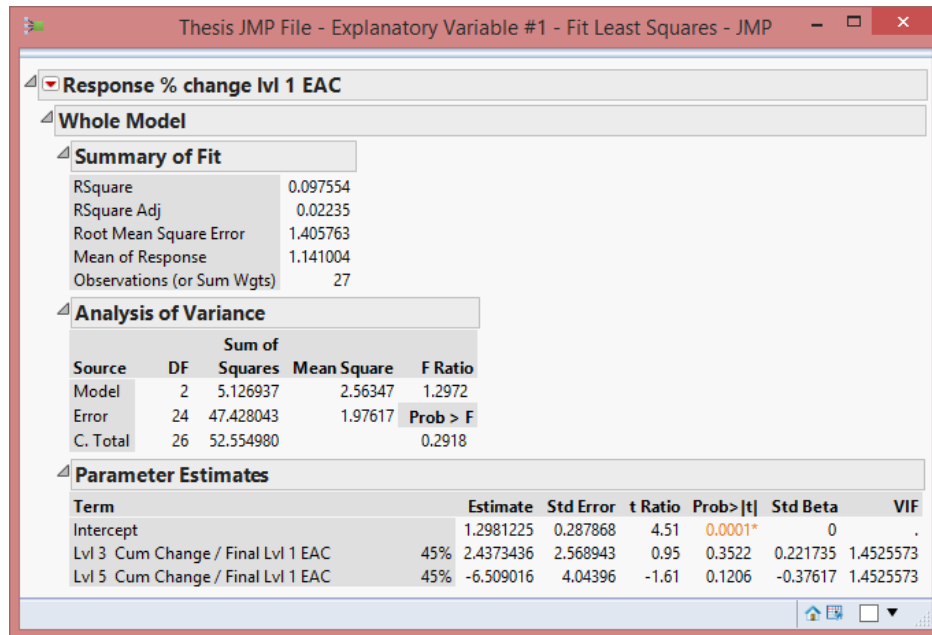
Growth Definition #1 Bin - 35%



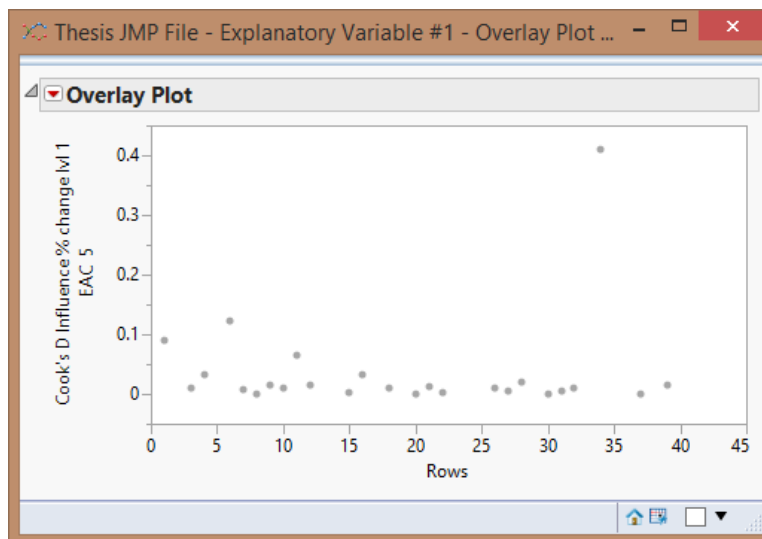
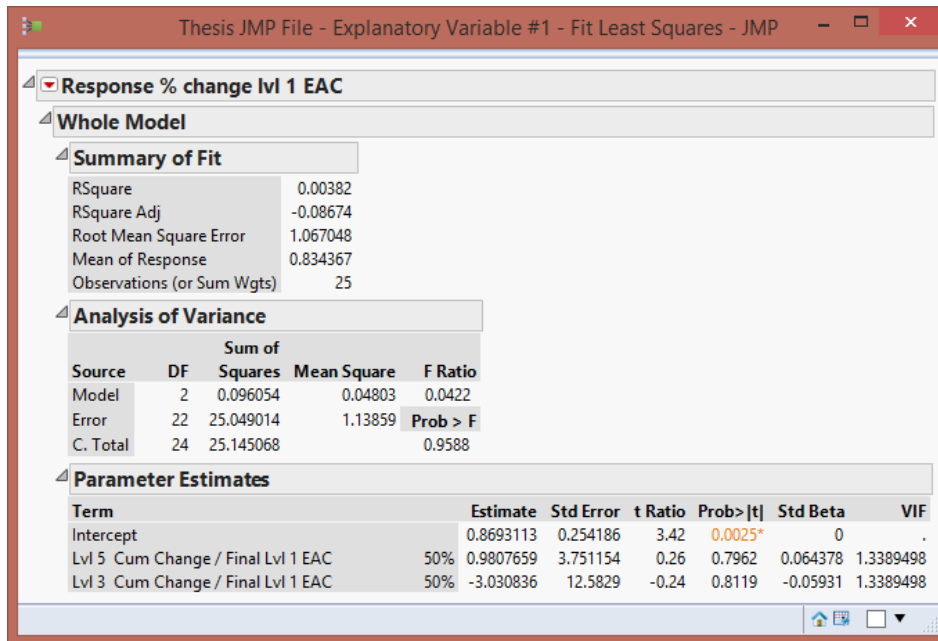
Growth Definition #1 Bin - 40%



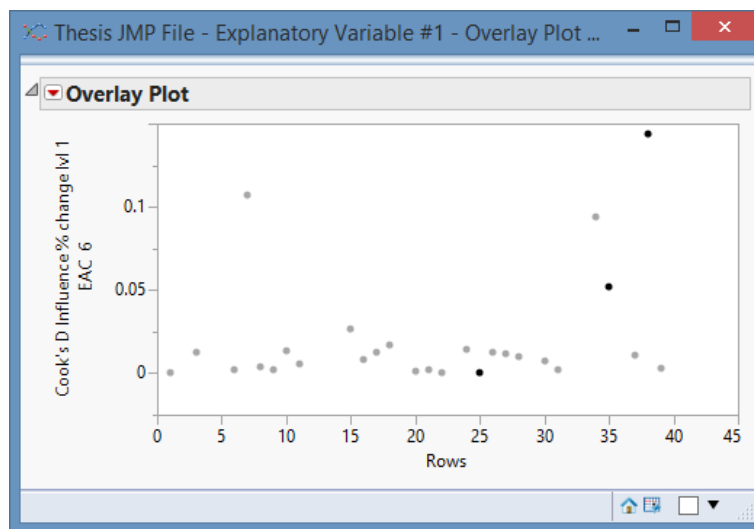
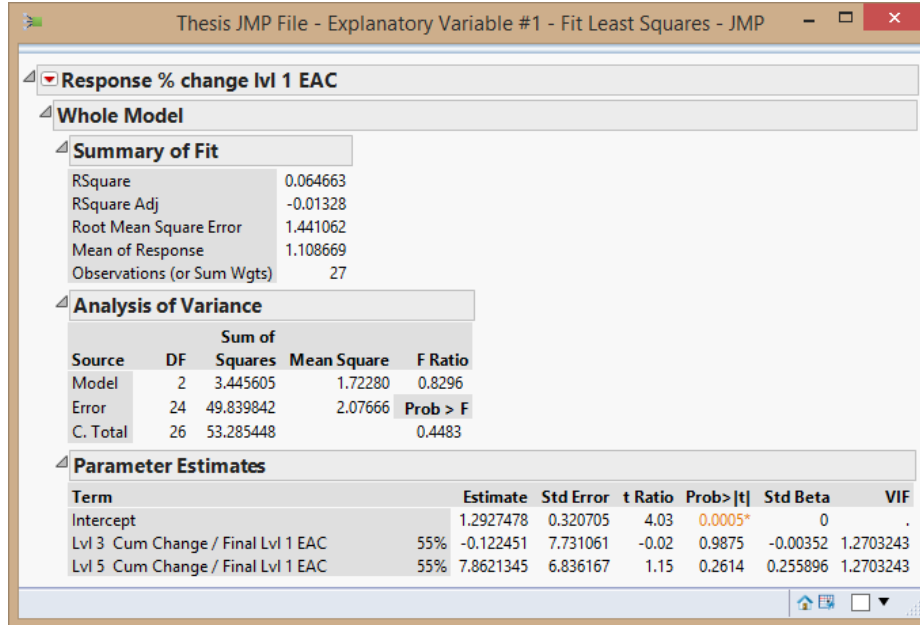
Growth Definition #1 Bin - 45%



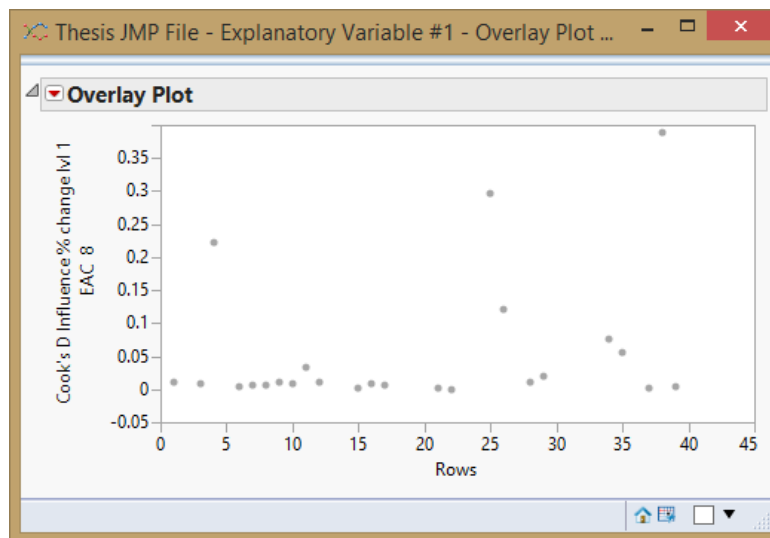
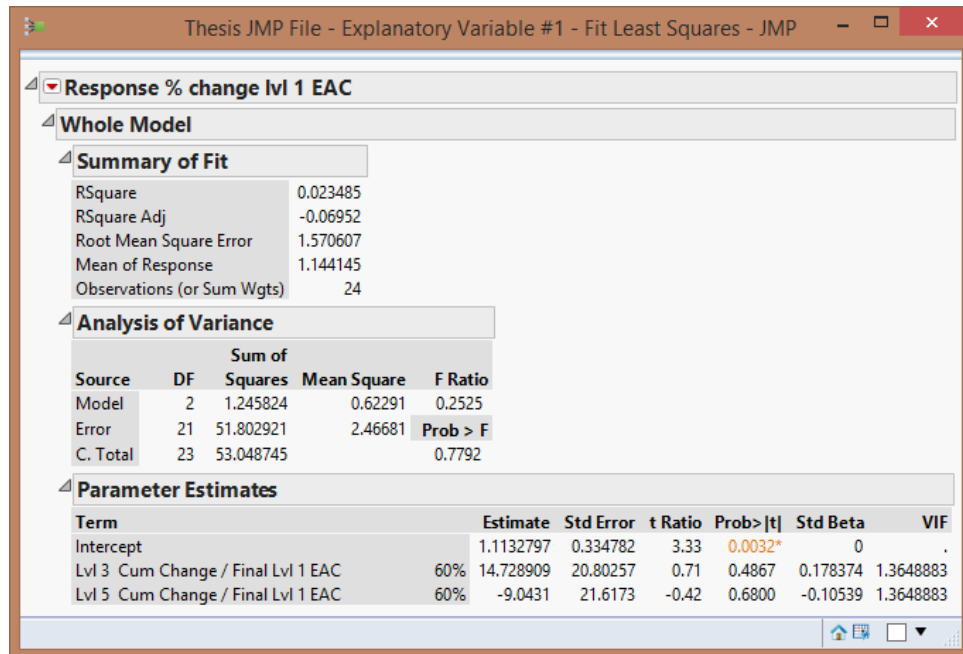
Growth Definition #1 Bin - 50%



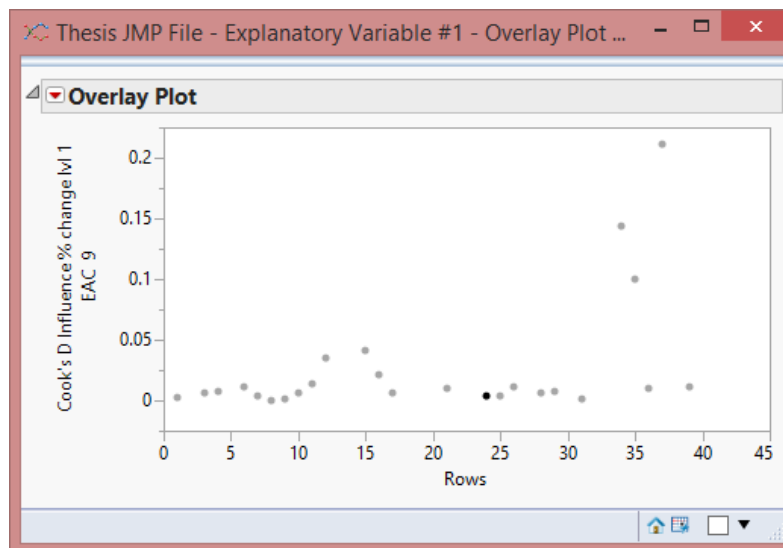
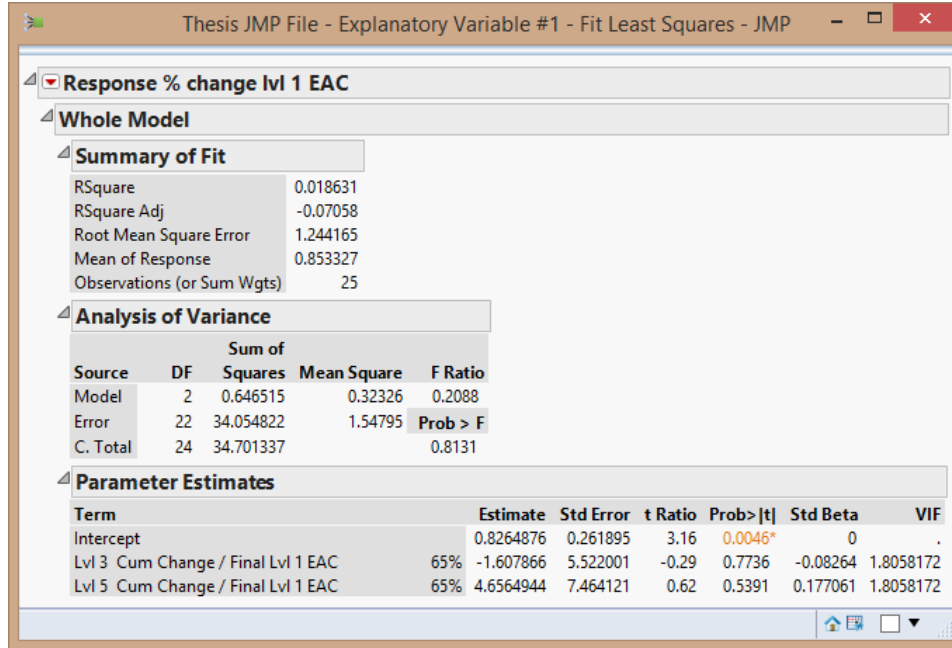
Growth Definition #1 Bin - 55%



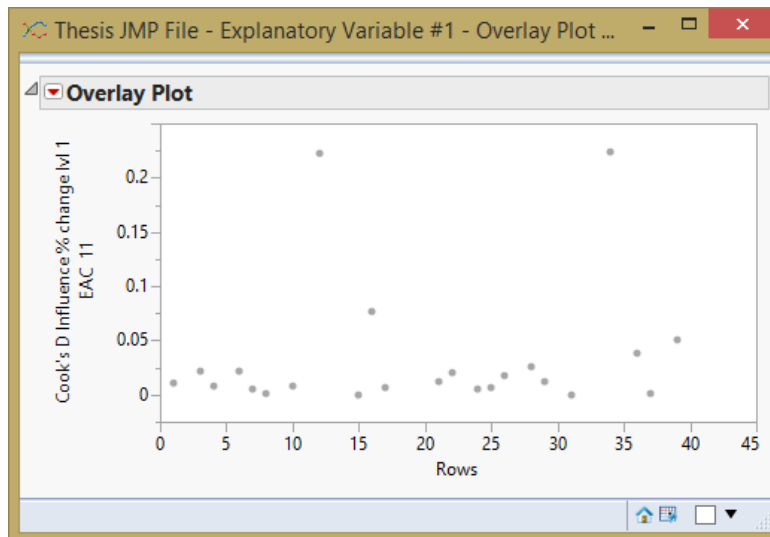
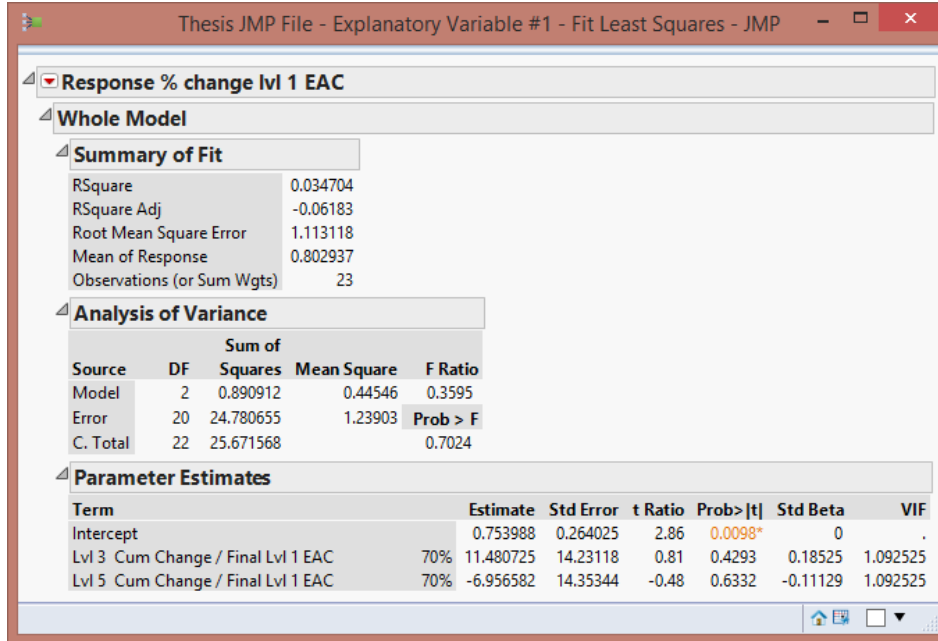
Growth Definition #1 Bin - 60%



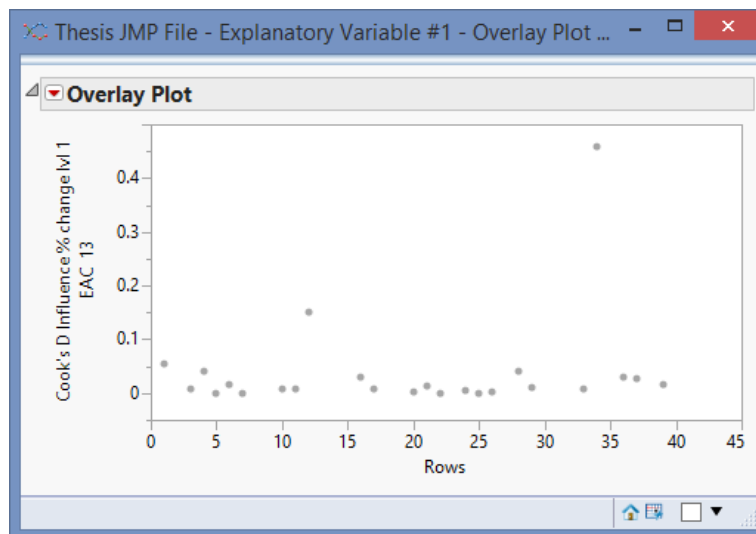
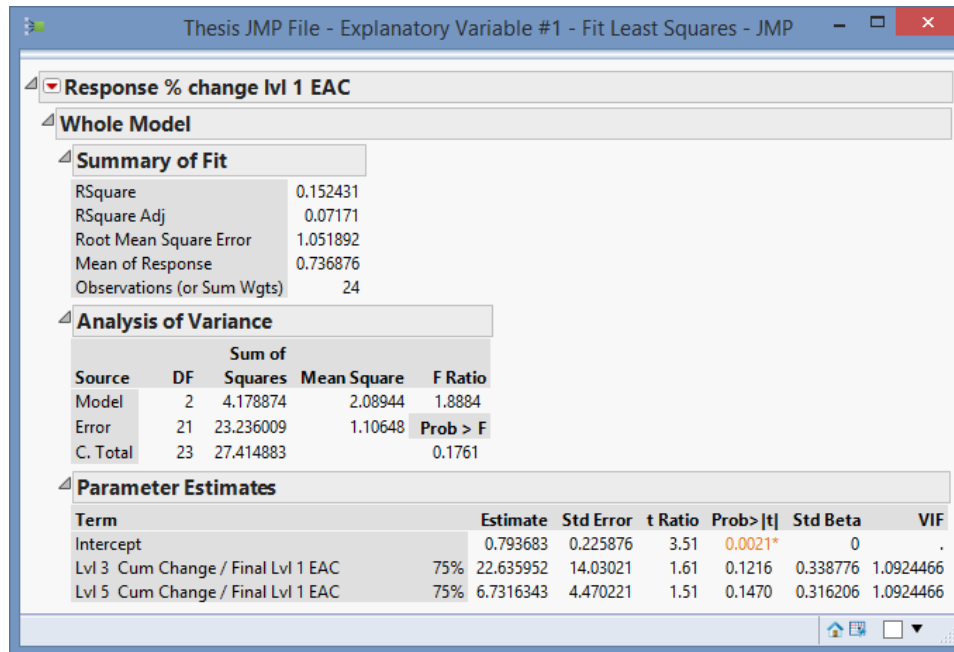
Growth Definition #1 Bin - 65%



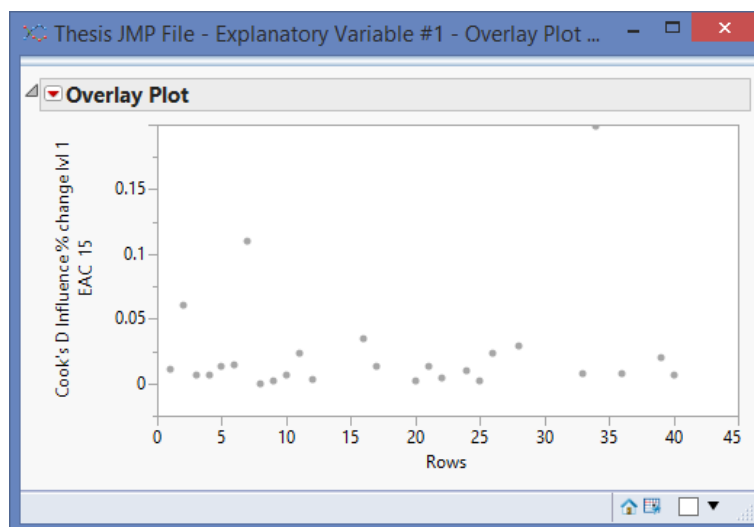
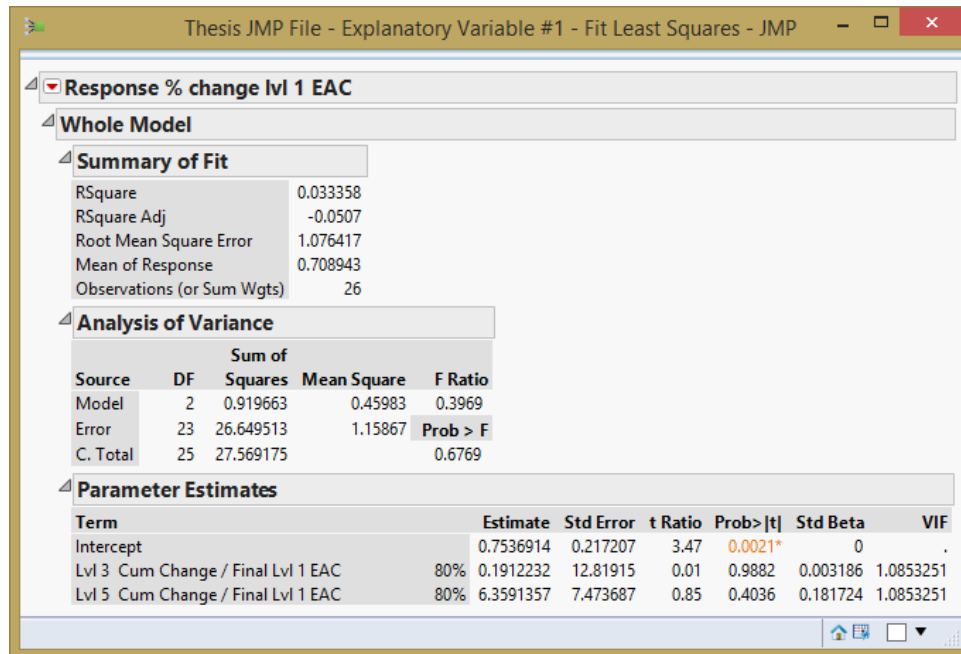
Growth Definition #1 Bin - 70%



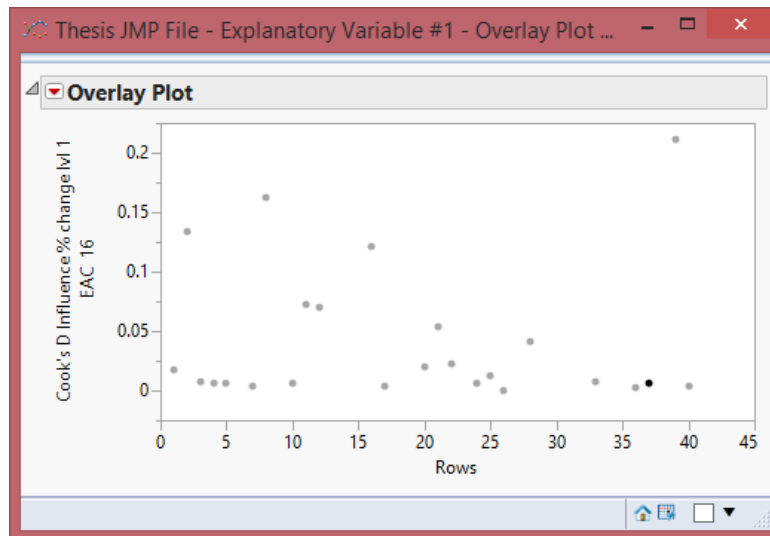
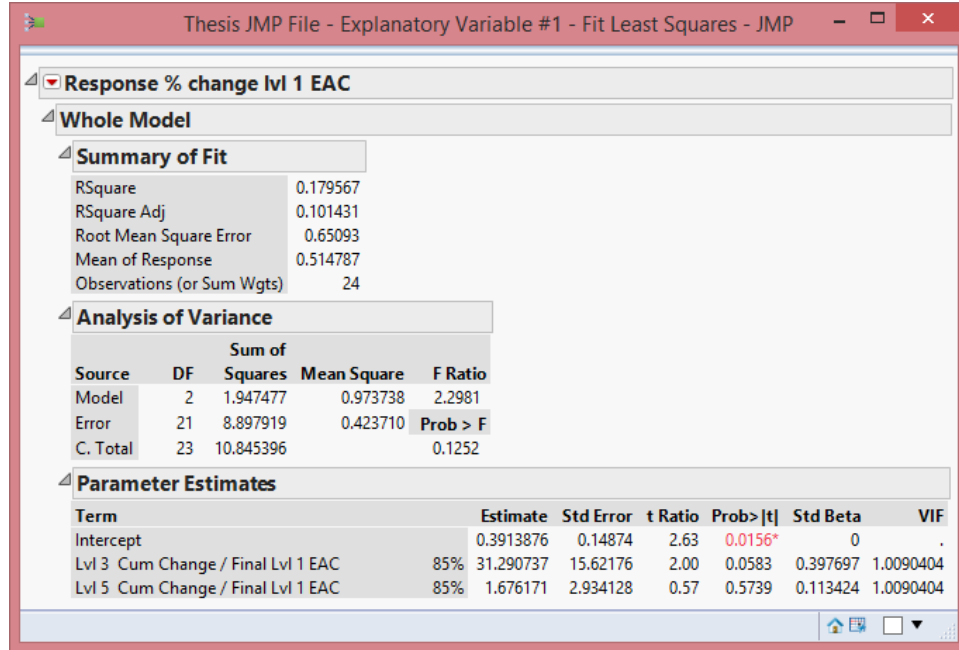
Growth Definition #1 Bin - 75%



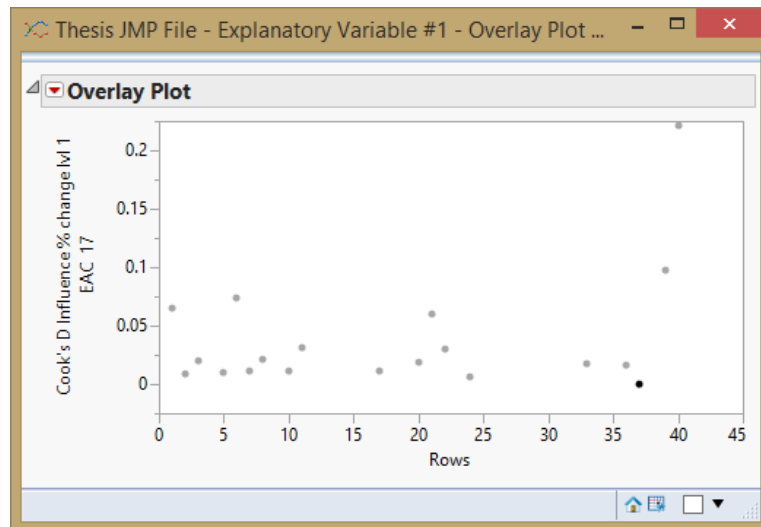
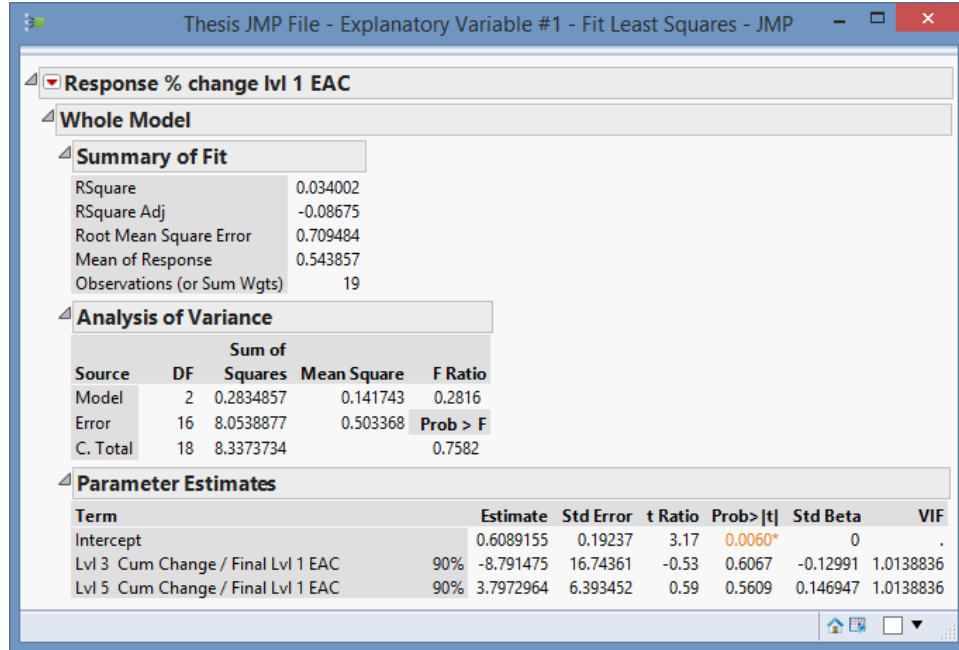
Growth Definition #1 Bin - 80%



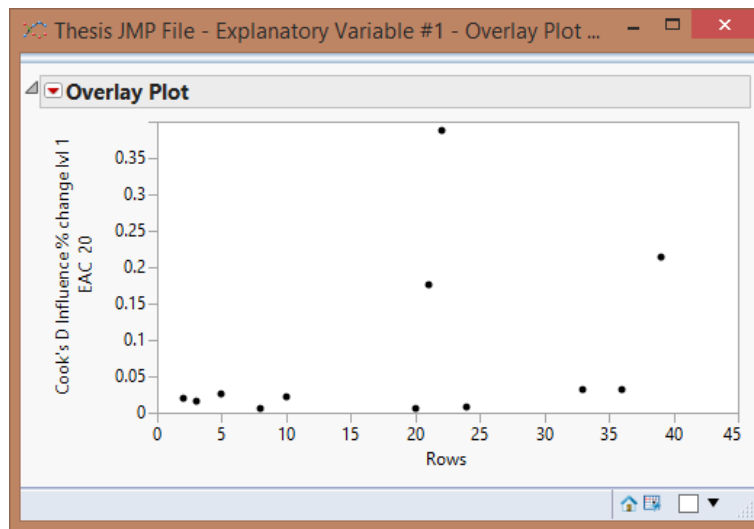
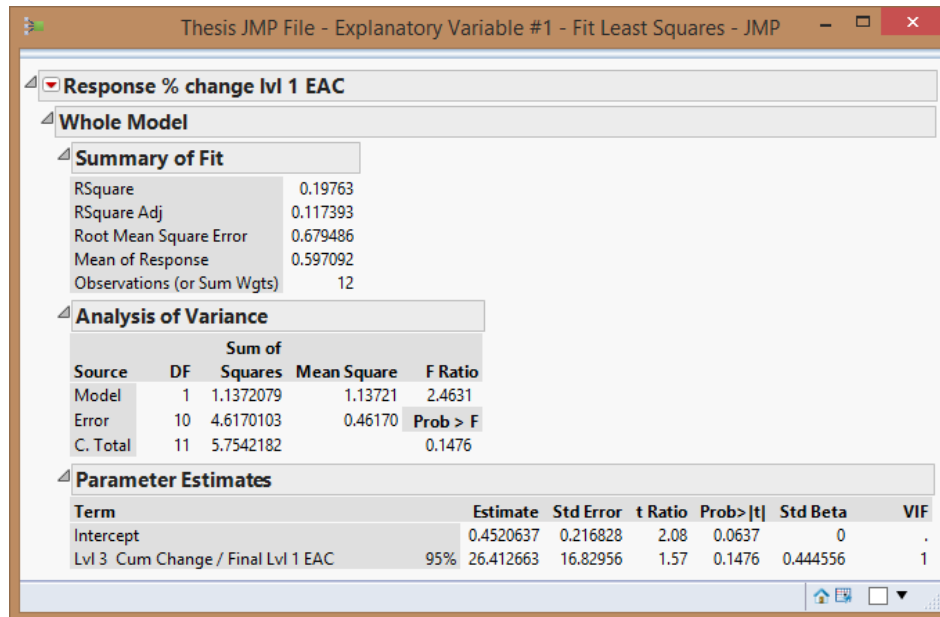
Growth Definition #1 Bin - 85%



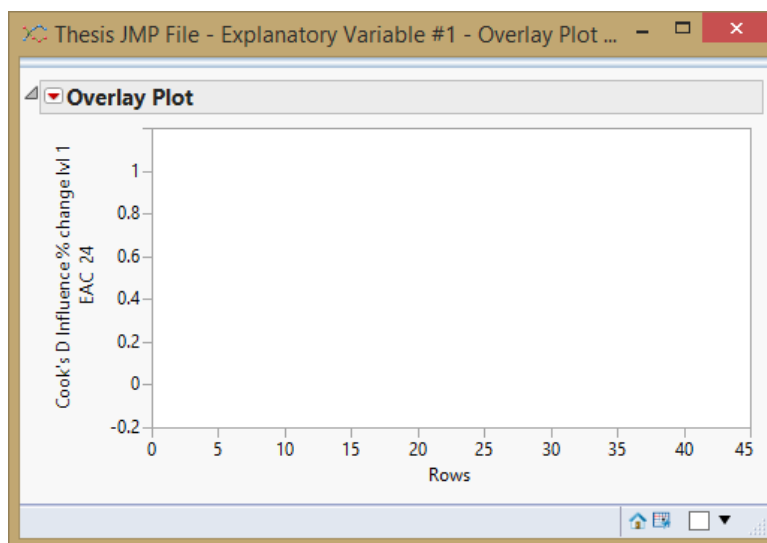
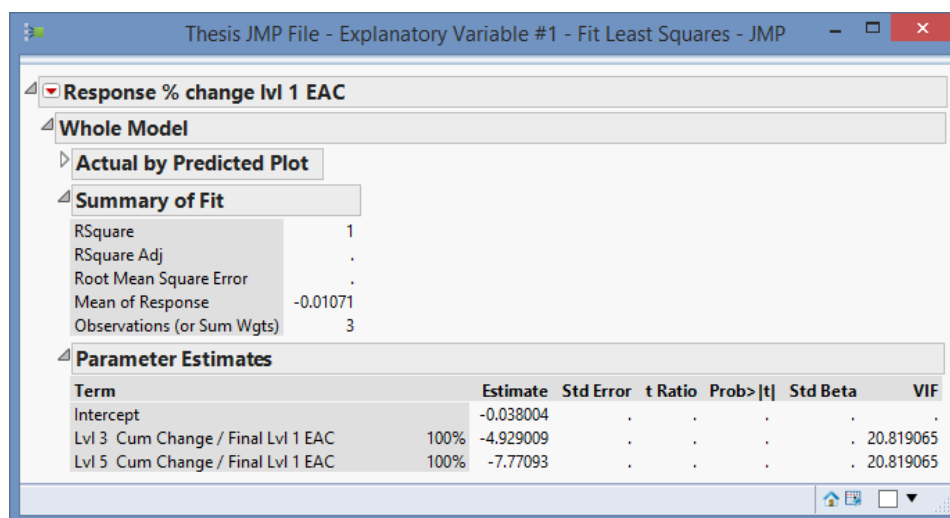
Growth Definition #1 Bin - 90%



Growth Definition #1 Bin - 95%

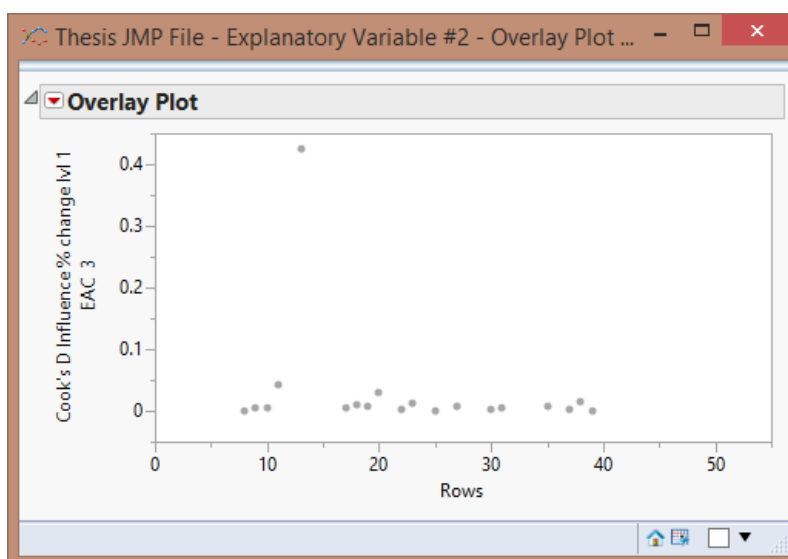
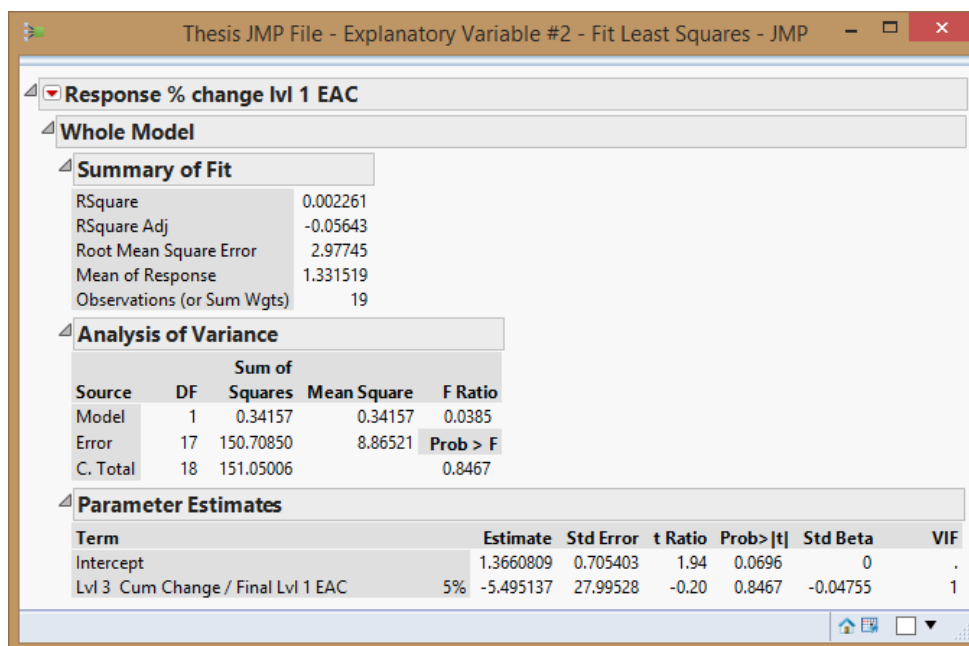


Growth Definition #1 Bin - 100%

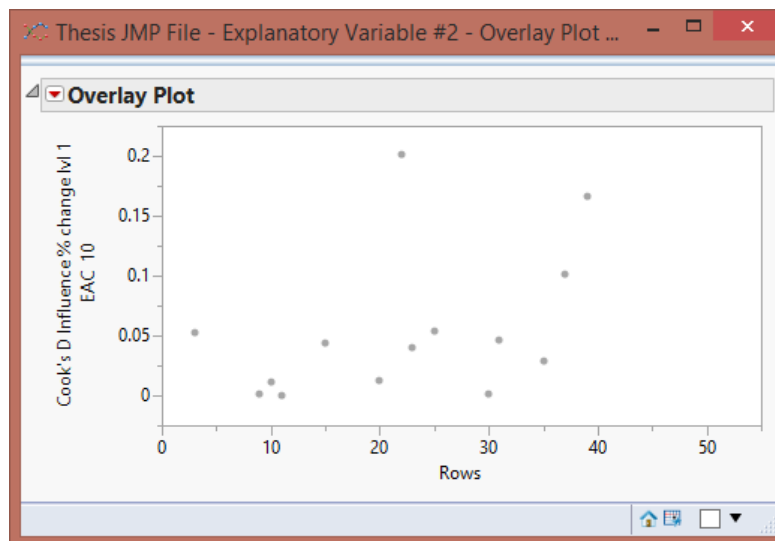
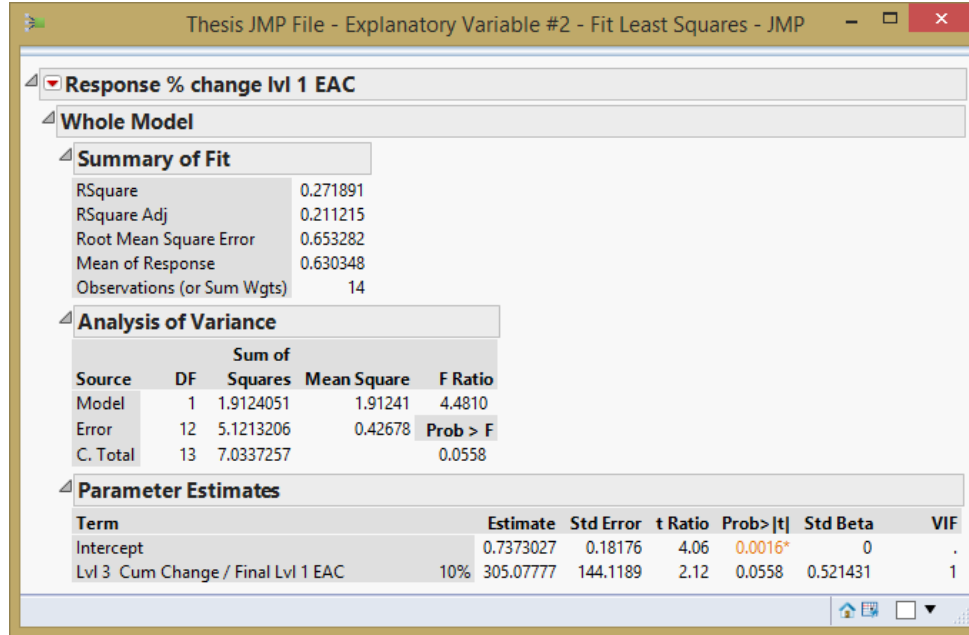


Appendix E - JMP® Output Screens for Growth Definition #2

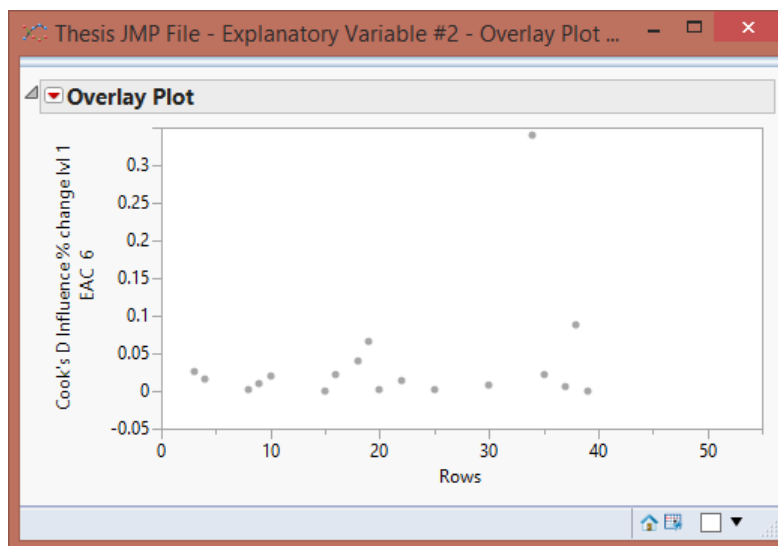
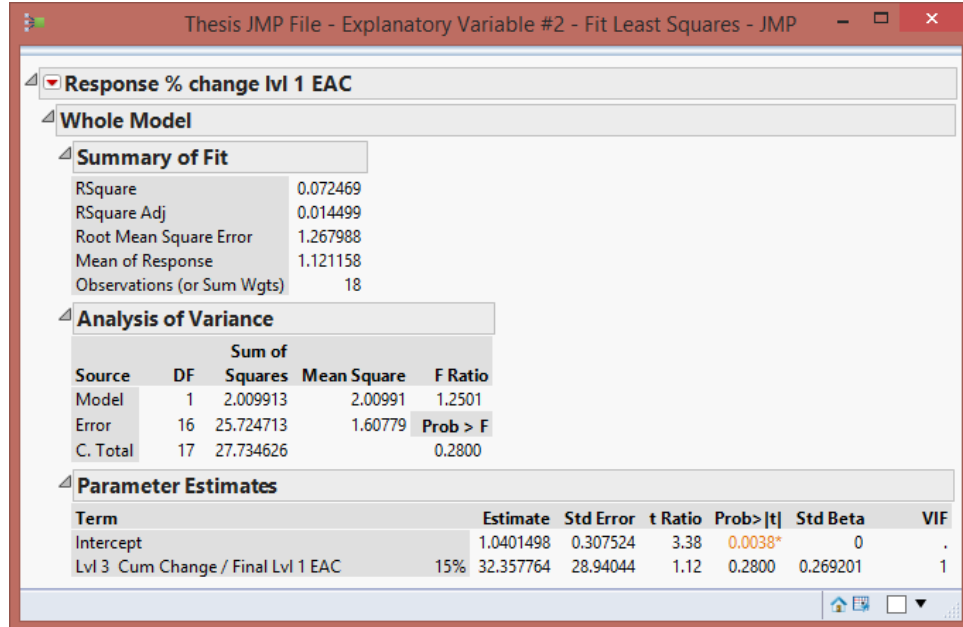
Growth Definition #2 Bin - 5%



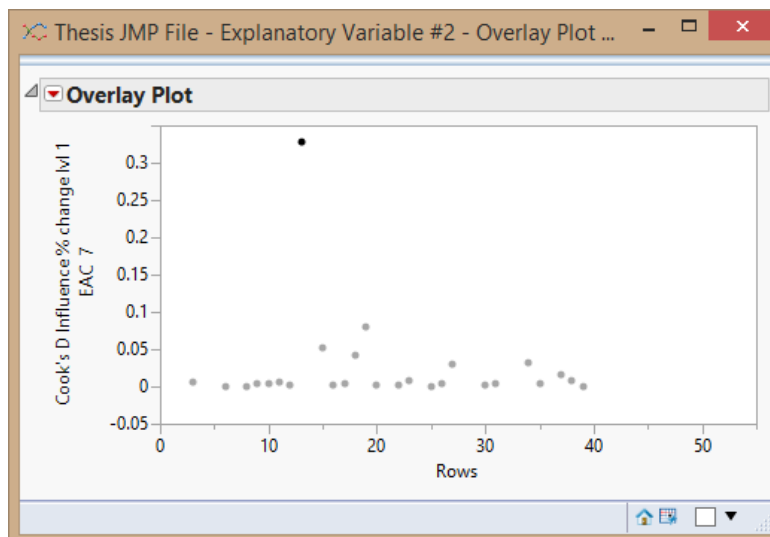
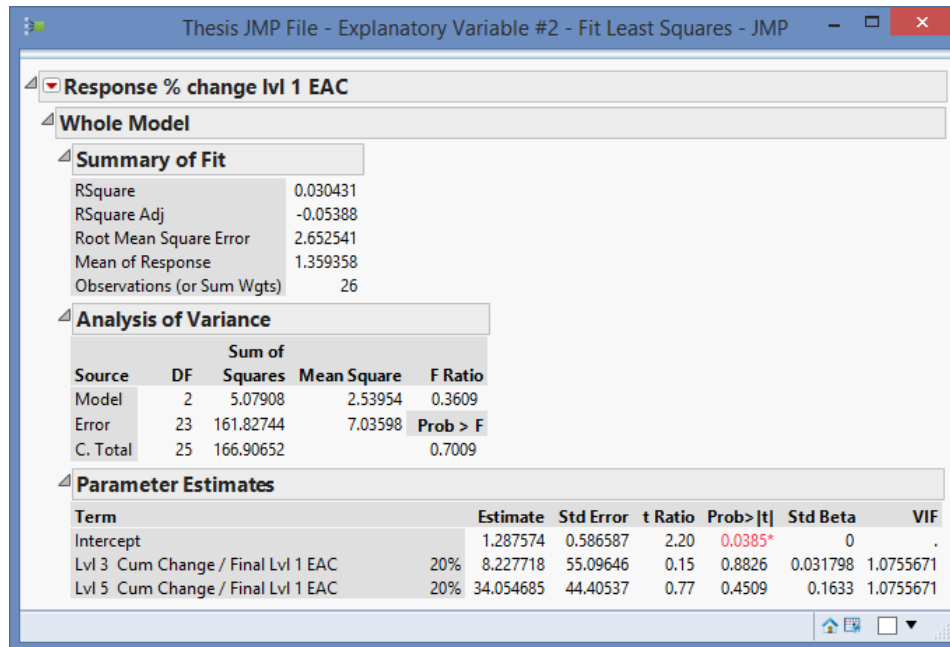
Growth Definition #2 Bin - 10%



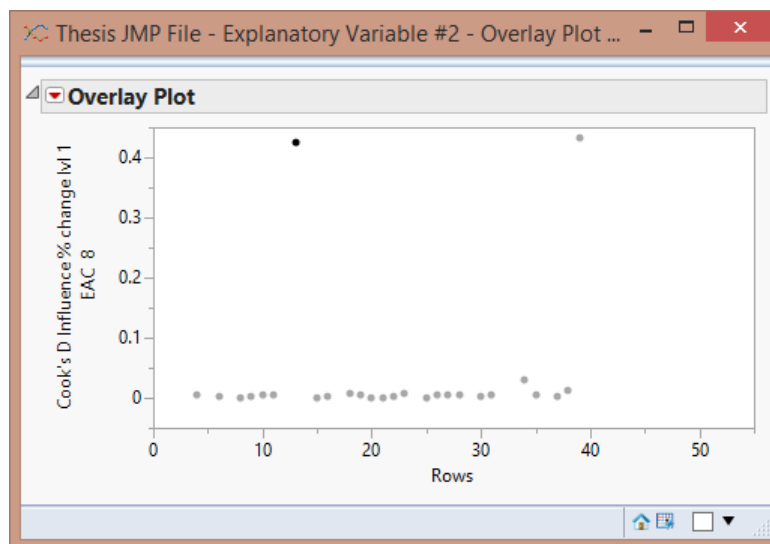
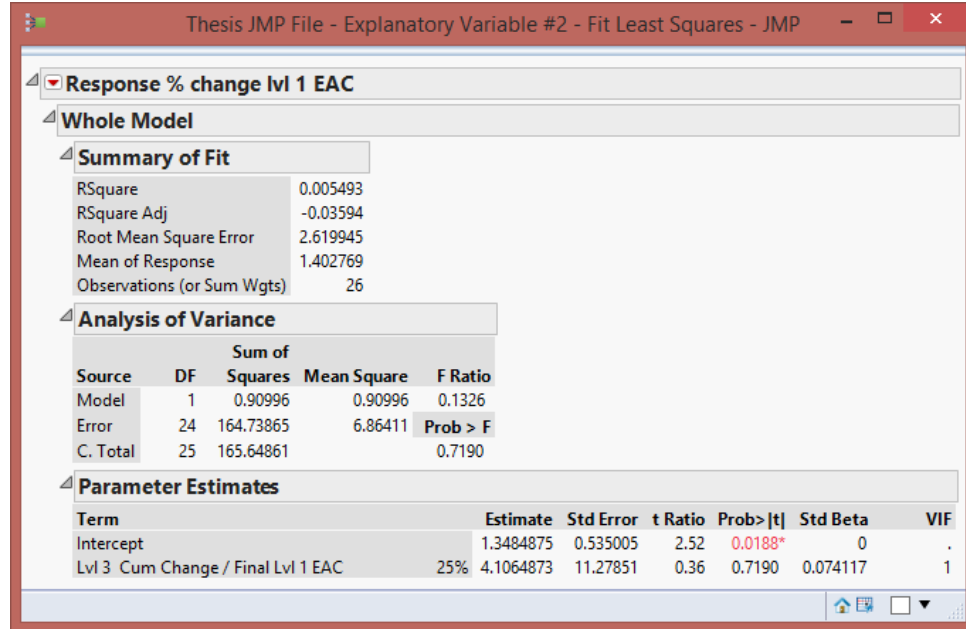
Growth Definition #2 Bin - 15%



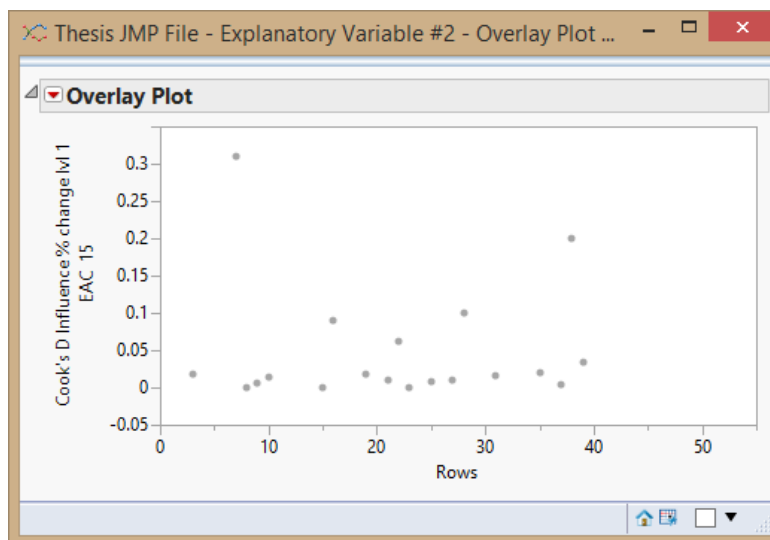
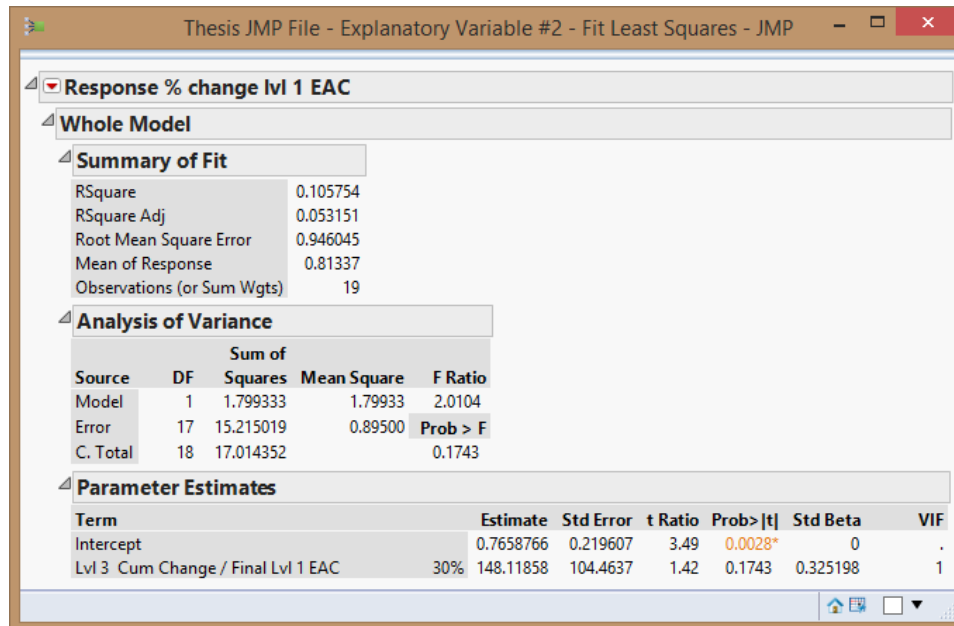
Growth Definition #2 Bin - 20%



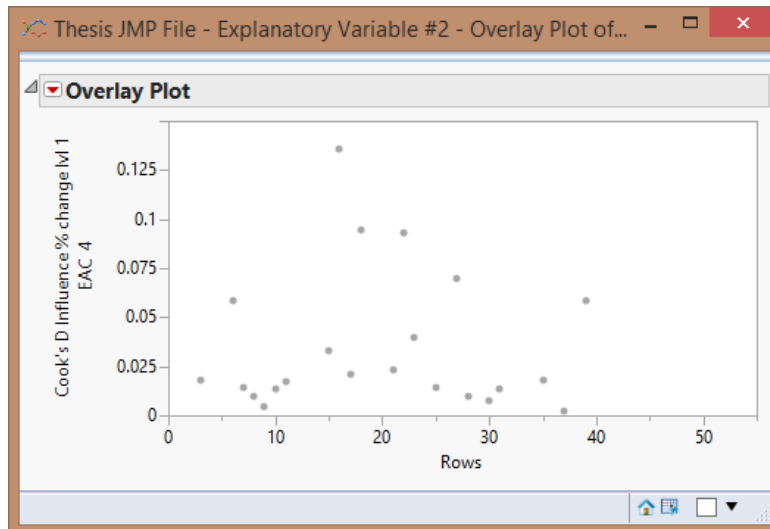
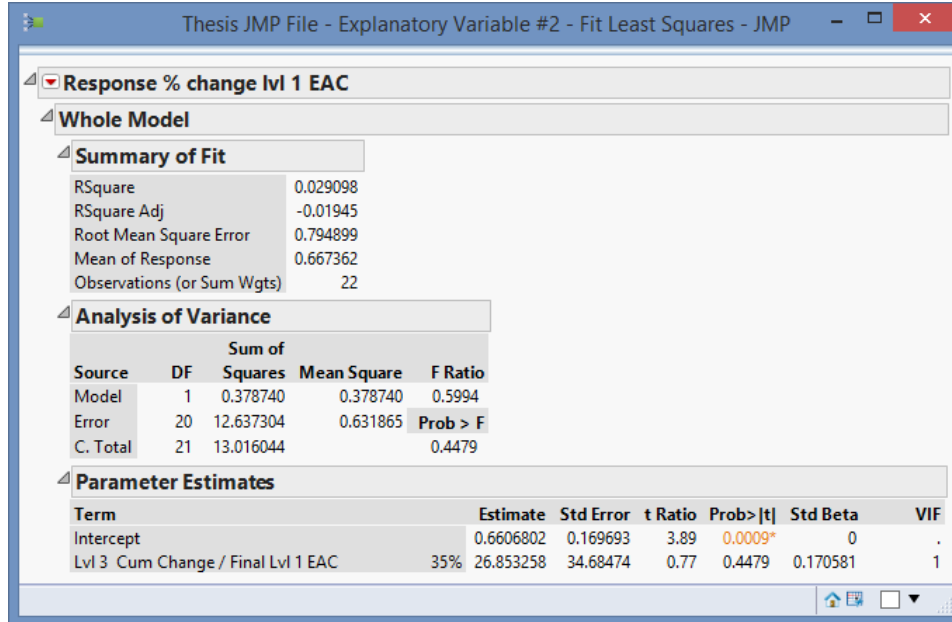
Growth Definition #2 Bin - 25%



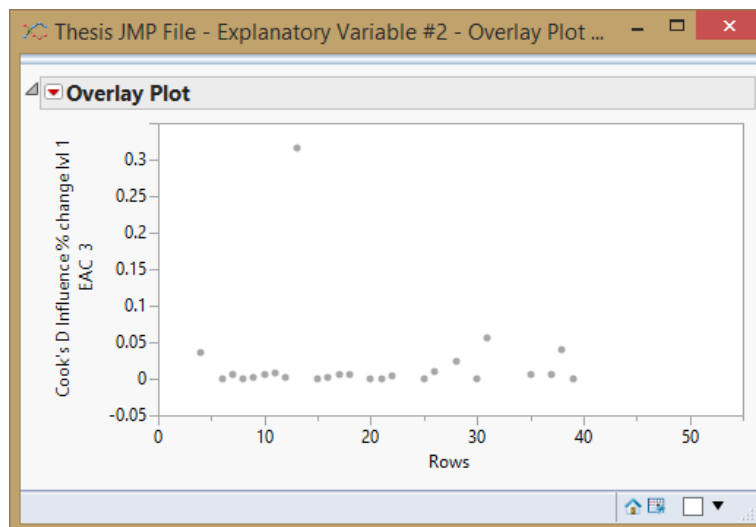
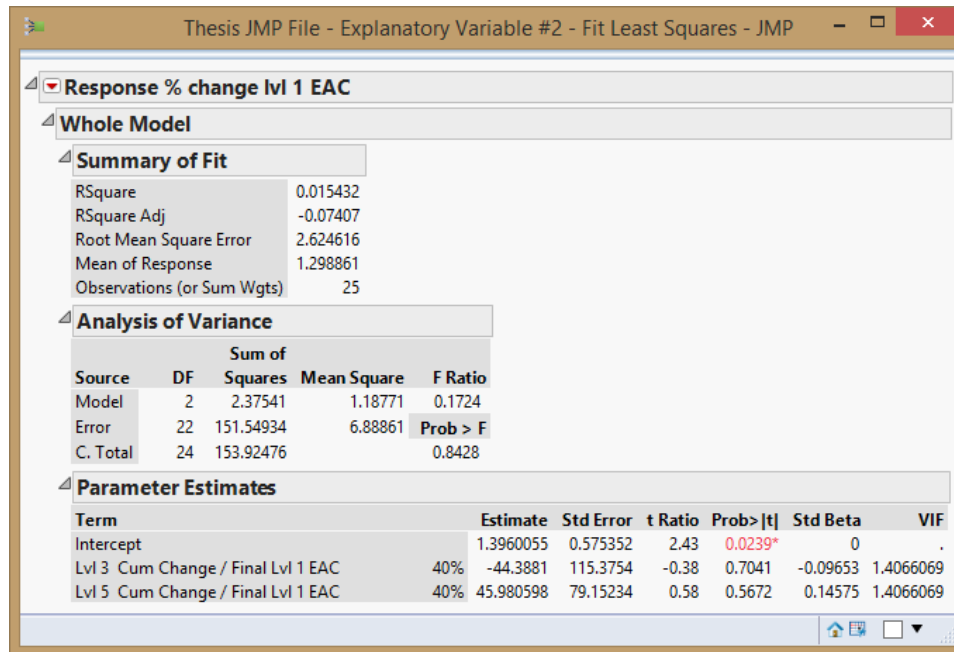
Growth Definition #2 Bin – 30%



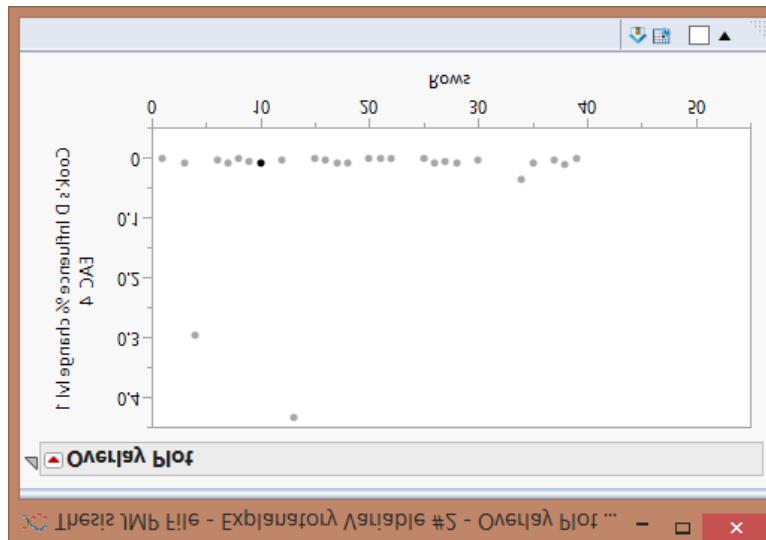
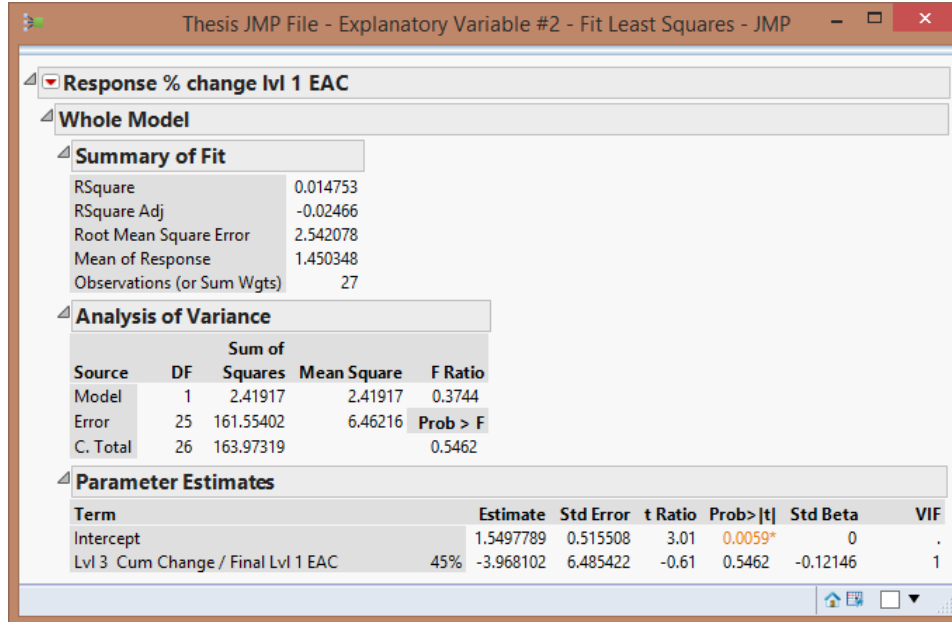
Growth Definition #2 Bin - 35%



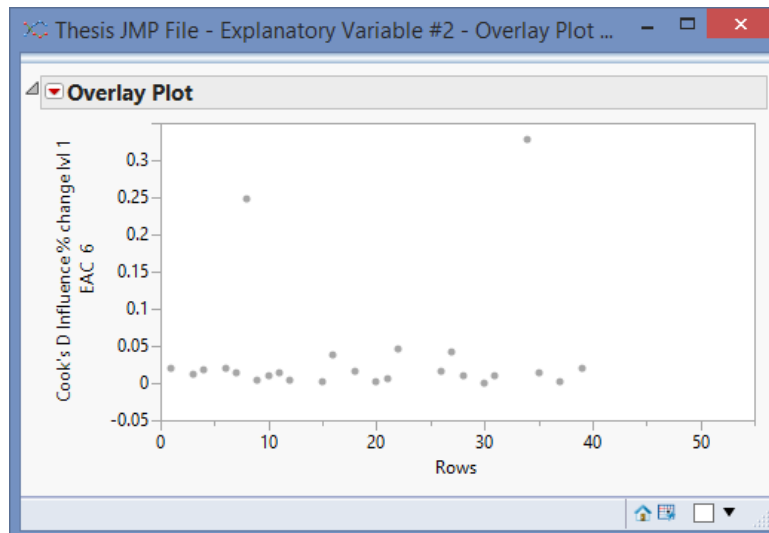
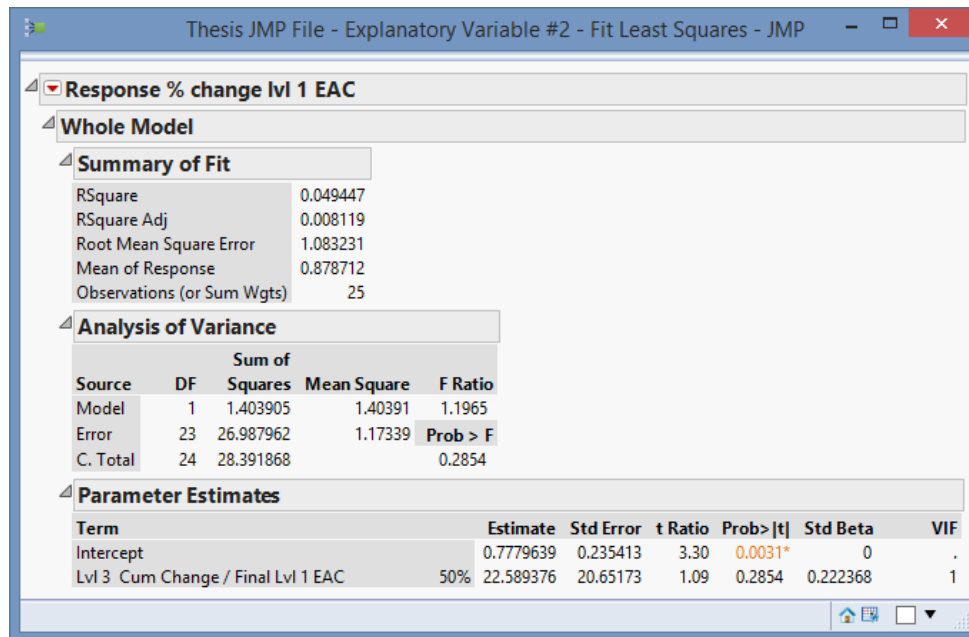
Growth Definition #2 Bin - 40%



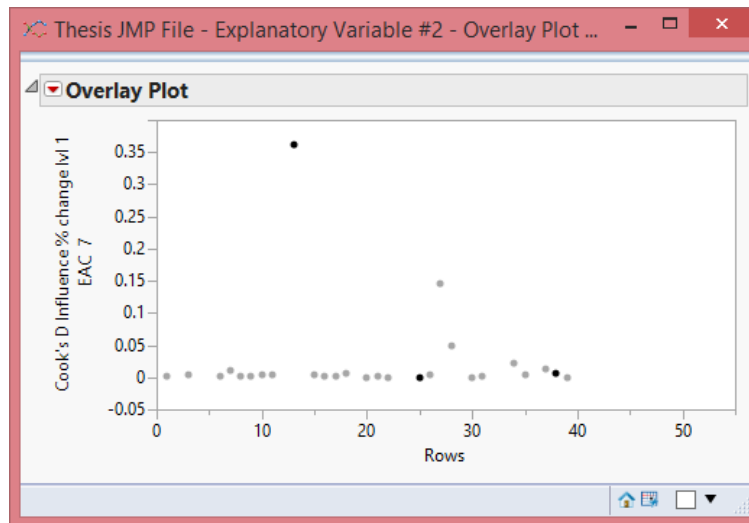
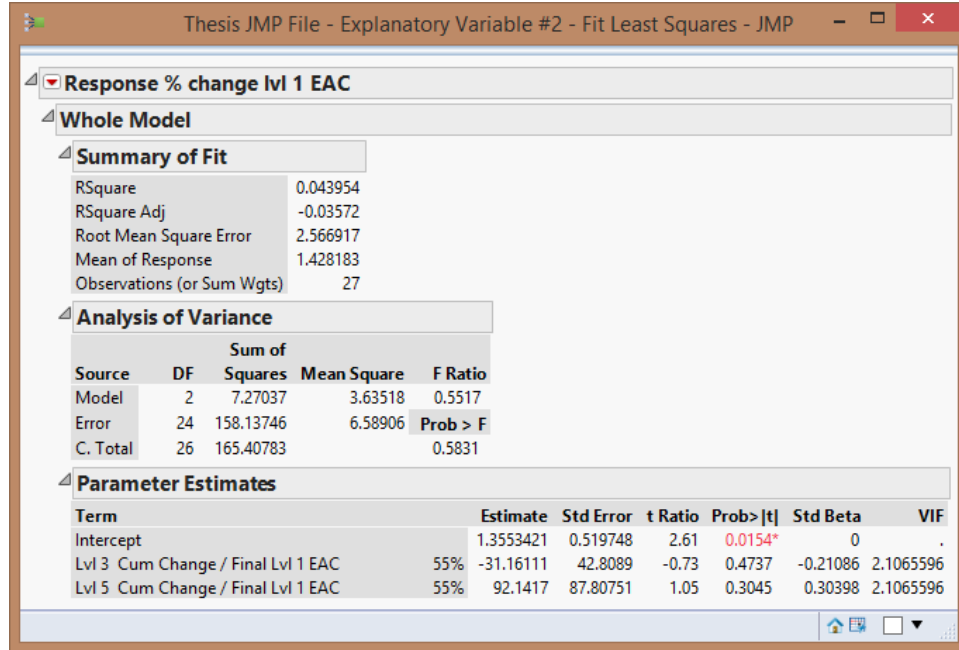
Growth Definition #2 Bin - 45%



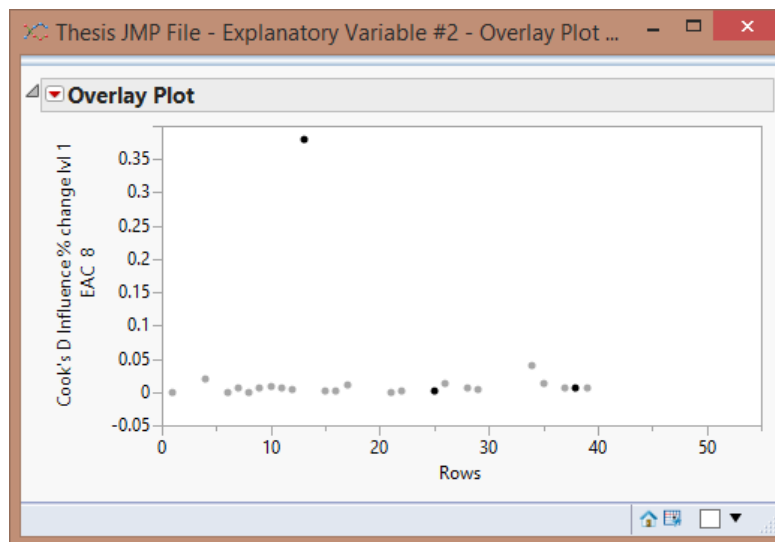
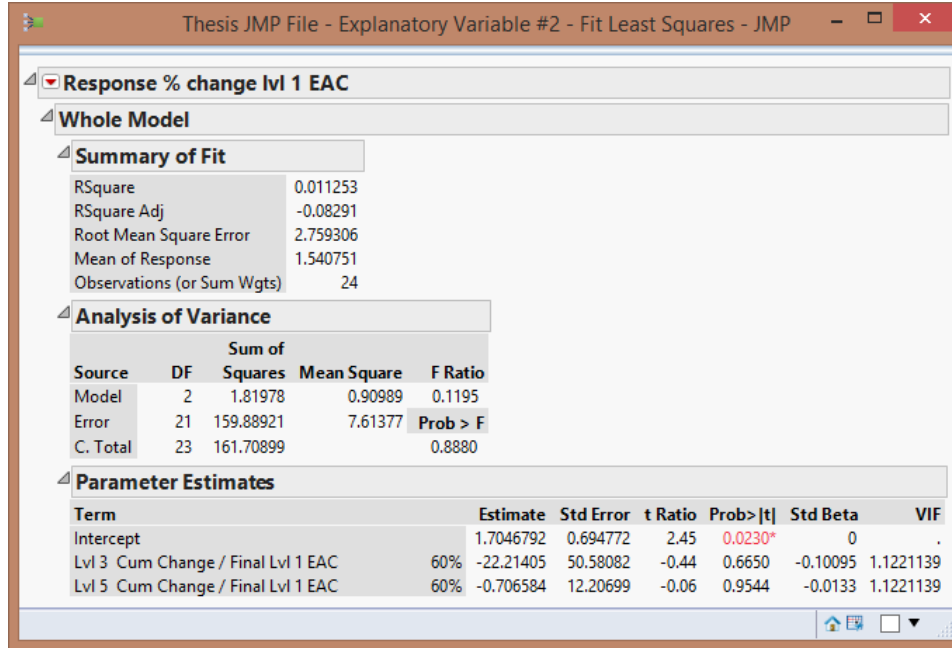
Growth Definition #2 Bin - 50%



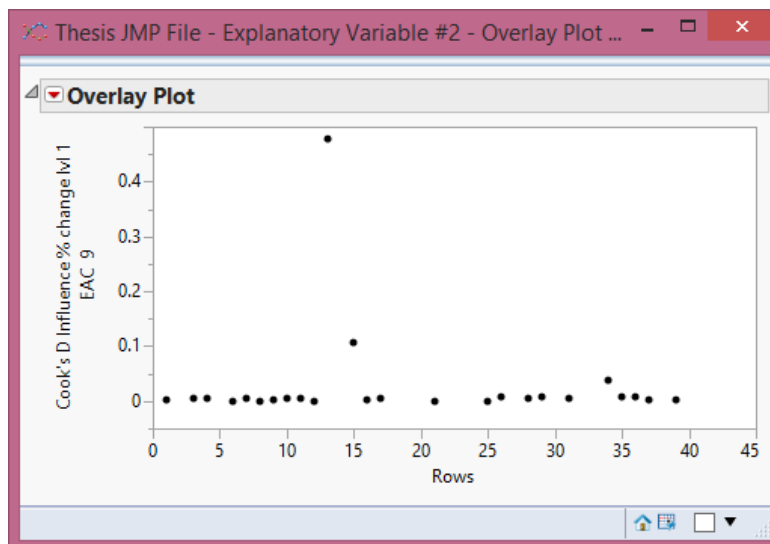
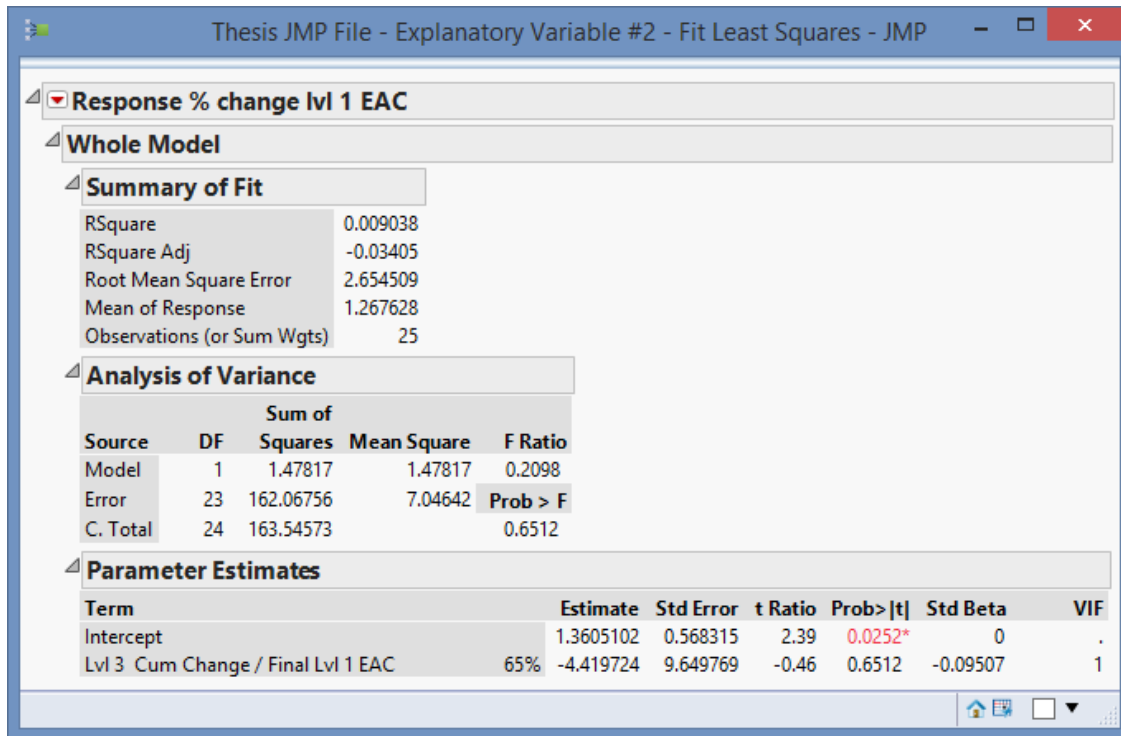
Growth Definition #2 Bin - 55%



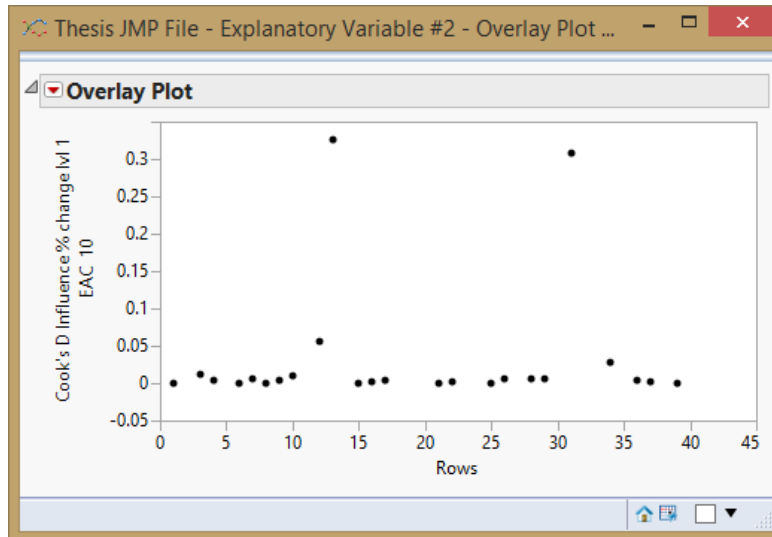
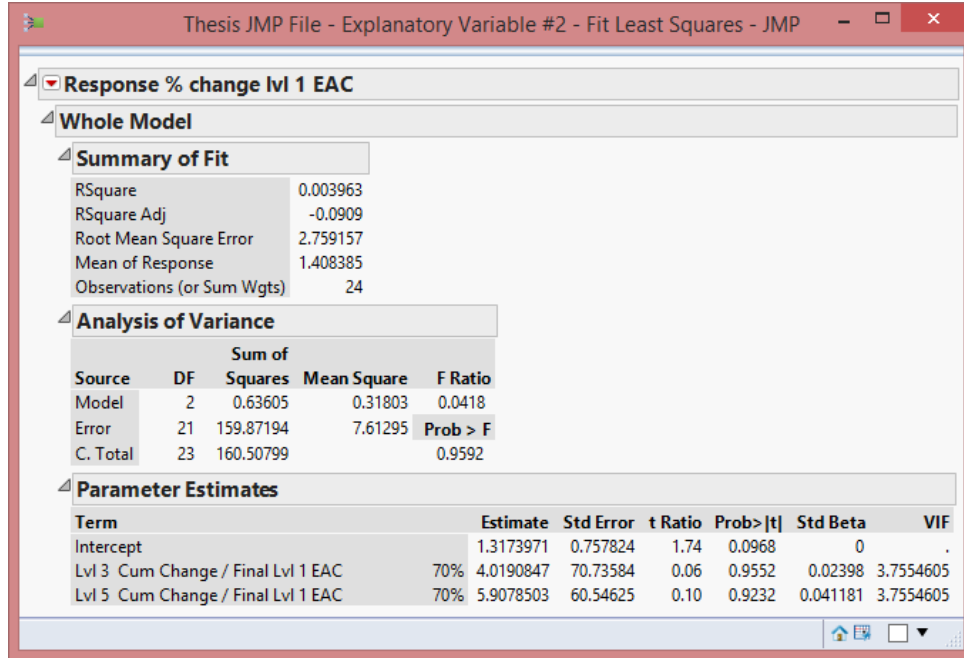
Growth Definition #2 Bin - 60%



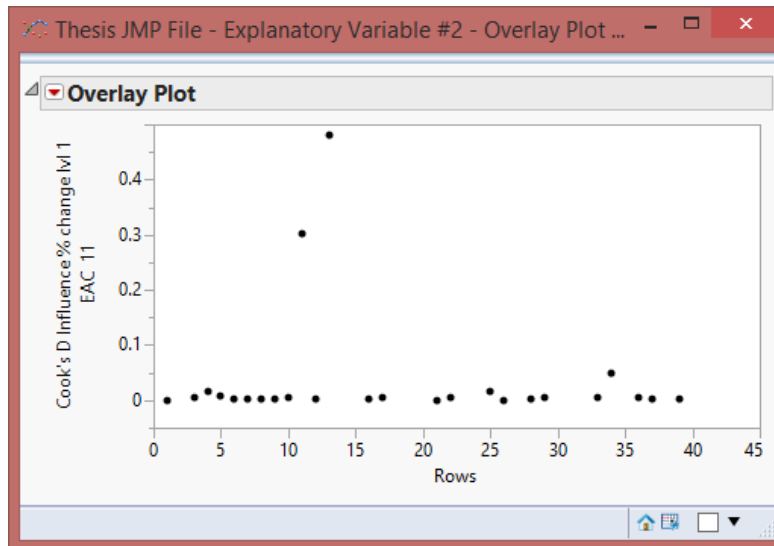
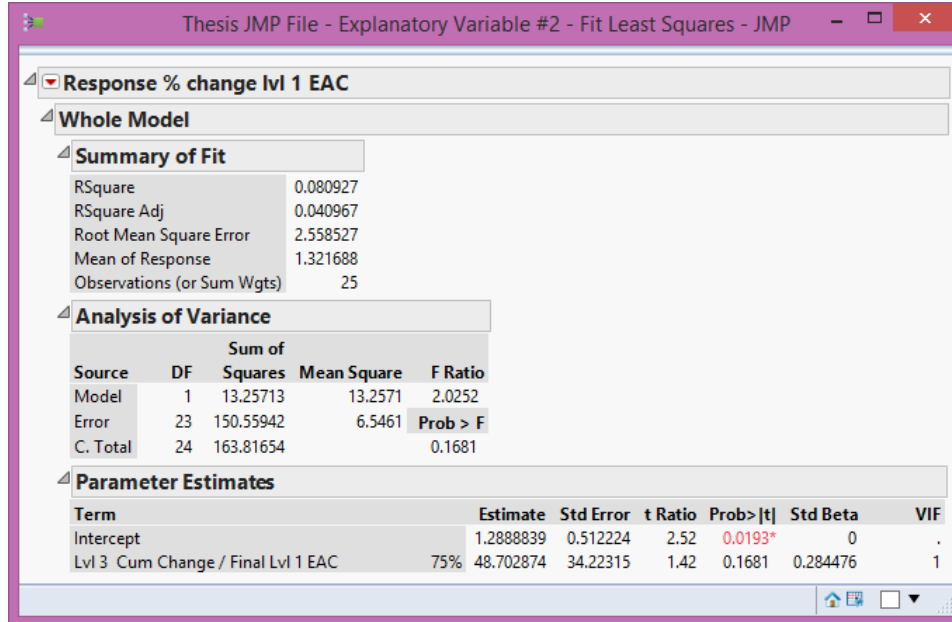
Growth Definition #2 Bin - 65%



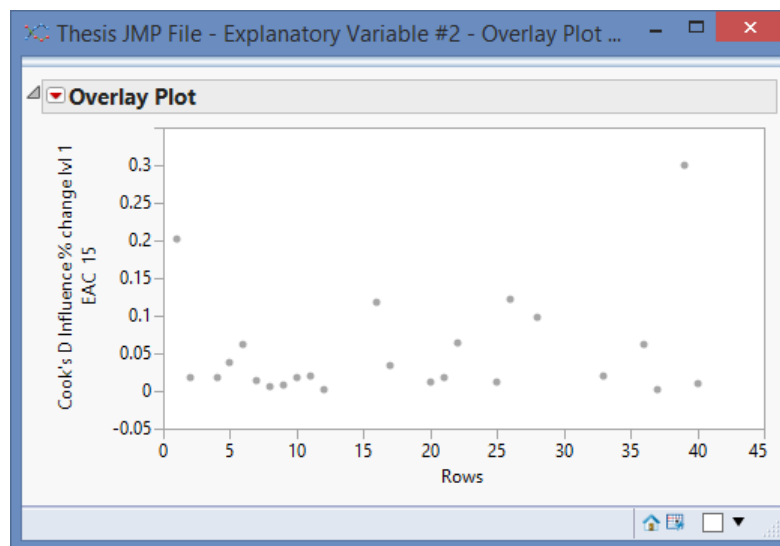
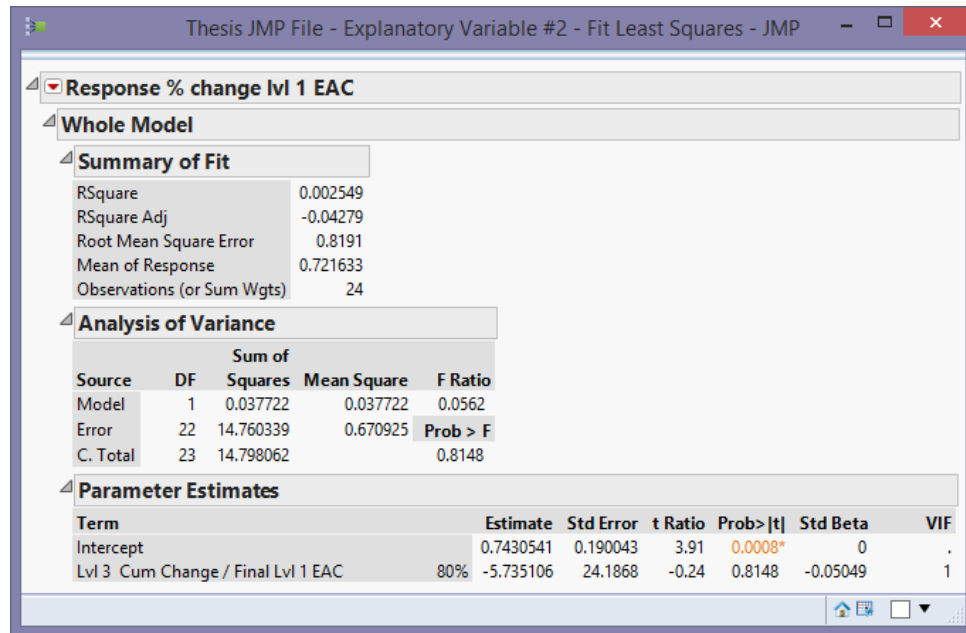
Growth Definition #2 Bin - 70%



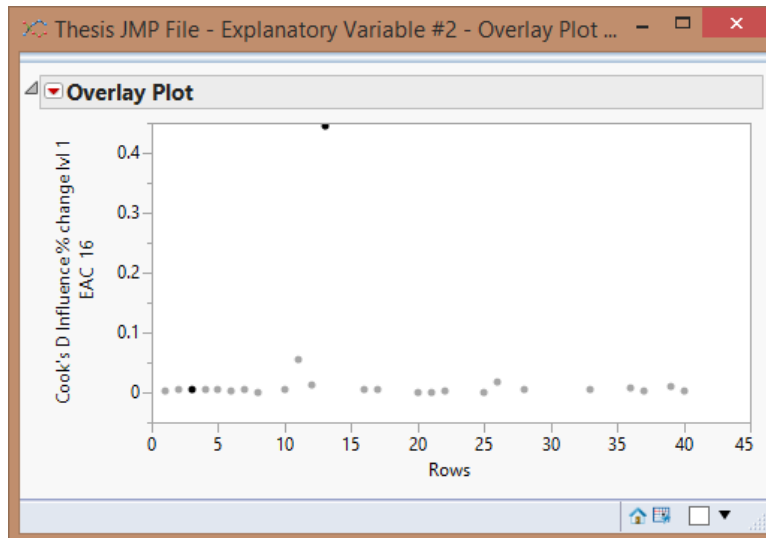
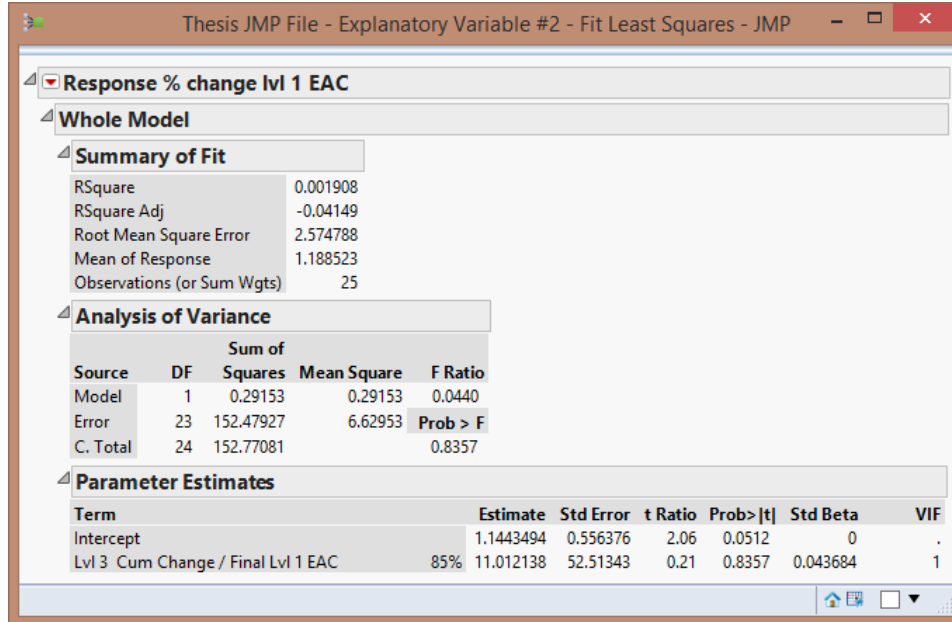
Growth Definition #2 Bin - 75%



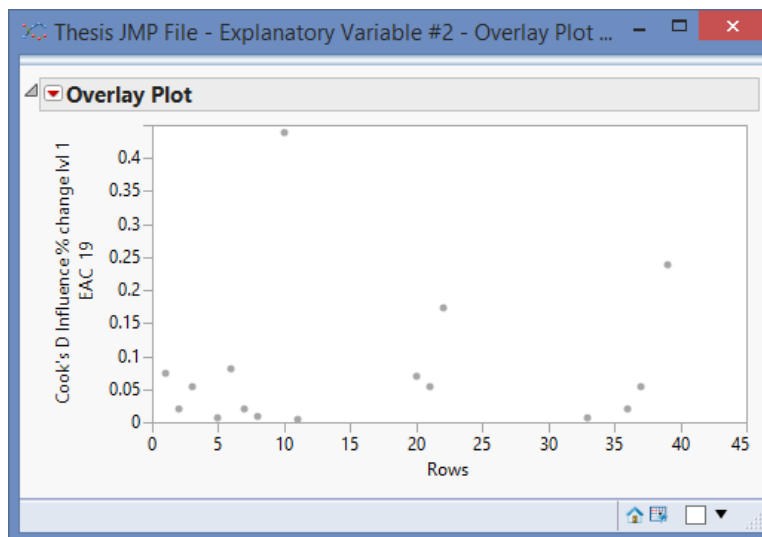
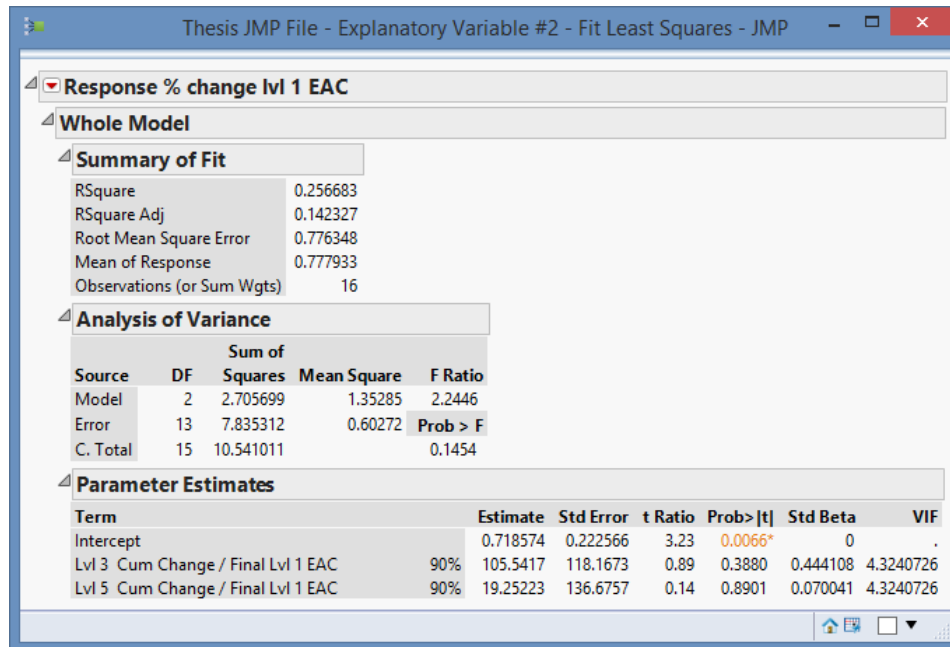
Growth Definition #2 Bin - 80%



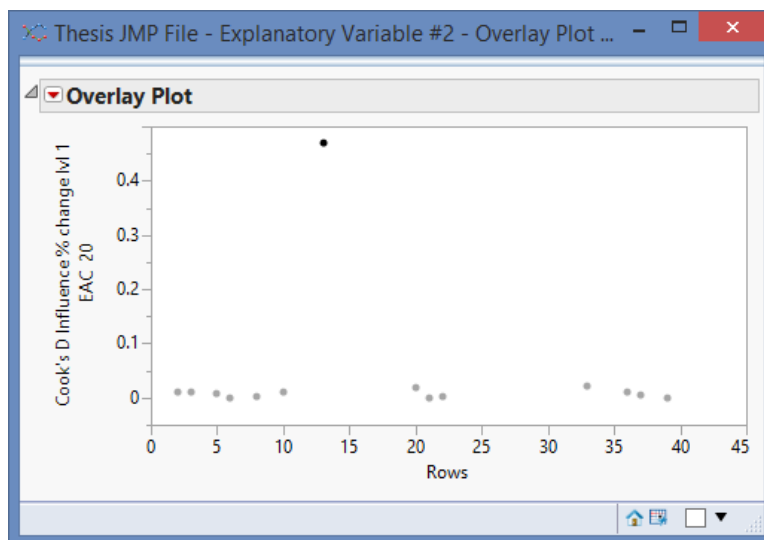
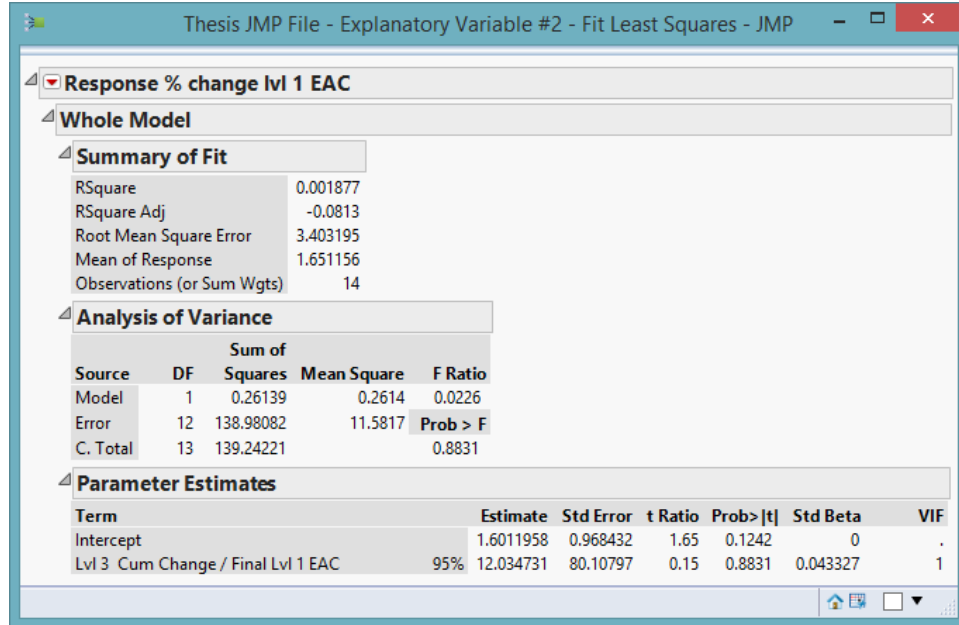
Growth Definition #2 Bin - 85%



Growth Definition #2 Bin - 90%



Growth Definition #2 Bin - 95%



Appendix F – JMP® Output Screens for Growth Definition #3

Growth Definition #3 Bin - 5%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.500839
RSquare Adj	0.084872
Root Mean Square Error	0.887337
Mean of Response	0.607487
Observations (or Sum Wgts)	34

Analysis of Variance

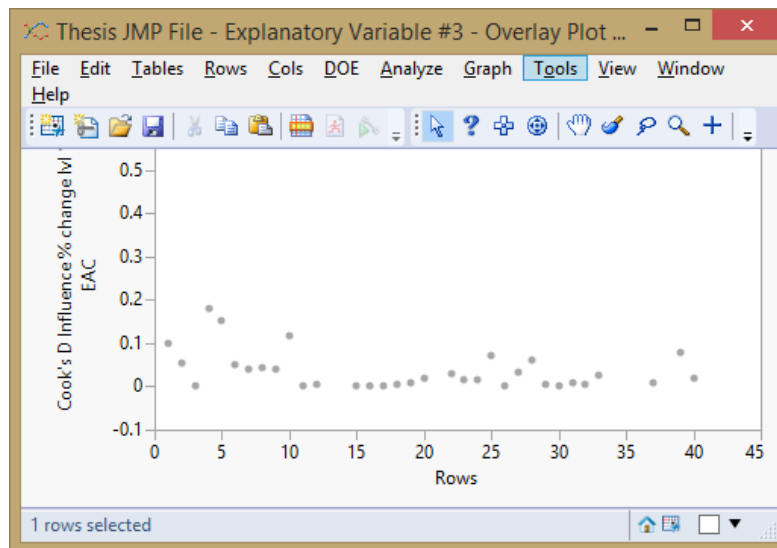
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	14.220252	0.948017	1.2040
Error	18	14.172596	0.787366	Prob > F
C. Total	33	28.392848		0.3498

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.3543905	0.695648	0.51	0.6166	0	.
# Lvl 3 Elements with EAC Data	-0.000044	0.019116	-0.00	0.9982	-0.0006	2.4516382
# Lvl 5 with EAC data elements <= 30	0.8351154	0.58104	1.44	0.1678	0.427526	3.1906335
RDT&E	-0.068881	0.420066	-0.16	0.8716	-0.03663	1.7994585
Air Force	0.902058	0.713495	1.26	0.2223	0.31804	2.2819553
Navy	-0.049727	0.487851	-0.10	0.9199	-0.02546	2.2492541
Aircraft	0.2845607	0.475243	0.60	0.5568	0.132088	1.7548484
Missile	0.2914338	0.589724	0.49	0.6272	0.112948	1.8836908
General Dynamics Corporation	0.5349049	0.705772	0.76	0.4583	0.166025	1.7304354
Lockheed Martin Corporation	0.4926465	0.836905	0.59	0.5634	0.126847	1.6744678
The Boeing Company	-0.87839	0.840381	-1.05	0.3098	-0.27264	2.4534615
Top 5 DOD Contractor	0.0398866	0.534491	0.07	0.9413	0.019888	2.5611525
12 - 24 Months	-1.084314	0.446805	-2.43	0.0260*	-0.58397	2.0880332
24 - 36	0.0235645	0.560123	0.04	0.9669	0.010938	2.4376646
% of Contract covered 25% - 50%	0.3591481	0.644293	0.56	0.5841	0.139192	2.2484295
% of Contract covered 50% - 75%	0.5809915	0.49691	1.17	0.2576	0.303828	2.4350294

Effect Tests

Effect Details



Growth Definition #3 Bin - 10%

Thesis JMP File - Explanatory Variable #3 - Fit Least Squares 2 - JMP

Response % change lvi 1 EAC

Whole Model

Summary of Fit

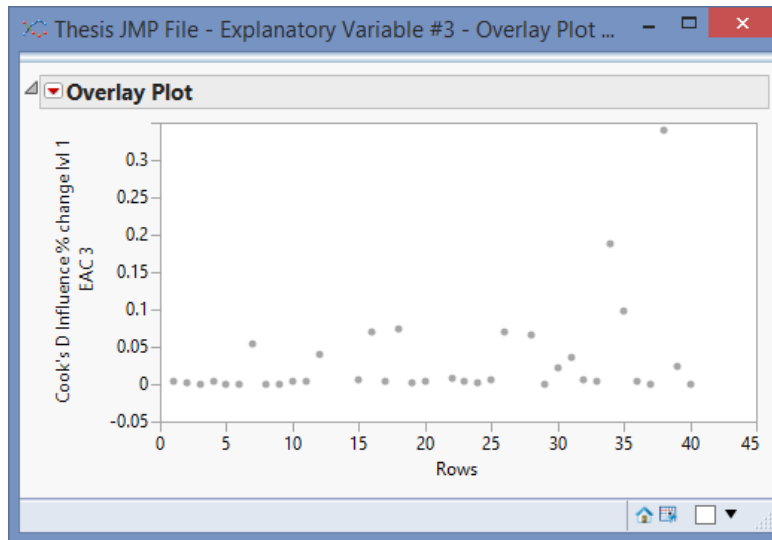
RSquare	0.225539
RSquare Adj	0.178602
Root Mean Square Error	1.19327
Mean of Response	0.820696
Observations (or Sum Wgts)	36

Analysis of Variance

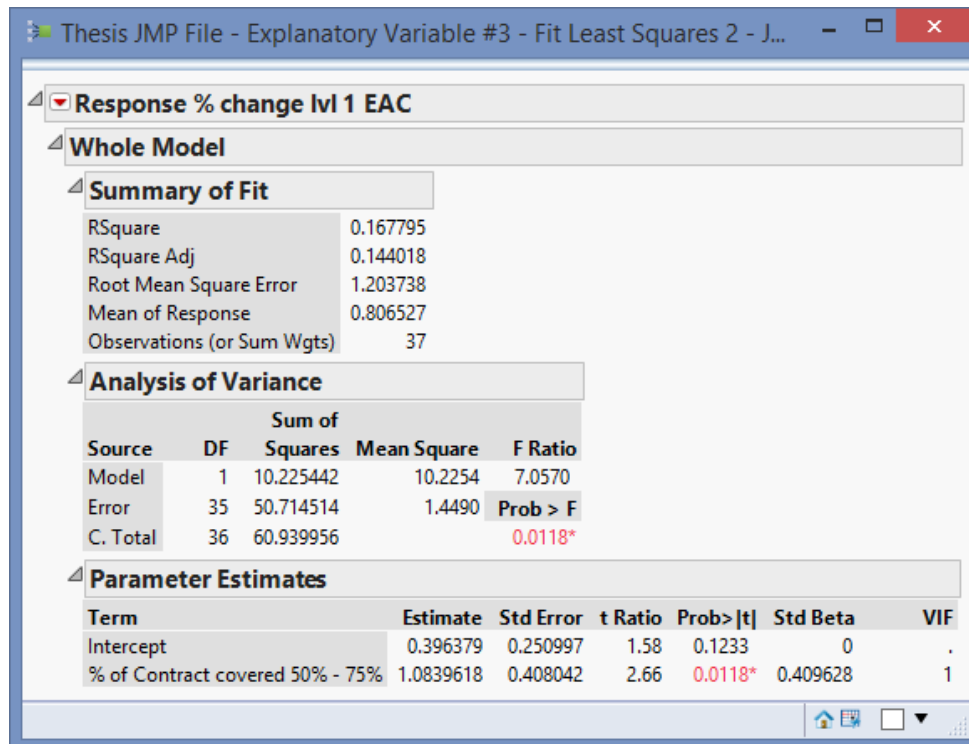
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	13.684036	6.84202	4.8051
Error	33	46.988487	1.42389	Prob > F
C. Total	35	60.672523		0.0147*

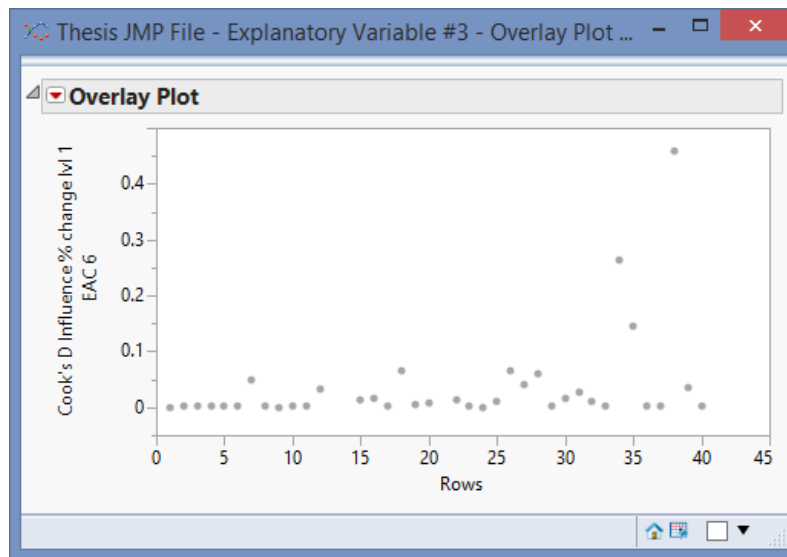
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.5459517	0.276188	1.98	0.0565	0	.
ELECTRONIC/AUTOMATED SOFTWARE	-0.573362	0.459546	-1.25	0.2209	-0.19124	1.0011161
% of Contract covered 50% - 75%	1.1577739	0.414283	2.79	0.0086*	0.428363	1.0011161



Growth Definition #3 Bin - 15%





Growth Definition #3 Bin - 20%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.747205
RSquare Adj	0.397181
Root Mean Square Error	0.482291
Mean of Response	0.463572
Observations (or Sum Wgts)	32

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	18	8.937827	0.496546	2.1347
Error	13	3.023854	0.232604	Prob > F
C. Total	31	11.961682		0.0841

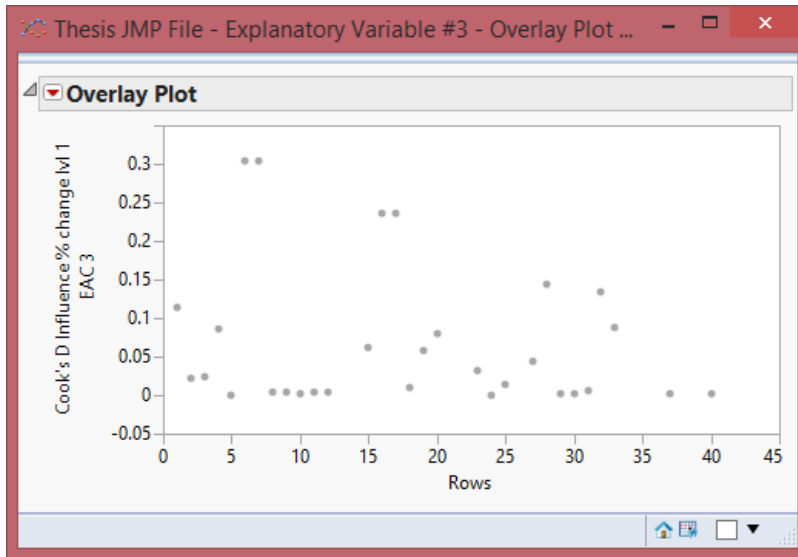
Lack Of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	1.4859253	0.438057	3.39	0.0048*	0	.
# Lvl 5 with EAC data elements > 30 and < 150	-0.509461	0.277445	-1.84	0.0893	-0.41337	2.6060836
RDT&E	0.2303898	0.247795	0.93	0.3694	0.182431	1.9798311
Air Force	0.8813121	0.444894	1.98	0.0692	0.476725	2.9782624
ELECTRONIC/AUTOMATED SOFTWARE	-0.225637	0.248786	-0.91	0.3809	-0.16593	1.7212942
Ordnance	0.1279465	0.465472	0.27	0.7877	0.050656	1.7465091
Ship	-0.6629	0.417073	-1.59	0.1360	-0.35858	2.6174318
Space	1.2021825	0.724801	1.66	0.1211	0.342121	2.1879244
UAV	-0.297676	0.450099	-0.66	0.5199	-0.11786	1.6330539
Other 2	-0.483521	0.555154	-0.87	0.3996	-0.19143	2.4843411
CPFF	-0.72487	0.475237	-1.53	0.1511	-0.34558	2.639811
CPIF	-0.407821	0.264449	-1.54	0.1470	-0.30918	2.0669906
Lockheed Martin Corporation	0.2529987	0.458416	0.55	0.5904	0.100167	1.6939585
Telephonics Corporation	0.1534961	0.560733	0.27	0.7886	0.043682	1.3095026
The Boeing Company	-1.420065	0.537571	-2.64	0.0203*	-0.67701	3.3777153
12 - 24 Months	-0.970825	0.27158	-3.57	0.0034*	-0.78772	2.4970512
24 - 36	-0.698966	0.353891	-1.98	0.0699	-0.47261	2.9444852
% of Contract covered 25% - 50%	0.497168	0.357712	1.39	0.1879	0.295256	2.3207787
% of Contract covered > 75%	-0.279752	0.289052	-0.97	0.3508	-0.21732	2.592955

Effect Tests

Effect Details



Growth Definition #3 Bin - 25%

Thesis JMP File - Explanatory Variable #3 - Fit Least Squares 2 - J...

Response % change lvl 1 EAC

Whole Model

Summary of Fit

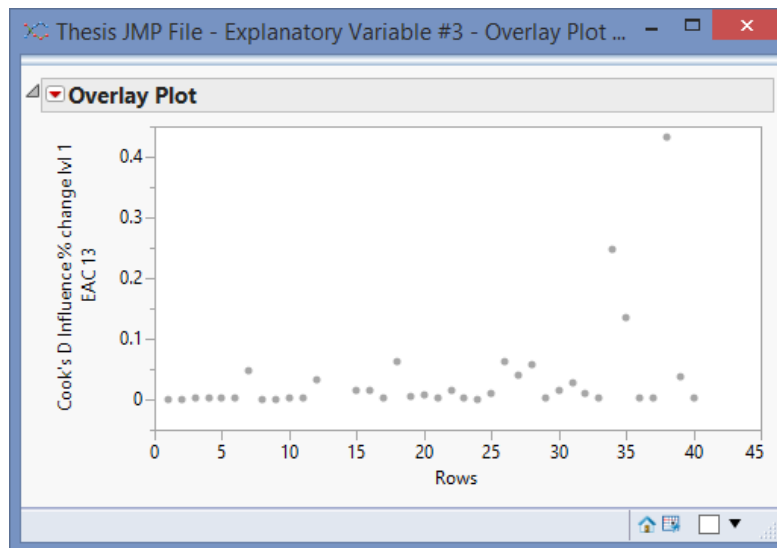
RSquare	0.178451
RSquare Adj	0.15563
Root Mean Square Error	1.187727
Mean of Response	0.831491
Observations (or Sum Wgts)	38

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	11.031171	11.0312	7.8197
Error	36	50.785003	1.4107	Prob > F
C. Total	37	61.816173		0.0082*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.396379	0.247658	1.60	0.1182	0	.
% of Contract covered 50% - 75%	1.1022828	0.394184	2.80	0.0082*	0.422435	1



Growth Definition #3 Bin – 30%

Thesis JMP File - Explanatory Variable #3 - Fit Least Squares 2 ...

Response % change lvl 1 EAC

Whole Model

Summary of Fit

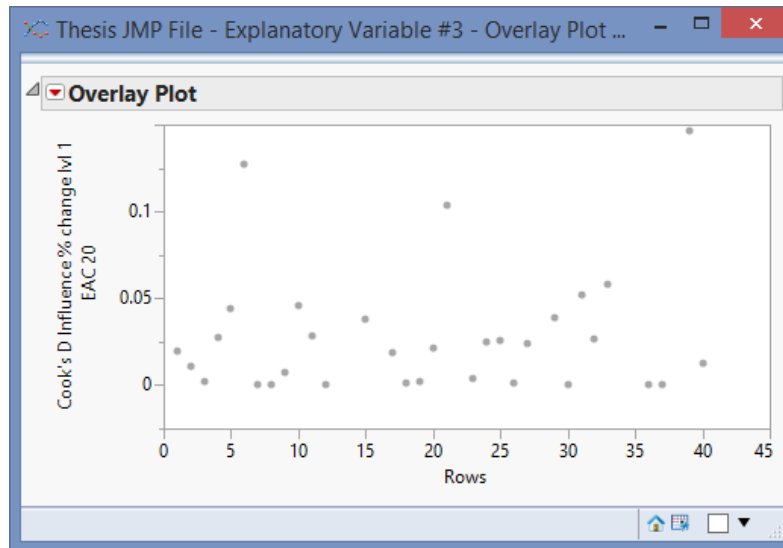
RSquare	0.515625
RSquare Adj	0.463728
Root Mean Square Error	0.425855
Mean of Response	0.4458
Observations (or Sum Wgts)	32

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	5.405490	1.80183	9.9355
Error	28	5.077875	0.18135	Prob > F
C. Total	31	10.483365		0.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	1.1476122	0.163679	7.01	<.0001*	0	.
Navy	-0.466747	0.165764	-2.82	0.0088*	-0.38731	1.09375
Washington Demil Company	-0.965266	0.456227	-2.12	0.0434*	-0.29343	1.1118608
12 - 24 Months	-0.779403	0.155058	-5.03	<.0001*	-0.67953	1.0564631



Growth Definition #3 Bin - 35%

Thesis JMP File - Explanatory Variable #3 - Fit Least Squares - JMP

Response % change lvl 1 EAC

Whole Model

Summary of Fit

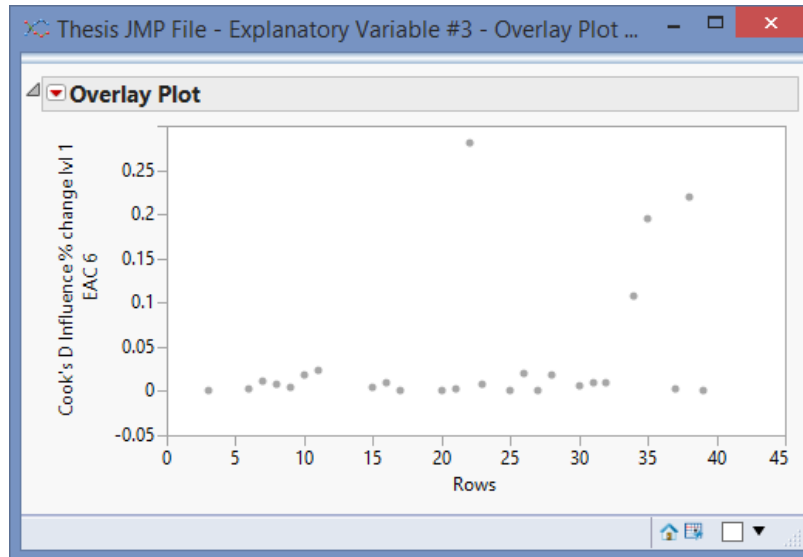
RSquare	0.308683
RSquare Adj	0.248569
Root Mean Square Error	1.243791
Mean of Response	1.180523
Observations (or Sum Wgts)	26

Analysis of Variance

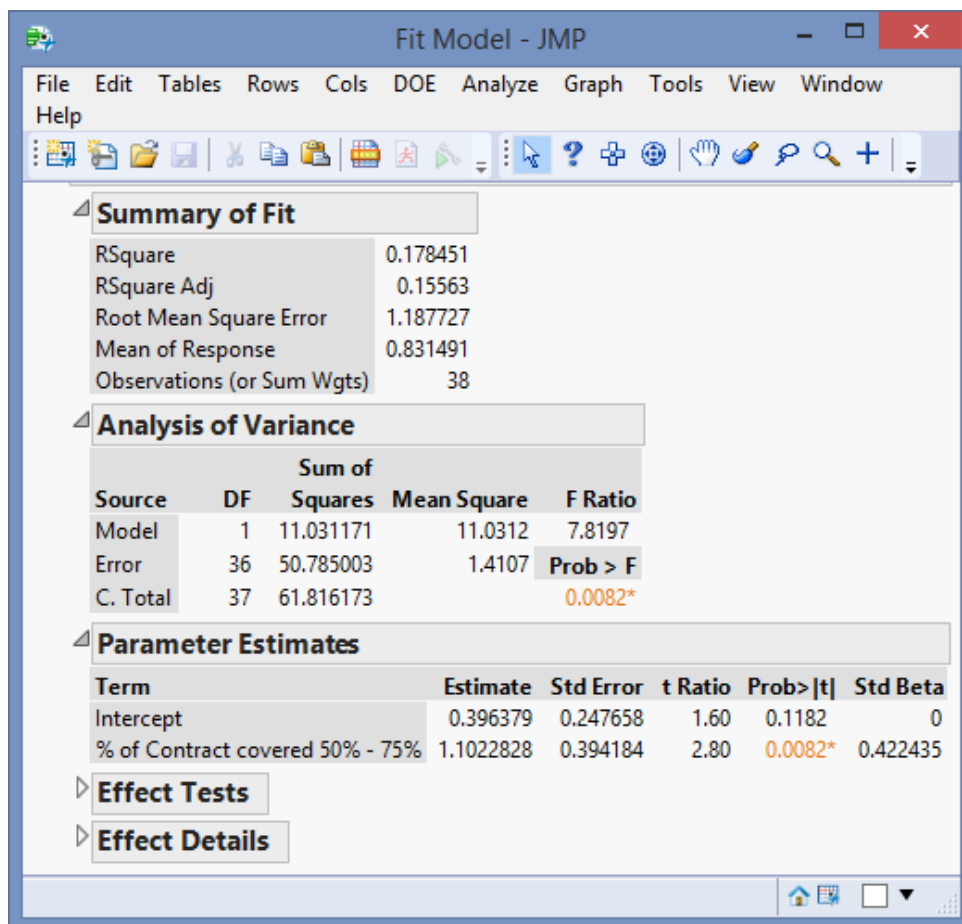
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	15.887604	7.94380	5.1349
Error	23	35.581378	1.54702	Prob > F
C. Total	25	51.468982		0.0143*

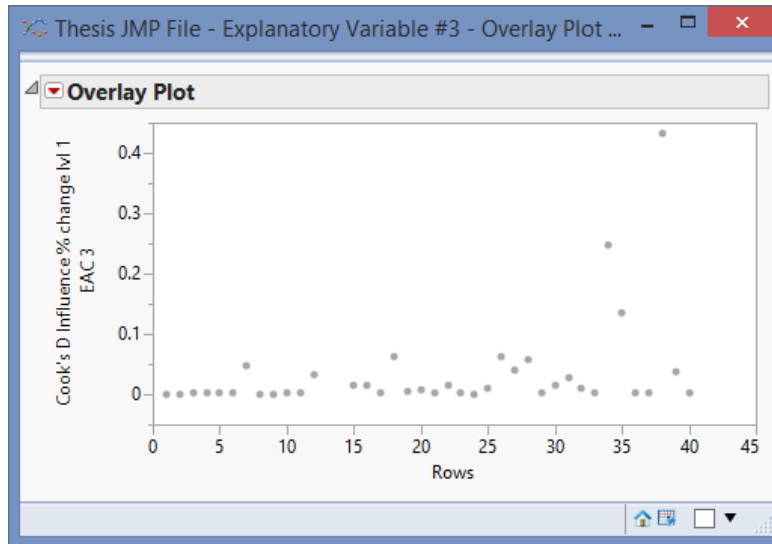
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	1.2467516	0.287181	4.34	0.0002*	0	.
FPIF	-1.091335	0.578953	-1.89	0.0721	-0.32681	1.0000001
Lvl 3 Cum Change / Final Lvl 1 EAC	35% 1.0103857	0.389785	2.59	0.0163*	0.449403	1.0000001



Growth Definition #3 Bin - 40%





Growth Definition #3 Bin - 45%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.993052
RSquare Adj	0.988421
Root Mean Square Error	0.094069
Mean of Response	0.86612
Observations (or Sum Wgts)	11

Analysis of Variance

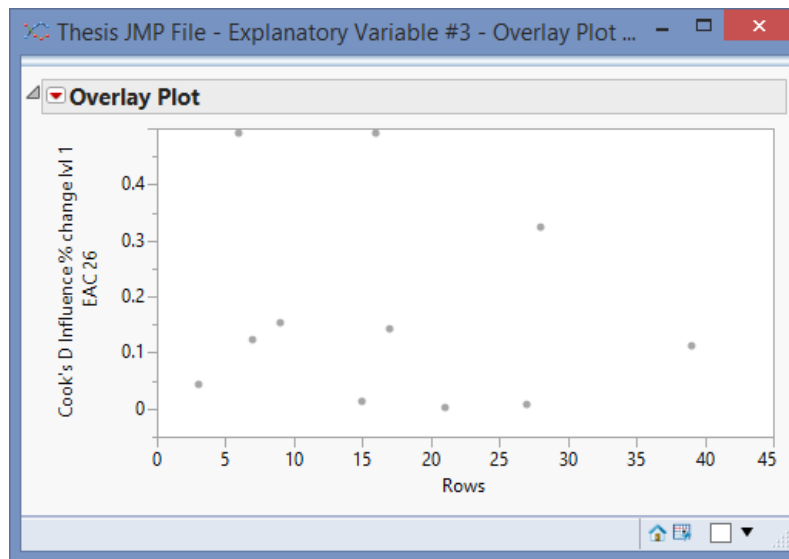
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	7.5890570	1.89726	214.4039
Error	6	0.0530941	0.00885	Prob > F
C. Total	10	7.6421511		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	-0.203701	0.062453	-3.26	0.0172*	0	.
CPAF	1.098726	0.082853	13.26	<.0001*	0.508419	1.2694015
Greater than 36	0.520096	0.06346	8.20	0.0002*	0.300164	1.158443
% of Contract covered 50% - 75%	-0.204551	0.06391	-3.20	0.0186*	-0.11805	1.1749083
Lvl 3 Cum Change / Final Lvl 1 EAC 45%	4.1069115	0.205551	19.98	<.0001*	0.691675	1.0349828

Effect Tests

Effect Details



Growth Definition #3 Bin - 50%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.991076
RSquare Adj	0.982151
Root Mean Square Error	0.049064
Mean of Response	0.368184
Observations (or Sum Wgts)	9

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	1.0693217	0.267330	111.0518
Error	4	0.0096290	0.002407	Prob > F
C. Total	8	1.0789507		0.0002*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	-0.019485	0.031365	-0.62	0.5681	0	.	
Army	0.2448289	0.04418	5.54	0.0052*	0.293971	1.2612773	
CPIF	0.0902074	0.036304	2.48	0.0679	0.122816	1.0949862	
Harris Corporation	0.5261825	0.062453	8.43	0.0011*	0.477595	1.4402397	
Lvl 3 Cum Change / Final Lvl 1 EAC	50%	1.8111293	0.145488	12.45	0.0002*	0.763015	1.6838318

Effect Tests

Effect Details

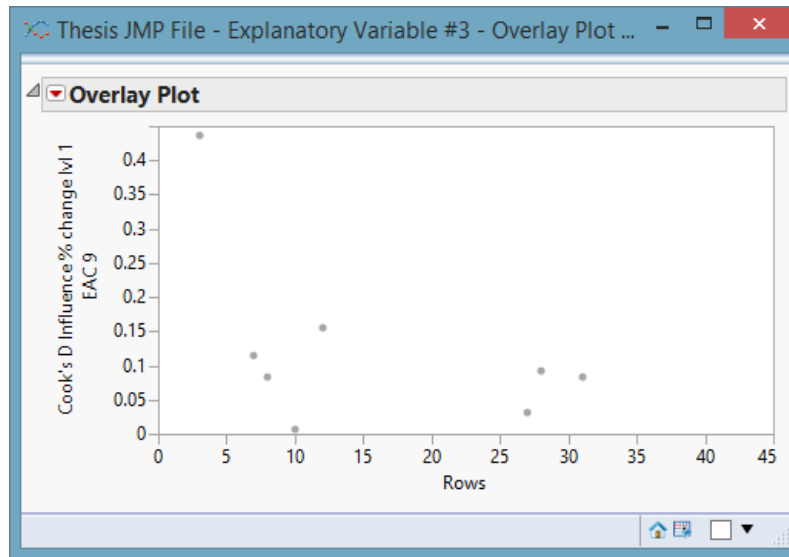
Home

Fit

Plot

Save

▼



Growth Definition #3 Bin - 55%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.996923
RSquare Adj	0.993406
Root Mean Square Error	0.057874
Mean of Response	0.753243
Observations (or Sum Wgts)	16

Analysis of Variance

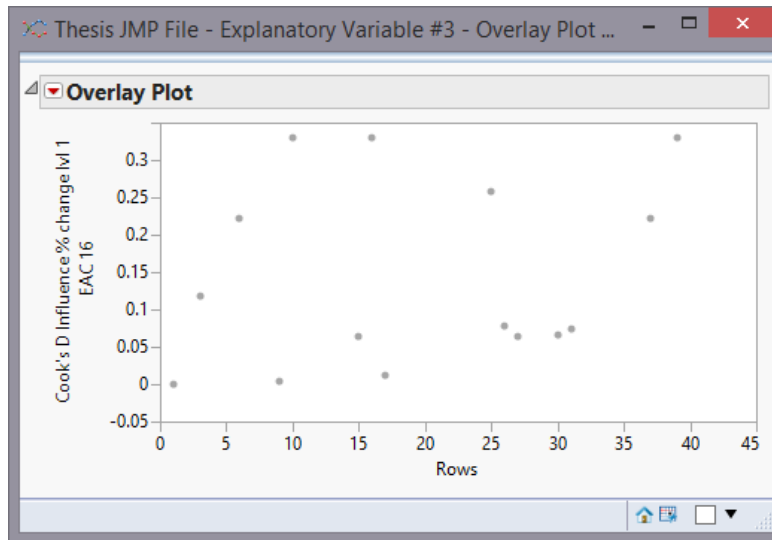
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	7.5962567	0.949532	283.4947
Error	7	0.0234457	0.003349	Prob > F
C. Total	15	7.6197024		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	-0.309122	0.068111	-4.54	0.0027*	0	.	
# Lvl 5 with EAC data elements > = 150	0.4501135	0.057376	7.84	0.0001*	0.302325	3.3786207	
Air Force	1.0977052	0.060175	18.24	<.0001*	0.526061	1.8919558	
Raytheon Company	0.1663711	0.071256	2.33	0.0522	0.058357	1.4211752	
The Boeing Company	-0.404951	0.055708	-7.27	0.0002*	-0.19407	1.6214933	
12 - 24 Months	0.2449866	0.072737	3.37	0.0120*	0.164549	5.429879	
Greater than 36	0.6935551	0.053188	13.04	<.0001*	0.502507	3.3784945	
% of Contract covered 50% - 75%	0.1591668	0.038451	4.14	0.0044*	0.114418	1.7380952	
Lvl 3 Cum Change / Final Lvl 1 EAC	55%	1.5566072	0.097711	15.93	<.0001*	0.44685	1.78989

Effect Tests

Effect Details



Growth Definition #3 Bin - 60%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.906008
RSquare Adj	0.843347
Root Mean Square Error	0.273841
Mean of Response	0.502396
Observations (or Sum Wgts)	16

Analysis of Variance

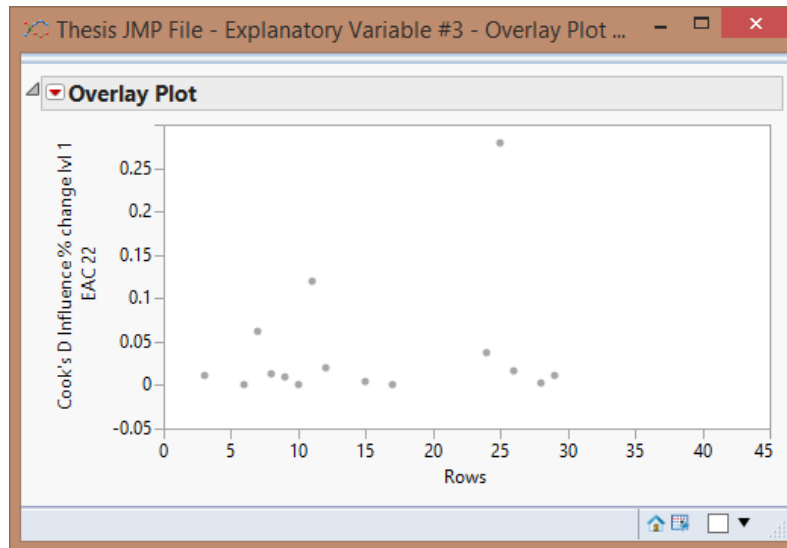
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	6.5055143	1.08425	14.4589
Error	9	0.6748991	0.07499	Prob > F
C. Total	15	7.1804134		0.0004*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	0.2030221	0.120872	1.68	0.1273	0	.	
Total # Lvl 3 Elements	-0.003159	0.0042	-0.75	0.4712	-0.08194	1.1364166	
Missile	-1.916312	0.417328	-4.59	0.0013*	-0.69243	2.1773584	
Ship	0.3176228	0.185375	1.71	0.1208	0.185059	1.1169902	
EG&G	1.221276	0.304057	4.02	0.0030*	0.441291	1.1558079	
Lockheed Martin Corporation	1.7343258	0.309927	5.60	0.0003*	0.8562	2.2416188	
Lvl 5 Cum Change / Final Lvl 1 EAC	60%	0.7810687	0.22803	3.43	0.0076*	0.396576	1.2835474

Effect Tests

Effect Details



Growth Definition #3 Bin - 65%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.993305
RSquare Adj	0.984379
Root Mean Square Error	0.157231
Mean of Response	0.843488
Observations (or Sum Wgts)	22

Analysis of Variance

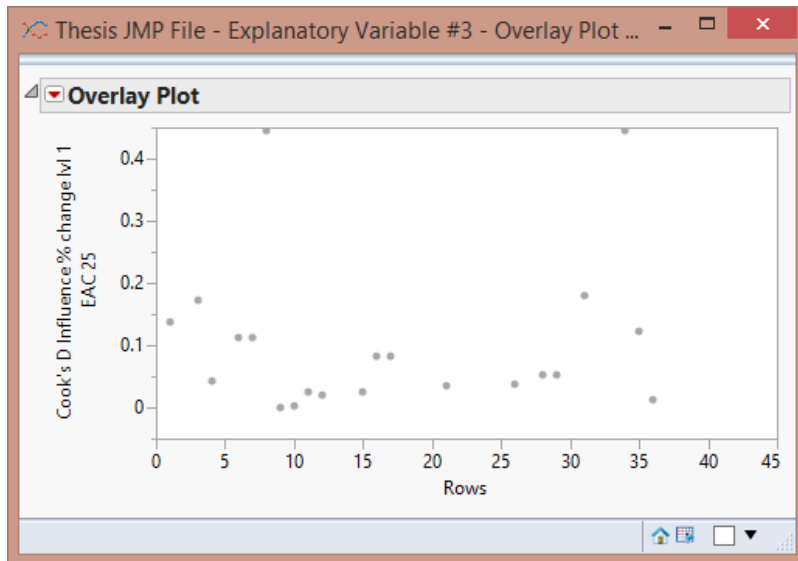
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	12	33.010959	2.75091	111.2762
Error	9	0.222493	0.02472	Prob > F
C. Total	21	33.233453		<.0001*

Parameter Estimates

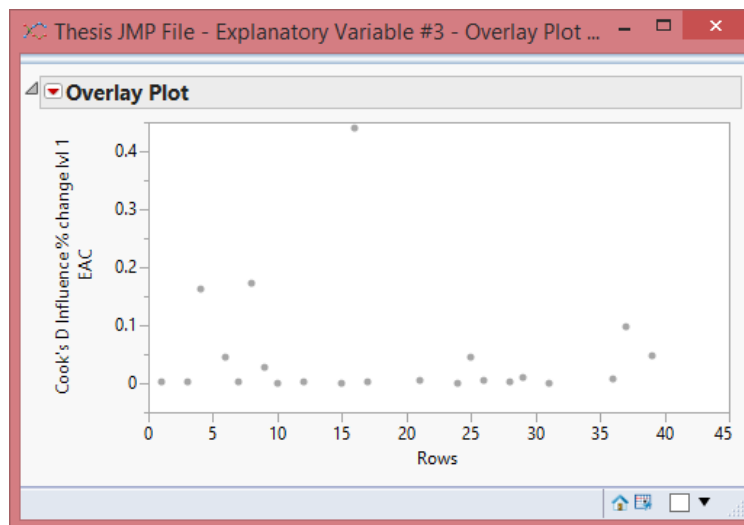
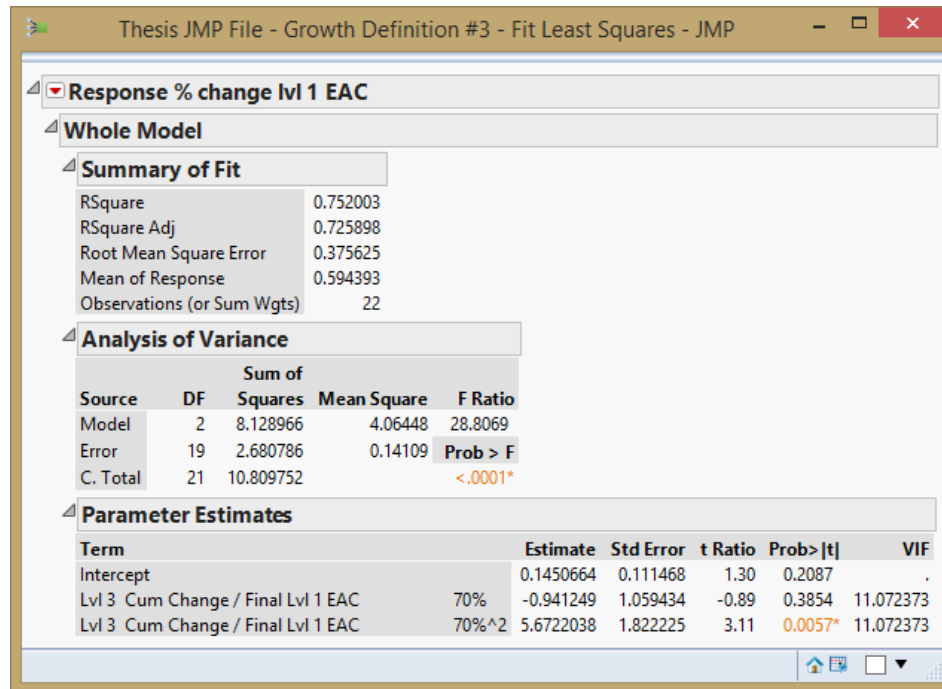
Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	0.3630338	0.105477	3.44	0.0074*	0	.	
# Lvl 5 with EAC data elements > 30 and < 150	-0.388665	0.127704	-3.04	0.0139*	-0.14084	2.8786318	
# Lvl 5 with EAC data elements > = 150	-1.270957	0.145218	-8.75	<.0001*	-0.43335	3.2958283	
Prod	0.5874598	0.106984	5.49	0.0004*	0.222625	2.209669	
Army	-1.026624	0.113984	-9.01	<.0001*	-0.38905	2.508289	
Other 2	1.3660033	0.238019	5.74	0.0003*	0.319509	4.1666377	
CPAF	-0.413122	0.11591	-3.56	0.0061*	-0.15656	2.593772	
CPFF	-0.936785	0.118478	-7.91	<.0001*	-0.26156	1.4711468	
Harris Corporation	-0.508516	0.205813	-2.47	0.0355*	-0.08618	1.6355665	
Lockheed Martin Corporation	0.8365008	0.165879	5.04	0.0007*	0.195658	2.0237081	
Northrop Grumman Corporation	-0.662312	0.095346	-6.95	<.0001*	-0.22583	1.4207923	
24 - 36	1.8089585	0.133042	13.60	<.0001*	0.505088	1.8550602	
Lvl 3 Cum Change / Final Lvl 1 EAC	65%	3.7900738	0.153593	24.68	<.0001*	0.77563	1.3281796

Effect Tests

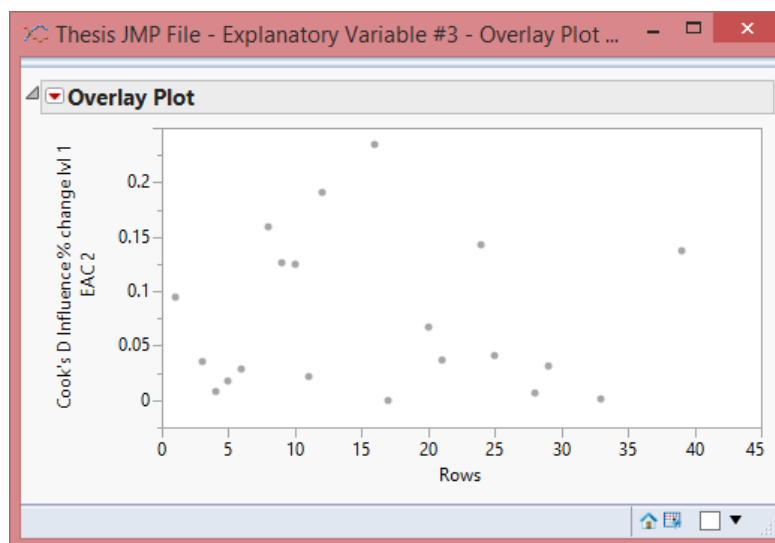
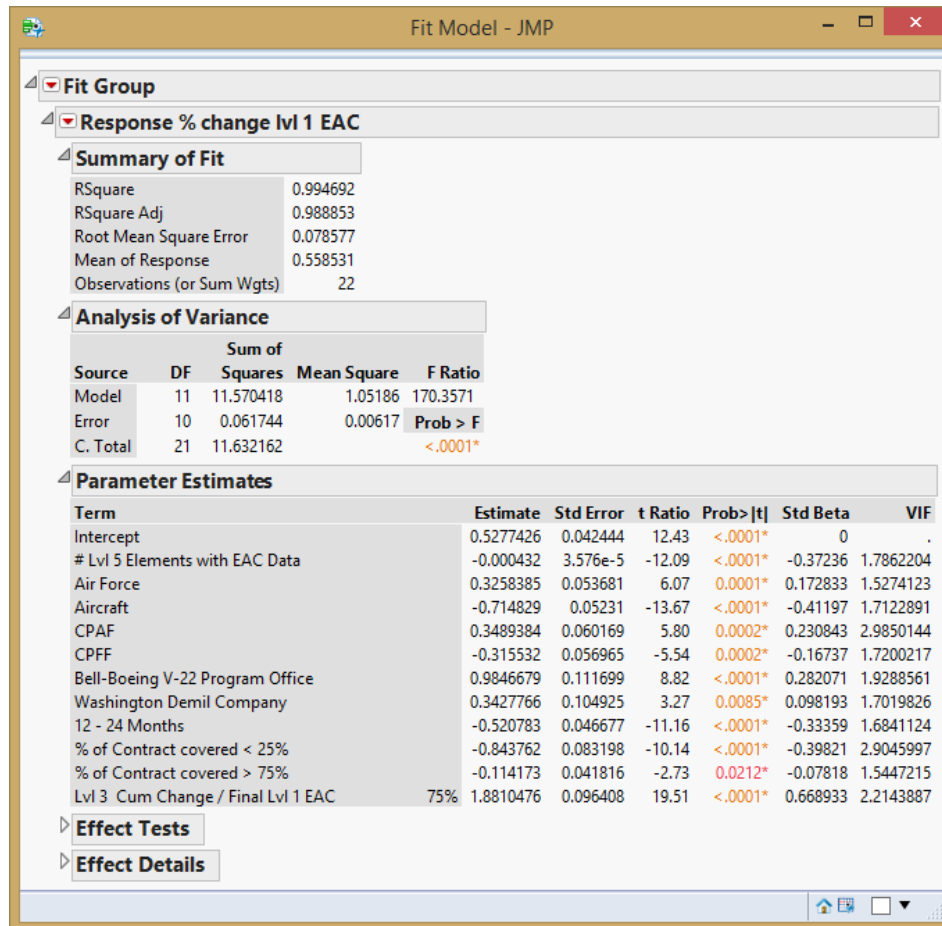
Effect Details



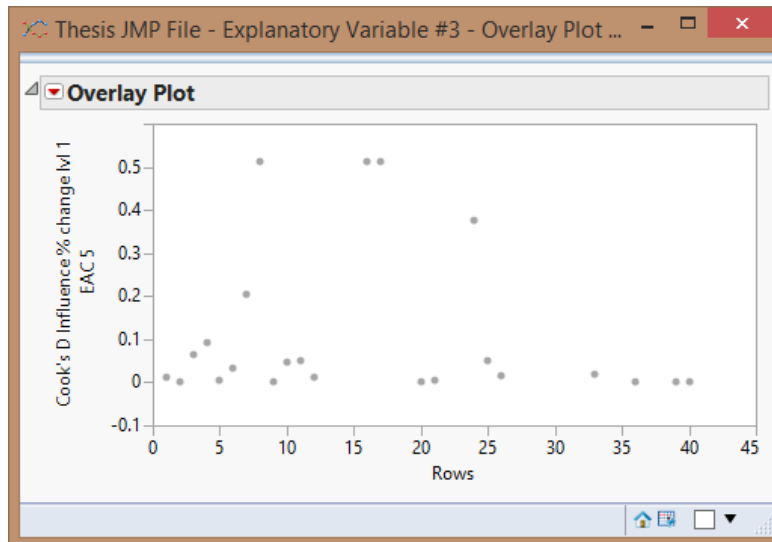
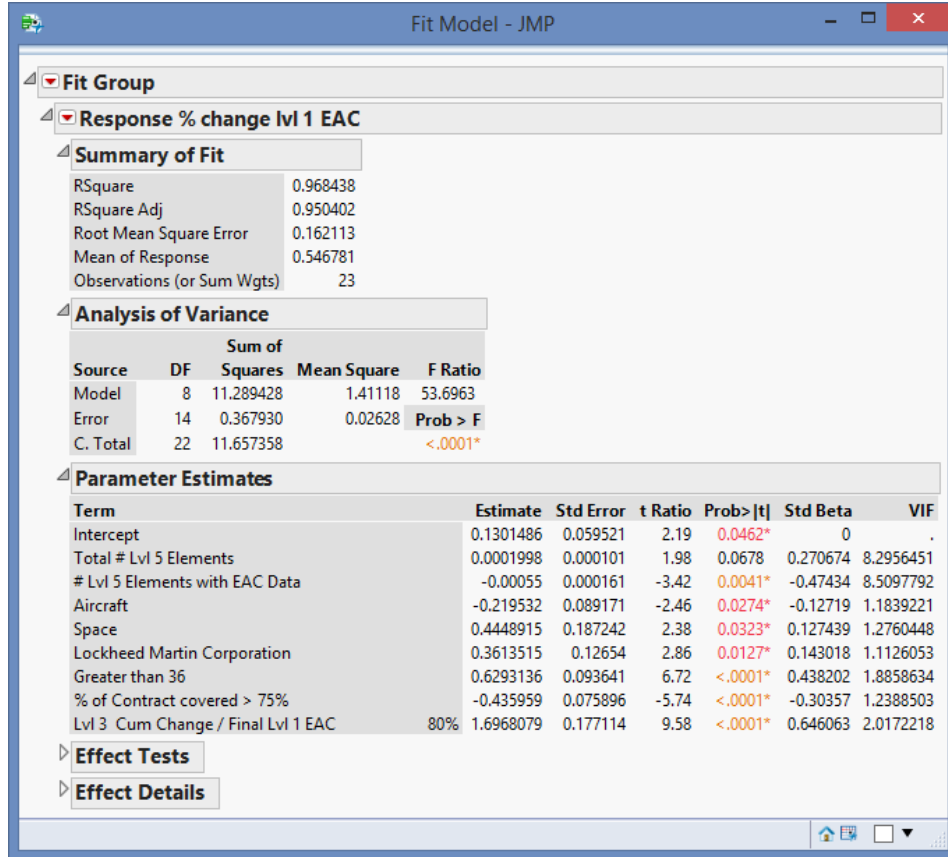
Growth Definition #3 Bin - 70%



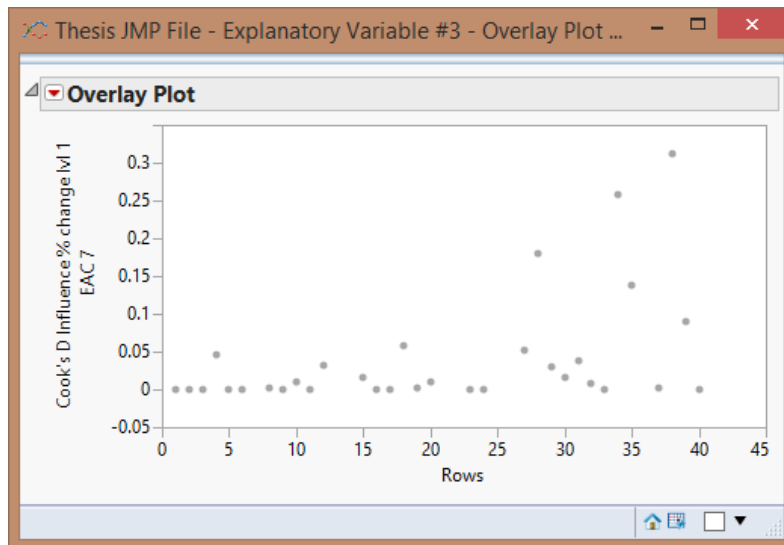
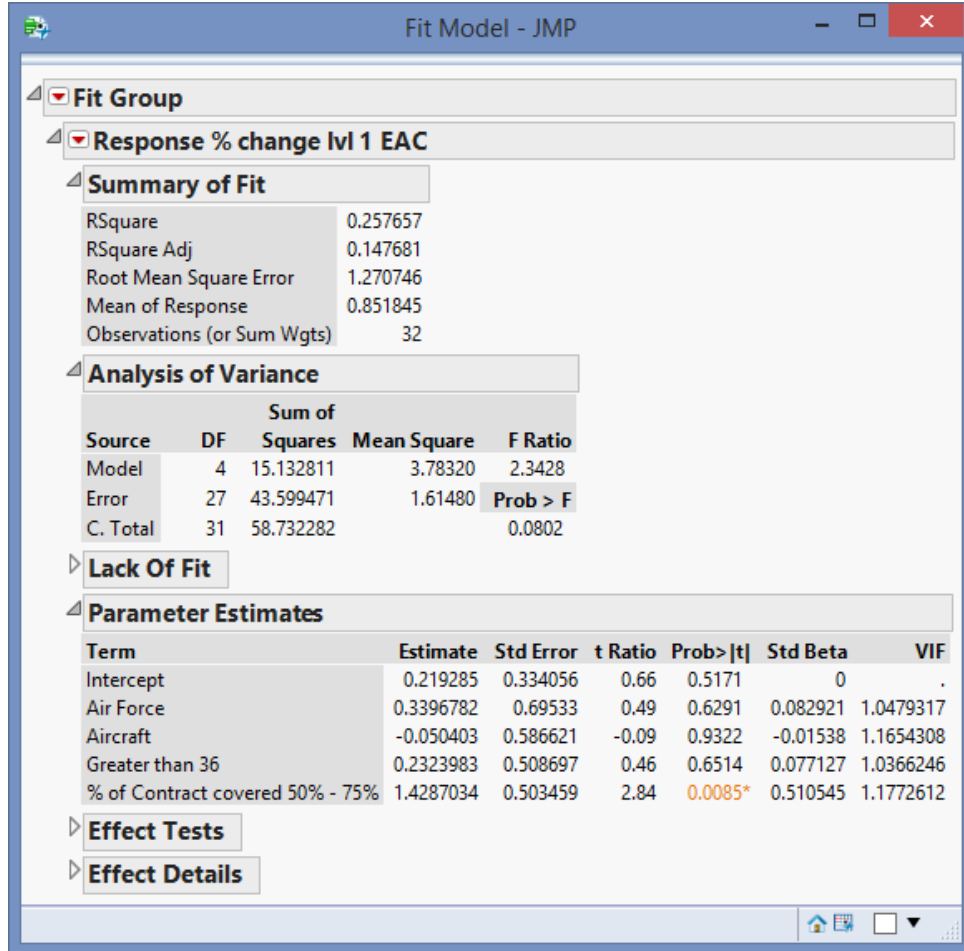
Growth Definition #3 Bin - 75%



Growth Definition #3 Bin - 80%



Growth Definition #3 Bin - 85%



Growth Definition #3 Bin - 90%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.046627
RSquare Adj	-0.08049
Root Mean Square Error	1.37501
Mean of Response	0.76196
Observations (or Sum Wgts)	35

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	2.773984	0.69350	0.3668
Error	30	56.719570	1.89065	Prob > F
C. Total	34	59.493553		0.8303

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	1	0.000548	0.00055	0.0003
Pure Error	29	56.719022	1.95583	Prob > F
Total Error	30	56.719570		0.9868

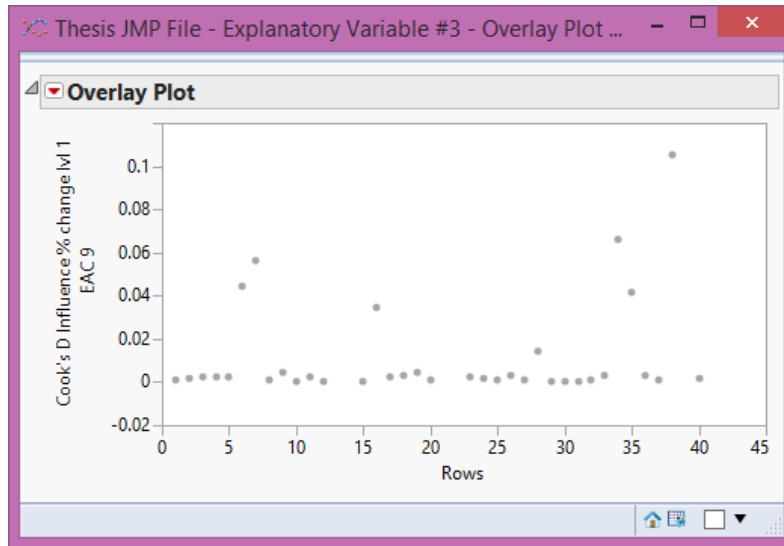
Max RSq
0.0466

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.7644462	0.277983	2.75	0.0100*	0	.
Other 2	-0.720439	1.463927	-0.49	0.6262	-0.12826	2.1374854
EG&G	1.6401147	1.944558	0.84	0.4057	0.209578	1.9428571
The Boeing Company	-0.834817	1.015051	-0.82	0.4173	-0.14863	1.0276372
Greater than 36	0.1383391	0.565156	0.24	0.8083	0.047934	1.2066952

Effect Tests

Effect Details



Growth Definition #3 Bin - 95%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.145953
RSquare Adj	-0.0602
Root Mean Square Error	1.346754
Mean of Response	0.81874
Observations (or Sum Wgts)	37

Analysis of Variance

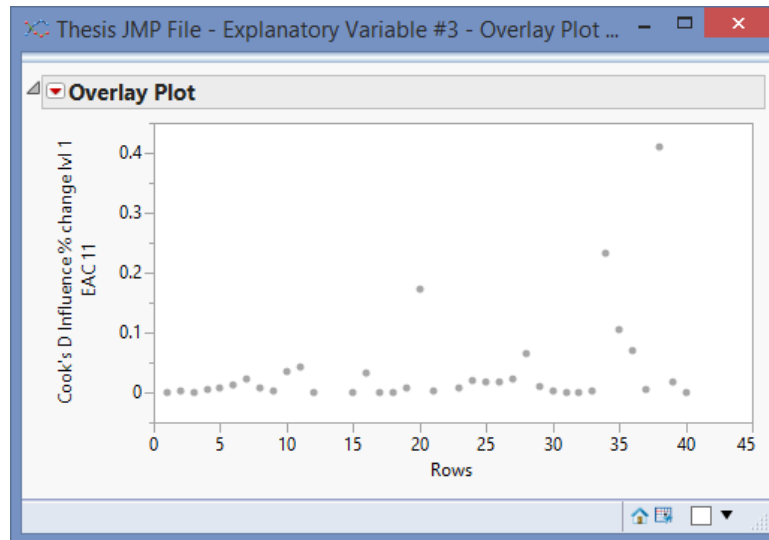
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	7	8.988916	1.28413	0.7080	
Error	29	52.598663	1.81375		
C. Total	36	61.587579			0.6654

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	-0.115251	0.620535	-0.19	0.8540	0	.
Total # Lvl 3 Elements	0.0213055	0.013372	1.59	0.1219	0.337286	1.5216863
Prod	0.8209731	0.529969	1.55	0.1322	0.30378	1.305801
Navy	-0.037243	0.500848	-0.07	0.9412	-0.01351	1.1213853
Aircraft	0.4053572	0.54172	0.75	0.4603	0.139532	1.1806871
CPFF	-0.188159	0.779173	-0.24	0.8109	-0.04529	1.1941628
CPIF	0.4347107	0.528186	0.82	0.4172	0.15773	1.2471456
Greater than 36	0.0461569	0.529181	0.09	0.9311	0.016747	1.2518482

Effect Tests

Effect Details



Growth Definition #3 Bin - 100%

Thesis JMP File - Explanatory Variable #3 - Fit Least Squares - J...

Response % change lvl 1 EAC

Whole Model

Summary of Fit

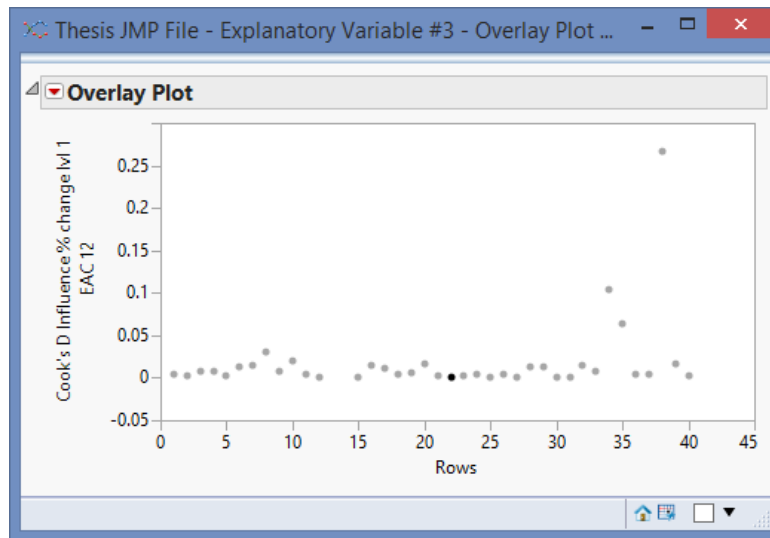
RSquare	0.034283
RSquare Adj	-0.11661
Root Mean Square Error	1.365844
Mean of Response	0.831491
Observations (or Sum Wgts)	38

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	5	2.119259	0.42385	0.2272	
Error	32	59.696914	1.86553		
C. Total	37	61.816173			0.9480

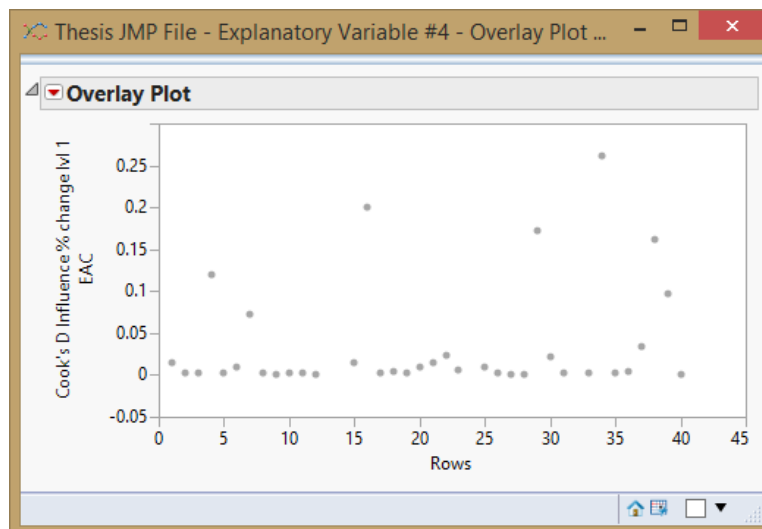
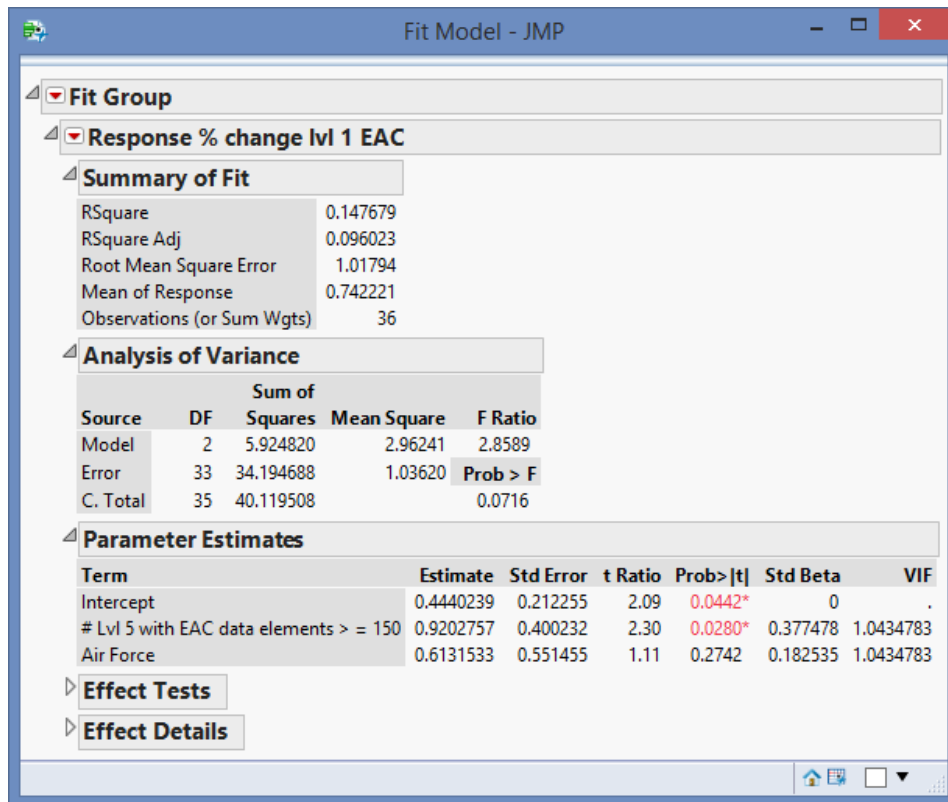
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.6714592	0.370852	1.81	0.0796	0	.
# Lvl 3 Elements with EAC Data	0.008747	0.017303	0.51	0.6166	0.113409	1.6676063
# Lvl 5 Elements with EAC Data	-0.000186	0.000541	-0.34	0.7333	-0.07201	1.4549512
Missile	-0.309341	0.672507	-0.46	0.6486	-0.08199	1.0526687
Top 3 DOD Contractor	0.1183296	0.492148	0.24	0.8115	0.045348	1.1787607
Greater than 36	0.175749	0.527354	0.33	0.7411	0.065372	1.2749774

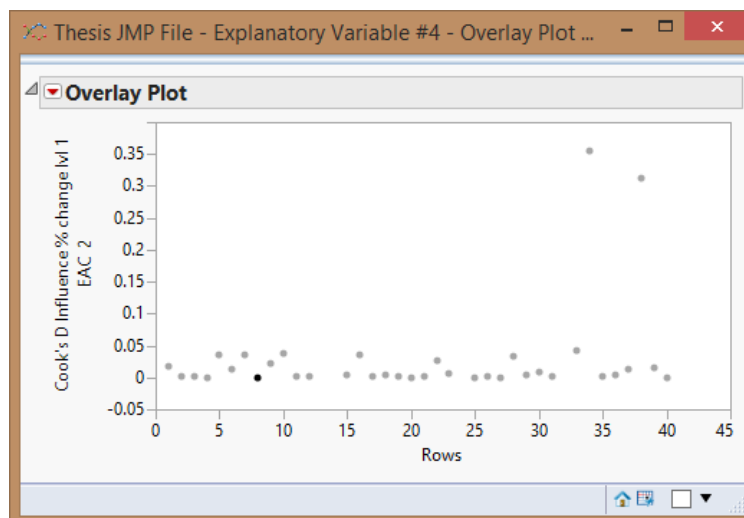
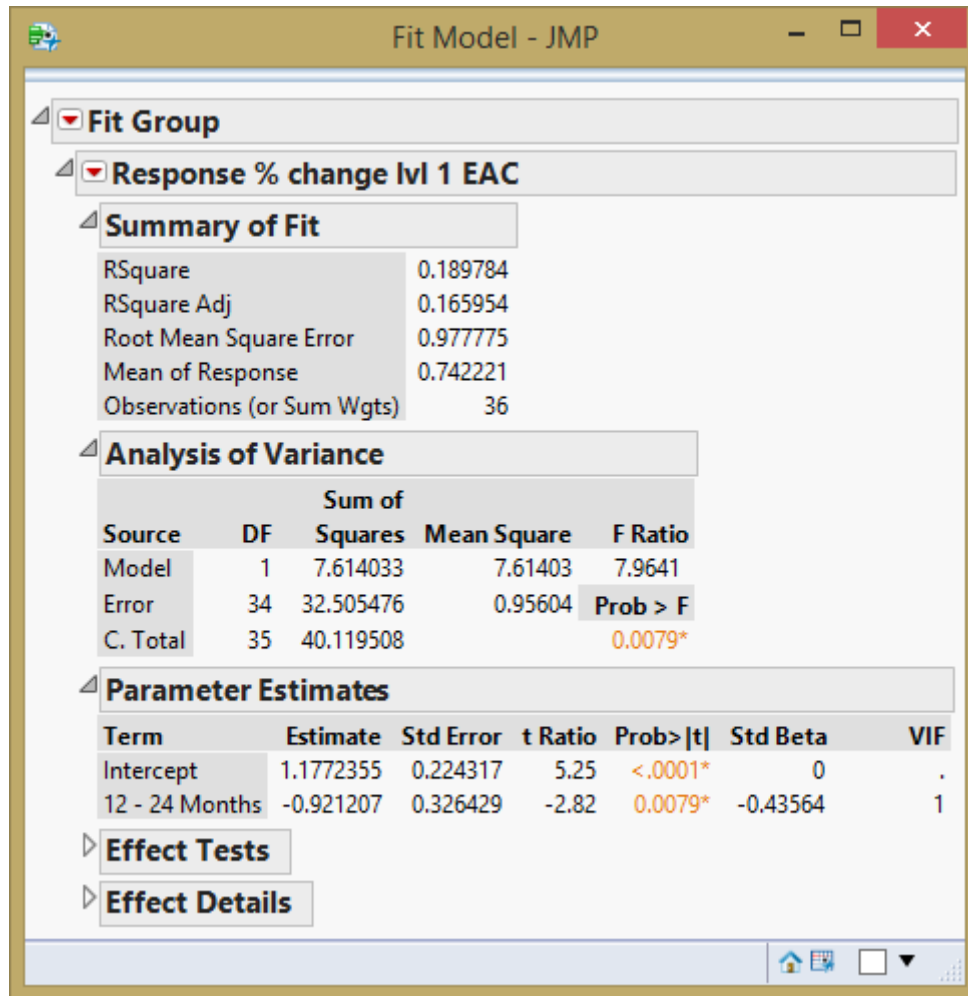


Appendix G – JMP® Output Screens for Growth Definition #4

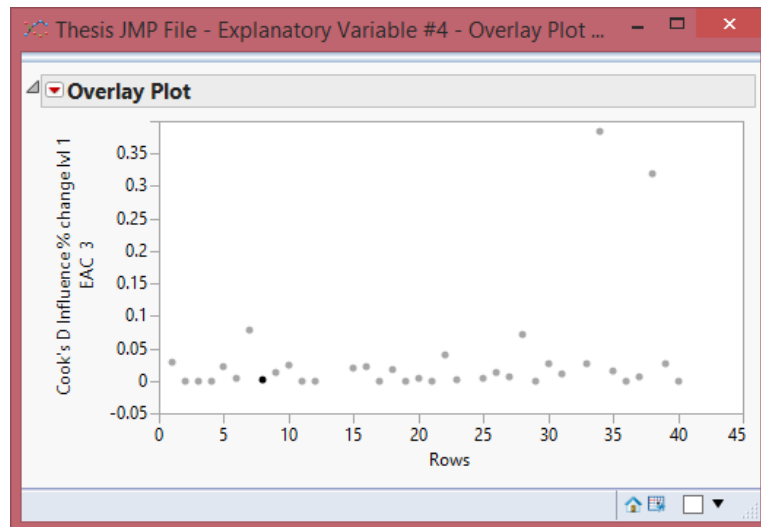
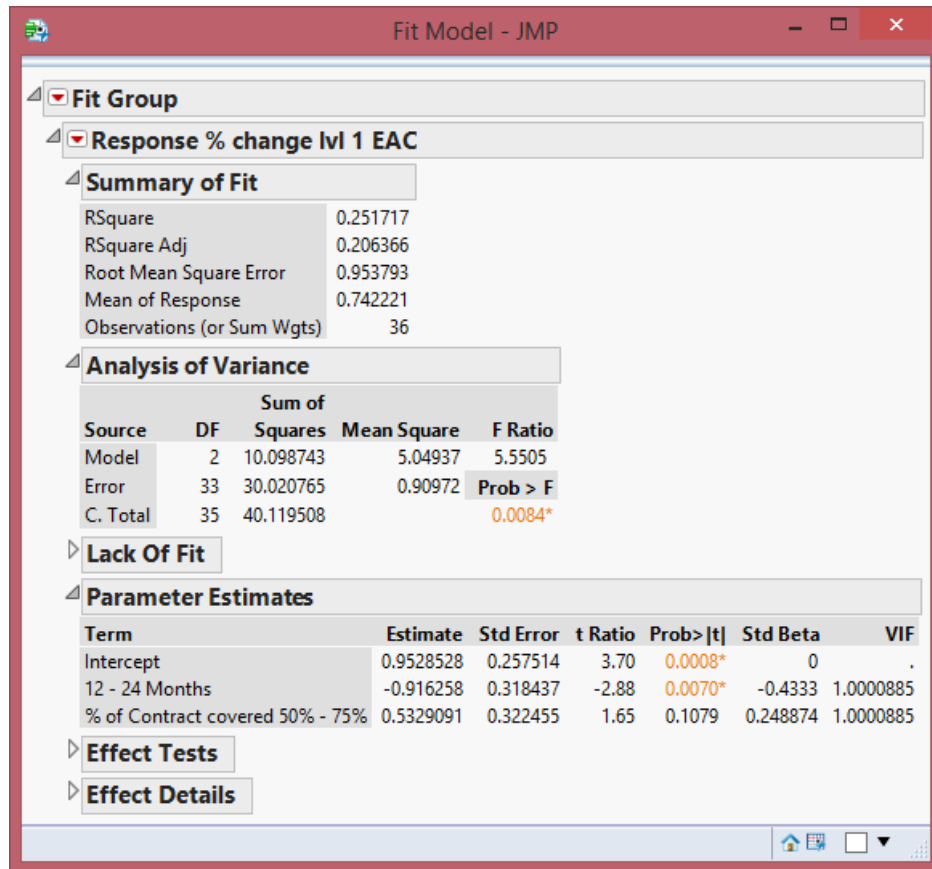
Growth Definition #4 Bin - 5%



Growth Definition #4 Bin - 10%



Growth Definition #4 Bin - 15%



Growth Definition #4 Bin - 20%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.644684
RSquare Adj	0.348587
Root Mean Square Error	0.447244
Mean of Response	0.366097
Observations (or Sum Wgts)	23

Analysis of Variance

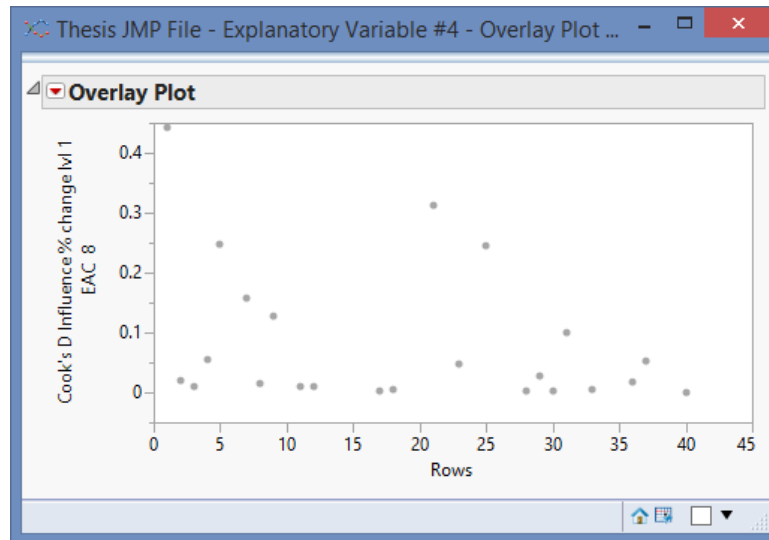
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	10	4.3551301	0.435513	2.1773
Error	12	2.4003214	0.200027	Prob > F
C. Total	22	6.7554515		0.1014

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.082598	0.260572	0.32	0.7567	0	.
# Lvl 3 Elements with EAC Data	0.0173387	0.007885	2.20	0.0482*	0.632838	2.7970384
RDT&E	0.4917713	0.251002	1.96	0.0737	0.442851	1.72547
Ordance	0.9115649	0.509883	1.79	0.0991	0.473938	2.3734167
CPAF	-0.044308	0.343916	-0.13	0.8996	-0.03762	2.8794365
CPIF	-0.46163	0.331802	-1.39	0.1894	-0.37403	2.4408633
FPIF	-0.132235	0.363262	-0.36	0.7222	-0.09248	2.1799065
Northrop Grumman Corporation	0.2559019	0.341407	0.75	0.4680	0.20734	2.5842139
Top 5 DOD Contractor	-0.553368	0.348049	-1.59	0.1378	-0.48631	3.1597044
Greater than 36	0.2728803	0.293683	0.93	0.3711	0.231681	2.0997045
% of Contract covered 50% - 75%	-0.091681	0.243527	-0.38	0.7131	-0.07784	1.443767

Effect Tests

Effect Details



Growth Definition #4 Bin - 25%

Thesis JMP File - Explanatory Variable #4 - Fit Least Squares - JMP

Response % change lvl 1 EAC

Whole Model

Summary of Fit

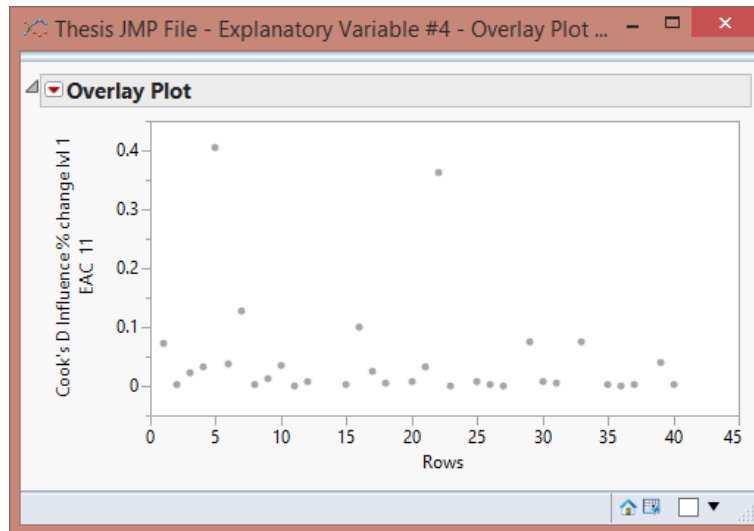
RSquare	0.55403
RSquare Adj	0.451114
Root Mean Square Error	0.550171
Mean of Response	0.5721
Observations (or Sum Wgts)	33

Analysis of Variance

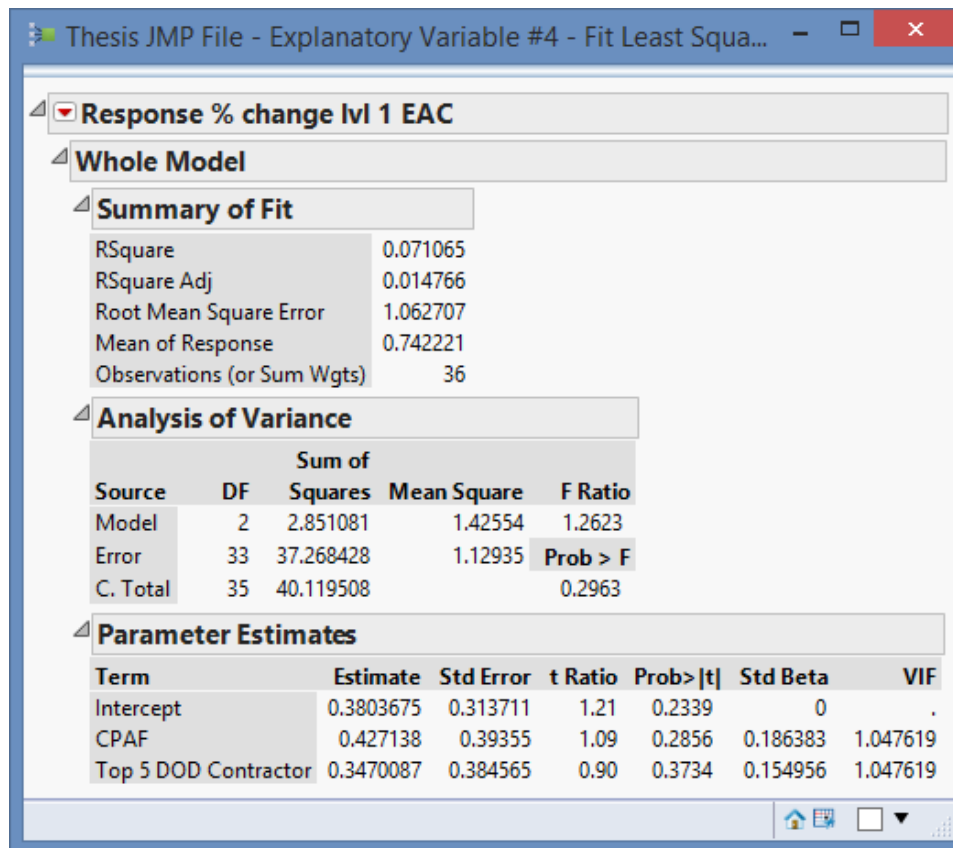
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	9.776815	1.62947	5.3833
Error	26	7.869904	0.30269	Prob > F
C. Total	32	17.646719		0.0010*

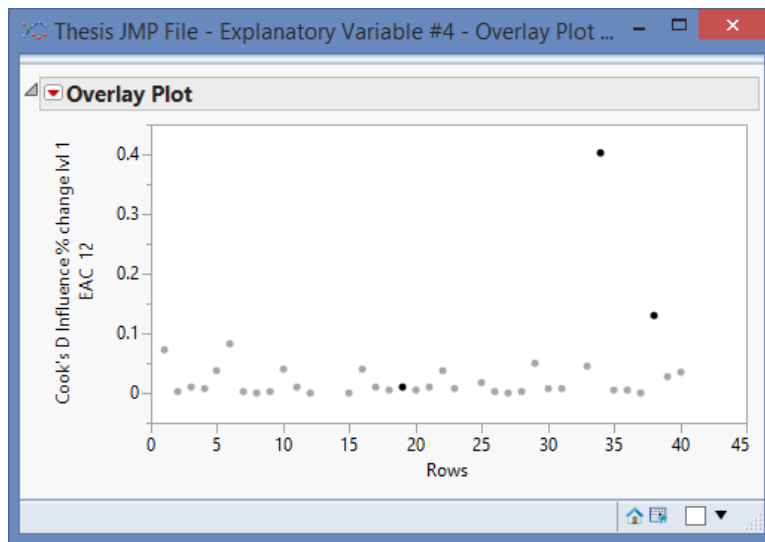
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.9780012	0.198162	4.94	<.0001*	0	.
Unknown	-1.081331	0.590698	-1.83	0.0786	-0.25348	1.1178194
Air Force	0.8356391	0.334895	2.50	0.0193*	0.372957	1.302462
General Dynamics Corporation	0.1483375	0.360604	0.41	0.6842	0.058315	1.1716361
Top 3 DOD Contractor	-0.306669	0.233771	-1.31	0.2010	-0.20491	1.4224781
12 - 24 Months	-1.025001	0.199613	-5.13	<.0001*	-0.69794	1.0770417
% of Contract covered 50% - 75%	0.2508276	0.209404	1.20	0.2418	0.1676	1.1413875



Growth Definition #4 Bin – 30%





Growth Definition #4 Bin - 35%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.949797
RSquare Adj	0.698785
Root Mean Square Error	0.503182
Mean of Response	0.769756
Observations (or Sum Wgts)	25

Analysis of Variance

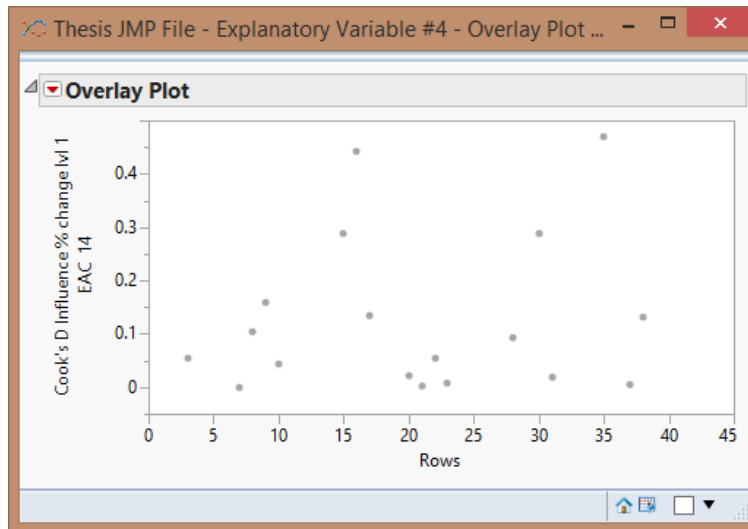
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	20	19.160847	0.958042	3.7839
Error	4	1.012767	0.253192	Prob > F
C. Total	24	20.173614		0.1026

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	-0.147145	0.657449	-0.22	0.8339	0	.	
Total # Lvl 3 Elements	0.010807	0.005381	2.01	0.1150	0.321579	2.0425465	
# Lvl 5 with EAC data elements <= 30	-0.207338	0.379643	-0.55	0.6140	-0.11307	3.4154896	
ELECTRONIC/AUTOMATED SOFTWARE	0.573556	0.403973	1.42	0.2287	0.255396	2.5781849	
Ordnance	-0.29859	0.63404	-0.47	0.6622	-0.06514	1.524246	
Ship	-0.044533	0.450875	-0.10	0.9261	-0.01817	2.6977499	
Space	0.2287475	0.677558	0.34	0.7526	0.0499	1.740661	
UAV	-0.300342	0.52503	-0.57	0.5979	-0.10865	2.8742409	
Other 2	-0.193878	0.821102	-0.24	0.8249	-0.05855	4.8996159	
CPAF	-0.20026	0.416466	-0.48	0.6557	-0.09521	3.1237354	
CPIF	0.1033562	0.394512	0.26	0.8063	0.055228	3.5407277	
Austal	-0.037358	0.948691	-0.04	0.9705	-0.00815	3.4124917	
Bell-Boeing V-22 Program Office	0.2358035	0.823681	0.29	0.7889	0.051439	2.5724049	
EG&G	0.037667	0.930557	0.04	0.9697	0.008217	3.2832771	
Harris Corporation	1.3823297	0.827161	1.67	0.1700	0.301547	2.5941895	
L-3 Communications	-0.214506	0.88916	-0.24	0.8212	-0.04679	2.9976518	
Rockwell Collins, Inc.	-0.412871	0.912154	-0.45	0.6743	-0.09007	3.1546988	
Telephonics Corporation	-0.333631	0.725644	-0.46	0.6696	-0.07278	1.9964961	
Top 5 DOD Contractor	0.1458827	0.683076	0.21	0.8413	0.077951	10.614773	
24 - 36	-0.945304	0.4598	-2.06	0.1090	-0.28549	1.5364069	
Lvl 5 Cum Change / Final Lvl 1 EAC	35%	5.4204906	1.180813	4.59	0.0101*	0.873975	2.8881353

Effect Tests

Effect Details



Growth Definition #4 Bin - 40%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.991617
RSquare Adj	0.984166
Root Mean Square Error	0.116233
Mean of Response	0.74883
Observations (or Sum Wgts)	18

Analysis of Variance

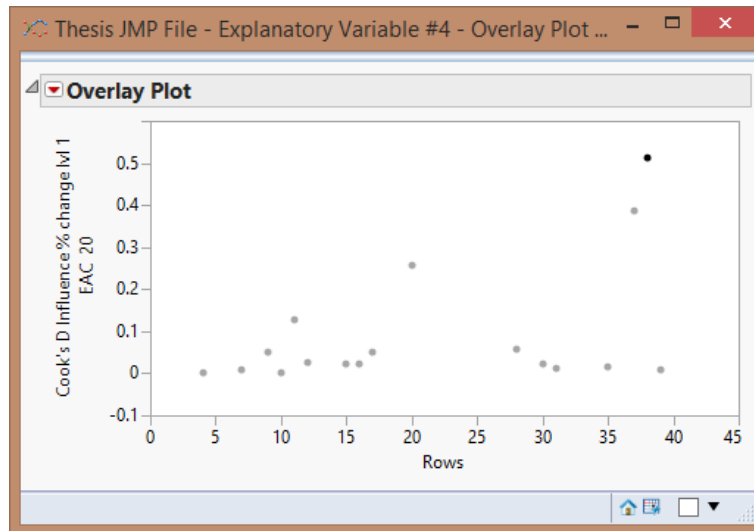
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	14.383262	1.79791	133.0793
Error	9	0.121590	0.01351	Prob > F
C. Total	17	14.504852		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	-0.192195	0.060115	-3.20	0.0109*	0	.	
Other	0.6083587	0.168439	3.61	0.0056*	0.155236	1.9833861	
Air Force	0.3647384	0.09264	3.94	0.0034*	0.151424	1.5881179	
ELECTRONIC/AUTOMATED SOFTWARE	0.6551209	0.124137	5.28	0.0005*	0.271979	2.851596	
UAV	0.3389011	0.1005	3.37	0.0082*	0.140698	1.8690345	
FPIF	0.2090361	0.100986	2.07	0.0684	0.073182	1.3419587	
24 - 36	-1.126123	0.113793	-9.90	<.0001*	-0.39425	1.7039269	
% of Contract covered 50% - 75%	0.3143528	0.071008	4.43	0.0017*	0.174008	1.6587157	
Lvl 5 Cum Change / Final Lvl 1 EAC	40%	5.1763685	0.237882	21.76	<.0001*	0.864675	1.6952483

Effect Tests

Effect Details



Growth Definition #4 Bin - 45%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.60629
RSquare Adj	0.570499
Root Mean Square Error	0.594744
Mean of Response	0.876028
Observations (or Sum Wgts)	25

Analysis of Variance

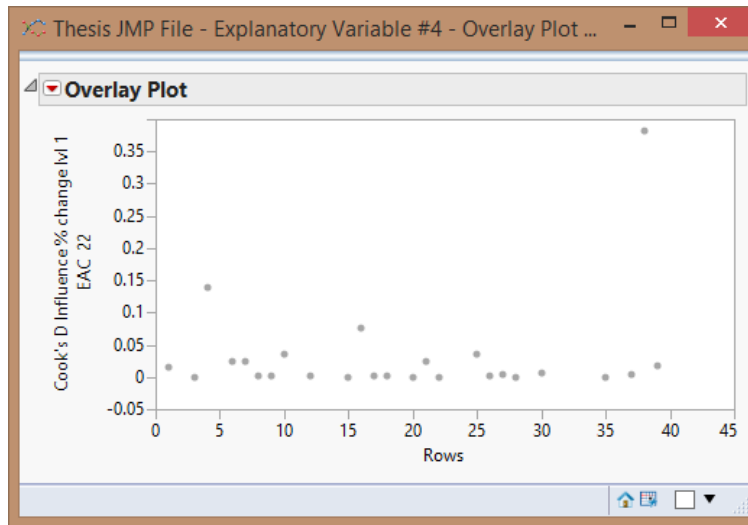
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	11.983595	5.99180	16.9394
Error	22	7.781846	0.35372	Prob > F
C. Total	24	19.765441		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.0288446	0.190369	0.15	0.8809	0	.
General Dynamics Corporation	1.370643	0.607283	2.26	0.0343*	0.302069	1.0009068
Lvl 3 Cum Change / Final Lvl 1 EAC 45%	3.6145707	0.665589	5.43	<.0001*	0.726816	1.0009068

Effect Tests

Effect Details



Growth Definition #4 Bin - 50%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.955606
RSquare Adj	0.947535
Root Mean Square Error	0.129672
Mean of Response	0.52029
Observations (or Sum Wgts)	14

Analysis of Variance

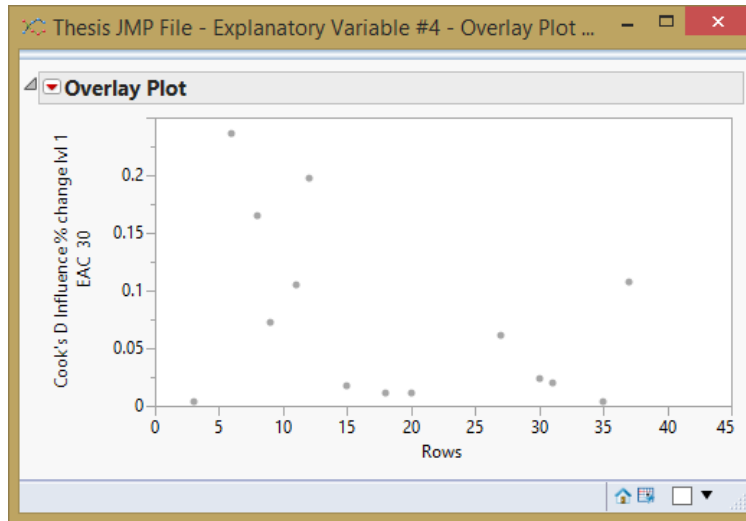
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	3.9815005	1.99075	118.3918
Error	11	0.1849643	0.01681	Prob > F
C. Total	13	4.1664647		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	-0.006869	0.048854	-0.14	0.8907	0	.	
Greater than 36	0.2572846	0.084783	3.03	0.0114*	0.225981	1.3740682	
Lvl 5 Cum Change / Final Lvl 1 EAC	50%	2.6238456	0.232486	11.29	<.0001*	0.840445	1.3740682

Effect Tests

Effect Details



Growth Definition #4 Bin - 55%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.999476
RSquare Adj	0.998951
Root Mean Square Error	0.021725
Mean of Response	0.581216
Observations (or Sum Wgts)	15

Analysis of Variance

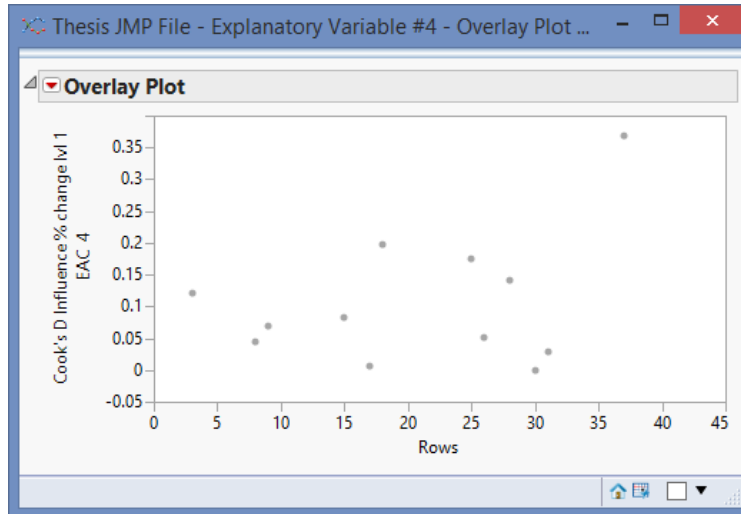
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	6.2958782	0.899411	1905.687
Error	7	0.0033037	0.000472	Prob > F
C. Total	14	6.2991819		<.0001*

Parameter Estimates

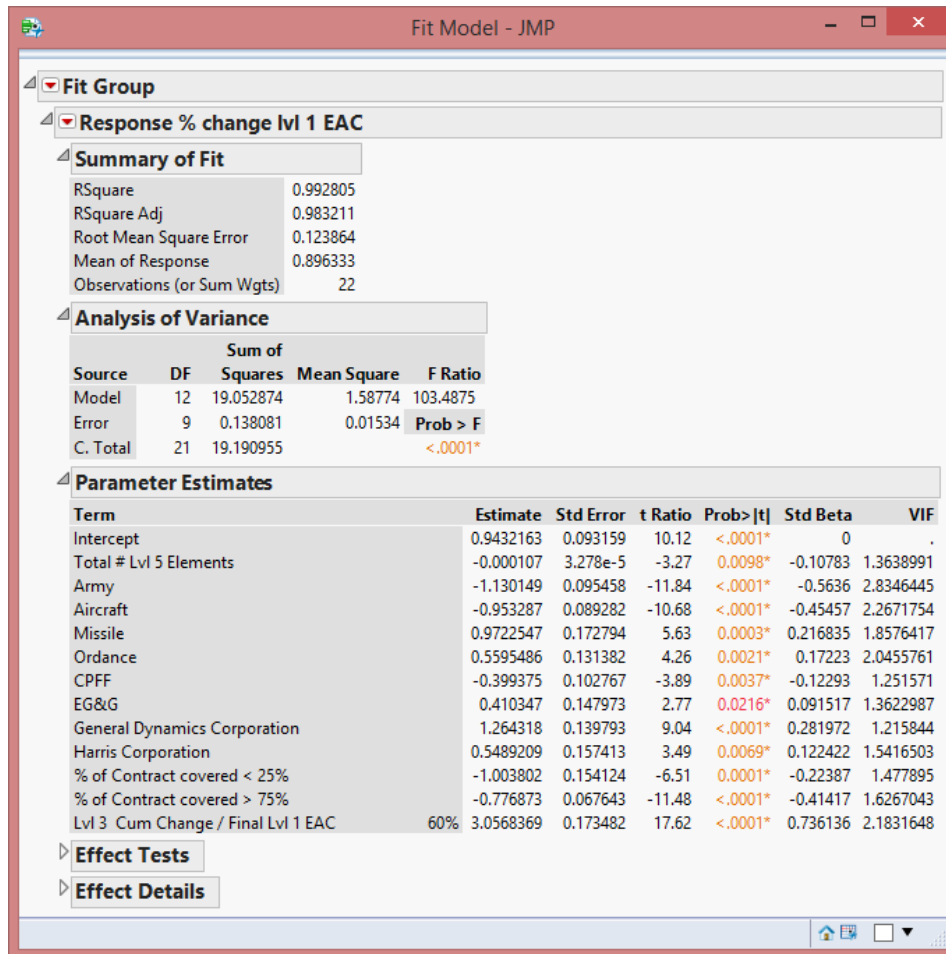
Term		Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept		-0.073183	0.013803	-5.30	0.0011*	0	.
Lvl 3 Cum Change / Final Lvl 1 EAC	55%	2.4132104	0.044128	54.69	<.0001*	0.714805	2.2802469
# Lvl 5 with EAC data elements <= 30		0.0497127	0.018538	2.68	0.0315*	0.033924	2.1360127
Ordnance		-0.129435	0.030879	-4.19	0.0041*	-0.04982	1.8856144
Other 2		0.5471308	0.026751	20.45	<.0001*	0.210604	1.4151295
CPFF		0.9081645	0.028908	31.42	<.0001*	0.349575	1.6525801
Top 3 DOD Contractor		0.0791745	0.01538	5.15	0.0013*	0.060953	1.8711487
Greater than 36		0.1624523	0.014454	11.24	<.0001*	0.12281	1.5936227

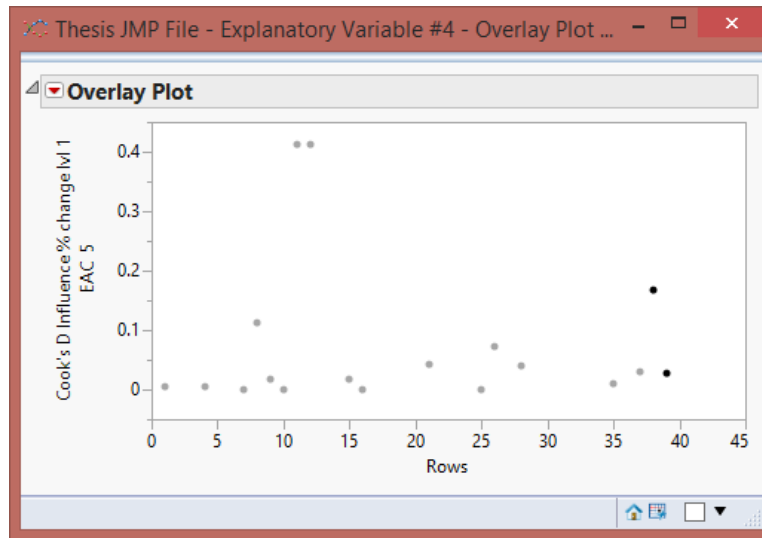
Effect Tests

Effect Details



Growth Definition #4 Bin - 60%





Growth Definition #4 Bin - 65%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.880398
RSquare Adj	0.861998
Root Mean Square Error	0.184267
Mean of Response	0.399791
Observations (or Sum Wgts)	16

Analysis of Variance

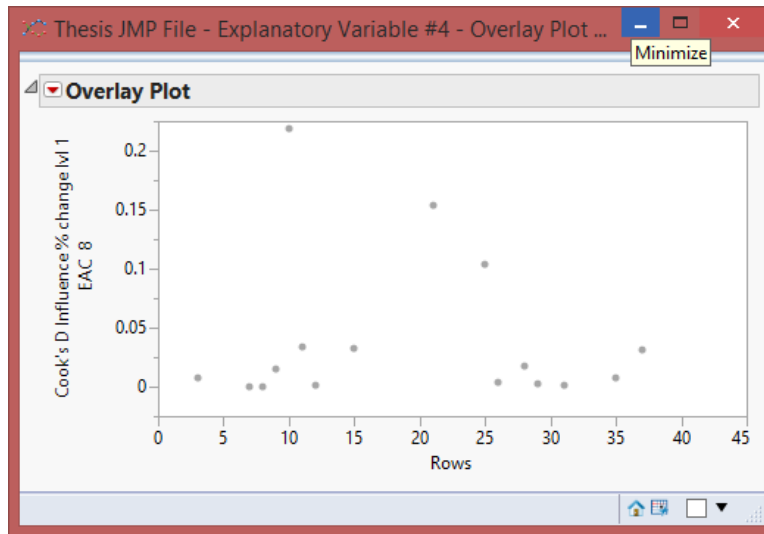
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	3.2492158	1.62461	47.8469
Error	13	0.4414058	0.03395	Prob > F
C. Total	15	3.6906215		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	-0.037043	0.067153	-0.55	0.5906	0	.
Other 2	-0.337536	0.19032	-1.77	0.0996	-0.17012	1.0001052
Lvl 3 Cum Change / Final Lvl 1 EAC	65%	2.2611883	0.234614	9.64	<.0001*	0.924491

Effect Tests

Effect Details



Growth Definition #4 Bin - 70%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.038553
RSquare Adj	-0.03012
Root Mean Square Error	0.082868
Mean of Response	0.063699
Observations (or Sum Wgts)	16

Analysis of Variance

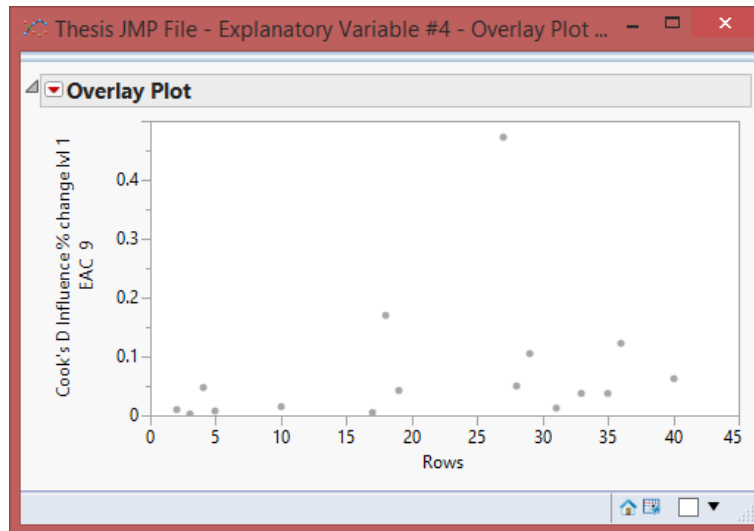
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00385513	0.003855	0.5614
Error	14	0.09613926	0.006867	Prob > F
C. Total	15	0.09999439		0.4661

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept	0.0773886	0.027623	2.80	0.0141*	0	.
# Lvl 5 with EAC data elements <= 30	-0.03129	0.041762	-0.75	0.4661	-0.19635	1

Effect Tests

Effect Details



Growth Definition #4 Bin - 75%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.994196
RSquare Adj	0.987102
Root Mean Square Error	0.09541
Mean of Response	0.700753
Observations (or Sum Wgts)	21

Analysis of Variance

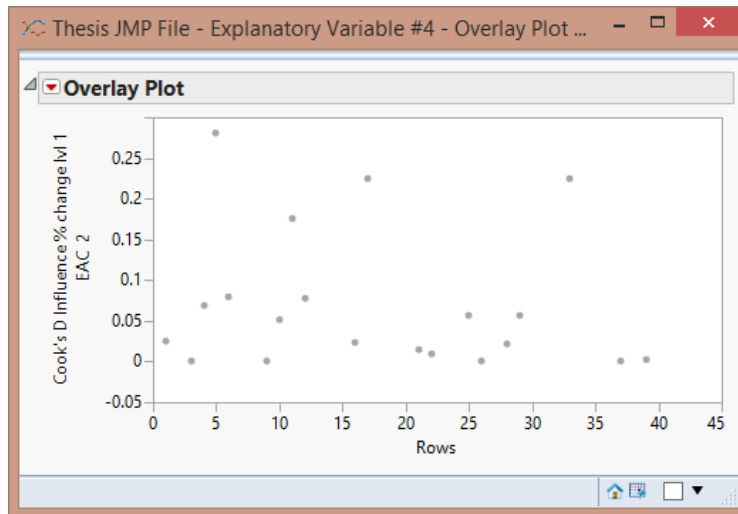
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	14.033377	1.27576	140.1460
Error	9	0.081928	0.00910	Prob > F
C. Total	20	14.115305		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	0.2780541	0.081161	3.43	0.0076*	0	.	
# Lvl 5 with EAC data elements <= 30	-0.55098	0.058677	-9.39	<.0001*	-0.32636	1.8730843	
Air Force	0.2577864	0.070861	3.64	0.0054*	0.12347	1.7861162	
Navy	0.7823285	0.074612	10.49	<.0001*	0.476574	3.2033219	
Aircraft	-1.288416	0.068453	-18.82	<.0001*	-0.66934	1.960961	
Missile	-0.231453	0.09375	-2.47	0.0356*	-0.08287	1.7470908	
UAV	-0.523581	0.124564	-4.20	0.0023*	-0.136	1.6233353	
Northrop Grumman Corporation	-0.494873	0.068475	-7.23	<.0001*	-0.23702	1.6678711	
Telephonics Corporation	0.224232	0.117733	1.90	0.0892	0.058245	1.4501696	
Washington Demil Company	-0.441245	0.120896	-3.65	0.0053*	-0.11461	1.5291329	
24 - 36	-0.876482	0.087954	-9.97	<.0001*	-0.3741	2.1852383	
Lvl 3 Cum Change / Final Lvl 1 EAC	75%	2.9142983	0.118253	24.64	<.0001*	0.841867	1.8094387

Effect Tests

Effect Details



Growth Definition #4 Bin - 80%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.924452
RSquare Adj	0.893344
Root Mean Square Error	0.260376
Mean of Response	0.69402
Observations (or Sum Wgts)	25

Analysis of Variance

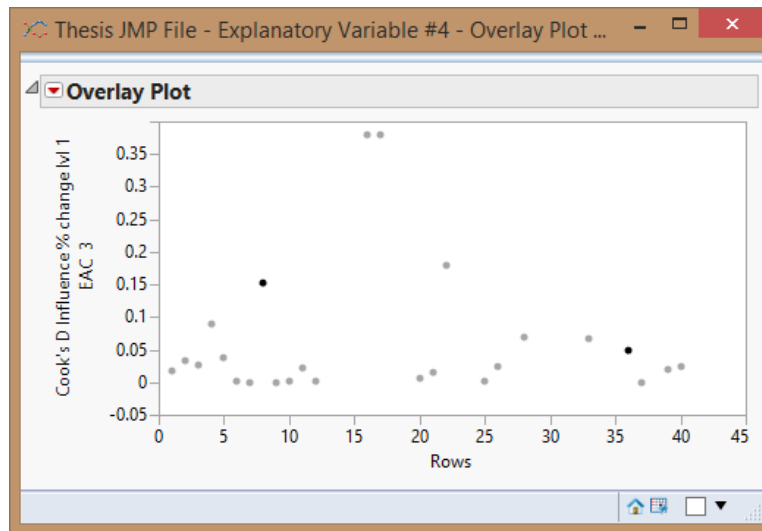
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	14.103023	2.01472	29.7176
Error	17	1.152524	0.06780	Prob > F
C. Total	24	15.255547		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF	
Intercept	0.3680267	0.111576	3.30	0.0042*	0	.	
Aircraft	-0.665264	0.133104	-5.00	0.0001*	-0.36372	1.1916438	
Lockheed Martin Corporation	0.4215441	0.213954	1.97	0.0653	0.146399	1.2423948	
Raytheon Company	-0.658754	0.153827	-4.28	0.0005*	-0.33732	1.3961251	
Washington Demil Company	-0.787952	0.298247	-2.64	0.0171*	-0.19766	1.2595745	
Top 3 DOD Contractor	-0.572206	0.133858	-4.27	0.0005*	-0.3516	1.5223413	
Greater than 36	0.2964735	0.136884	2.17	0.0448*	0.189611	1.7246019	
Lvl 3 Cum Change / Final Lvl 1 EAC	80%	2.4253323	0.268396	9.04	<.0001*	0.769095	1.6300296

Effect Tests

Effect Details



Growth Definition #4 Bin - 85%

Fit Model - JMP

Fit Group

Response % change lvl 1 EAC

Summary of Fit

RSquare	0.901075
RSquare Adj	0.89448
Root Mean Square Error	0.170752
Mean of Response	0.399814
Observations (or Sum Wgts)	17

Analysis of Variance

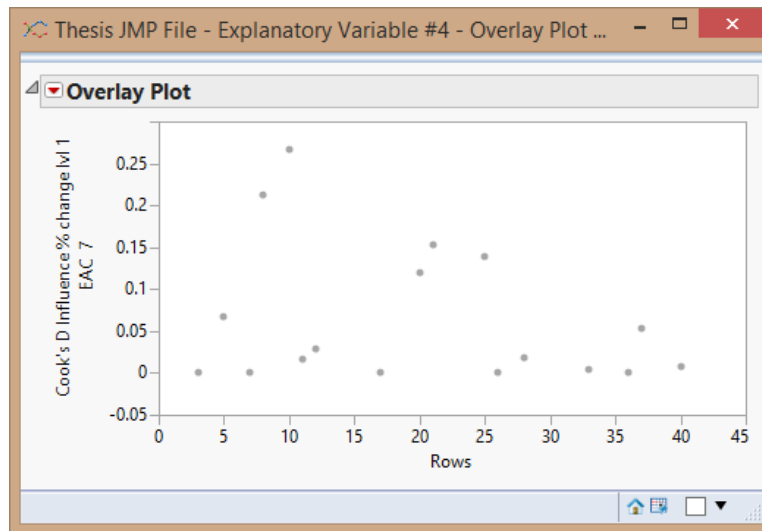
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.9836484	3.98365	136.6303
Error	15	0.4373461	0.02916	Prob > F
C. Total	16	4.4209946		<.0001*

Parameter Estimates

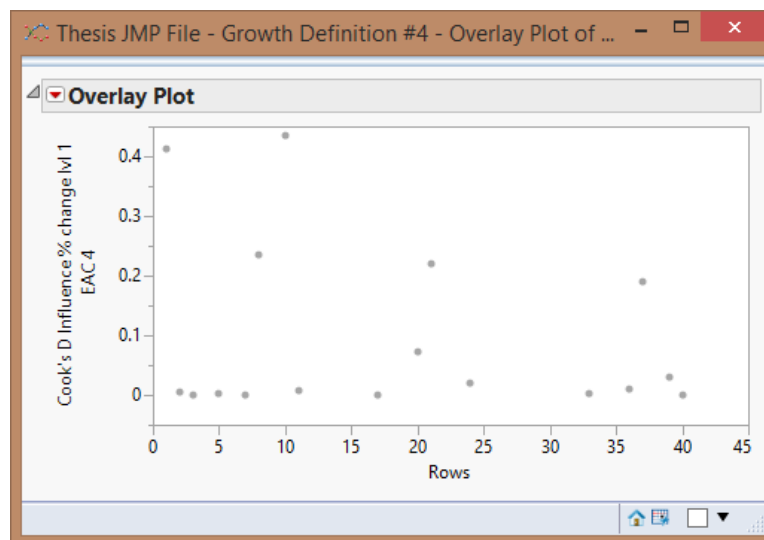
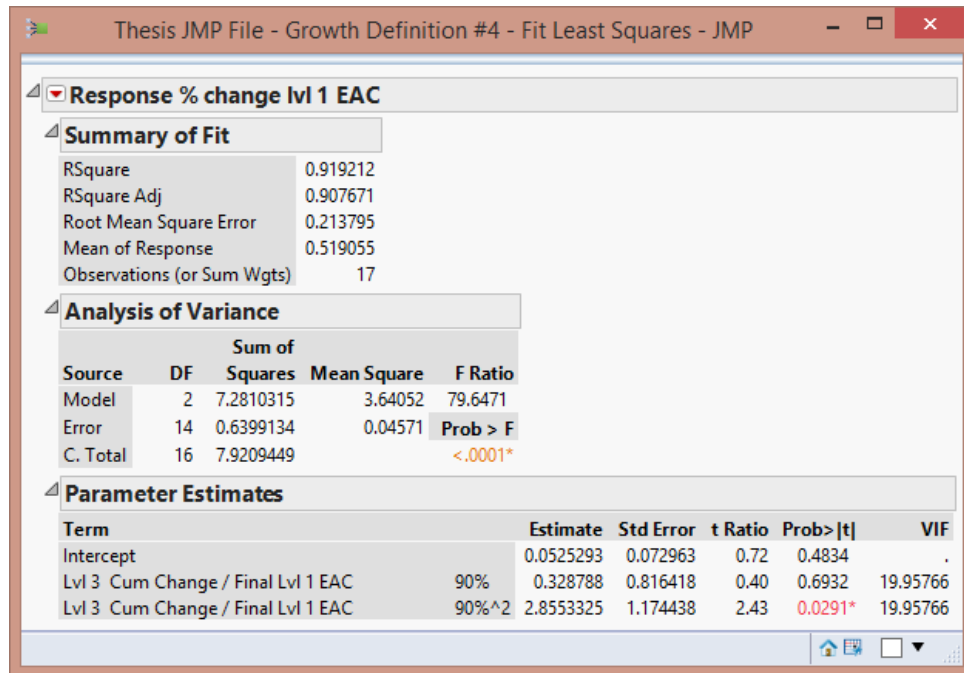
Term		Estimate	Std Error	t Ratio	Prob> t	Std Beta	VIF
Intercept		-0.060239	0.057133	-1.05	0.3084	0	.
Lvl 3 Cum Change / Final Lvl 1 EAC	85%	2.0945481	0.179191	11.69	<.0001*	0.94925	1

Effect Tests

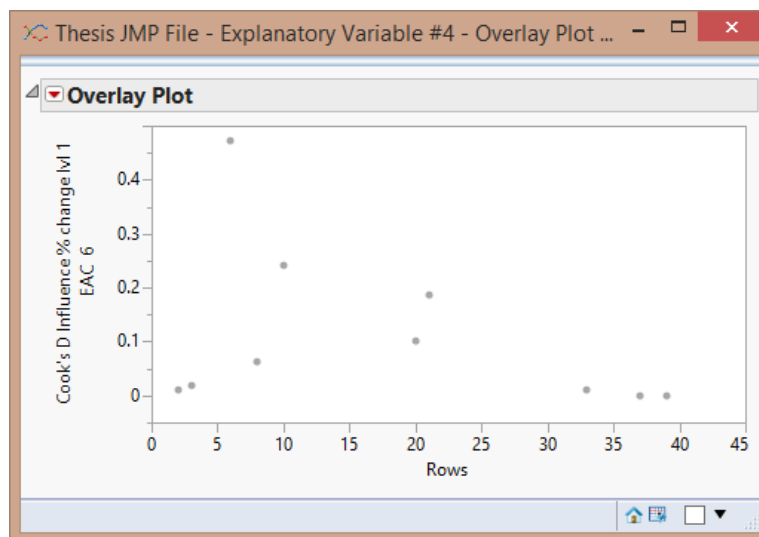
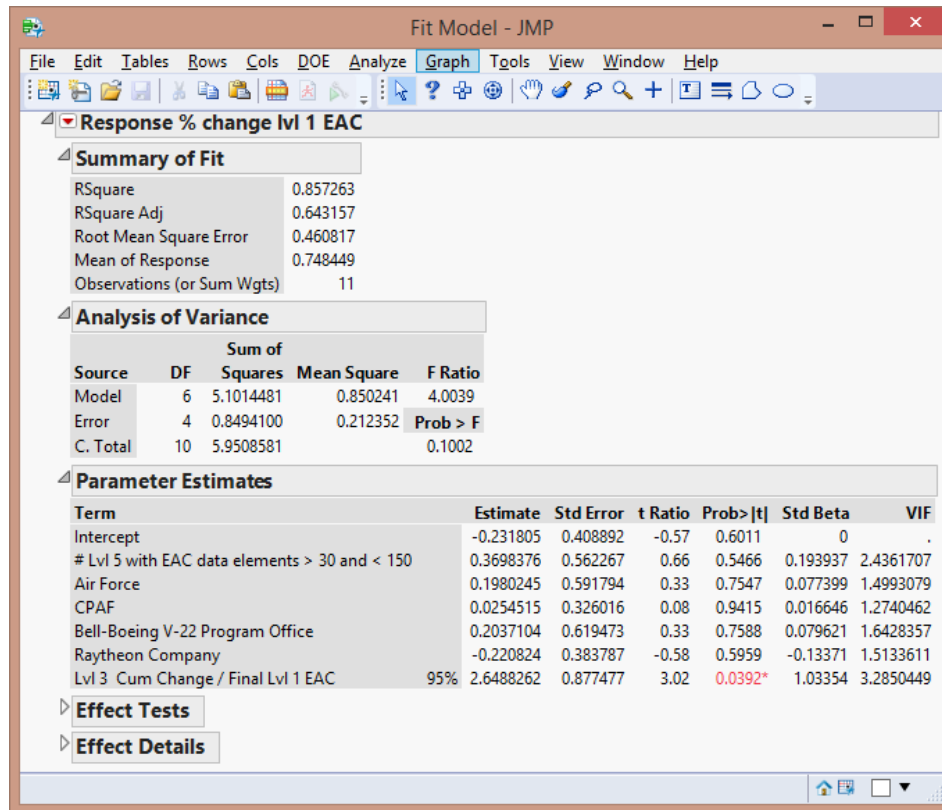
Effect Details



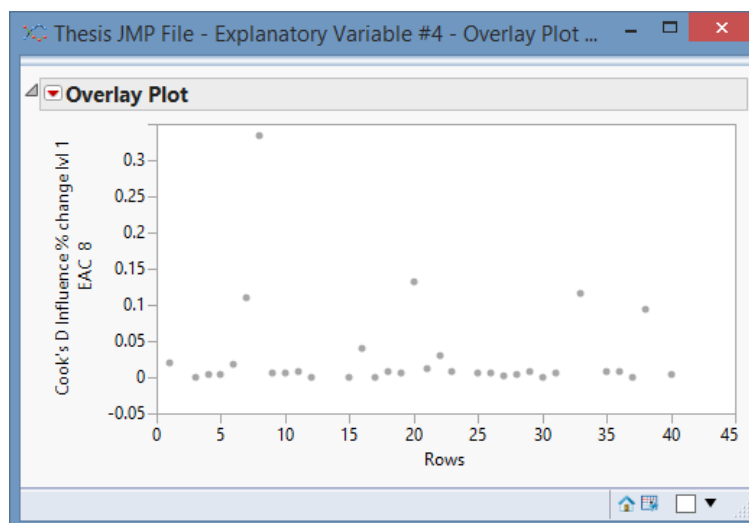
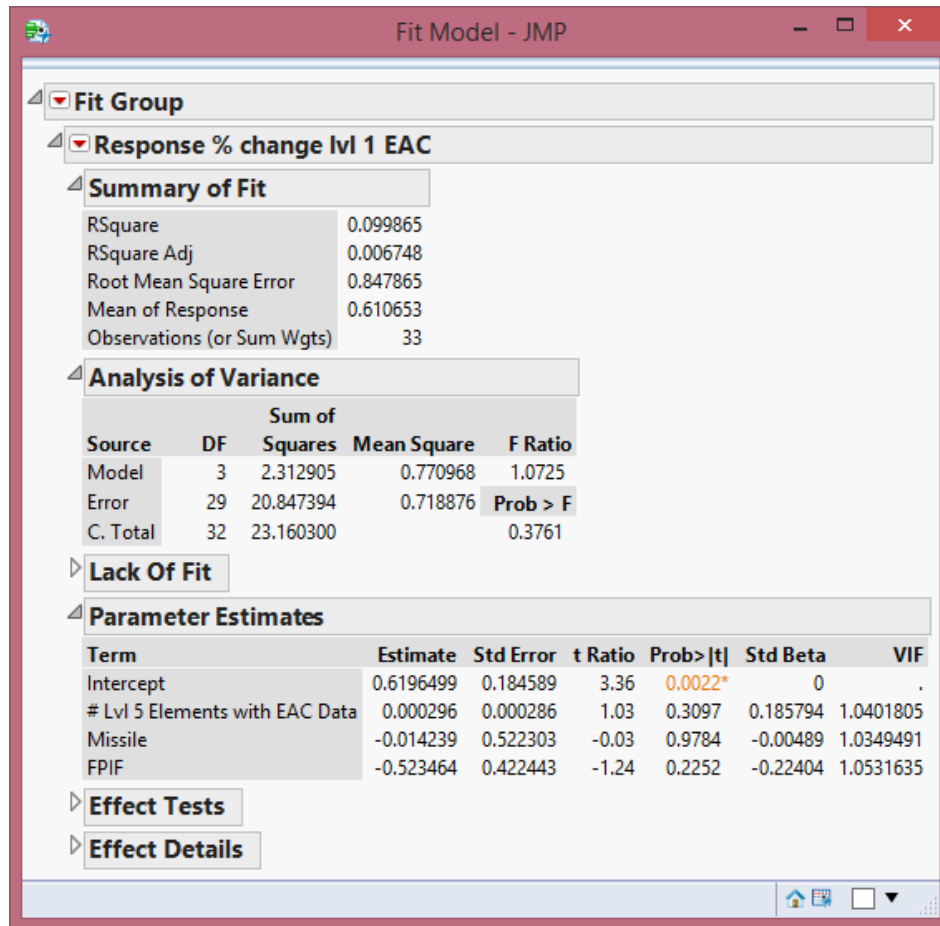
Growth Definition #4 Bin - 90%



Growth Definition #4 Bin - 95%

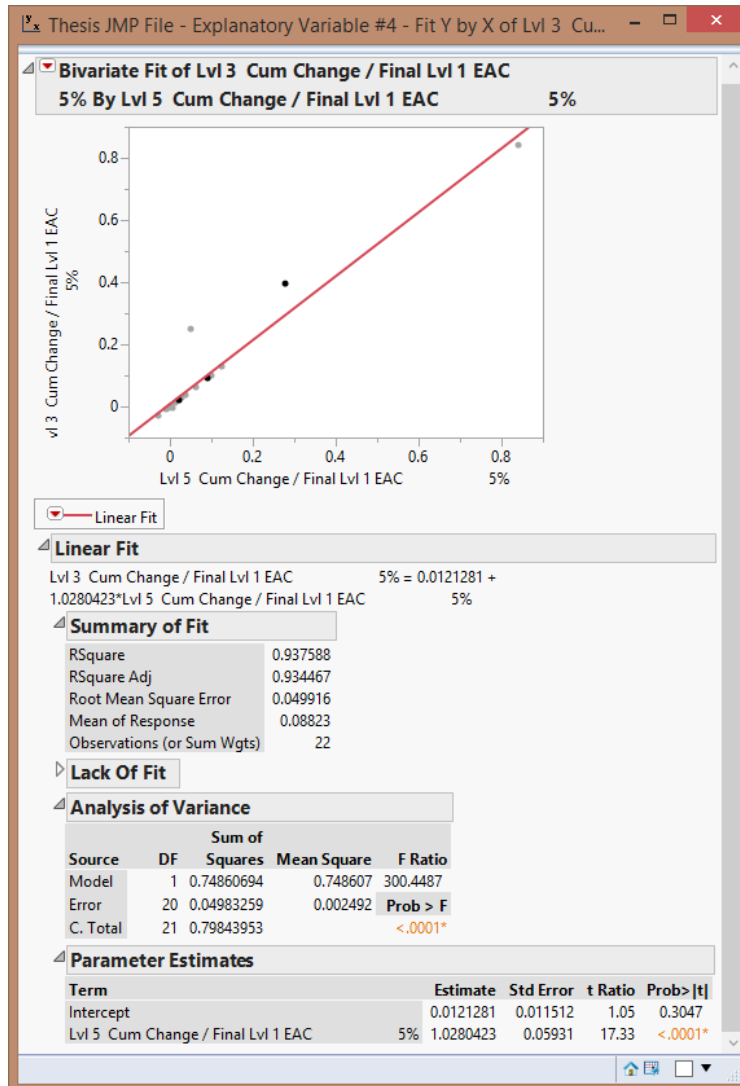


Growth Definition #4 Bin - 100%

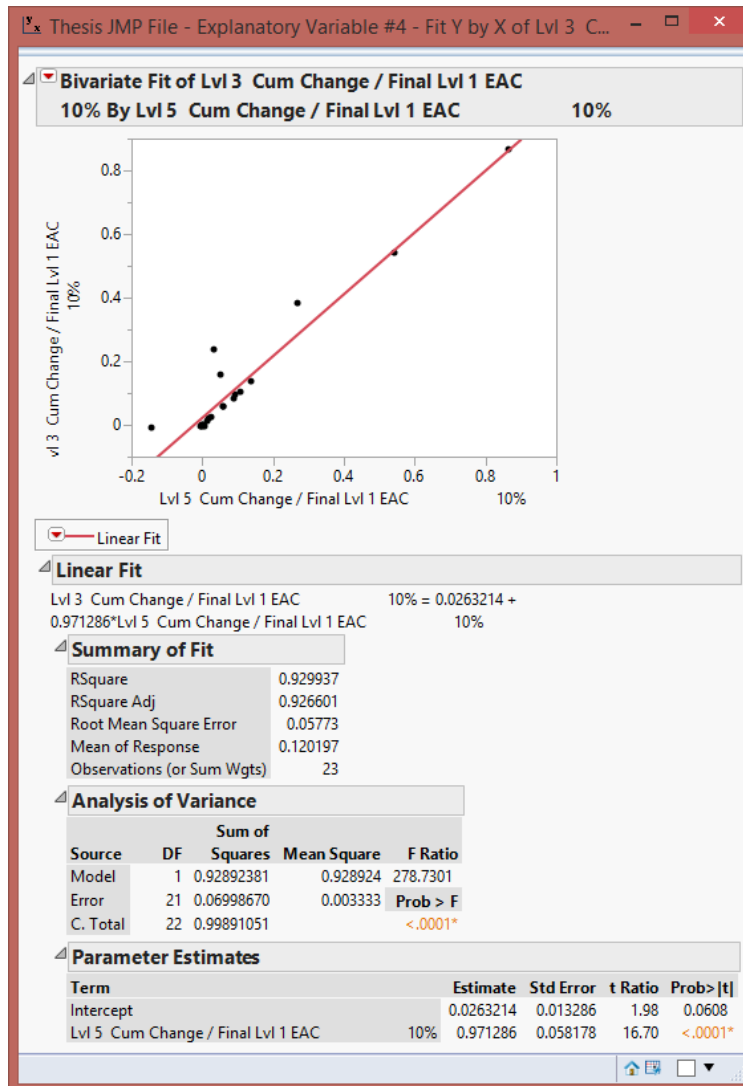


Appendix H – Relationship between Level Three and Level Five Data (Using Contractor's EAC or LRE

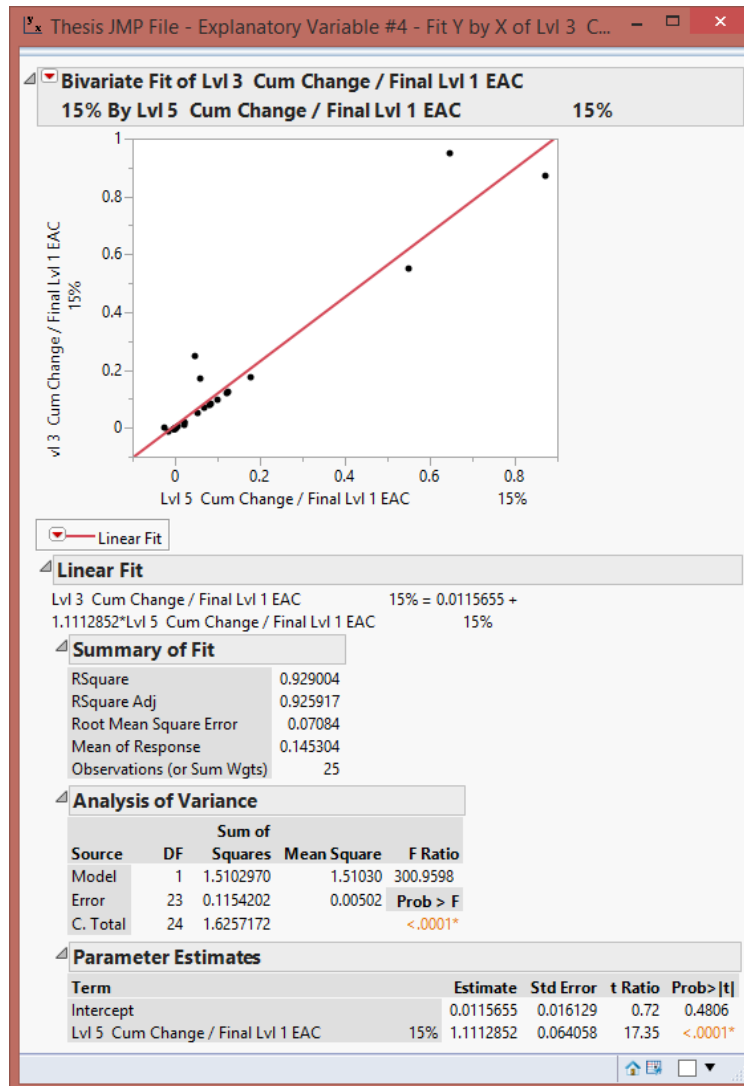
Comparing Level 3 with Level 5 at Bin - 5%



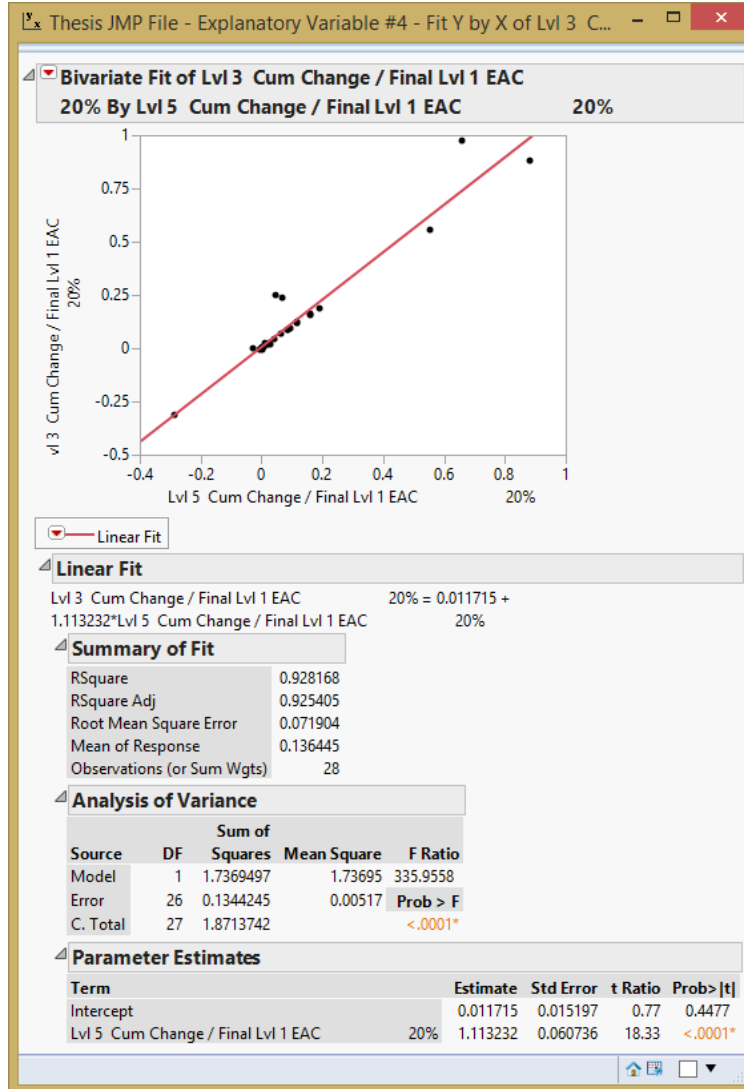
Comparing Level 3 with Level 5 at Bin - 10%



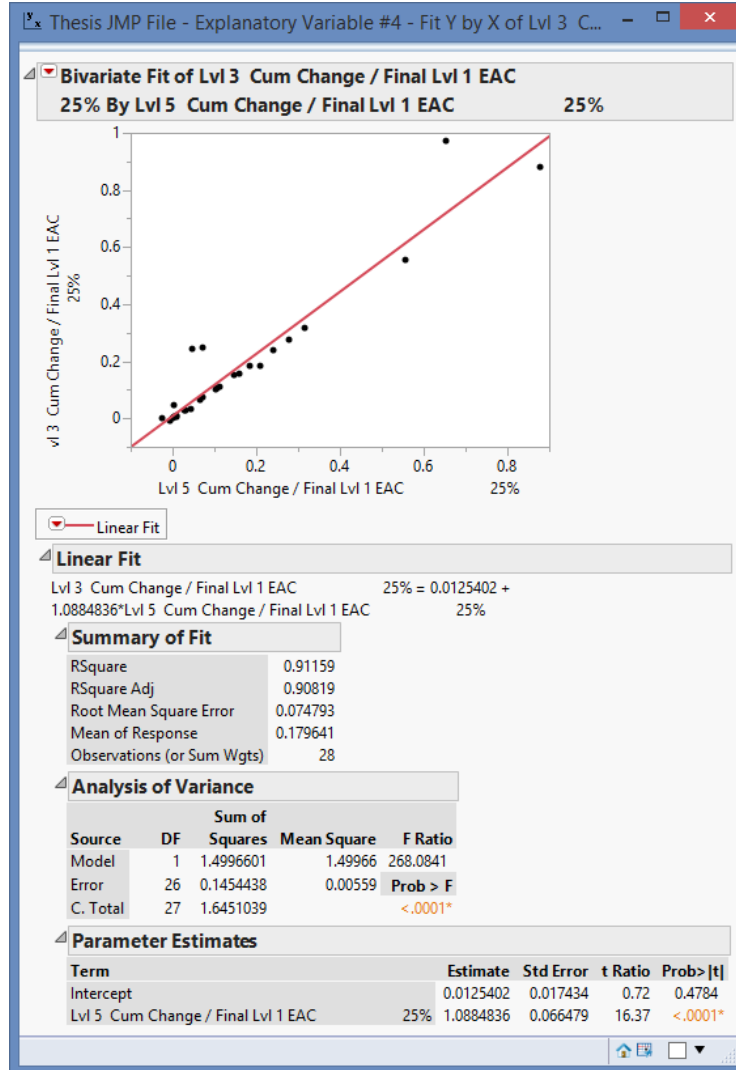
Comparing Level 3 with Level 5 at Bin - 15%



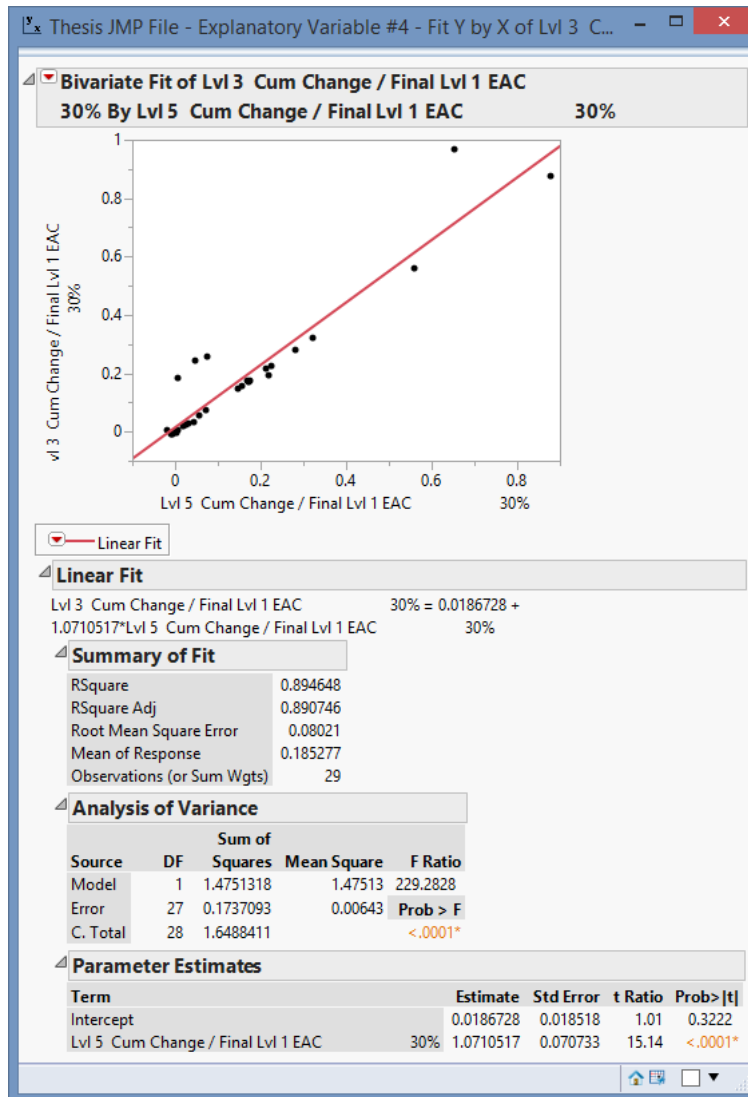
Comparing Level 3 with Level 5 at Bin - 20%



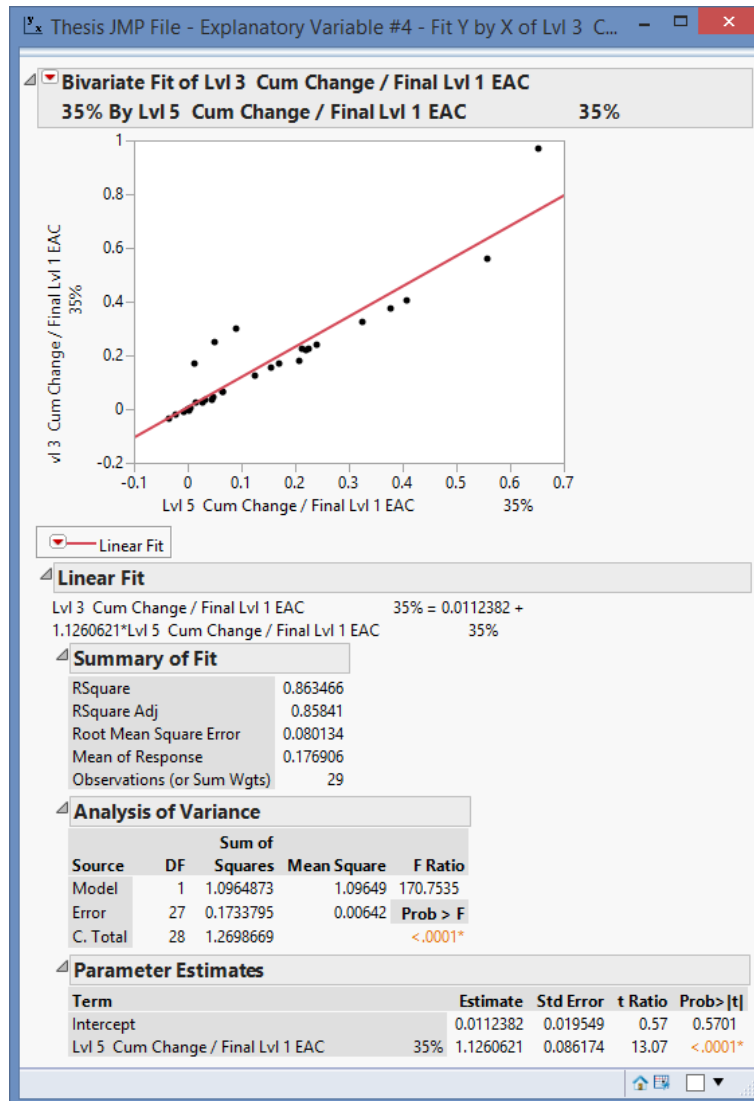
Comparing Level 3 with Level 5 at Bin - 25%



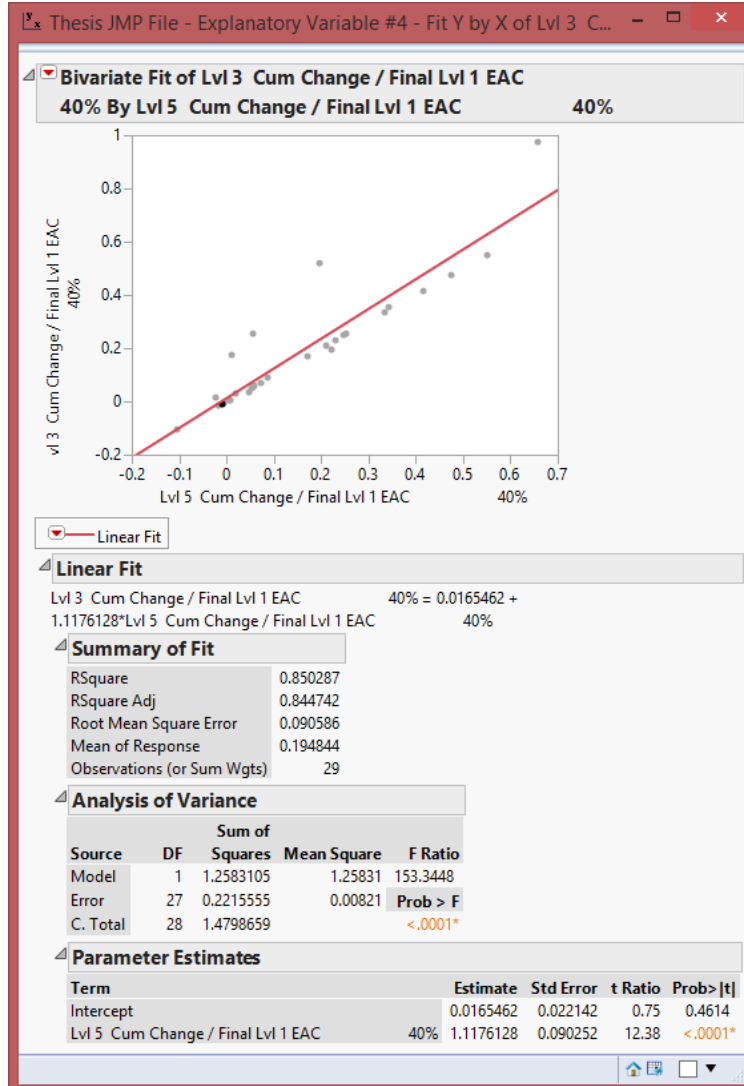
Comparing Level 3 with Level 5 at Bin – 30%



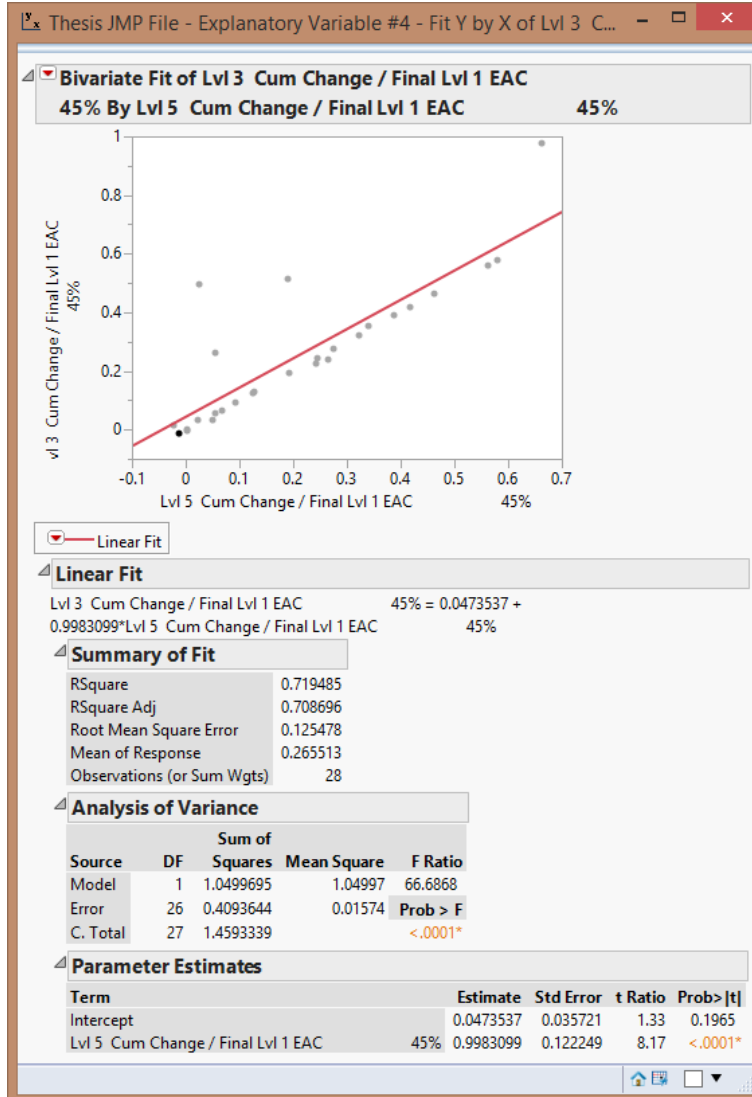
Comparing Level 3 with Level 5 at Bin - 35%



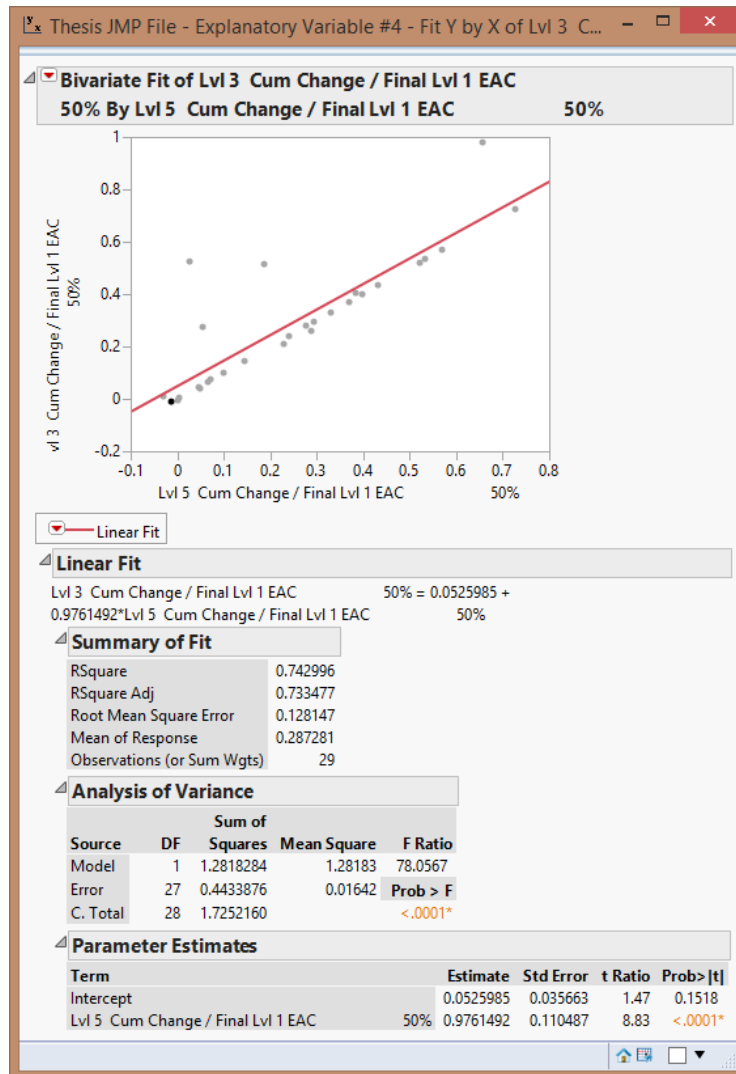
Comparing Level 3 with Level 5 at Bin - 40%



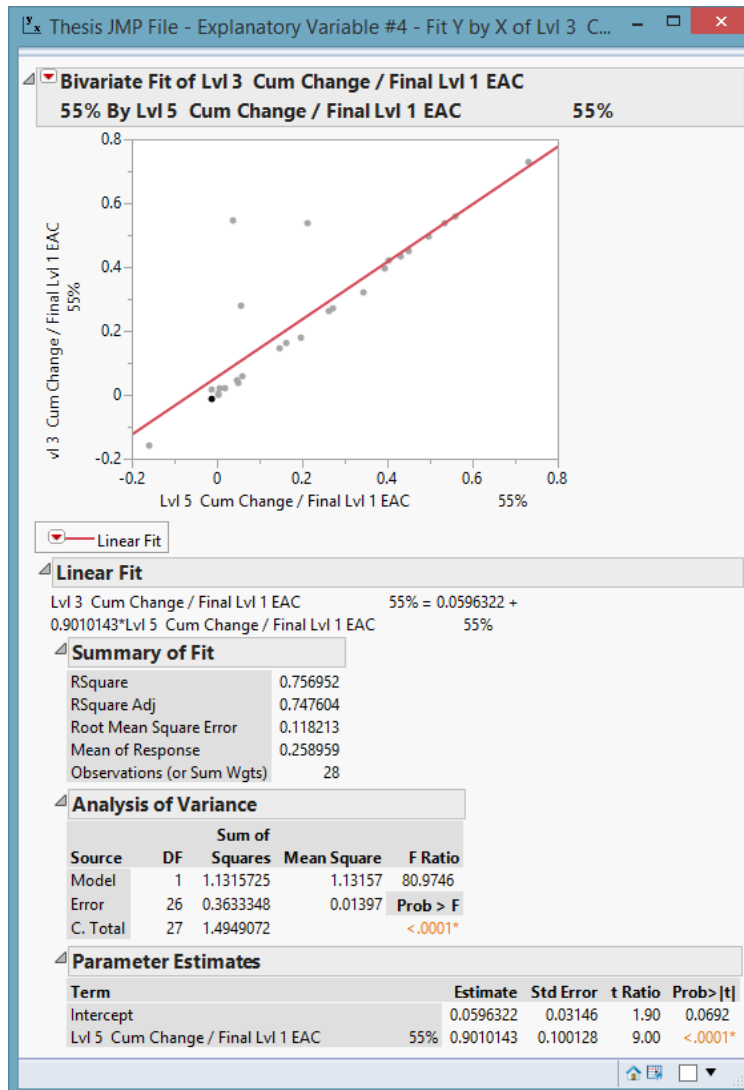
Comparing Level 3 with Level 5 at Bin - 45%



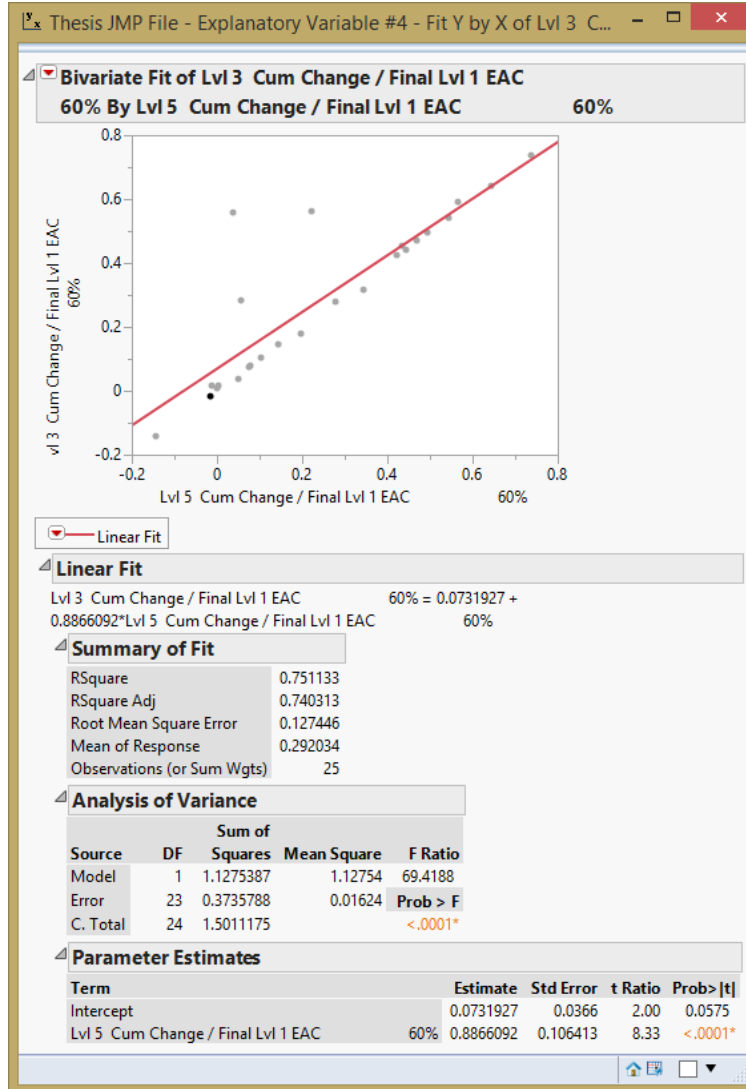
Comparing Level 3 with Level 5 at Bin - 50%



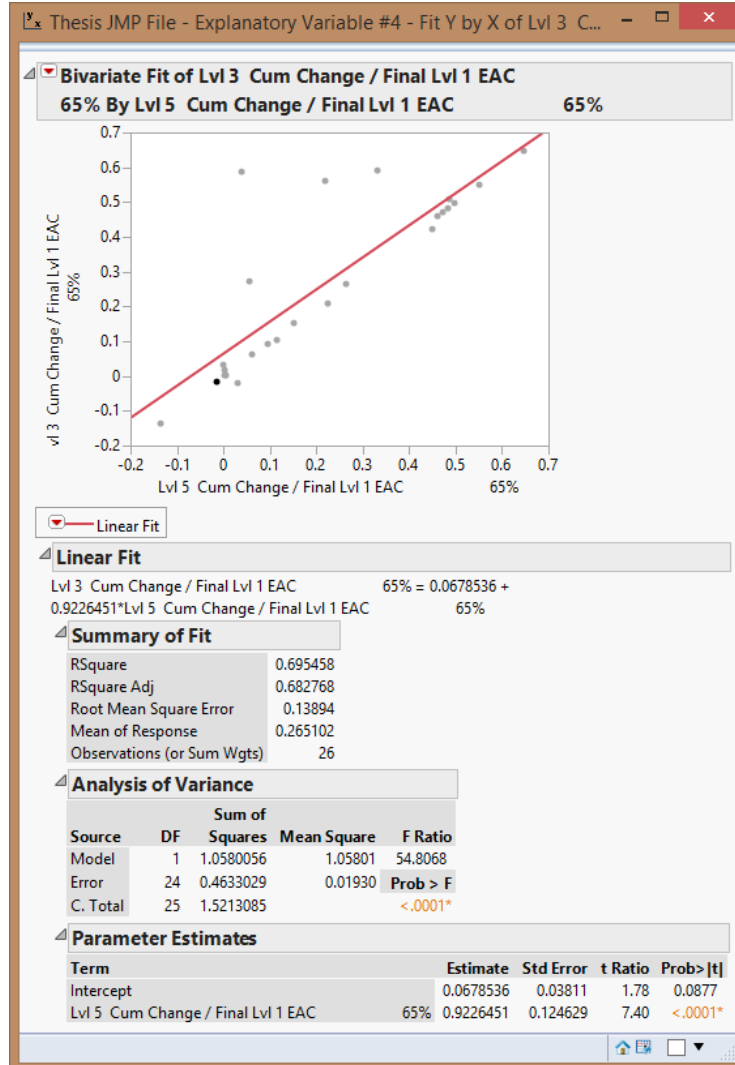
Comparing Level 3 with Level 5 at Bin - 55%



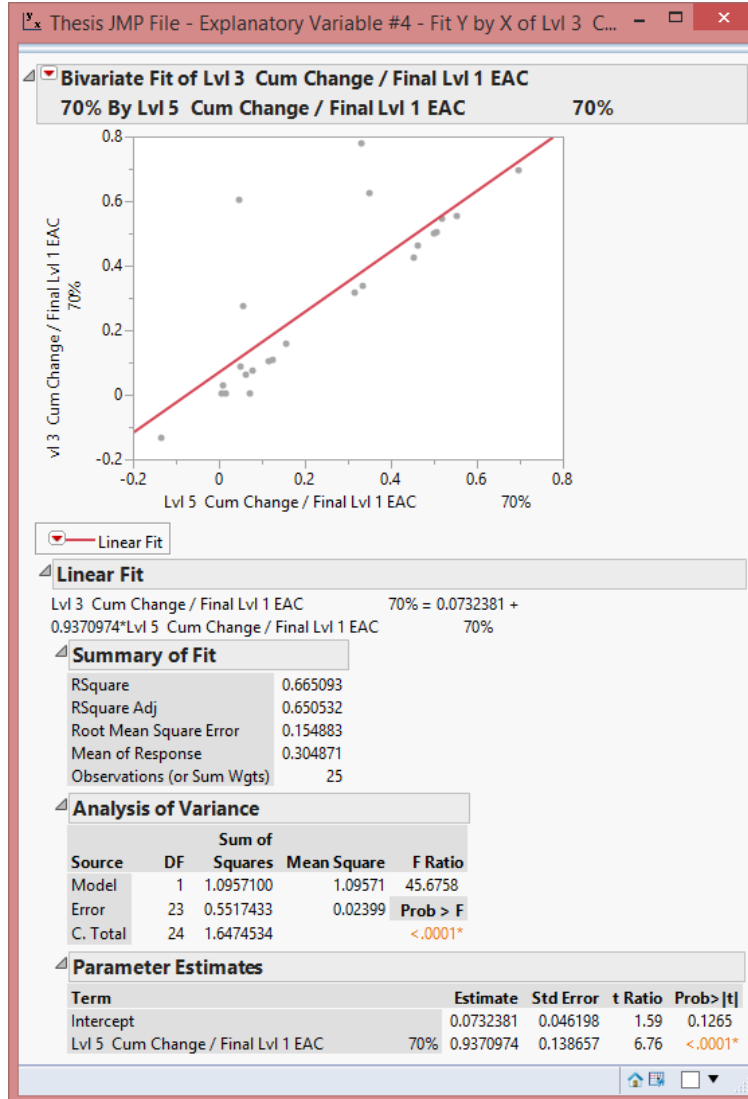
Comparing Level 3 with Level 5 at Bin - 60%



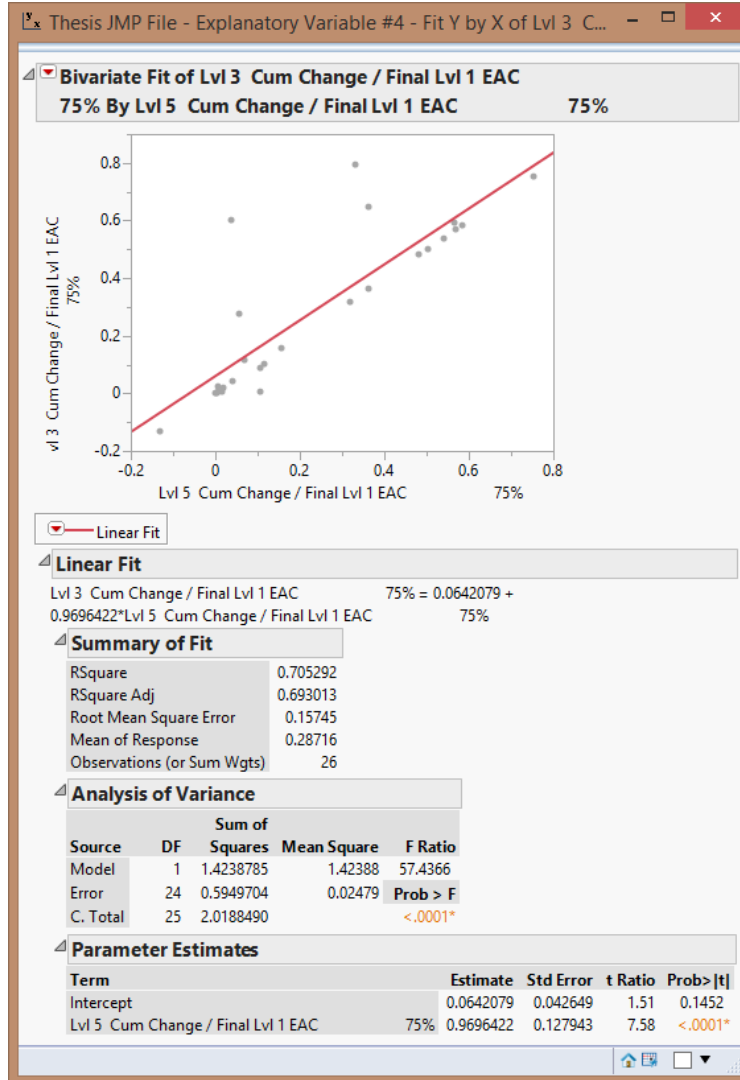
Comparing Level 3 with Level 5 at Bin - 65%



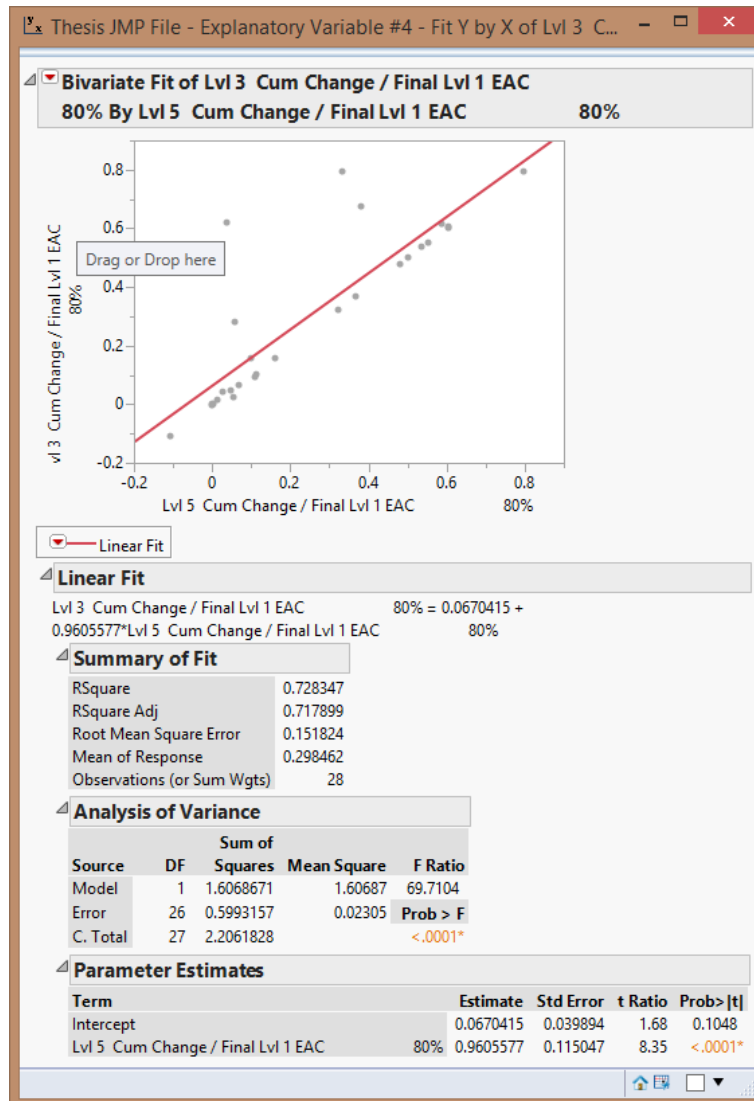
Comparing Level 3 with Level 5 at Bin - 70%



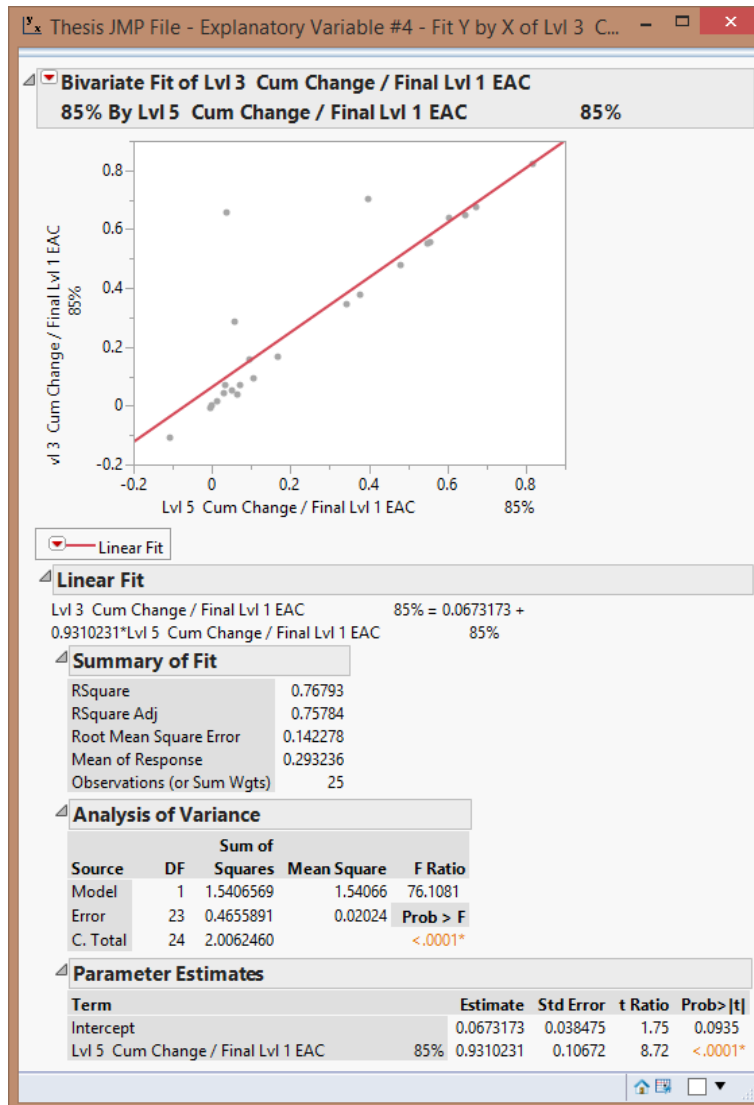
Comparing Level 3 with Level 5 at Bin - 75%



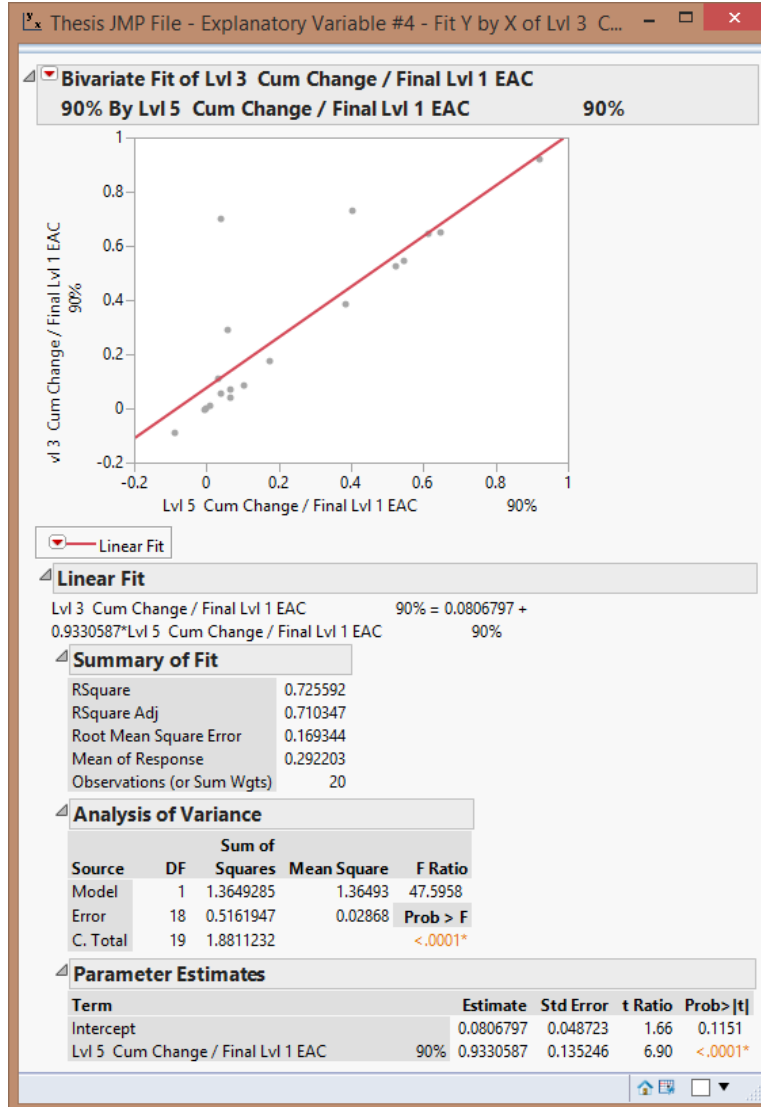
Comparing Level 3 with Level 5 at Bin - 80%



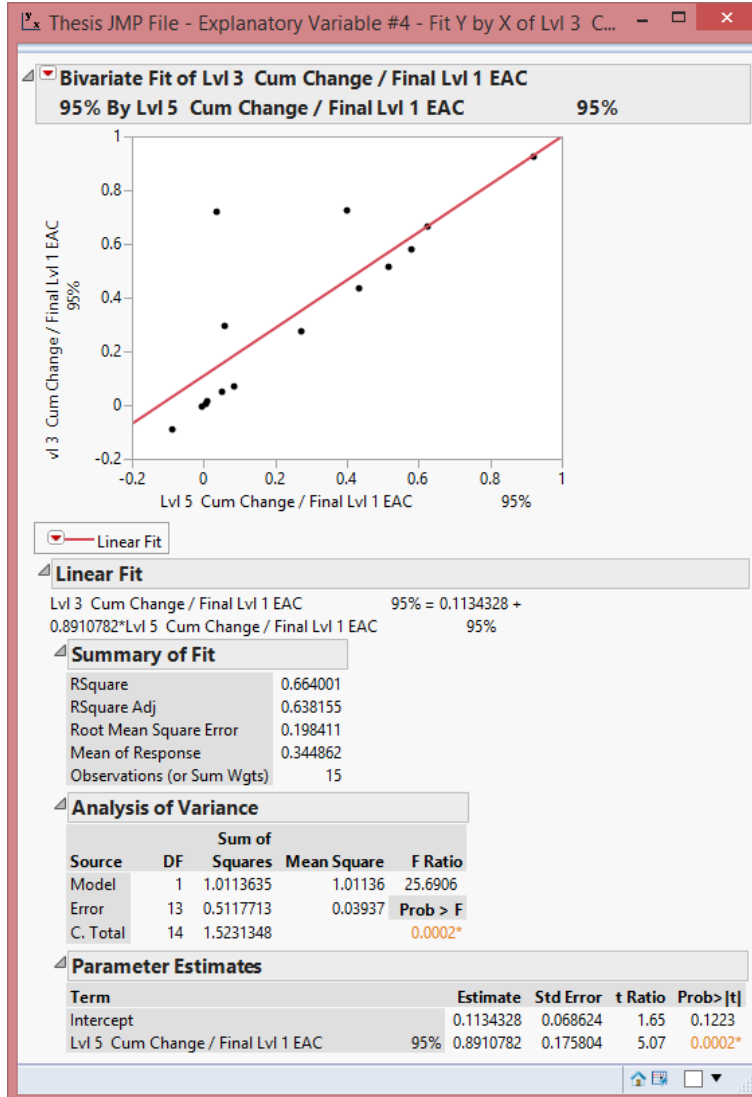
Comparing Level 3 with Level 5 at Bin - 85%



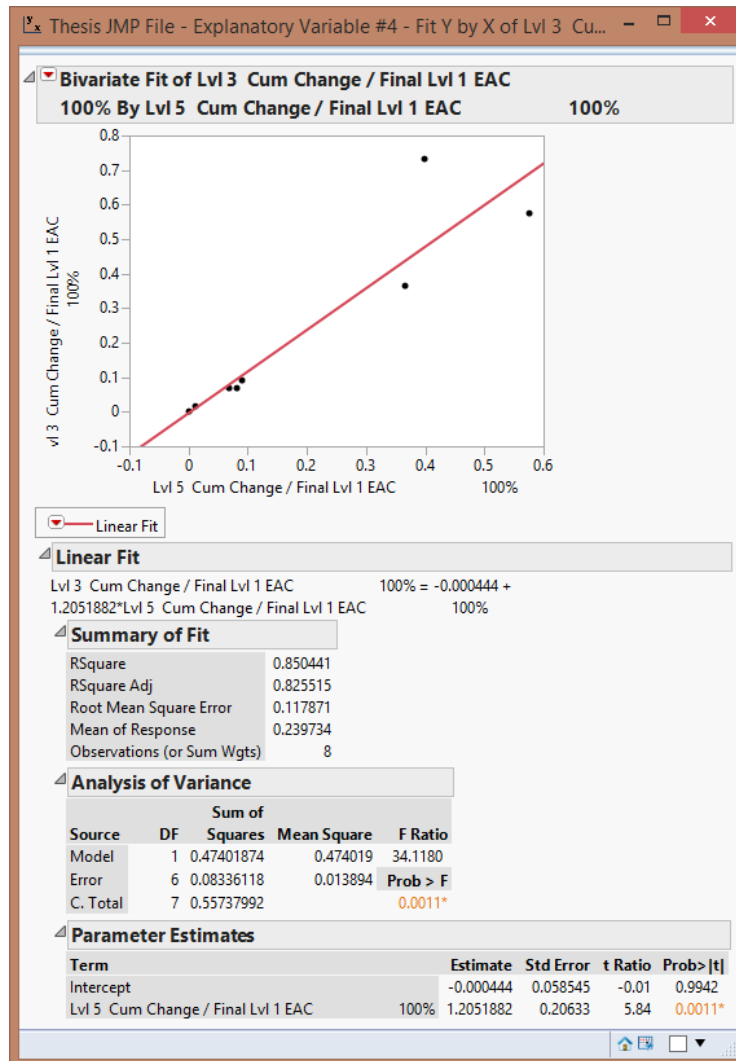
Comparing Level 3 with Level 5 at Bin - 90%



Comparing Level 3 with Level 5 at Bin - 95%

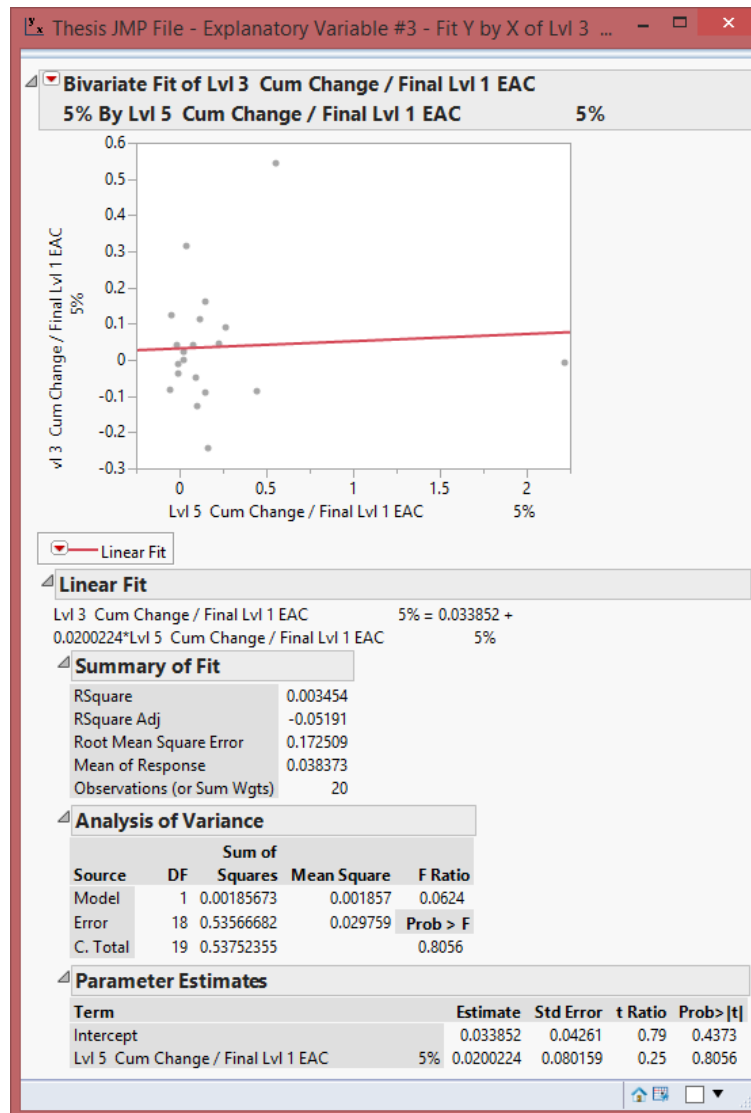


Comparing Level 3 with Level 5 at Bin - 100%

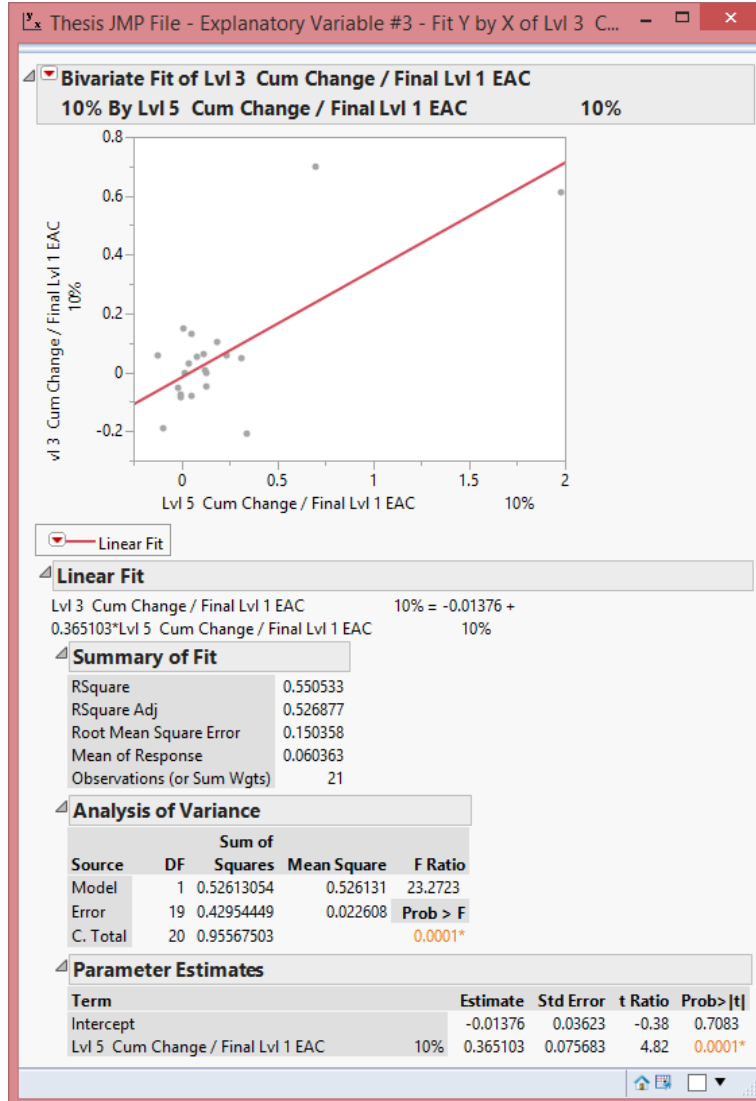


Appendix I – Relationship between Level Three and Level Five Data (Using Recalculated EAC)

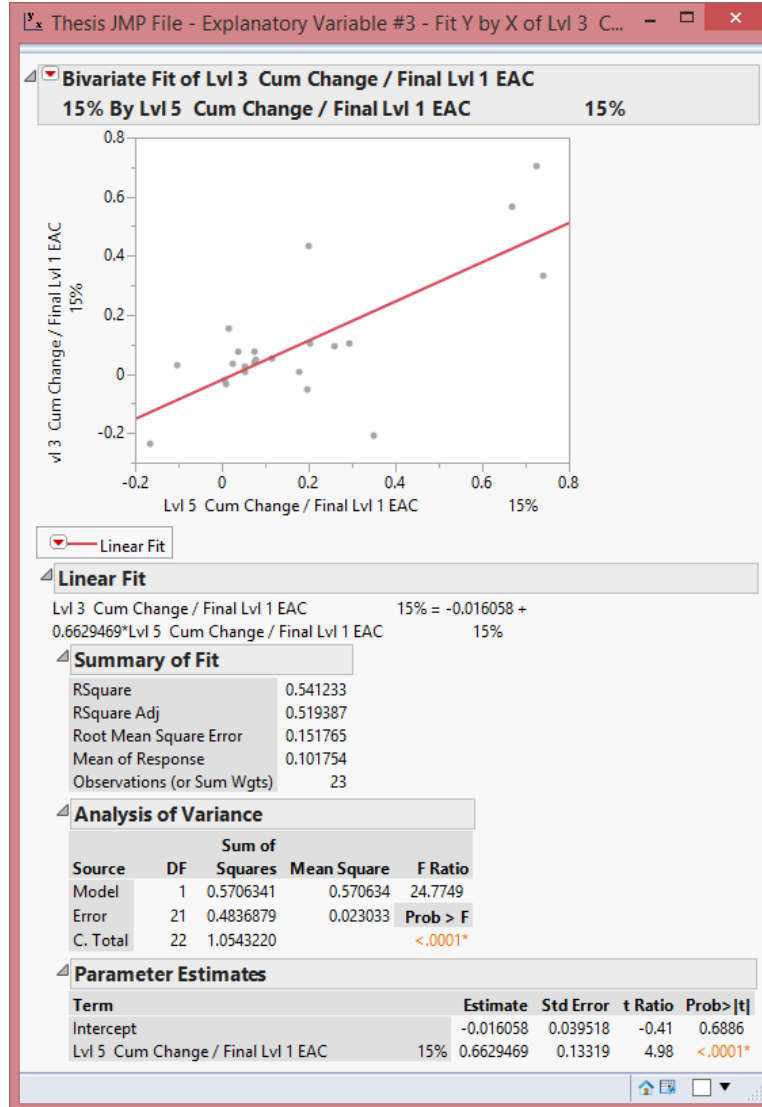
Comparing Level 3 with Level 5 at Bin - 5%



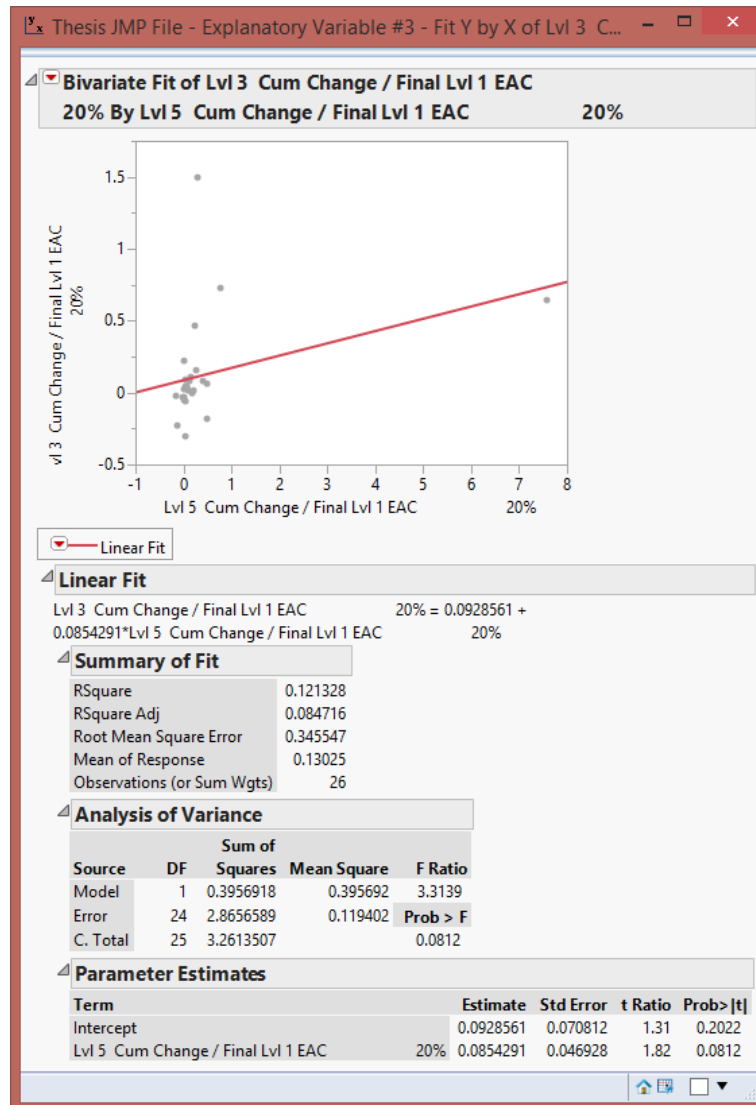
Comparing Level 3 with Level 5 at Bin - 10%



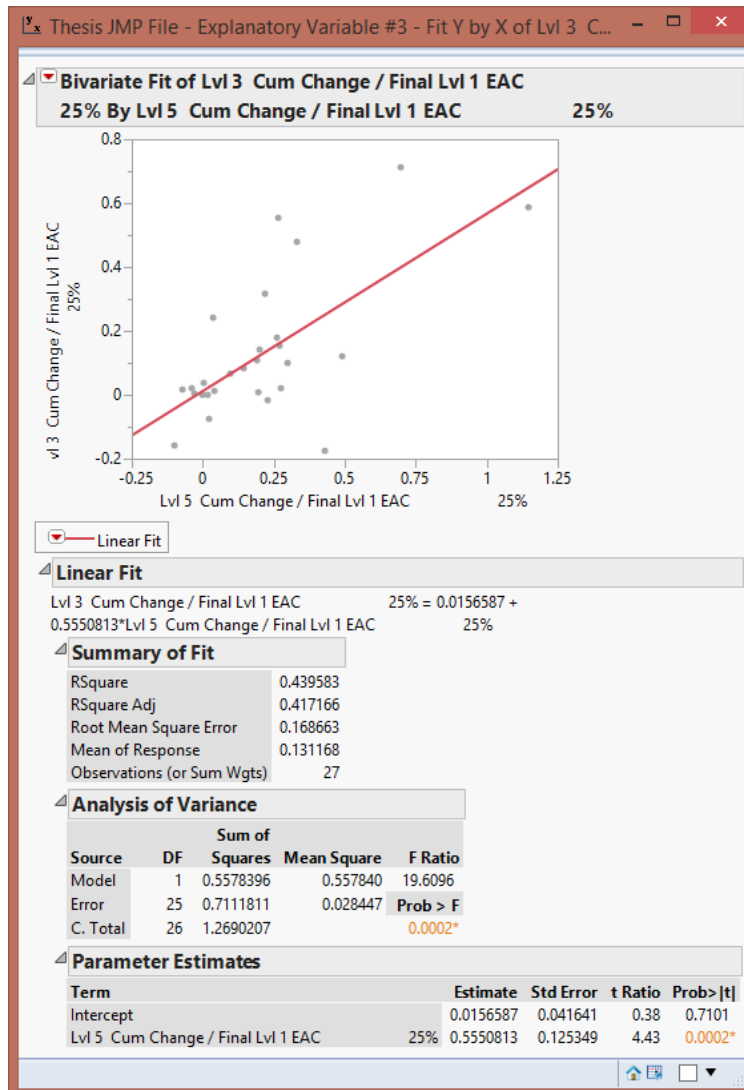
Comparing Level 3 with Level 5 at Bin - 15%



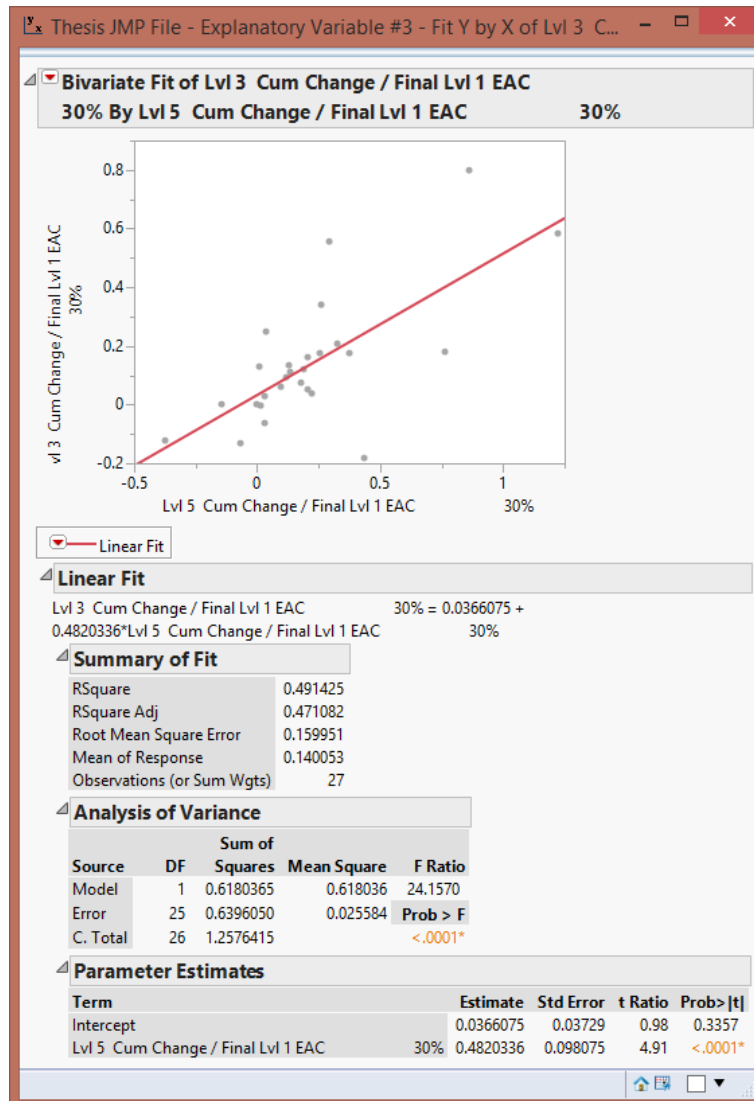
Comparing Level 3 with Level 5 at Bin - 20%



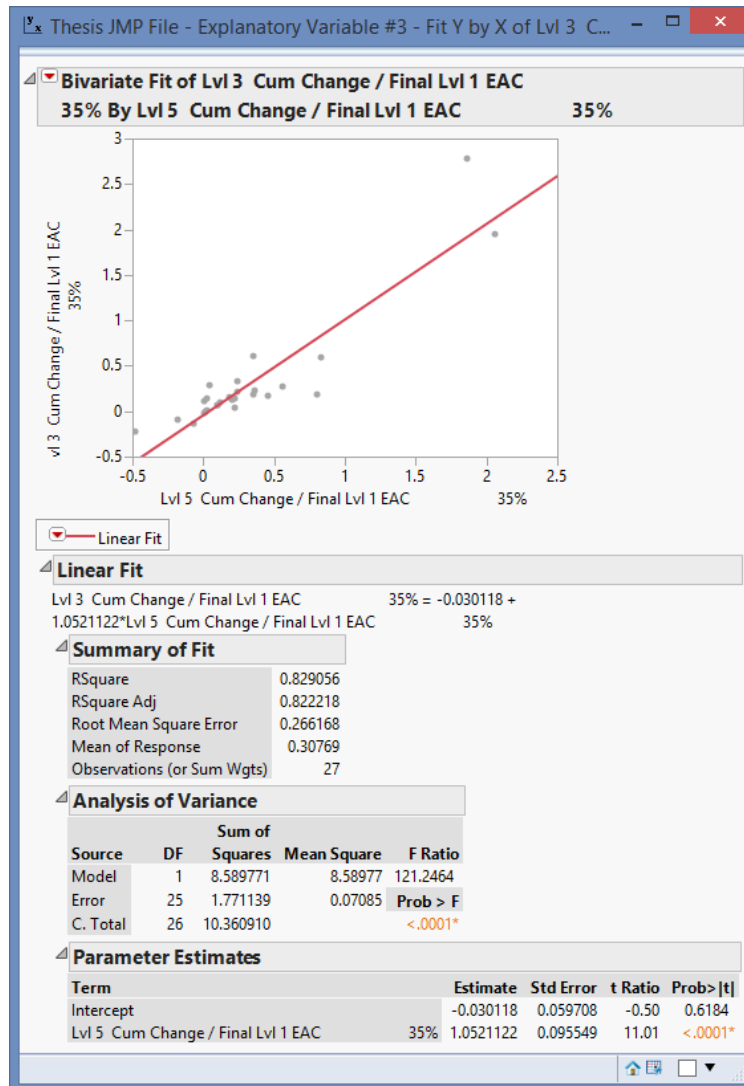
Comparing Level 3 with Level 5 at Bin - 25%



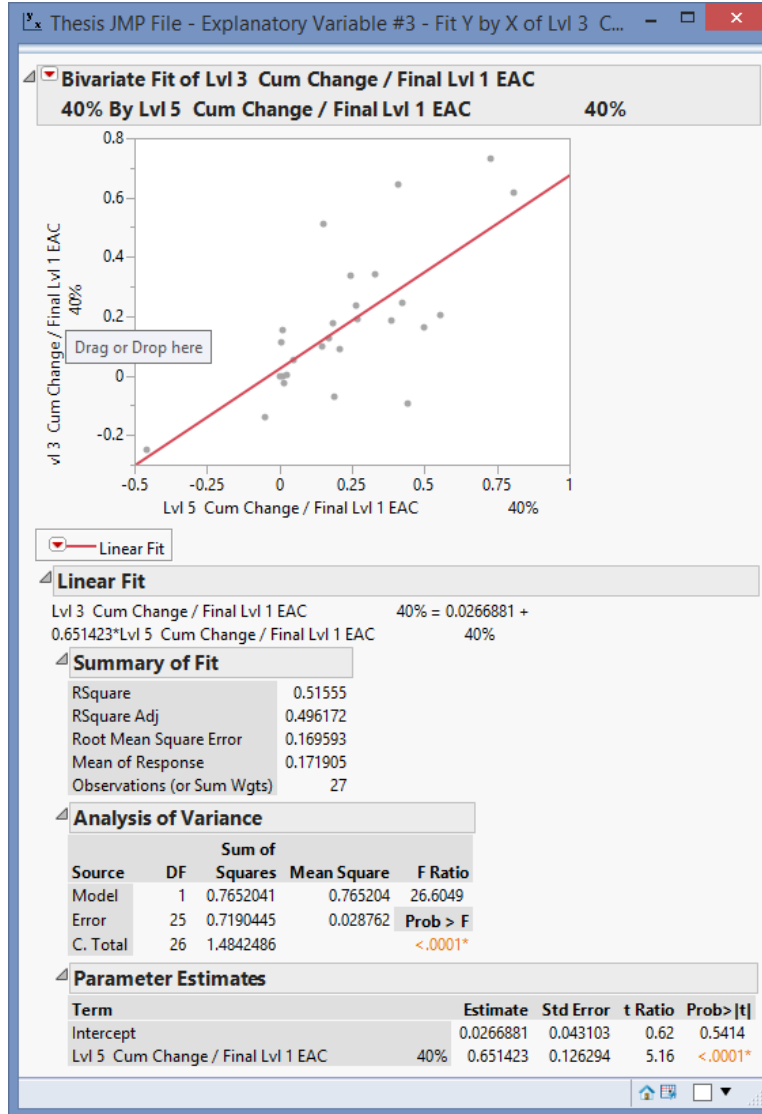
Comparing Level 3 with Level 5 at Bin – 30%



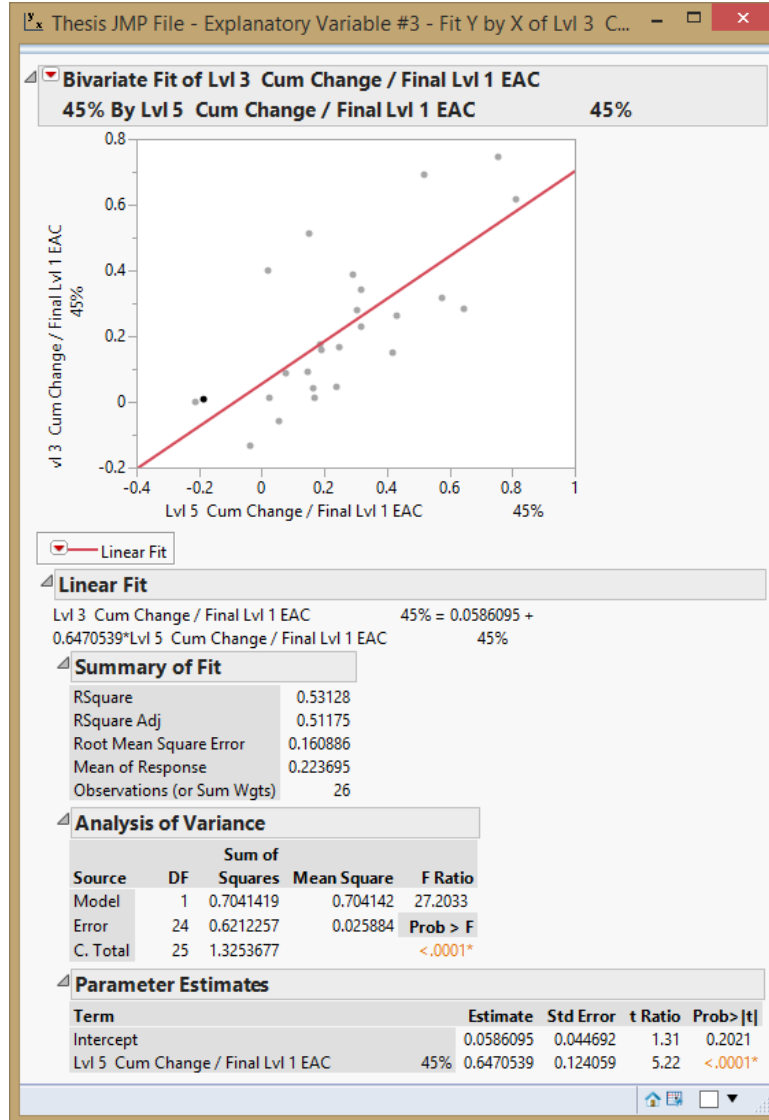
Comparing Level 3 with Level 5 at Bin - 35%



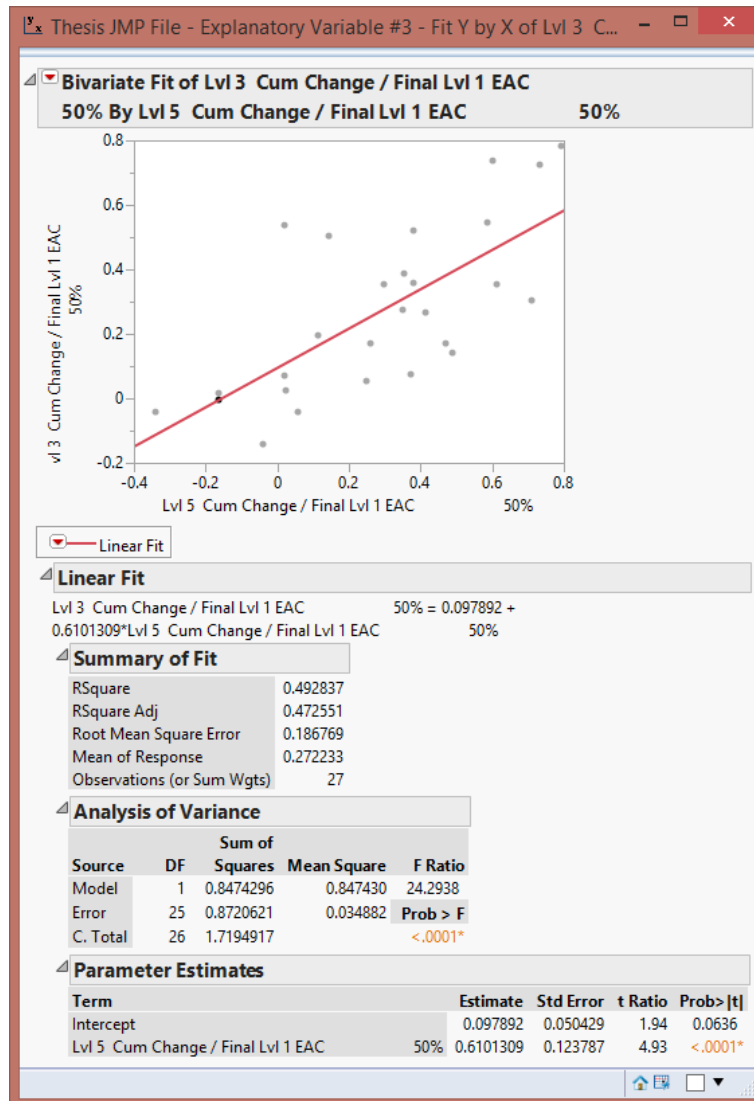
Comparing Level 3 with Level 5 at Bin - 40%



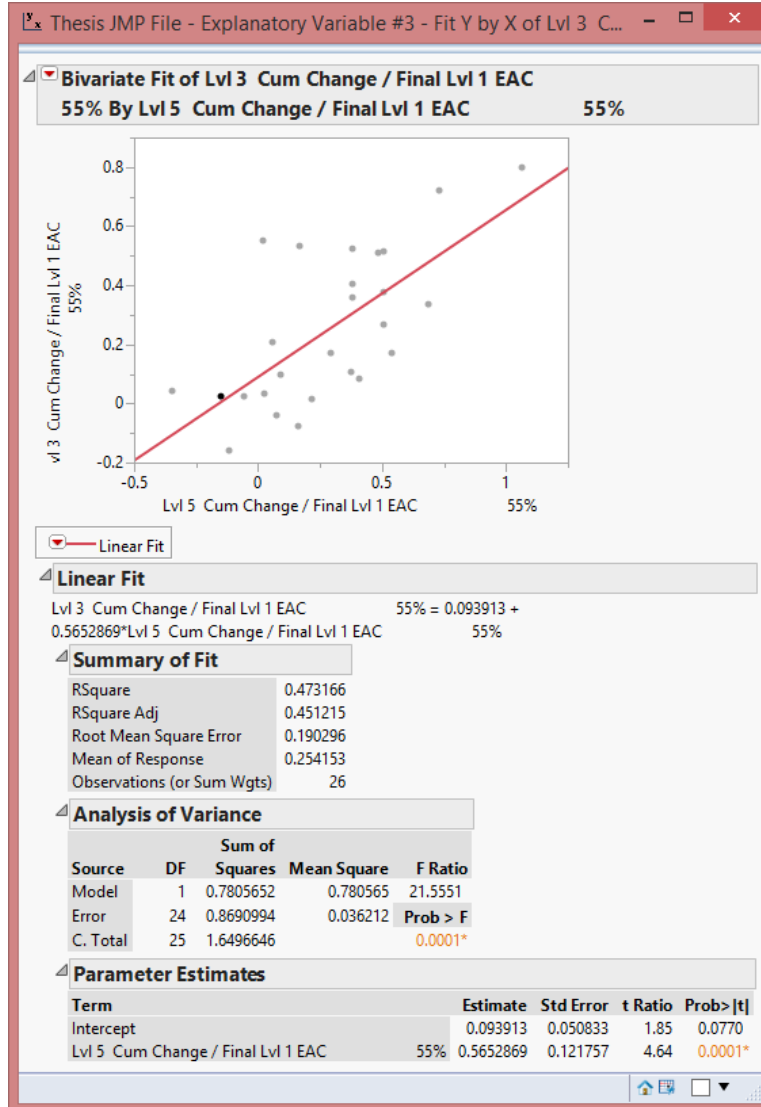
Comparing Level 3 with Level 5 at Bin - 45%



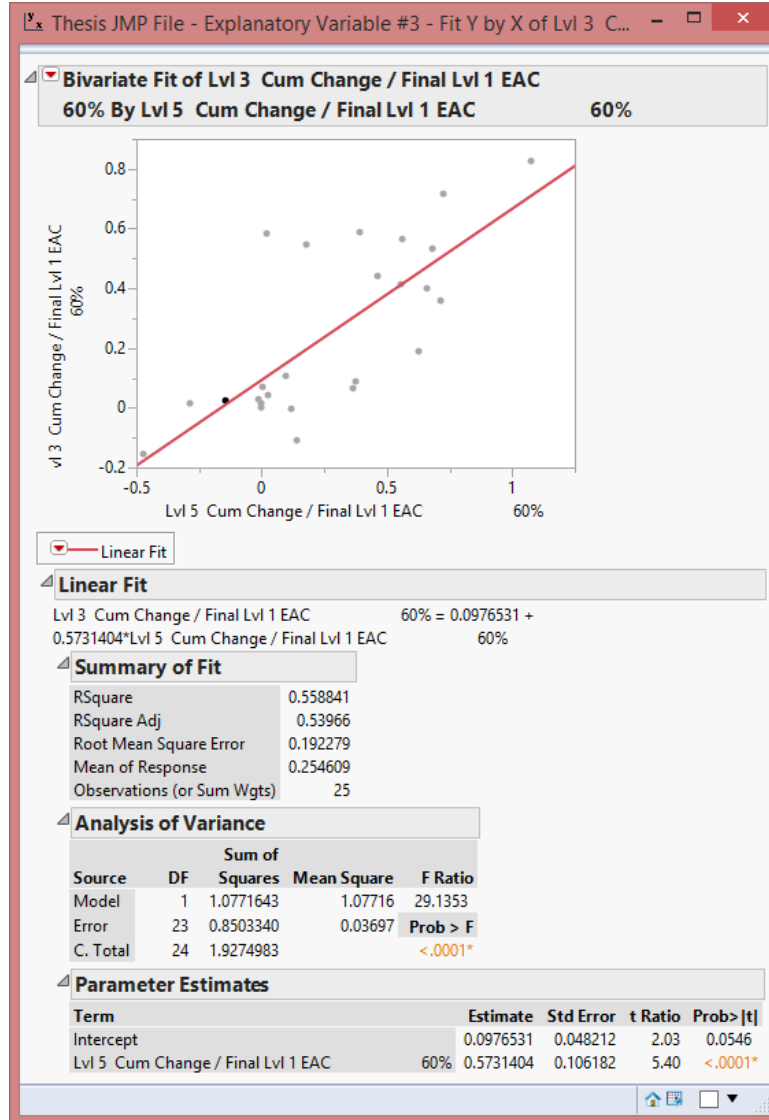
Comparing Level 3 with Level 5 at Bin - 50%



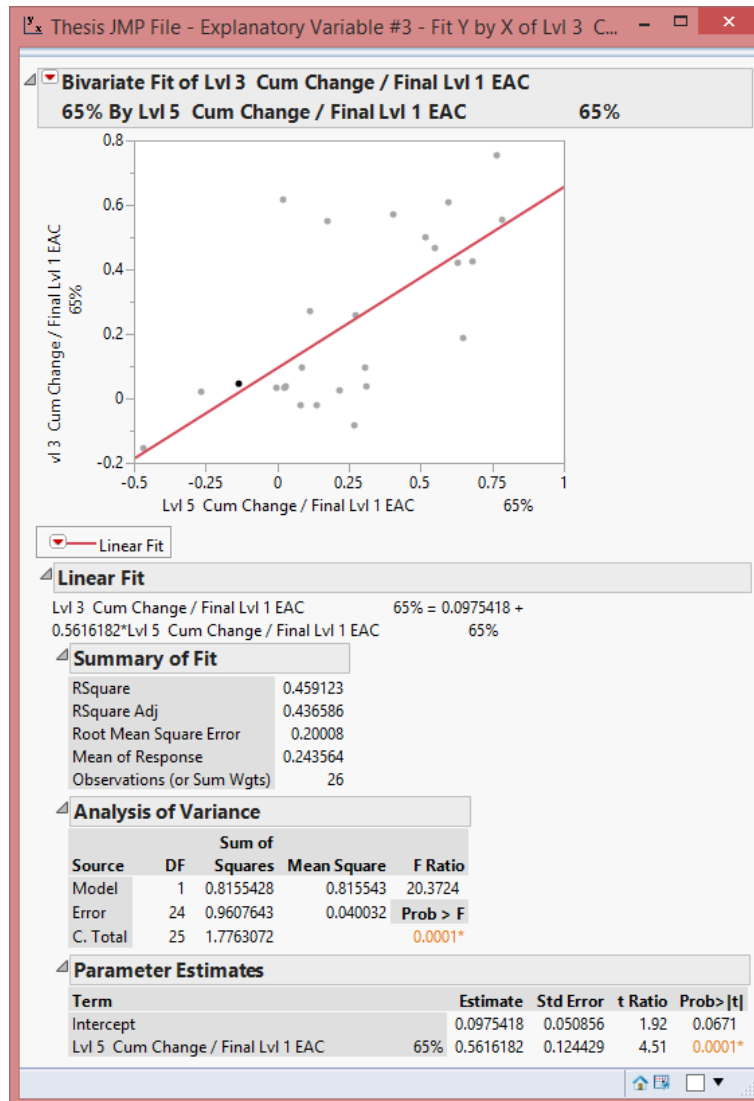
Comparing Level 3 with Level 5 at Bin - 55%



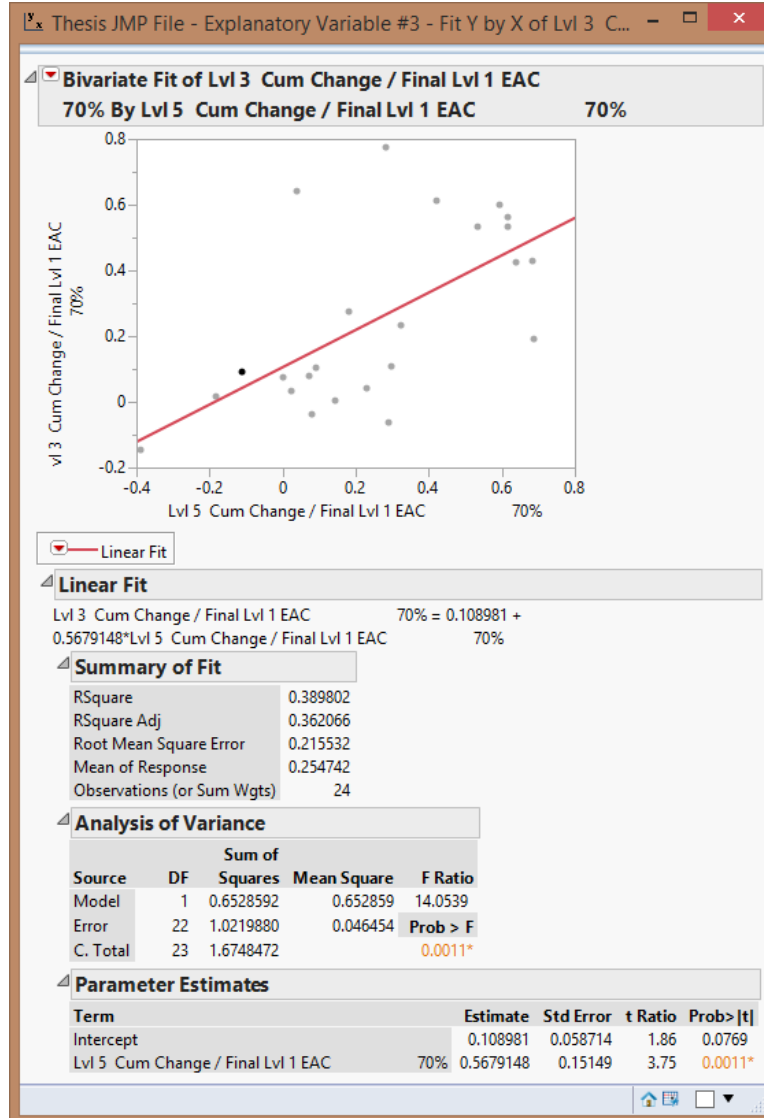
Comparing Level 3 with Level 5 at Bin - 60%



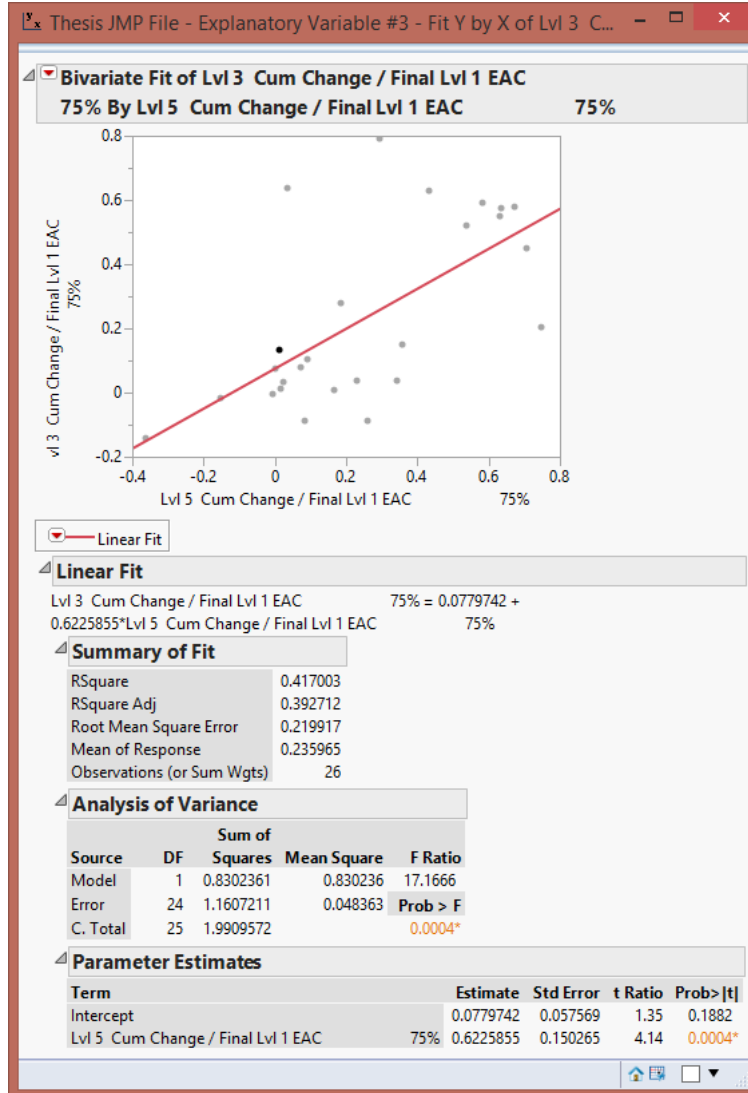
Comparing Level 3 with Level 5 at Bin - 65%



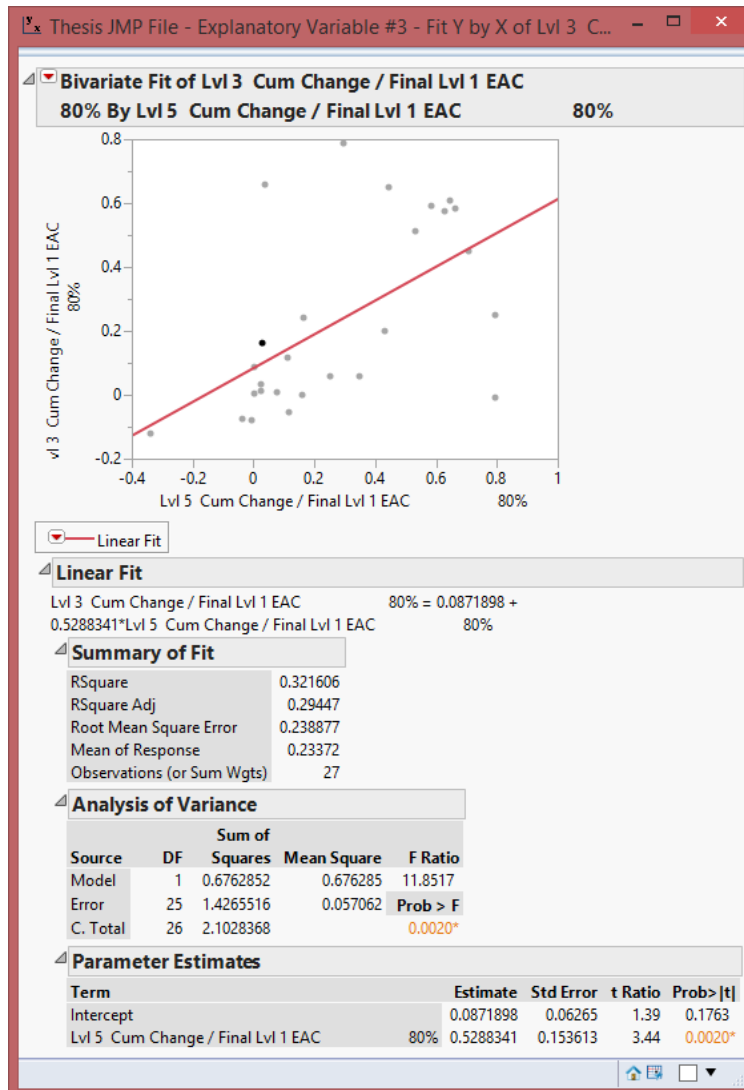
Comparing Level 3 with Level 5 at Bin - 70%



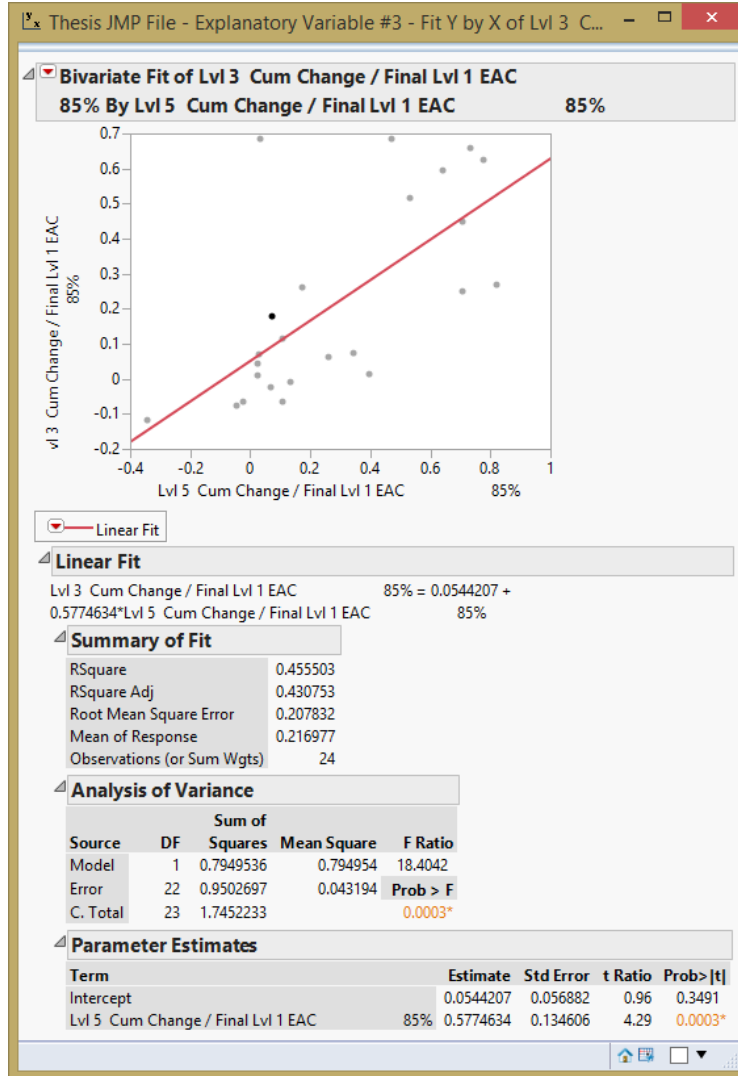
Comparing Level 3 with Level 5 at Bin - 75%



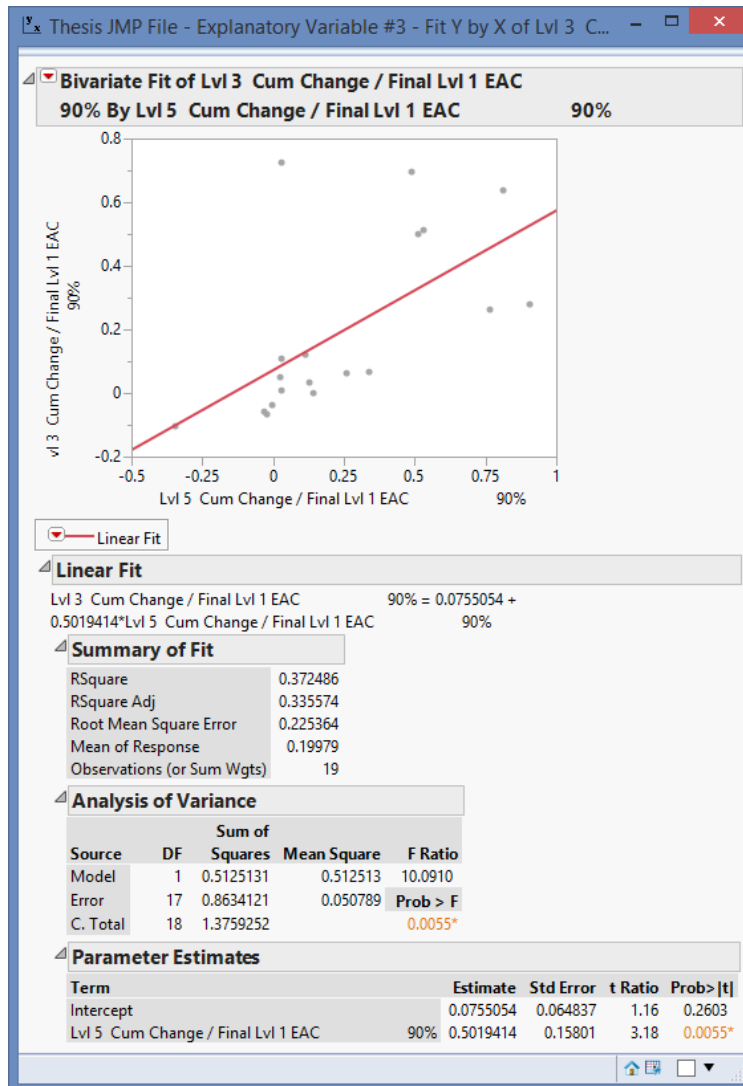
Comparing Level 3 with Level 5 at Bin - 80%



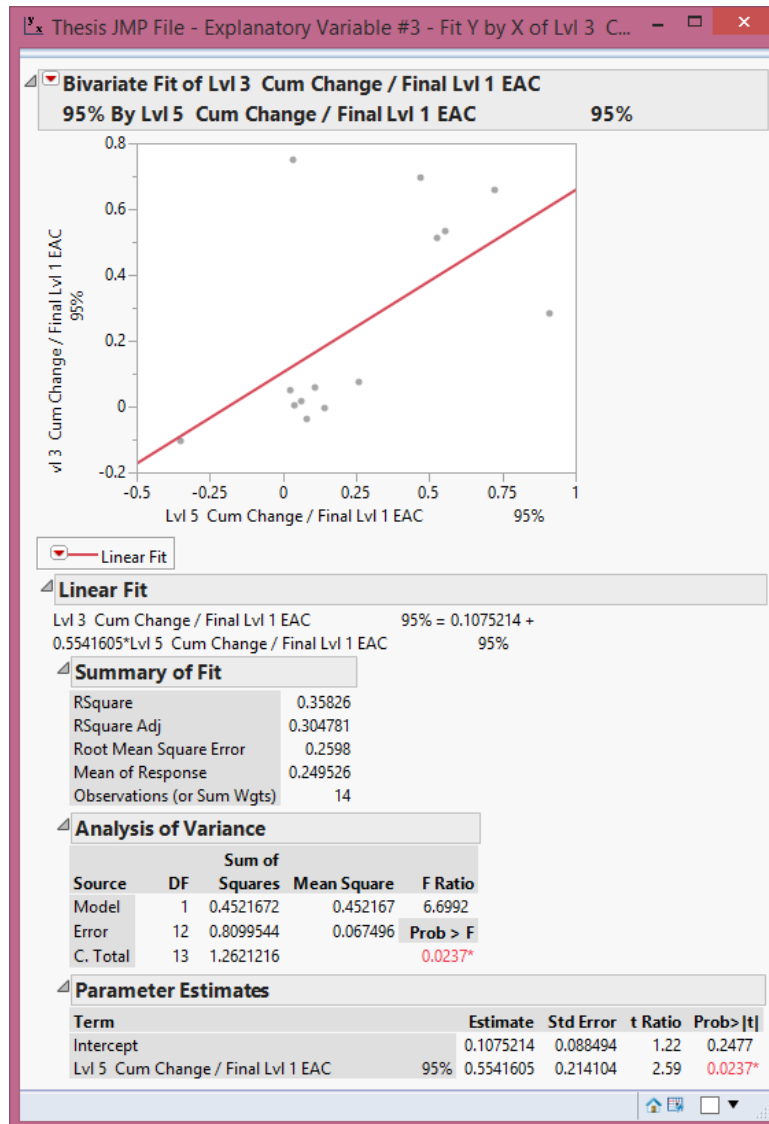
Comparing Level 3 with Level 5 at Bin - 85%



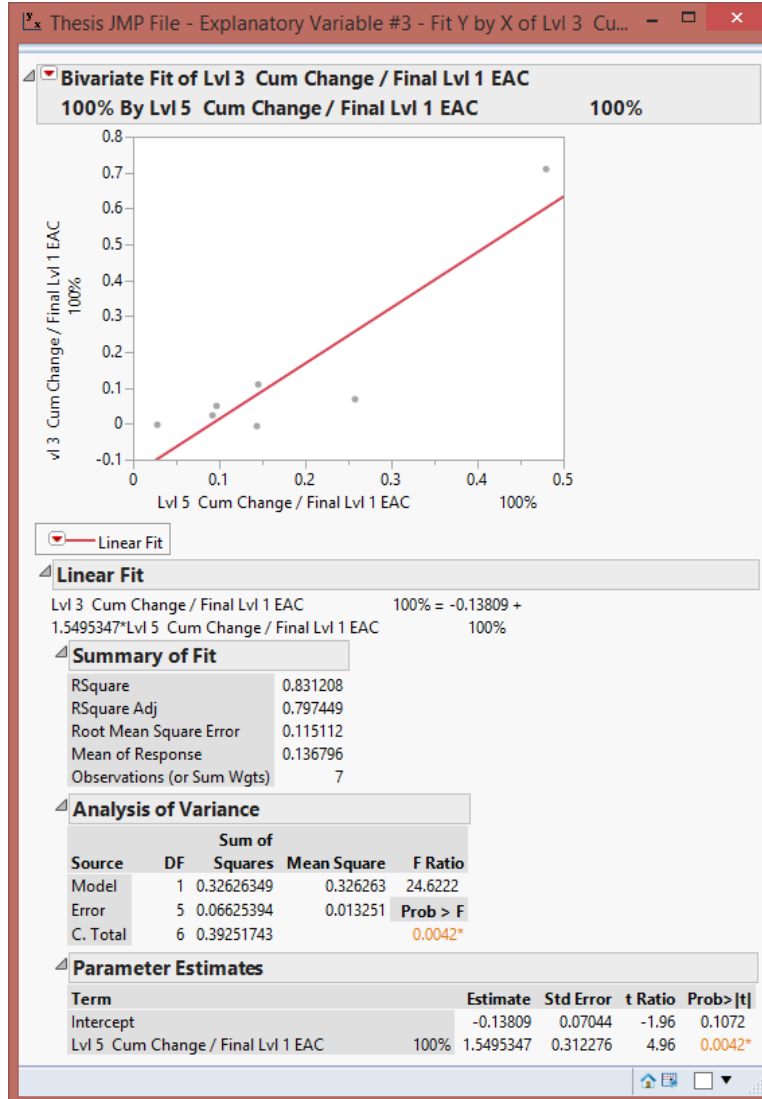
Comparing Level 3 with Level 5 at Bin - 90%



Comparing Level 3 with Level 5 at Bin - 95%



Comparing Level 3 with Level 5 at Bin - 100%



Works Cited

- Albert, Neil F. *Developing Work Breakdown Structures*. Presentation. MCR. July 2008.
- Bushey, Douglas B. *Making Strategic Decisions in DoD Acquisition Using Earned Value Management*. U.S. Army War College, Carlisle Barracks PA, February 2007.
- Christensen, David and Templin, Carl. “EAC Evaluation Methods: Do They Still Work?” *Acquisition Review Quarterly*, Spring 2002.
- CIO Insight. *Whodunit*. (October 2010) n pag. <http://www.cioinsight.com/c/a/Past-Opinions/How-to-Lie-with-Earned-Value/1/>
- Defense Acquisition University. *Control Accounts*.
<https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=80533d01-b4d8-4129-a2c6-d843de986821>
- Defense Acquisition University. *Earned Value Management ‘Gold Card’*. August 2013
- Defense Cost and Resource Center Portal (DCARC Portal). Office of the Secretary of Defense, Cost Assessment and Program Evaluation (OSD CAPE). n pag. <http://dcarc.pae.osd.mil/EVM/Index.aspx>
- Department of the Air Force. *Cost Risk and Uncertainty Analysis Handbook*, July 2007.
- Department of Defense Handbook: *Work Breakdown Structure*. MIL- HDBK-881, 3 October 2011.
- Department of Defense *IPMR Implementation Guide*, OUSD AT&L (PARCA) 31 July 2012.
- Etxegoien, Jon F. *Evolutionary Earned Value in Program Management, and a Case Study: Tracking the Things That Matter*. MS. Thesis. Naval Post Graduate School, Monterey CA, September 2002.
- Fleming, Quentin W. and Koppelman, Joel M. “Earned Value Project Management a Powerful Tool for Software Projects” *Crosstalk The Journal of Defense Software Engineering*, July 1998.

- Fonnesbeck, Robert W. and Lee, David J. *Cost Analysis for Aircraft System Test and Evaluation: Empirical Survey Data Structuring and Parametric Modeling, Volume 1*. MS. Thesis. Naval Post Graduate School, Monterey CA, June 1987.
- Lile, Ronald. *The Defense Cost and Resource Center: An Update*. Presentation. DCARC February 2007.
- Lukas, Joseph A. "EVM.01 Earned Value Analysis – Why it Doesn't Work." AACE International Transactions, 2008.
- Office of the Secretary of Defense Central Repository (CR) for Earned Value Management (EVM) Data. Office of the Under Secretary of Defense (Acquisition, Technology and Logistics), 12 March 2008.
- Pflieger, Mathew. OUSD (AT&L)/ Performance Assessments and Root Cause Analyses. Director for Earned Value Management. Electronic Mail, January 2013.
- Performance Assessments and Root Cause Analyses. Director for Earned Value Management. <http://www.acq.osd.mil/evm/>
- Rosado, William R. *Comparison of Development Test and Evaluation and Overall Program Estimate at Completion*. MS. Thesis. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2011.
- Solomon, Paul J. "Practical Performance-Based Earned Value" Crosstalk The Journal of Defense Software Engineering, May 2006.
- Solomon, Paul J. "Basing Earned Value on Technical Performance" Crosstalk The Journal of Defense Software Engineering, February 2013.
- Thickstun, Kristine E. *Predicting Over Target Baseline (OTB) Acquisition Contracts*. MS. Thesis. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2010.
- Tracy, Steven P. *Estimate at Completion: A Regression Approach to Earned Value*. MS Thesis. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2005.
- Trahan, Elizabeth N. *An Evaluation of Growth Models as Predictive Tools for Estimates At Completion (EAC)*. MS Thesis. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2009.

United States Government Accountability Office. *GAO Cost Estimating and Assessment Guide*, March 2009.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 074-0188	
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 27-03-2014		2. REPORT TYPE Master's Thesis		3. DATES COVERED (From - To) Sep 2012 - Mar 2014	
TITLE AND SUBTITLE Comparing the Predictive Capabilities of Level Three EVM Cost Data with Level Five EVM Cost Data				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Johnson, Joshua, D, CPT				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/ENC) 2950 Hobson Way, Building 640 WPAFB OH 45433-8865				8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENC-14-M-04	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Performance Assessments and Root Cause Analyses Deputy Director of Earned Value Management Mr. Gordon M. Kranz 3620 Defense Pentagon Room 3C889A 517-256-0646 parcaevm@osd.mil				10. SPONSOR/MONITOR'S ACRONYM(S) PARCA	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT DISTRUBTION STATEMENT A. APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.					
13. SUPPLEMENTARY NOTES This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.					
14. ABSTRACT Contract cost growth has been a concern for the Department of Defense (DoD) for decades. Earned value management is a tool used by the DoD to assist in identifying cost overruns before they occur. Current DoD regulations require contracts to report their earned value management (EVM) data down to level three of the work breakdown structure (WBS). Previous research has shown level three EVM data can predict contract cost growth earlier than using level one EVM data. Our research examines if level five EVM data would better predict cost growth than level three. Our results indicate that level five is not a better predictor of cost growth then level three. Our results do not support the DoD requiring contractors to provide level five EVM data.					
15. SUBJECT TERMS Work Breakdown Structure, Earned Value Management, Lower Level, Cost Growth					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 230	19a. NAME OF RESPONSIBLE PERSON Edward D. White, PhD (ENC)
a. REPORT U	b. ABSTRAC T U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) (937) 255-3636, ext 4540 Edward.White@afit.edu