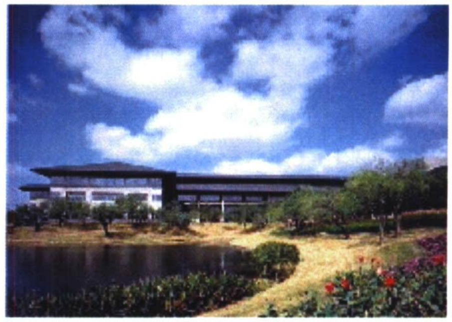
2004-05

Spring 2004

Forecasting Models for Change in the Construction Industry

David Walls

Austin

Forecasting Models for Change in the Construction Industry

By: David Walls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Introduction

Austin Commercial is a large construction manager based in Texas and has operations throughout the United States. In recent years, a major problem has come to their attention: an inability to manage change in construction projects. My main job in this project was to help them find a way to quantify these changes and calculate the impacts that these changes have. The primary methods I used were regression-modeling techniques that allowed forecasts to be made on information that Austin Commercial was currently collecting. Based on the forecasts it would then be possible to predict the actual impacts that these changes were having on construction projects. In the end, accurate models were found, and I believe these models will help Austin Commercial solve its change management problems. In the rest of this report the methods of my research, formulation of the models, explanations of the outputs, and impacts to Austin Commercial will be clearly shown.

Problem Background and Description

Austin Commercial is a company that has always focused on providing exactly what its customers want. In the construction industry, though, that can sometimes be a hard goal to reach. Many times customers change what they want numerous times throughout a project or are not exactly sure what they want until later in a project. This causes the architects, engineers, and designers to be constantly changing, revising, and tweaking all construction related documents that Austin Commercial must build off of. So it is not surprising that the construction industry is one the hardest industries to predict; almost every project is different and has a completely different set of circumstances.

Austin Commercial's main problem is that they have not done a good job in forecasting and anticipating the changes that do take place in any given construction project. As said earlier, they want to always please their customers, and therefore, have a history of always saying yes to any changes that are proposed without paying attention to the impact they will have later on in the project. Austin Commercial feels that if they had a way to help predict potential changes and their possible impact on cost to the project, they would better be able to prepare for the modifications at an earlier time. Then, by anticipating the changes earlier, they would have the resources in place to deal with any alterations, and their impact, later in a job. This would make Austin Commercial a much more efficient construction manager while at the same time continuing its history of satisfying the customer with a completed project that is exactly what they wanted.

The purpose of this study is to develop forecasting models that will allow Austin Commercial to forecast the amount of changes that take place on any given construction project and estimate the impacts of those changes on the cost of the project. To do this, the best indicators of changes must be identified and an accurate representation of varying types of construction projects must be chosen. In the end, the research prepared to develop these forecasting models will help answer the questions of whether the changes in a construction project can be accurately predicted and whether these forecasted changes can give accurate projections of the impact to cost of a project. The answers to these questions will definitely help Austin Commercial perform more efficiently and, in the long run, gain a competitive advantage.

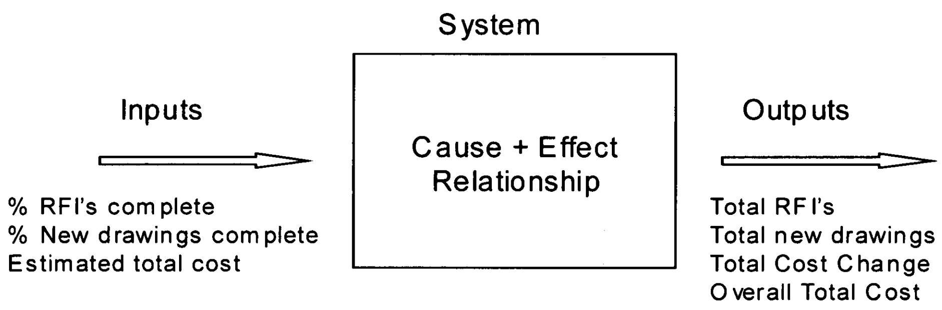
Situation Analysis

After numerous initial discussions with Austin Commercial to identify and lay out the overall problem, my first task was to identify the leading indicators of the changes that take place on a project. In discussions with the President of Austin Commercial and various other managers it was decided that RFI's (Requests for Information) and new drawings issued would be the most accurate indicators of change on a project that they have tracked historically. RFI's are standard documents that Austin Commercial issues to either an architect or designer/engineer when information is needed to help clarify a drawing or any other construction related document that has been issued to them. These RFI's often lead to an identification of a place or spec where new information is needed in the drawings/documents, or to and identification of a tweak that needs to be made to current drawings/documents so that Austin Commercial can proceed with construction in the confidence that they are building the project accurately. New drawings issued are the result of the architect or designer/engineer issuing a completely new drawing. These result from changes to the overall project and are usually architecturally, structurally, civilly, mechanically, or electrically related. With these items being the best indicators of the amount of changes in a particular job, I felt the best approach would be a forecasting model that takes both the RFI's and new drawings issued into account.

My first step in this process was the collection of this data in previous projects that Austin Commercial had completed. Again after discussions with top managers within the company and some mangers at various different ongoing projects, we were able to come up with a list of past projects that Austin Commercial wanted to be included in this model. While several of the projects listed ended up having incomplete and lost data, we were able to come up with some recently completed projects that gave me some good information to work with. Here is the list of projects that I used in the forecasting models:

- Akin, Gump, Strauss, Hauer, and Field Project
- Alcon Laboratories Building G Project
- Austin Ventures Project
- CarrAmerica Project
- Clark, Thomas, and Winters Project
- Crossmark Project
- CTW Storage/Fitness Center Project
- Ft. Worth Convention Center Phase 1 Project
- Ft. Worth Convention Center Phase 2 Project
- Hall Office Project
- Love Field CUP Project
- Mabel Peters Caruth Center Project
- Terrace V Project (RFI info only)
- TriQuint Semiconductor Project
- University of North Texas Recreation Center Project
- University of Texas Southwestern Medical Center Project

The data collected on these projects was RFI's broken down into divisions (electrical, mechanical, architectural, structural, civil, and total) and then broken down further by month over the life of the project. New drawings issued were also collected by divisions and then broken down by month over the life of the project. In addition, the initial cost estimate of the project, the total final cost, and the overall change of the cost were collected. My next step was calculating the percentage of the RFI's and new drawings, by division and total, issued out of their overall totals at specific key points of any construction project: 10%, 25%, 50%, 75%, 100%. Based on this data that was calculated, I felt the most effective way to give Austin Commercial what they wanted was to use regression modeling. Using regression models I could obtain the most accurate fit of the relationship between the inputs and outputs of my project.



Regression analysis assumes a cause-and-effect relationship between the inputs and outputs in a system and finds the relationship between them. In the context of Austin Commercial's problem, regression analysis will allow us to look at various different models to best acquire a fit for the inputs that we have data on and the desired output information. Both a cubic regression model and its corresponding 95% confidence interval were used for each of the RFI and new drawings issued divisions. Based on these forecasts it was then easy to calculate a projected total RFI and total new drawings issued for each of the divisions. And, with the historical totals for each division, I was able to set up a multiple regression model using those values and Austin Commercial's initial projected budget (that was also collected) to forecast the total change in cost for the project and the overall total final cost based on the forecasted RFI and new drawings issued data. Below is a simple example of a simple linear regression model being solved by the least squares method:

<u>Ex:</u> Find the equation $y = a + bx$ that best fits the given data points. (0,1), (1,1), (2,2), (3,2) (using matrix notation)

$$\mathrm{x} = \begin{pmatrix} 1 & 0 \\ 1 & 1 \\ 1 & 2 \\ 1 & 3 \end{pmatrix}, \; y = \begin{pmatrix} 1 \\ 1 \\ 2 \\ 2 \end{pmatrix}$$

$$x^T x = \begin{pmatrix} 4 & 6 \\ 6 & 14 \end{pmatrix} \quad x^T y = \begin{pmatrix} 6 \\ 11 \end{pmatrix}$$

Normal Equations:

$$\begin{pmatrix} 4 & 6 \\ 6 & 14 \end{pmatrix} \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} 6 \\ 11 \end{pmatrix}$$

$$\begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} 4 & 6 \\ 6 & 14 \end{pmatrix}^{-1} \begin{pmatrix} 6 \\ 11 \end{pmatrix} = \begin{pmatrix} 9/10 \\ 2/5 \end{pmatrix}$$

The resultant equation:

$$y = (9/10) + (2/5)x$$

Technical Description of the Model

As stated earlier, the overall model that I designed for Austin Commercial consists of two regression models that both had to be solved several times. A cubic regression model was solved to allow forecasting of the twelve following items:

1. Total Architectural RFI's
2. Total Structural RFI's
3. Total Civil RFI's
4. Total Mechanical RFI's
5. Total Electrical RFI's
6. Overall Total RFI's
7. Total New Architectural Drawings
8. Total New Structural Drawings
9. Total New Civil Drawings
10. Total New Mechanical Drawings
11. Total New Electrical Drawings
12. Overall Total New Drawings

These models used the data that was calculated from the percentage of the RFI's and new drawings, by division and total, issued out of their overall totals at some key points of any construction project: 10%, 25%, 50%, 75%, 100%. One assumption that was made with this data was that when calculating the percentage of the RFI's and new drawings issued out of their overall totals, RFI's and new drawings issued in a month at key points of the construction project (10%, 25%, 50%, 75%, 100%) and were divided within that month according to the percentage. For example, if I were calculating the percentage of overall

RFI's that had been issued at 10% into a project and 10% fell half way through a certain month, I would include 50% of that month's RFI's in the calculation.

The second model that was used was a multiple regression model. This model was solved twice to allow the forecasting of the two following things:

1. Total Change in Cost
2. Overall Final Cost

These models used the historical data of the twelve items listed earlier and Austin Commercial's initial projected budget. Clearly, the main assumption that will be made when using these models is that the forecasted values used from the previous models are accurate.

The solution method that was used for all of the models was the least squares method. The least squares method, in general, takes an equation Ax=b that has more equations than unknowns and is likely to not have a solution. Instead, it finds a "best-fit" approximation by minimizing the norm of b-Ax. In essence, the least squares method finds the solution that has the least amount of residual or error when compared to the original data. The example that I calculated earlier and the general forms that I will provide below, use the normal equations to solve the least square problem. Below is the general form for all of the cubic regression models that were solved (in matrix notation) and the solution method:

$$y = a + bx + cx^2 + dx^3$$

$$x=\begin{pmatrix}1 & x_1 & x_1^{\,2} & x_1^{\,3}\\ 1 & x_2 & x_2^{\,2} & x_2^{\,3}\\ 1 & x_n & x_n^{\,2} & x_n^{\,3}\end{pmatrix}, y=\begin{pmatrix}y_1\\ y_2\\ y_n\end{pmatrix}, z=\begin{pmatrix}a\\ b\\ c\\ d\end{pmatrix}$$

$$(x^T x)z = x^T y$$

$$z = (x^T x)^{-1}(x^T y)$$

Below is the general form of the multiple regression models that were solved (in matrix notation) and the solution method:

$$y=b_0+b_1x+b_2x+\text{K}+b_nx$$

$$x=\begin{pmatrix}1 & x_{11} & x_{12} & x_{1k}\\ 1 & x_{21} & x_{22} & x_{2k}\\ 1 & x_{n1} & x_{n2} & x_{nk}\end{pmatrix}, y=\begin{pmatrix}y_1\\ y_2\\ y_n\end{pmatrix}, b=\begin{pmatrix}b_0\\ b_1\\ b_n\end{pmatrix}$$

$$(x^T x)b=x^T y$$

$$b=(x^T x)^{-1}(x^T y)$$

The statistical software Minitab was used to solve these models. It was very useful throughout the project and effortlessly allowed me to run various models and find the most accurate for Austin Commercial. Minitab solved all of the models using the least squares method, which was described in the previous paragraph. Listed below are the formal mathematical statements of all the models that were solved, starting with the cubic regression models:

RFI Architectural

RFI Arch = - 0.00494 + 1.244*(% Complete) + 0.9534*(% Complete^2)

- 1.195*(% Complete^3)

Variables

- RFI Arch = Percentage of Architectural RFI's out of total
- % Complete = Percentage of construction job completed (in terms of time)

RFI Structural

RFI Struct = - 0.01638 + 3.170*(% Complete) - 3.166*(% Complete^2)

+ 1.004*(% Complete^3)

Variables

- RFI Struct = Percentage of Structural RFI's out of total
- % Complete = Percentage of construction job completed (in terms of time)

RFI Civil

RFI Civil = 0.01071 + 2.911*(% Complete) - 3.513*(% Complete^2)

+ 1.599*(% Complete^3)

Variables

- RFI Civil = Percentage of Civil RFI's out of total
- % Complete = Percentage of construction job completed (in terms of time)

RFI Mechanical

RFI Mech = - 0.01573 + 1.376*(% Complete) + 0.8258*(% Complete^2)

- 1.191*(% Complete^3)

Variables

- RFI Mech = Percentage of Mechanical RFI's out of total
- % Complete = Percentage of construction job completed (in terms of time)

RFI Electrical

RFI Elect = 0.00820 + 0.9328*(% Complete) + 1.513*(% Complete^2)

- 1.454*(% Complete^3)

Variables

- RFI Elect = Percentage of Electrical RFI's out of total
- % Complete = Percentage of construction job completed (in terms of time)

RFI Total

RFI Total = - 0.00587 + 1.743*(% Complete) - 0.1548*(% Complete^2)

- 0.5846*(% Complete^3)

Variables

- RFI Total = Percentage of Total RFI's out of total
- % Complete = Percentage of construction job completed (in terms of time)

New Drawings Architectural

Draw Arch = - 0.002571 + 2.073*(% Complete) - 1.125*(% Complete^2)

+ 0.0557*(% Complete^3)

Variables

- Draw Arch = Percentage of Architectural new drawings issued out of total
- % Complete = Percentage of construction job completed (in terms of time)

New Drawings Structural

$$\text{Draw Struct} = 0.01635 + 4.644*(\%\text{ Complete}) - 7.147*(\%\text{ Complete}^2) + 3.494*(\%\text{ Complete}^3)$$

Variables

- Draw Struct = Percentage of Structural new drawings issued out of total
- % Complete = Percentage of construction job completed (in terms of time)

New Drawings Civil

$$\text{Draw Civil} = 0.02906 + 2.234*(\%\text{ Complete}) - 1.973*(\%\text{ Complete}^2) + 0.7171*(\%\text{ Complete}^3)$$

Variables

- Draw Civil = Percentage of Civil new drawings issued out of total
- % Complete = Percentage of construction job completed (in terms of time)

New Drawings Mechanical

$$\text{Draw Mech} = 0.00795 + 1.721*(\%\text{ Complete}) - 0.1697*(\%\text{ Complete}^2) - 0.5566*(\%\text{ Complete}^3)$$

Variables

- Draw Mech = Percentage of Mechanical new drawings issued out of total
- % Complete = Percentage of construction job completed (in terms of time)

New Drawings Electrical

$$\text{Draw Elect} = -0.01913 + 1.557*(\%\text{ Complete}) + 0.436*(\%\text{ Complete}^2) - 0.9813*(\%\text{ Complete}^3)$$

Variables

- Draw Elect = Percentage of Electrical new drawings issued out of total
- % Complete = Percentage of construction job completed (in terms of time)

New Drawings Total

Draw Total = 0.000133 + 1.962*(% Complete) - 0.8395*(% Complete^2)

- 0.1224*(% Complete^3)

Variables

- Draw Total = Percentage of Total new drawings issued out of total
- % Complete = Percentage of construction job completed (in terms of time)

In the Appendix I have provided a graph of all of the cubic regression models with their 95% percent confidence intervals. Here are the two multiple regression models:

Total Change in Cost

Total Change Cost = - 27744 - 341607*RFI - Arch. - 344462*RFI - Struct.

- 481711*RFI - Civil - 341647*RFI - Mech.

- 238332*RFI - Elect. + 334499*Total RFI

+ 24422*Draw - Arch. + 4850*Draw- Struct.

+ 92551*Draw - Civil + 32861*Draw - Mech.

- 35229*Draw - Elect. - 10990*Total New Drawings

- 0.199*Total Original Budget

Variables

- Total Change Cost = total change in cost of an entire project
- RFI – Arch = forecast of the total Architectural RFI's for an entire project
- RFI - Struct = forecast of the total Structutal RFI's for an entire project

- RFI - Civil = forecast of the total Civil RFI's for an entire project
- RFI – Mech = forecast of the total Mechanical RFI's for an entire project
- RFI – Elect = forecast of the total Electrical RFI's for an entire project
- Total RFI = forecast of the Total RFI's for an entire project
- Draw - Arch = forecast of the total Architectural new drawings for an entire project
- Draw- Struct = forecast of the total Structural new drawings for an entire project
- Draw - Civil = forecast of the total Civil new drawings for an entire project
- Draw - Mech = forecast of the total Mechanical new drawings for an entire project
- Draw - Elect = forecast of the total Electrical new drawings for an entire project
- Total New Drawings = forecast of the Total new drawings for an entire project
- Total Original Budget = Austin Commercial's initial budget for the project

Total Change in Cost

Total Final Cost = 80322 - 283487*RFI - Arch. - 279272*RFI - Struct. - 509581*RFI - Civil - 282740*RFI - Mech. - 266662*RFI - Elect. + 291597*Total RFI + 34000*Draw - Arch. + 13713*Draw- Struct. + 147181*Draw - Civil+ 48314*Draw - Mech. + 6054*Draw - Elect. - 33991*Total New Drawings + 0.899*Total Original Budget

Variables

- Total Final Cost = Final cost of the Project
- RFI – Arch = forecast of the total Architectural RFI's for an entire project
- RFI - Struct = forecast of the total Structutal RFI's for an entire project
- RFI - Civil = forecast of the total Civil RFI's for an entire project

- RFI – Mech = forecast of the total Mechanical RFI's for an entire project
- RFI – Elect = forecast of the total Electrical RFI's for an entire project
- Total RFI = forecast of the Total RFI's for an entire project
- Draw - Arch = forecast of the total Architectural new drawings for an entire project
- Draw- Struct = forecast of the total Structural new drawings for an entire project
- Draw - Civil = forecast of the total Civil new drawings for an entire project
- Draw - Mech = forecast of the total Mechanical new drawings for an entire project
- Draw - Elect = forecast of the total Electrical new drawings for an entire project
- Total New Drawings = forecast of the Total new drawings for an entire project
- Total Original Budget = Austin Commercial's initial budget for the project

Output and Analysis

All of Minitab's models outputs are provided in the Appendix (I will be referring to various numbers from those outputs throughout this section). My analysis of the output will be divided into a study of the cubic regression models and then the multiple regression models. The central statistic to focus on in the cubic regression models is the coefficient of the determination term (R-squared). R-squared is the ratio of the explained variation to the total variation, and it indicates the portion of the total variation of Y (in my models RFI Arch, RFI Struct, etc.) from its mean that is explained by the regression equation. In essence, the R-squared tells you how much X (in my models % Complete) accounts for the variation in Y. The closer the R-squared is to 100% the more accurate the model is. In my models the R-squared values ranged from 100% to 99.3%, which means that all of the models were very accurate in using X to account for variations in Y, and therefore are accurate models. It is interesting to note that the architectural RFI and new drawings issued models, and Total RFI and new drawings issued models, have R-squared values of 100%, while the civil models for RFI's and new drawings issued both have the lowest R-squared terms in their group. This gives some clear direction to Austin Commercial in terms of what divisions produce the most accurate forecasts. You can also clearly see this by examining the charted confidence intervals where the civil models have wider confidence intervals than the architectural models. Overall, however, based on these outputs Austin Commercial can be confident in the total project forecasts by divisions that these models produce, and therefore, can be confident that the multiple regression models are using accurate data.

For the multiple regression models that were used to forecast the overall total change in cost and final cost, I will again analyze the R-squared values as well as the T-stat, F-ratio, and P value. The R-squared value for the total change in cost was 99.5% and was 100% for the total cost. The T-stat is the coefficient divided by the standard error, and is used to test the hypothesis that the regression coefficient is zero, and if true, it would show that the corresponding independent variable does not explain anything about the dependent variable. The P-value is simply the probability that this is the case. The F-ratio is the ratio of explained variance to the unexplained variance and implies that a large F-ratio means that there is a good fit of data. The P-value in response to the F-ratio gives the probability that the regression is not significant. In analyzing these values it is important to note that the total change in cost model has larger P-values (in reference to the T-stat) overall, than the final cost model. This implies that there is a higher probability that its independent variables do not explain the resulting dependent variable. Also, in both models, the constant and Draw-Struct variable's P-values are higher than most of the others while the Total RFI and Civil RFI variables seem to have strong effects on the result based on the same values. It is also interesting to note that Austin Commercial's initial budget seems to be more significant in the total cost model that the change in cost model. In terms of the F-ratios and corresponding P-values, both models do have relatively large F-ratios and small P-values, but the total cost model has a significantly higher F-ratio and smaller P-value. This would again lead one to believe that while they both are good fits to the date, the total cost model is a better fit, taken as a whole.

Overall, based on the analysis of the outputs, I feel that both the cubic and multiple regression models are strong models that can be used in conjuncture with each other to produce some valuable information for Austin Commercial. Austin Commercial can also gain valuable information from the analysis of the model's output.

Summary, Conclusion, and Limitations

In summary, based on historical data from Austin Commercial, I was able to design two sets of regression models to help Austin Commercial forecast changes and their cost impacts for their construction projects. The first set of models allowed forecasts to be made for total RFI's and total new drawings issued by divisions using the current percent complete of a job and its current totals of RFI' and new drawings issued by division. The second set of models allowed this data, along with Austin's Commercial's initial budget for the job, to forecast the amount of change in cost on that job and its total overall cost. As seen in the previous section, all of these models are accurate and have given Austin Commercial some needed insight into the indicators and reasons for the change that takes place in all construction projects.

In conclusion, I recommend that Austin Commercial begin to use these models to help forecast change in its projects and the cost effects of that change. To help them with this, I have designed an Excel spreadsheet that will allow them to start doing this. Some examples of the spreadsheet using current Austin Commercial projects have been attached in the Appendix. Austin Commercial has begun implementing a new policy where all jobs are required to turn in monthly totals for RFI's and new drawings. I believe that this is a great start for Austin Commercial because it will allow them to begin forecasting these changes and be able to plan and manage them with greater aptitude. Also, by doing this, they will begin to amass more historical data that will allow them to update their models in the future. I look forward to the possibility of doing more research for them in this area in the near future. I really believe that by realizing and trying to solve this change management problem Austin Commercial can set itself apart from its competitors and better serve its customers in the long run.

Below is a list of limitations that I can see for the models:

- Only uses data from last 3 years – assumes last 3 years is indicative of future
- Projects that were used for data ranged from cost of about $500,000 to $50,000,000 – model may not be accurate for extremely large projects
- Assumes RFI's and new drawings issued are the best indicators for change in a project

Amount of projects used - Would have like to included more projects in the data (hopefully more data will be available in the future)

Appendix

Cubic Regression Model's Output

Cubic Regression Analysis: RFI Arch versus % Complete

The regression equation is
RFI Arch = - 0.00494 + 1.244*(% Complete) + 0.9534*(% Complete^2)
- 1.195*(% Complete^3)

S = 0.0143716   R-Sq = 100.0%   R-Sq(adj) = 99.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.915359	0.305120	1477.28	0.001
Error	2	0.000413	0.000207		
Total	5	0.915772			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	0.869834	75.74	0.001
Quadratic	1	0.040082	20.53	0.020
Cubic	1	0.005444	26.36	0.036

Cubic Regression Analysis: RFI Struct versus % Complete

```
The regression equation is
RFI Struct = - 0.01638 + 3.170*(% Complete) - 3.166*(% Complete^2)
             + 1.004*(% Complete^3)


S = 0.0373065   R-Sq = 99.7%   R-Sq(adj) = 99.2%


Analysis of Variance

Source      DF        SS        MS       F      P
Regression   3  0.895262  0.298421  214.42  0.005
Error        2  0.002784  0.001392
Total        5  0.898045


Sequential Analysis of Variance

Source     DF        SS      F      P
Linear      1  0.740297  18.77  0.012
Quadratic   1  0.151117  68.36  0.004
Cubic       1  0.003848   2.76  0.238
```

Cubic Regression Analysis: RFI Civil versus % Complete

The regression equation is
RFI Civil = 0.01071 + 2.911*(% Complete) - 3.513*(% Complete^2)
+ 1.599*(% Complete^3)

S = 0.0428816   R-Sq = 99.5%   R-Sq(adj) = 98.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.746197	0.248732	135.27	0.007
Error	2	0.003678	0.001839		
Total	5	0.749874			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	0.669237	33.20	0.005
Quadratic	1	0.067212	15.02	0.030
Cubic	1	0.009747	5.30	0.148

Cubic Regression Analysis: RFI Mech versus % Complete

The regression equation is
RFI Mech = - 0.01573 + 1.376*(% Complete) + 0.8258*(% Complete^2)
- 1.191*(% Complete^3)

S = 0.0282991   R-Sq = 99.8%   R-Sq(adj) = 99.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.945243	0.315081	393.44	0.003
Error	2	0.001602	0.000801		
Total	5	0.946845			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	0.887439	59.75	0.002
Quadratic	1	0.052395	22.42	0.018
Cubic	1	0.005409	6.75	0.122

Cubic Regression Analysis: RFI Elect versus % Complete

The regression equation is
RFI Elect = 0.00820 + 0.9328*(% Complete) + 1.513*(% Complete^2)
- 1.454*(% Complete^3)

S = 0.0185344   R-Sq = 99.9%   R-Sq(adj) = 99.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.902419	0.300806	875.65	0.001
Error	2	0.000687	0.000344		
Total	5	0.903106			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	0.868600	100.69	0.001
Quadratic	1	0.025755	8.83	0.059
Cubic	1	0.008064	23.47	0.040

Cubic Regression Analysis: RFI Total versus % Complete

```
The regression equation is
RFI Total = - 0.00587 + 1.743*(% Complete) - 0.1548*(% Complete^2)
            - 0.5846*(% Complete^3)


S = 0.0138130   R-Sq = 100.0%   R-Sq(adj) = 99.9%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.891508	0.297169	1557.51	0.001
Error	2	0.000382	0.000191		
Total	5	0.891890			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	0.830486	54.10	0.002
Quadratic	1	0.059719	106.32	0.002
Cubic	1	0.001303	6.83	0.120

Cubic Regression Analysis: Draw Arch versus % Complete

```
The regression equation is
Draw Arch = - 0.002571 + 2.073*(% Complete) - 1.125*(% Complete^2)
            + 0.0557*(% Complete^3)


S = 0.0103671   R-Sq = 100.0%   R-Sq(adj) = 99.9%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.844067	0.281356	2617.85	0.000
Error	2	0.000215	0.000107		
Total	5	0.844282			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	0.783878	51.91	0.002
Quadratic	1	0.060177	796.00	0.000
Cubic	1	0.000012	0.11	0.771

Cubic Regression Analysis: Draw Struct versus % Complete

```
The regression equation is
Draw Struct = 0.01635 + 4.644*(% Complete) - 7.147*(% Complete^2)
              + 3.494*(% Complete^3)


S = 0.0368015   R-Sq = 99.7%   R-Sq(adj) = 99.2%


Analysis of Variance

Source      DF        SS        MS       F      P
Regression   3  0.797960  0.265987  196.39  0.005
Error        2  0.002709  0.001354
Total        5  0.800669


Sequential Analysis of Variance

Source     DF        SS      F      P
Linear      1  0.556318   9.11  0.039
Quadratic   1  0.195081  11.88  0.041
Cubic       1  0.046561  34.38  0.028
```

Cubic Regression Analysis: Draw Civil versus % Complete

The regression equation is
Draw Civil = 0.02906 + 2.234*(% Complete) - 1.973*(% Complete^2)
+ 0.7171*(% Complete^3)

S = 0.0511321   R-Sq = 99.3%   R-Sq(adj) = 98.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.742524	0.247508	94.67	0.010
Error	2	0.005229	0.002614		
Total	5	0.747753			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	0.696452	54.30	0.002
Quadratic	1	0.044111	18.40	0.023
Cubic	1	0.001961	0.75	0.478

Cubic Regression Analysis: Draw Mech versus % Complete

```
The regression equation is
Draw Mech = 0.00795 + 1.721*(% Complete) - 0.1697*(% Complete^2)
            - 0.5566*(% Complete^3)


S = 0.0146176   R-Sq = 100.0%   R-Sq(adj) = 99.9%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.871537	0.290512	1359.60	0.001
Error	2	0.000427	0.000214		
Total	5	0.871965			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	0.813754	55.92	0.002
Quadratic	1	0.056602	105.54	0.002
Cubic	1	0.001182	5.53	0.143

Cubic Regression Analysis: Draw Elect versus Time

```
Cubic Regression Analysis: Draw Elect versus % Complete

The regression equation is
Draw Elect = - 0.01913 + 1.557*(% Complete) + 0.436*(% Complete^2)
             - 0.9813*(% Complete^3)


S = 0.0412807   R-Sq = 99.6%   R-Sq(adj) = 99.1%


Analysis of Variance

Source      DF        SS        MS       F      P
Regression   3  0.938036  0.312679  183.49  0.005
Error        2  0.003408  0.001704
Total        5  0.941444


Sequential Analysis of Variance

Source     DF        SS      F      P
Linear      1  0.873680  51.57  0.002
Quadratic   1  0.060684  25.71  0.015
Cubic       1  0.003673   2.16  0.280
```

Cubic Regression Analysis: Draw Total versus % Complete

```
The regression equation is
Draw Total = 0.000133 + 1.962*(% Complete) - 0.8395*(% Complete^2)
             - 0.1224*(% Complete^3)


S = 0.00492864   R-Sq = 100.0%   R-Sq(adj) = 100.0%


Analysis of Variance

Source      DF        SS        MS         F      P
Regression   3  0.850426  0.283475  11669.75  0.000
Error        2  0.000049  0.000024
Total        5  0.850475


Sequential Analysis of Variance

Source     DF        SS        F      P
Linear      1  0.792119    54.30  0.002
Quadratic   1  0.058250  1653.22  0.000
Cubic       1  0.000057     2.35  0.265
```

Multiple Regression Model's Output

Multiple Regression Analysis: Total Change versus RFI - Arch., RFI - Struct, ...

```
The regression equation is
Total Change Cost = - 27744 - 341607*RFI - Arch. - 344462*RFI - Struct.
                    - 481711*RFI - Civil - 341647*RFI - Mech.
                    - 238332*RFI - Elect. + 334499*Total RFI
                    + 24422*Draw - Arch. + 4850*Draw- Struct.
                    + 92551*Draw - Civil + 32861*Draw - Mech.
                    - 35229*Draw - Elect. - 10990*Total New Drawings
                    - 0.199*Total Original Budget
```

15 cases used, 1 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	-27744	210634	-0.13	0.917
RFI - Arch.	-341607	141680	-2.41	0.250
RFI - Struct.	-344462	130224	-2.65	0.230
RFI - Civil	-481711	143631	-3.35	0.184
RFI - Mech.	-341647	148049	-2.31	0.260
RFI - Elect.	-238332	98658	-2.42	0.250
Total RFI	334499	136317	2.45	0.246
Draw - Arch.	24422	30078	0.81	0.566
Draw- Struct.	4850	26823	0.18	0.886
Draw - Civil	92551	46649	1.98	0.297
Draw - Mech.	32861	30101	1.09	0.472
Draw - Elect.	-35229	17012	-2.07	0.286
Total New Drawings	-10990	21999	-0.50	0.705
Total Original Budget	-0.1989	0.1779	-1.12	0.464

S = 213905   R-Sq = 99.5%   R-Sq(adj) = 93.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	13	9.65358E+12	7.42583E+11	16.23	0.192
Residual Error	1	45755325592	45755325592		
Total	14	9.69934E+12			

Source	DF	Seq SS
RFI - Arch.	1	4.24689E+11
RFI - Struct.	1	86955836786
RFI - Civil	1	3.23255E+12
RFI - Mech.	1	3.29388E+12
RFI - Elect.	1	19444010799
Total RFI	1	1.25200E+11
Draw - Arch.	1	321593680
Draw- Struct.	1	330239623
Draw - Civil	1	3.69799E+11
Draw - Mech.	1	1.01570E+11
Draw - Elect.	1	1.94085E+12
Total New Drawings	1	756956856
Total Original Budget	1	57238211620

Unusual Observations

	Total
RFI -	Change

Obs	Arch.	Cost	Fit	SE Fit	Residual	St Resid
1	28	92073	94975	213885	-2902	-1.00 X
2	99	2535227	2525362	213677	9865	1.00 X
4	168	69055	71464	213891	-2409	-1.00 X
7	134	1271289	1279107	213762	-7818	-1.00 X
9	69	746000	752773	213798	-6773	-1.00 X
10	69	1100000	1088050	213571	11950	1.00 X
11	32	218777	232707	213451	-13930	-1.00 X
12	35	1127608	1132273	213854	-4665	-1.00 X
14	137	97800	95800	213896	2000	1.00 X
15	81	328360	332860	213858	-4500	-1.00 X
16	66	1302481	1306922	213859	-4441	-1.00 X

X denotes an observation whose X value gives it large influence.

Multiple Regression Analysis: Total Final versus RFI - Arch., RFI - Struct, ...

```
The regression equation is
Total Final Cost = 80322 - 283487*RFI - Arch. - 279272*RFI - Struct.
                   - 509581*RFI - Civil - 282740*RFI - Mech.
                   - 266662*RFI - Elect. + 291597*Total RFI + 34000*Draw -
Arch.
                   + 13713*Draw- Struct. + 147181*Draw - Civil
                   + 48314*Draw - Mech. + 6054*Draw - Elect.
                   - 33991*Total New Drawings + 0.899*Total Original Budget
```

15 cases used, 1 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	80322	36941	2.17	0.274
RFI - Arch.	-283487	24848	-11.41	0.056
RFI - Struct.	-279272	22839	-12.23	0.052
RFI - Civil	-509581	25190	-20.23	0.031
RFI - Mech.	-282740	25965	-10.89	0.058
RFI - Elect.	-266662	17303	-15.41	0.041
Total RFI	291597	23908	12.20	0.052
Draw - Arch.	34000	5275	6.45	0.098
Draw- Struct.	13713	4704	2.92	0.210
Draw - Civil	147181	8181	17.99	0.035
Draw - Mech.	48314	5279	9.15	0.069
Draw - Elect.	6054	2984	2.03	0.292
Total New Drawings	-33991	3858	-8.81	0.072
Total Original Budget	0.89886	0.03119	28.81	0.022

S = 37515.1   R-Sq = 100.0%   R-Sq(adj) = 100.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	13	3.66278E+15	2.81753E+14	200196.07	0.002
Residual Error	1	1407382839	1407382839		
Total	14	3.66278E+15			

Source	DF	Seq SS
RFI - Arch.	1	1.65921E+15
RFI - Struct.	1	1.15632E+15
RFI - Civil	1	1.69360E+12
RFI - Mech.	1	4.11506E+14
RFI - Elect.	1	1.89130E+14
Total RFI	1	9.02716E+13
Draw - Arch.	1	9.34224E+13
Draw- Struct.	1	3.25355E+11
Draw - Civil	1	2.97541E+13
Draw - Mech.	1	2.56553E+13
Draw - Elect.	1	3.13016E+12
Total New Drawings	1	1.19468E+12
Total Original Budget	1	1.16852E+12

Unusual Observations

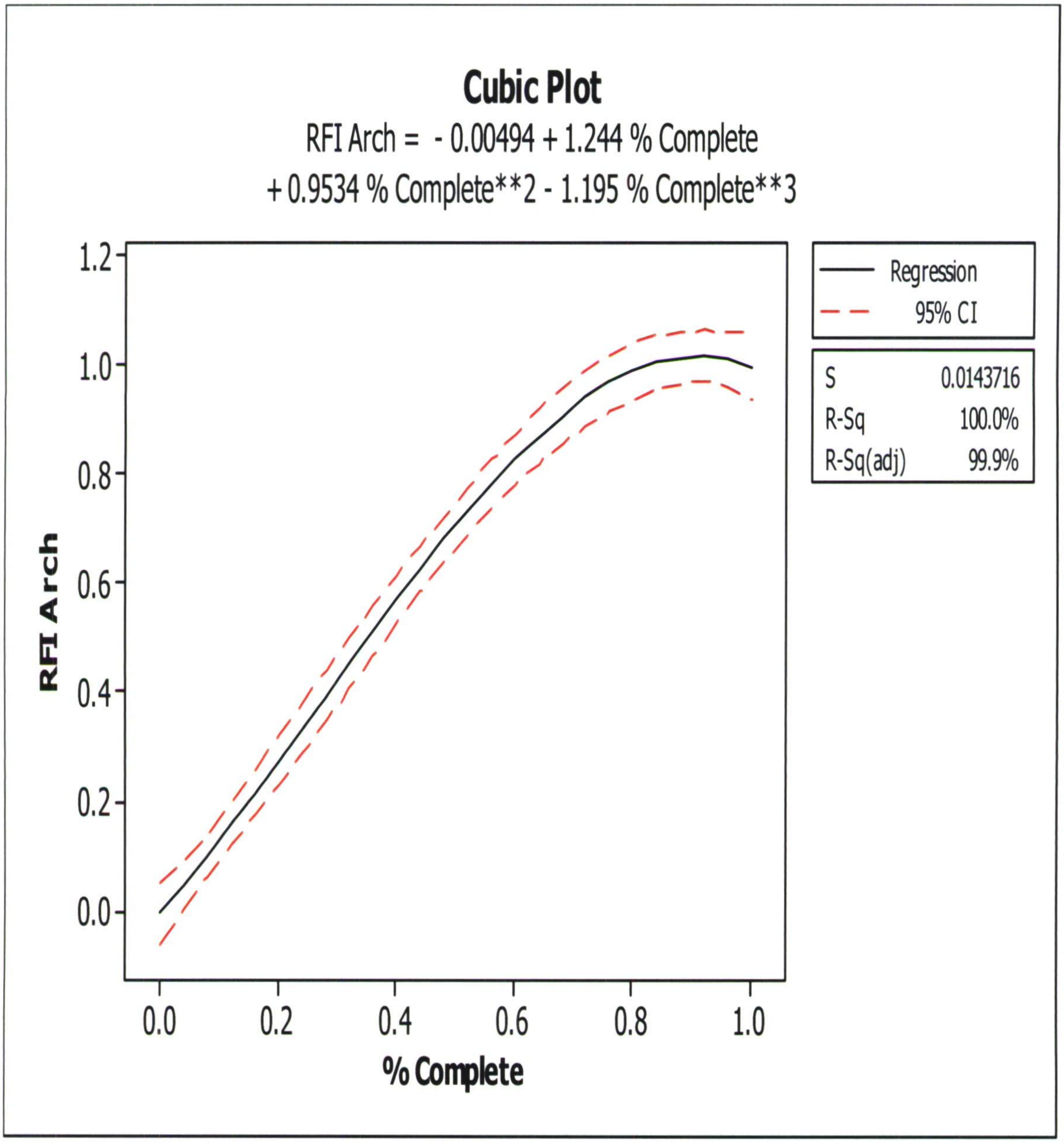
```
             Total
     RFI -   Final
```

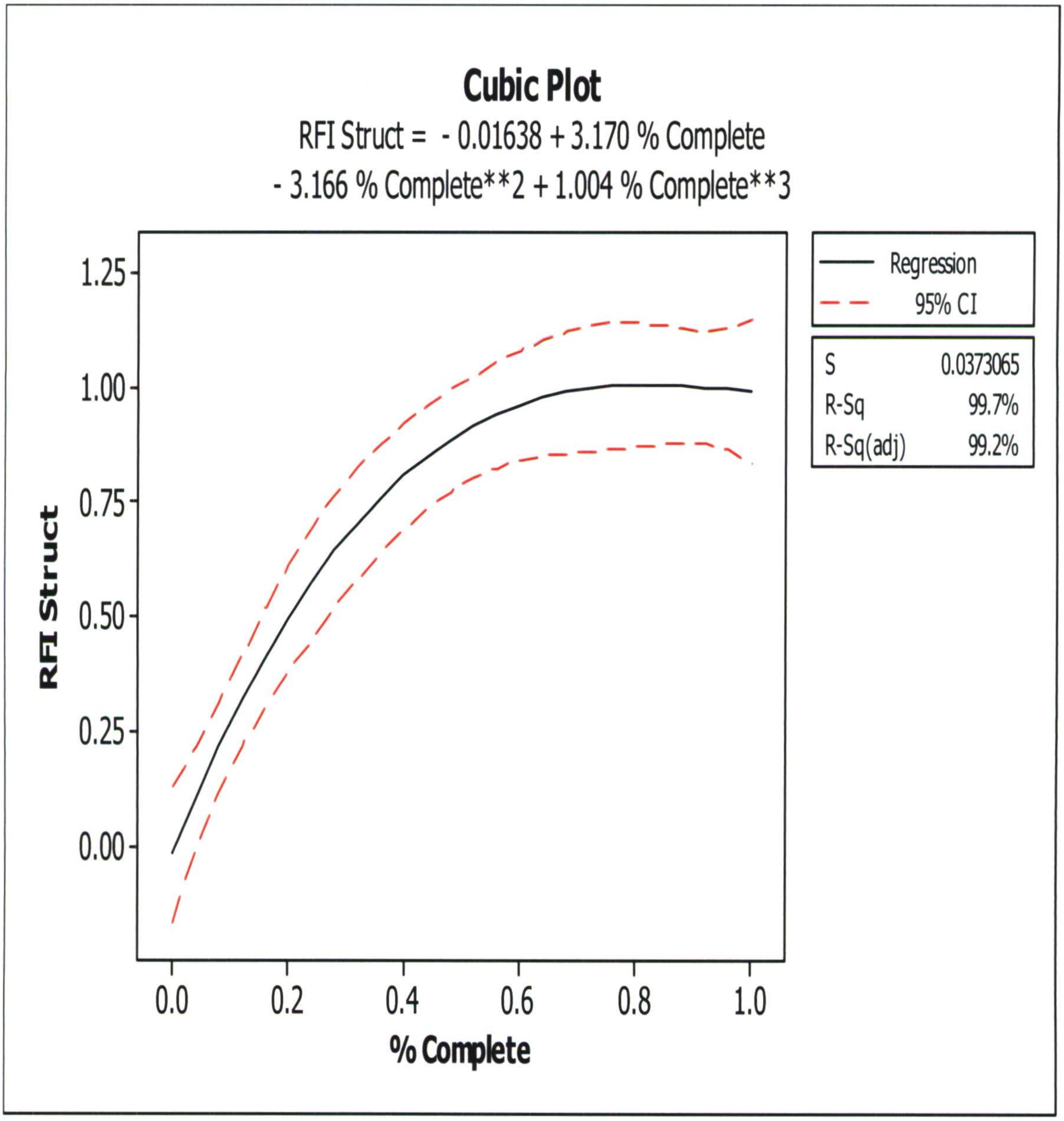
Obs	Arch.	Cost	Fit	SE Fit	Residual	St Resid	
1	28	4230314	4229805	37512	509	1.00	X
2	99	45978369	45980099	37475	-1730	-1.00	X
4	168	47478370	47477947	37513	423	1.00	X
7	134	23148875	23147504	37490	1371	1.00	X
9	69	44500000	44498812	37496	1188	1.00	X
10	69	28600000	28602096	37457	-2096	-1.00	X
11	32	6982700	6980257	37435	2443	1.00	X
12	35	15816058	15815240	37506	818	1.00	X
14	137	12406042	12406393	37513	-351	-1.00	X
15	81	24504281	24503492	37507	789	1.00	X
16	66	10948705	10947926	37507	779	1.00	X

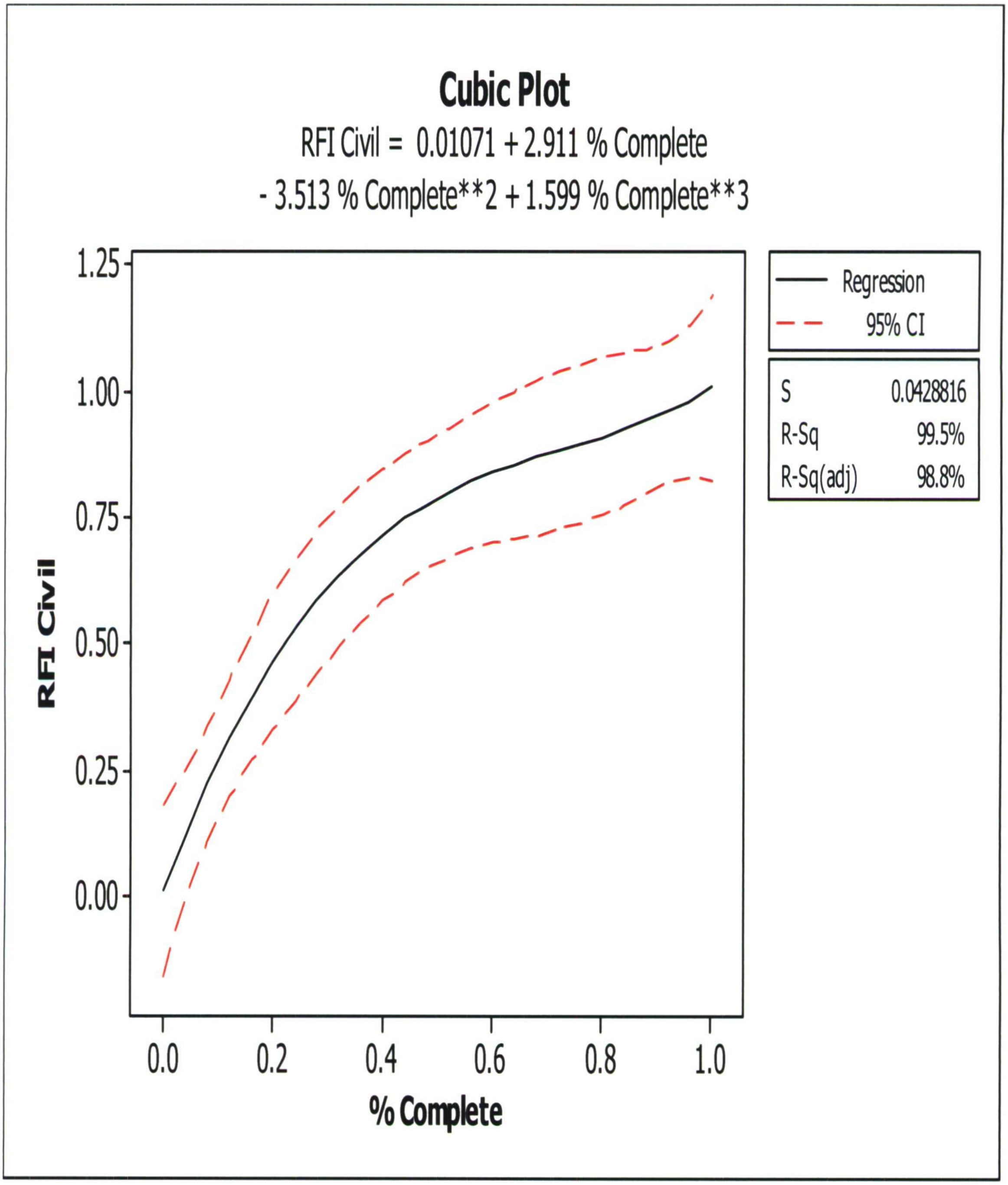
X denotes an observation whose X value gives it large influence.

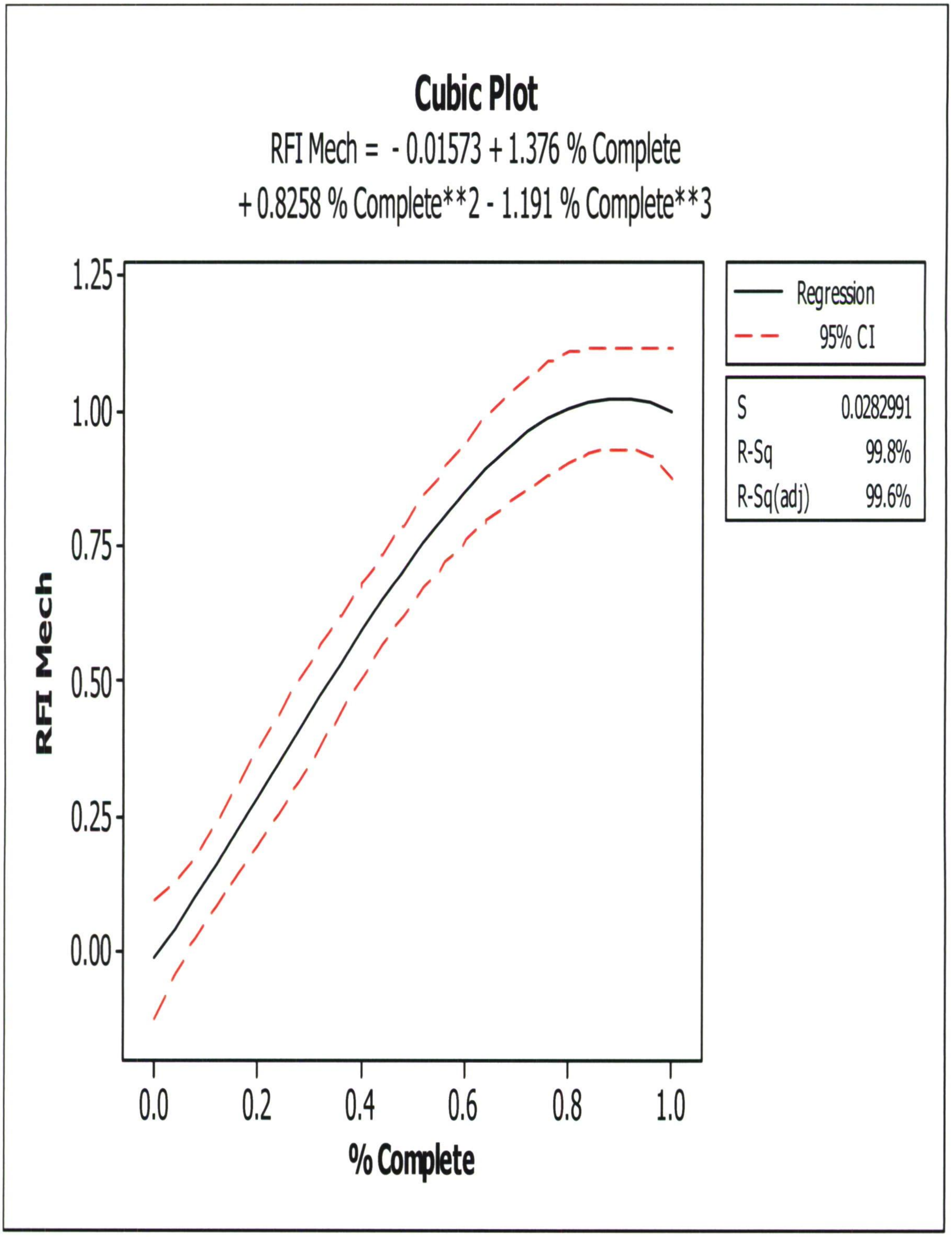
Cubic model graphs with confidence intervals

Note that these graphs show the relationship between the percentage complete in a project and the current percentage of RFI' and new drawings issued (there is a graph for each division) out of the their totals for the project.

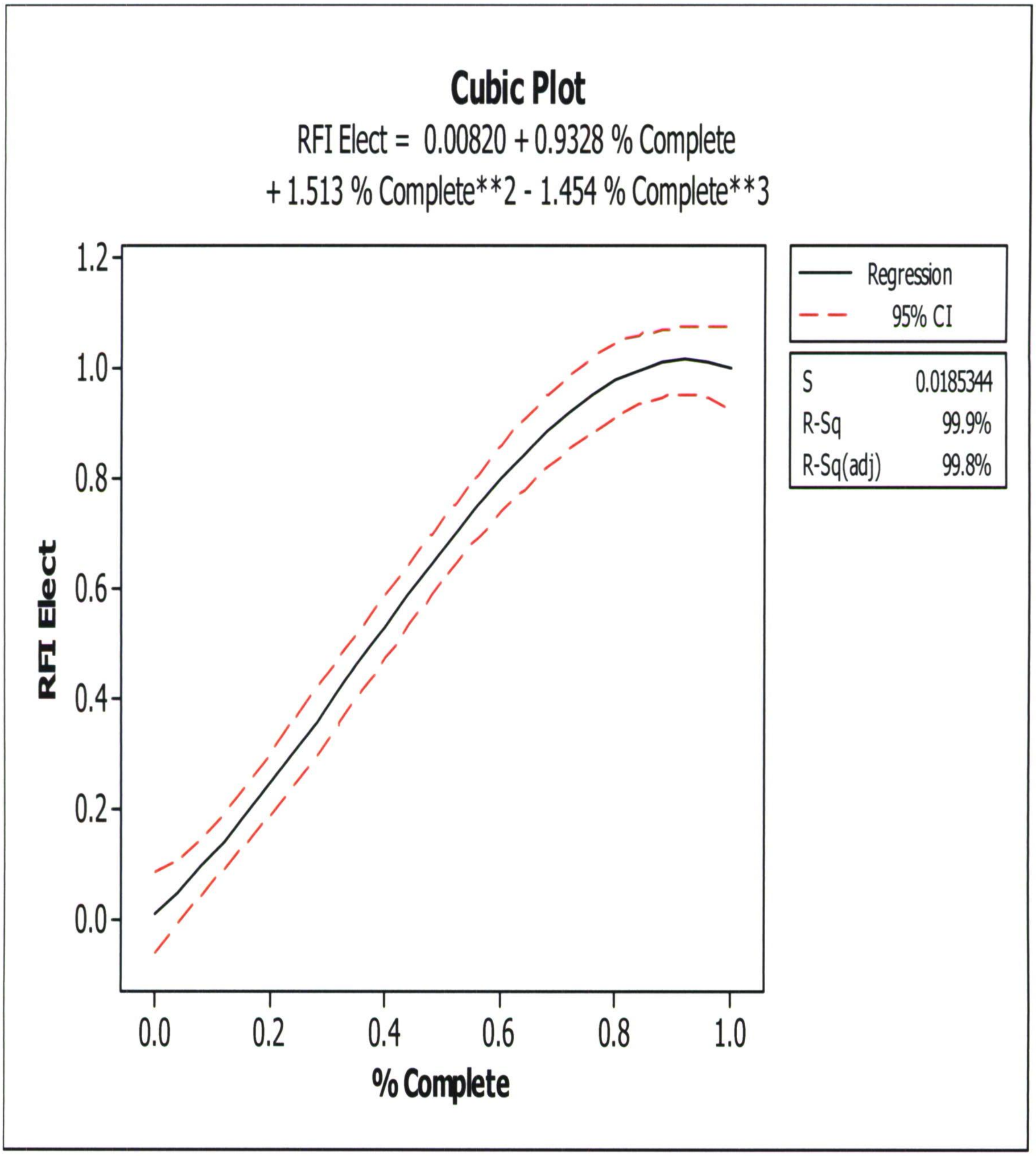

Cubic Plot
RFI Arch = - 0.00494 + 1.244 % Complete
+ 0.9534 % Complete**2 - 1.195 % Complete**3
Regression
95% CI
S 0.0143716
R-Sq 100.0%
R-Sq(adj) 99.9%
RFI Arch
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
% Complete


Cubic Plot
RFI Struct = - 0.01638 + 3.170 % Complete
- 3.166 % Complete**2 + 1.004 % Complete**3
Regression
95% CI
S 0.0373065
R-Sq 99.7%
R-Sq(adj) 99.2%
RFI Struct
1.25
1.00
0.75
0.50
0.25
0.00
0.0
0.2
0.4
0.6
0.8
1.0
% Complete

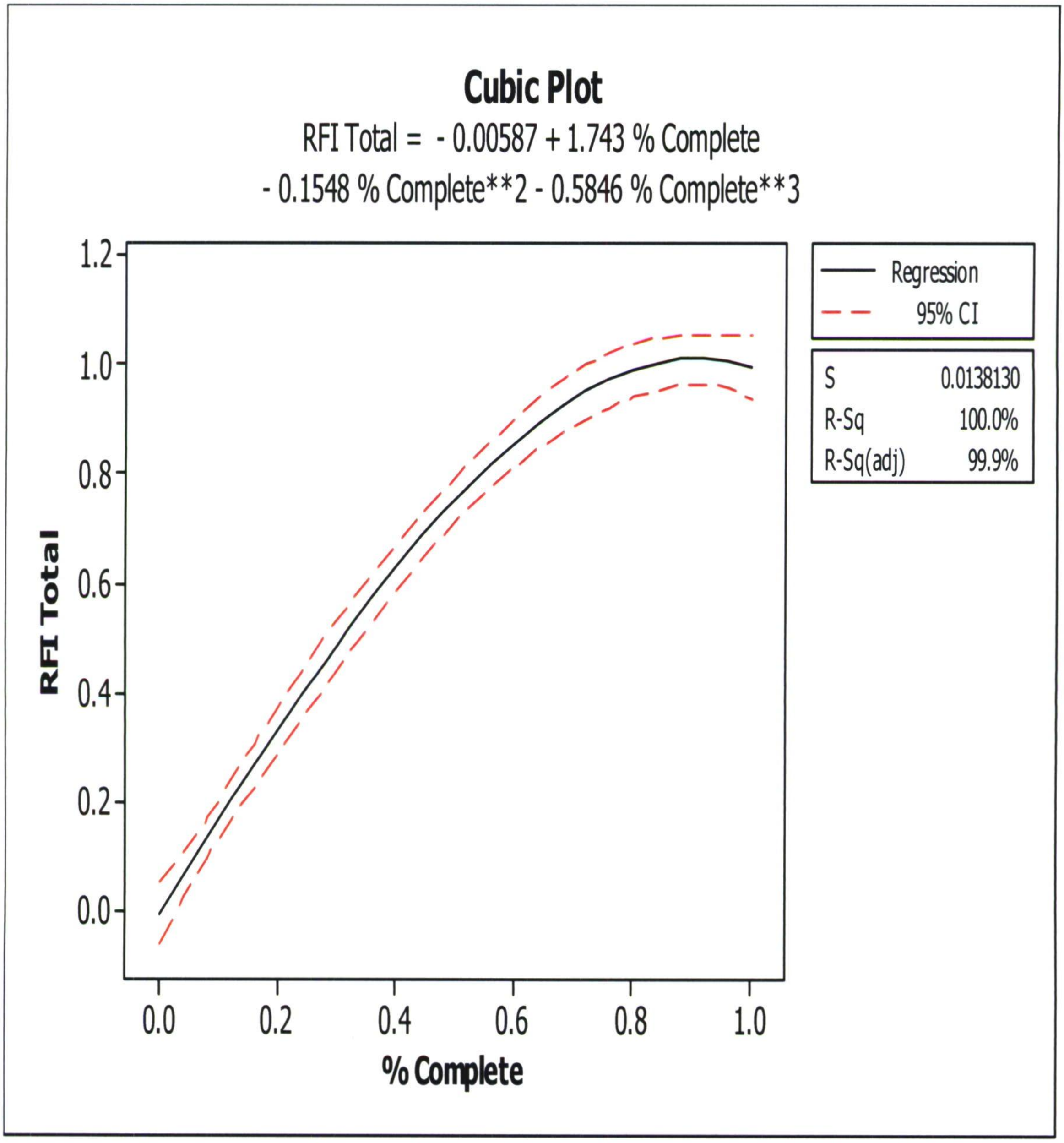

Cubic Plot
RFI Civil = 0.01071 + 2.911 % Complete
- 3.513 % Complete**2 + 1.599 % Complete**3
Regression
95% CI
S 0.0428816
R-Sq 99.5%
R-Sq(adj) 98.8%
RFI Civil
% Complete
1.25
1.00
0.75
0.50
0.25
0.00
0.0
0.2
0.4
0.6
0.8
1.0

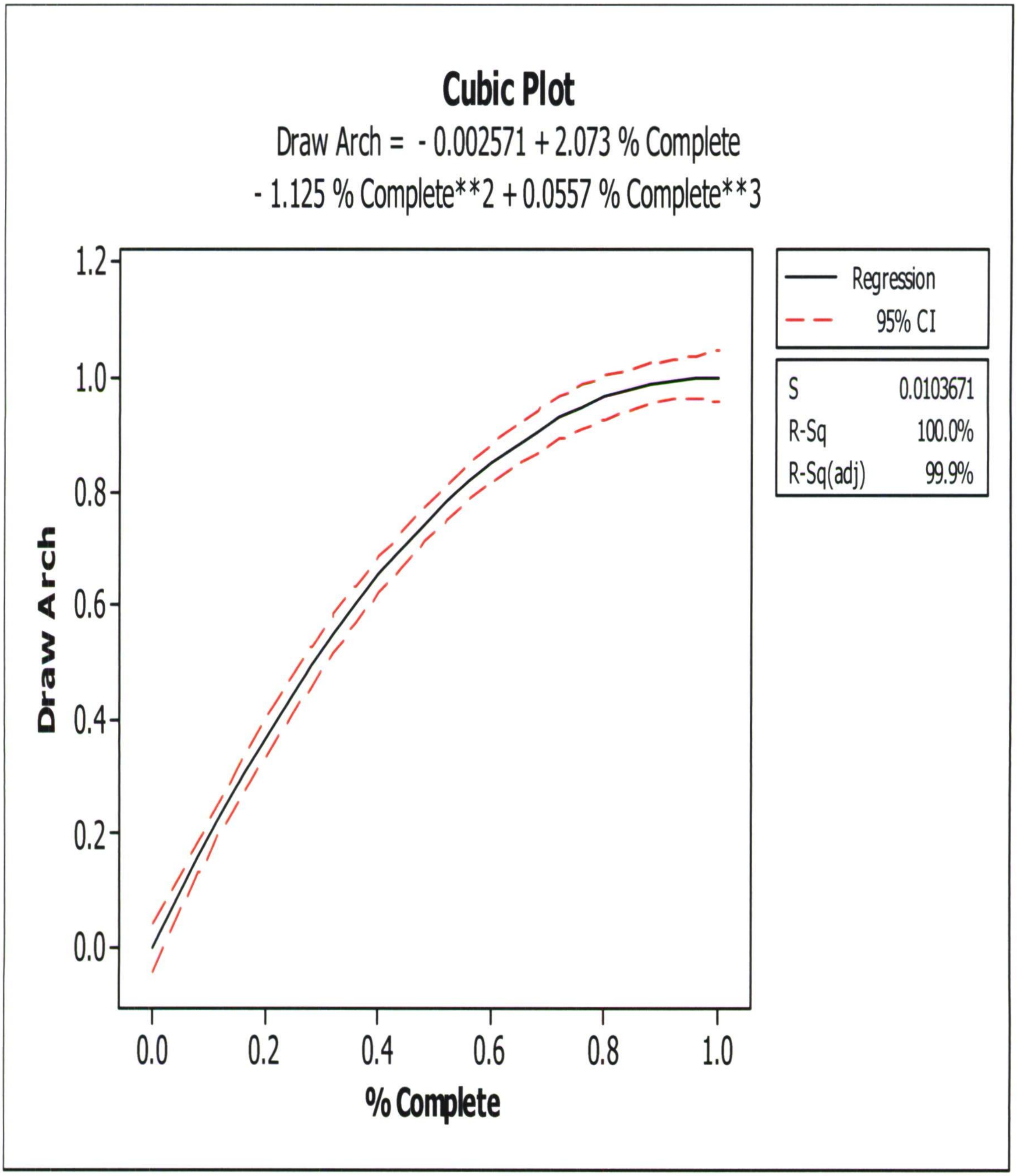


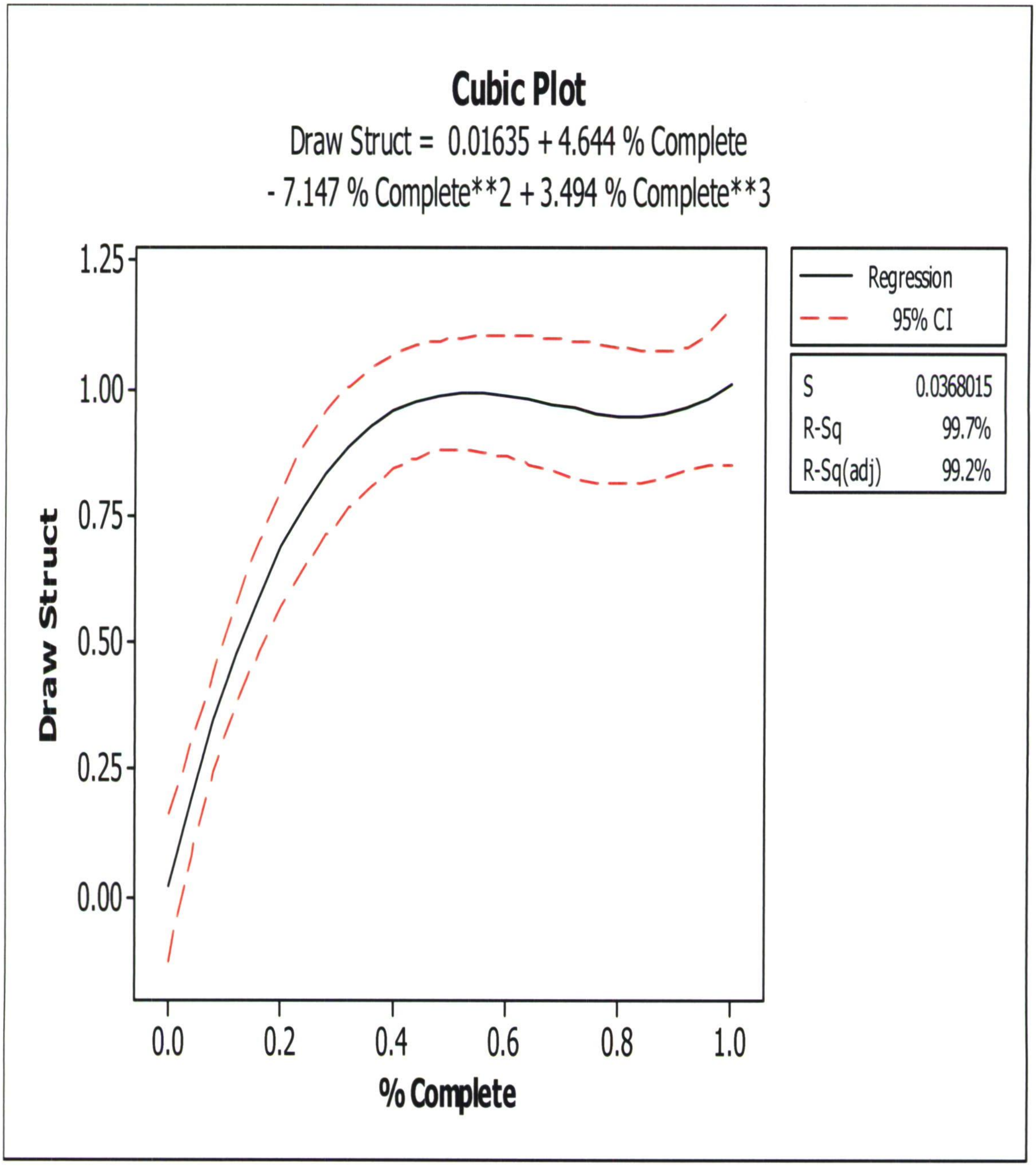
Cubic Plot
RFI Mech = - 0.01573 + 1.376 % Complete
+ 0.8258 % Complete**2 - 1.191 % Complete**3
Regression
95% CI
S 0.0282991
R-Sq 99.8%
R-Sq(adj) 99.6%
RFI Mech
% Complete
1.25
1.00
0.75
0.50
0.25
0.00
0.0
0.2
0.4
0.6
0.8
1.0

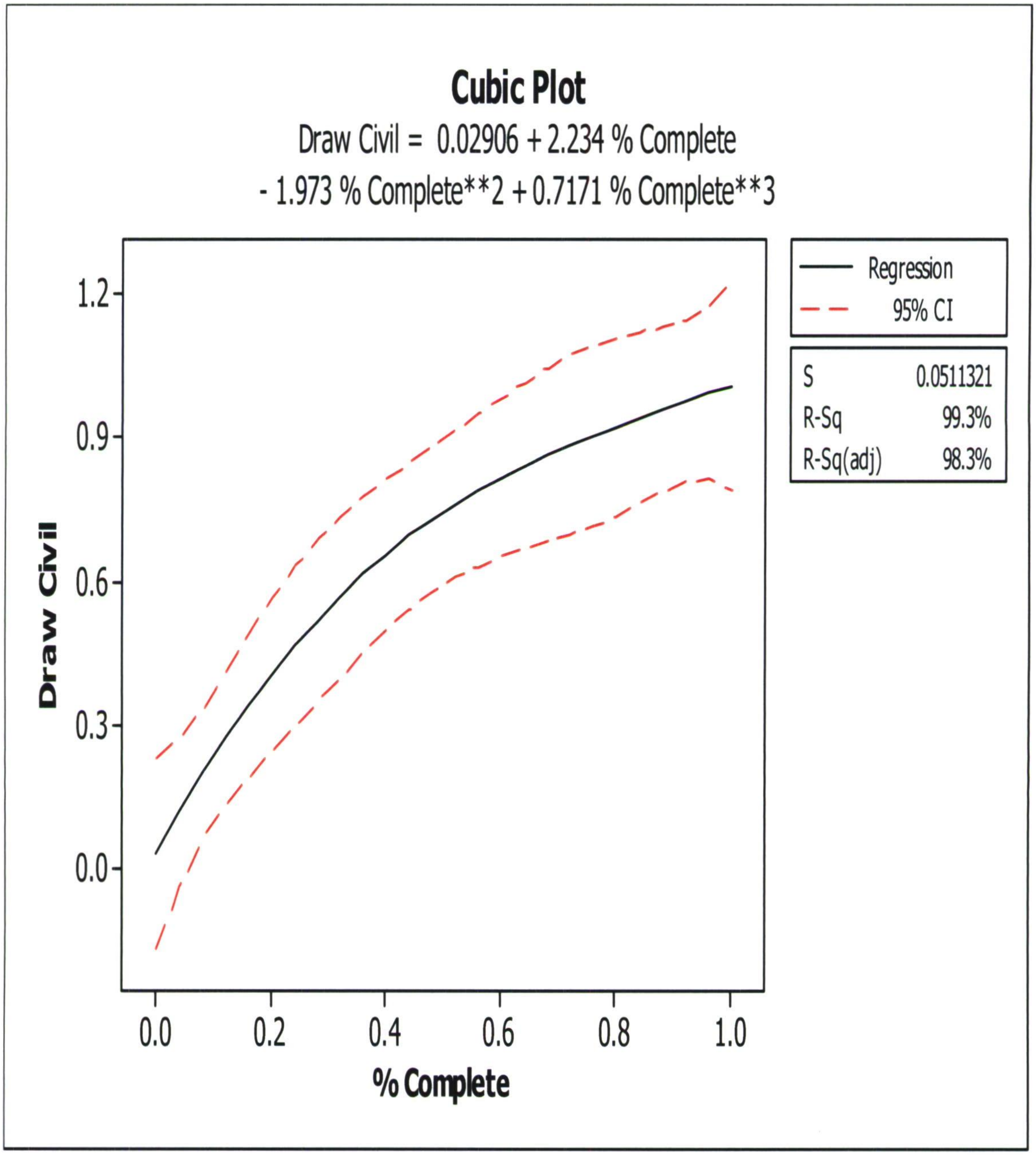


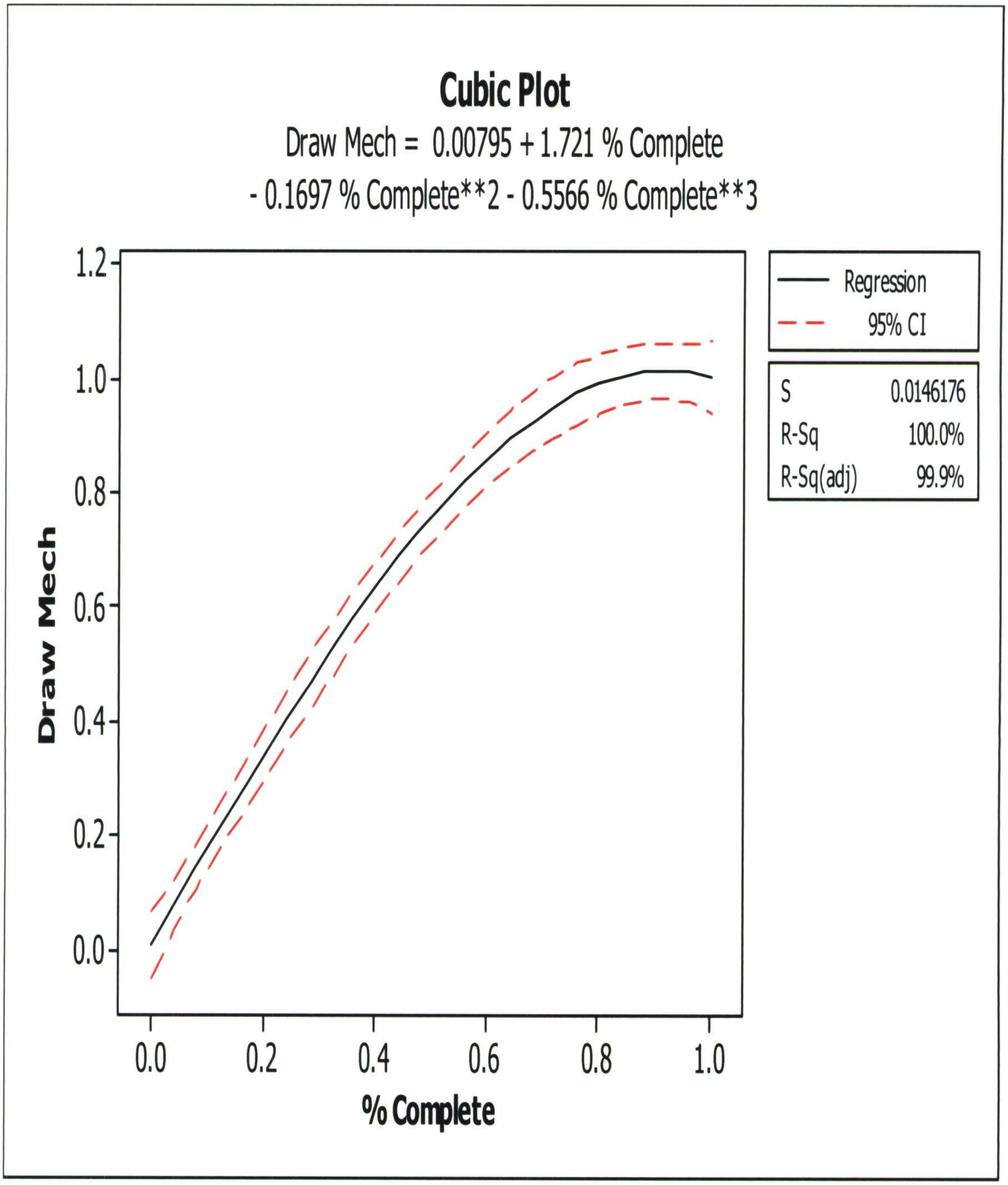
Cubic Plot
RFI Elect = 0.00820 + 0.9328 % Complete
+ 1.513 % Complete**2 - 1.454 % Complete**3
RFI Elect
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
% Complete
Regression
95% CI
S 0.0185344
R-Sq 99.9%
R-Sq(adj) 99.8%


Cubic Plot
RFI Total = - 0.00587 + 1.743 % Complete
- 0.1548 % Complete**2 - 0.5846 % Complete**3
Regression
95% CI
S 0.0138130
R-Sq 100.0%
R-Sq(adj) 99.9%
RFI Total
% Complete
0.0
0.2
0.4
0.6
0.8
1.0
1.2

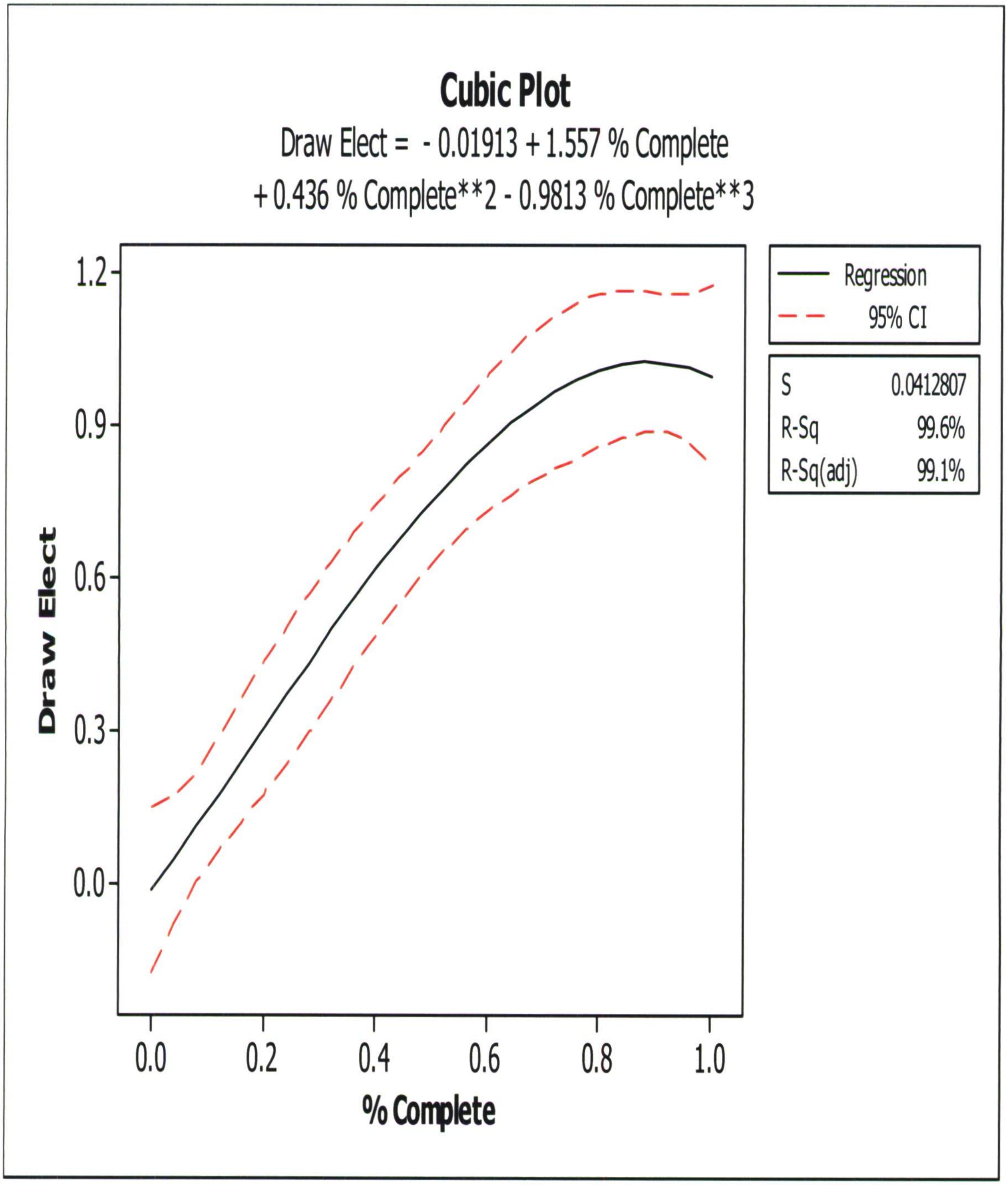

Cubic Plot
Draw Arch = - 0.002571 + 2.073 % Complete
- 1.125 % Complete**2 + 0.0557 % Complete**3
Regression
95% CI
S 0.0103671
R-Sq 100.0%
R-Sq(adj) 99.9%
Draw Arch
% Complete
0.0
0.2
0.4
0.6
0.8
1.0
1.2

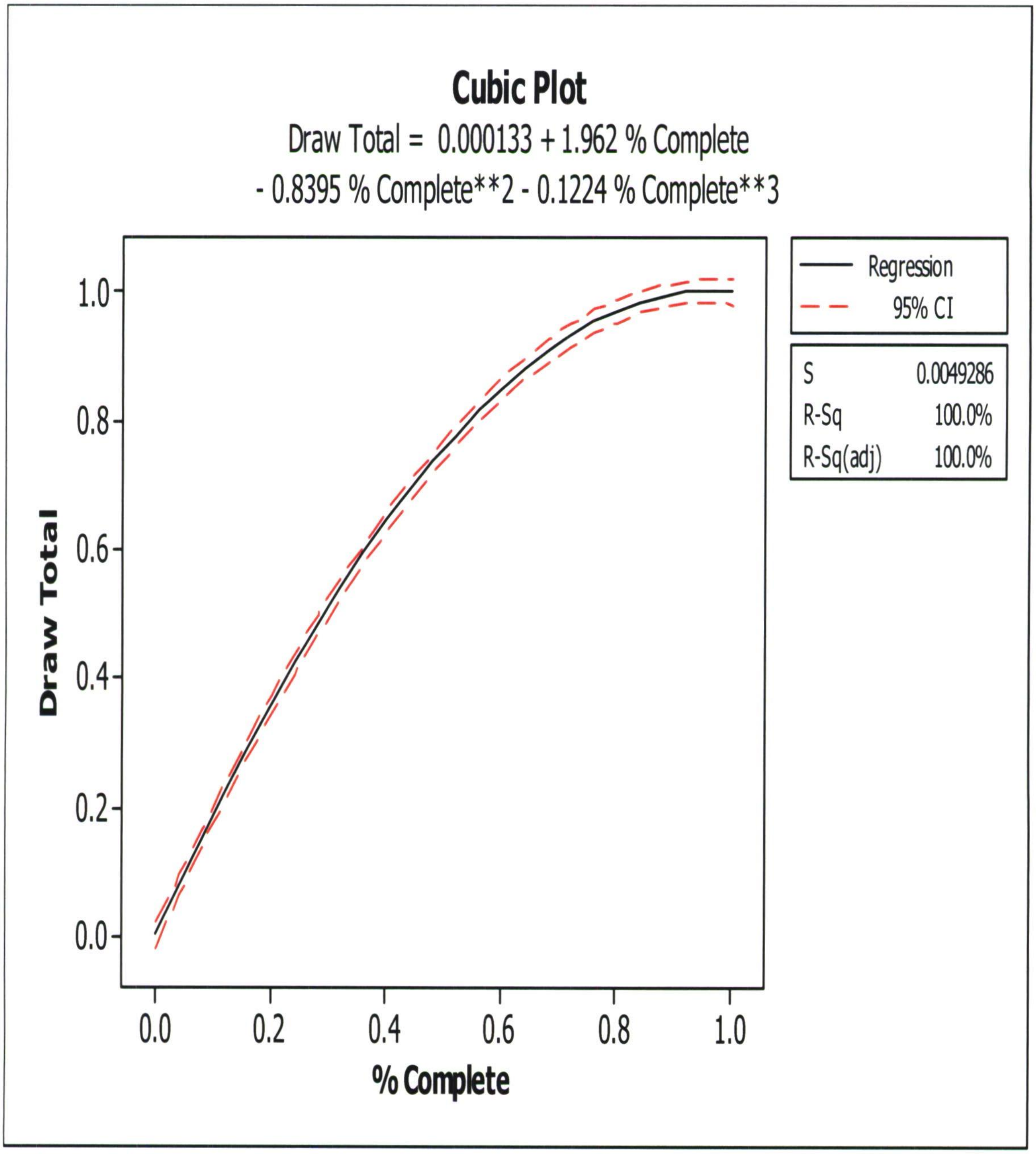

Cubic Plot
Draw Struct = 0.01635 + 4.644 % Complete
- 7.147 % Complete**2 + 3.494 % Complete**3
Regression
95% CI
S 0.0368015
R-Sq 99.7%
R-Sq(adj) 99.2%
Draw Struct
1.25
1.00
0.75
0.50
0.25
0.00
0.0
0.2
0.4
0.6
0.8
1.0
% Complete


Cubic Plot
Draw Civil = 0.02906 + 2.234 % Complete
- 1.973 % Complete**2 + 0.7171 % Complete**3
Regression
95% CI
S 0.0511321
R-Sq 99.3%
R-Sq(adj) 98.3%
Draw Civil
1.2
0.9
0.6
0.3
0.0
0.0
0.2
0.4
0.6
0.8
1.0
% Complete



Cubic Plot
Draw Mech = 0.00795 + 1.721 % Complete
- 0.1697 % Complete**2 - 0.5566 % Complete**3
Regression
95% CI
S 0.0146176
R-Sq 100.0%
R-Sq(adj) 99.9%
Draw Mech
% Complete
0.0
0.2
0.4
0.6
0.8
1.0
1.2


Cubic Plot
Draw Elect = - 0.01913 + 1.557 % Complete
+ 0.436 % Complete**2 - 0.9813 % Complete**3
1.2
0.9
0.6
0.3
0.0
Draw Elect
0.0
0.2
0.4
0.6
0.8
1.0
% Complete
Regression
95% CI
S 0.0412807
R-Sq 99.6%
R-Sq(adj) 99.1%



Cubic Plot
Draw Total = 0.000133 + 1.962 % Complete
- 0.8395 % Complete**2 - 0.1224 % Complete**3
Regression
95% CI
S 0.0049286
R-Sq 100.0%
R-Sq(adj) 100.0%
Draw Total
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
% Complete

Example spreadsheet output

These are examples of the Excel spreadsheet using some of Austin Commercial's ongoing project data to forecast total RFI's and new drawings by division and the total change in cost and total cost. I have also included Austin Commercial's most recent total cost projection as a comparison.

Forecasting Change

Job:	DFW - Sky and Ped. Bridges
Job Number:	9923
Original Budget:	$22,643,415.00
Current % Complete:	69.00%

Division	RFI's	% Complete
Archectural	33	69.00%
Structural	101	69.00%
Civil	11	69.00%
Mechanical	28	69.00%
Electrical	26	69.00%
Total	230	69.00%

Division	Drawings	% Complete
Archectural	130	69.00%
Structural	118	69.00%
Civil	31	69.00%
Mechanical	144	69.00%
Electrical	78	69.00%
Total	556	69.00%

Division	% RFI Forecast	RFI Forecast
Archectural	91.48%	36
Structural	99.34%	102
Civil	87.20%	13
Mechanical	93.56%	30
Electrical	89.45%	29
Total	93.11%	247

Division	% Drawing Forecast	Drawing Forecast
Archectural	91.05%	143
Structural	96.58%	122
Civil	86.67%	36
Mechanical	93.18%	155
Electrical	94.04%	83
Total	91.40%	608

Forecasted Total Change in Cost: $10,386,150.72

Forecasted Total Cost: $30,295,854.44

Current Forecasted Total Cost: $27,431,726.00

Forecasting Change

Job:	DFW - Hotel
Job Number:	9923

Original Budget:	$45,636,999.00
Current % Complete:	73.00%

Division	RFI's	% Complete
Archectural	144	73.00%
Structural	98	73.00%
Civil	4	73.00%
Mechanical	209	73.00%
Electrical	216	73.00%
Total	708	73.00%

Division	Drawings	% Complete
Archectural	556	73.00%
Structural	362	73.00%
Civil	0	73.00%
Mechanical	375	73.00%
Electrical	288	73.00%
Total	1656	73.00%

Division	% RFI Forecast	RFI Forecast
Archectural	94.64%	152
Structural	100.11%	98
Civil	88.57%	5
Mechanical	96.55%	216
Electrical	92.98%	232
Total	95.66%	740

Division	% Drawing Forecast	Drawing Forecast
Archectural	93.29%	596
Structural	95.71%	378
Civil	88.74%	0
Mechanical	95.73%	392
Electrical	96.81%	297
Total	93.74%	1767

Forecasted Total Change in Cost: $20,629,342.38

Forecasted Total Cost: $47,126,313.61

Current Forecasted Total Cost: $45,354,558.00

Forecasting Change

Job: DFW - Parking Garage
Job Number: 9923

Original Budget: $143,910,498.00
Current % Complete: 85.00%

Division	RFI's	% Complete
Archectural	48	80.00%
Structural	259	85.00%
Civil	38	85.00%
Mechanical	58	85.00%
Electrical	64	85.00%
Total	559	85.00%

Division	Drawings	% Complete
Archectural	363	85.00%
Structural	738	85.00%
Civil	23	85.00%
Mechanical	139	85.00%
Electrical	190	85.00%
Total	1677	85.00%

Division	% RFI Forecast	RFI Forecast
Archectural	98.86%	49
Structural	100.73%	257
Civil	92.89%	41
Mechanical	101.91%	57
Electrical	100.13%	64
Total	100.48%	556

Division	% Drawing Forecast	Drawing Forecast
Archectural	98.09%	370
Structural	94.58%	780
Civil	94.29%	24
Mechanical	100.64%	138
Electrical	101.67%	187
Total	98.61%	1701

Forecasted Total Change in Cost: $7,774,524.62

Forecasted Total Cost: $128,993,135.51

Current Forecasted Total Cost: $111,793,713.00