

A Tutorial for Building CMMI Process Performance Models

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Acknowledgment

This tutorial reuses portions of a full day tutorial given at the 2009 SEPG North America, but with 5 hands-on, guided exercises added to enable participant skill development with process performance models.

Appropriate acknowledgment is made to the authors of the 2009 SEPG NA tutorial:

Kevin Schaaff, Robert Stoddard, Rusty Young and Dave Zubrow



Topics

Introduction (**10 min**)

Overview of the Steps to Build PPMs (**80 mins**)

- Preparing to Build PPMs
- Developing PPMs
- Using PPMs

Exercise 1: Constructing a Product Business Case with Monte Carlo Simulation and Optimization (**40 mins**)

Exercise 2: Scheduling Projects with Monte Carlo Simulation and Optimization (**30 mins**)

Exercise 3: Predicting Product Requirements Change with Linear Regression (**30 mins**)

Exercise 4: Predicting Delivered Defects with Dummy Variable Regression (**30 mins**)

Exercise 5: Predicting Customer Satisfaction using Ordinal Logistic Regression Questions (**30 mins**)



Introduction



What is a PPM?

OPP SP 1.5

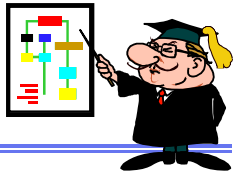
- **PPMs** are used to estimate or predict the value of a process-performance measure from the values of other process, product, and service measurements
- **PPMs** typically use process and product measurements collected throughout the life of the project to estimate progress toward achieving objectives that cannot be measured until later in the project's life

Glossary

- A description of the relationships among attributes of a process and its work products that is developed from historical process-performance data and calibrated using collected process and product measures from the project and that is used to predict results to be achieved by following a process



Purpose and Usage of Process Performance Models at the Organizational Level



- Identifying Organizational Priorities for Quality and Process Performance
- Establishing and Revising Organizational Quality and Process Performance Objectives



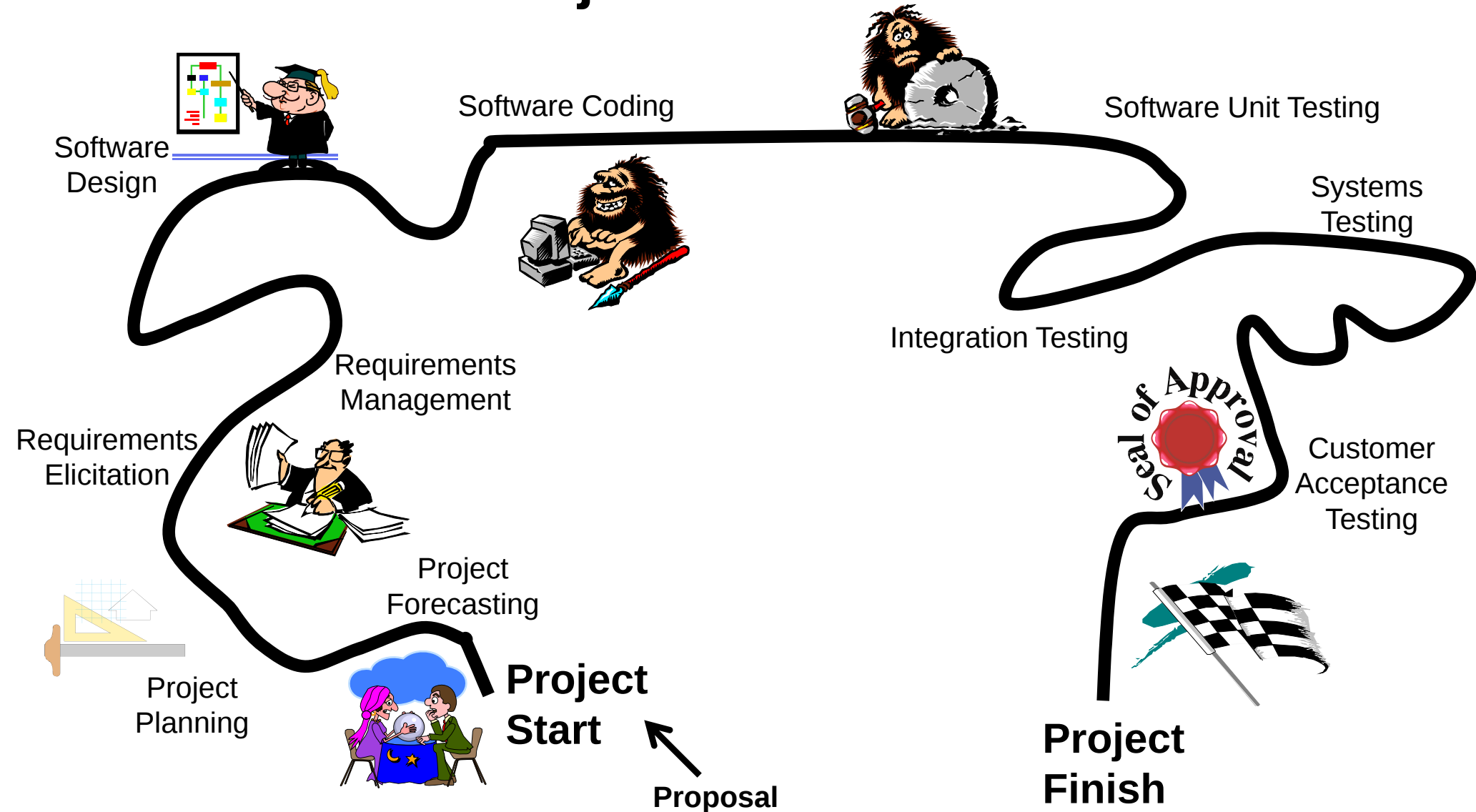
- Identifying Process Performance Measures
- Defining New Process Performance Baselines



- Analyzing Process and Technology Improvement Proposals
- Identifying Process and Technology Improvement Proposals
- Prioritizing Candidate Process and Technology Improvements for Deployment



Purpose and Usage of Process Performance Models at the Project Level



Healthy Ingredients of CMMI Process Performance Models

Statistical, probabilistic or simulation in nature

Predict interim and/or final project outcomes

Use controllable factors tied to sub-processes to conduct the prediction

Model the variation of factors and understand the predicted range or variation of the outcomes

Enable “what-if” analysis for project planning, dynamic re-planning and problem resolution during project execution

Connect “upstream” activity with “downstream” activity

Enable projects to achieve mid-course corrections to ensure project success



All Models (Qualitative and Quantitative)

Quantitative Models (Deterministic, Statistical, Probabilistic)

Statistical or Probabilistic Models

Interim outcomes predicted

Controllable x factors involved

**Process Performance
Model -
With controllable x
factors tied to
Processes and/or
Sub-processes**

Only phases
or lifecycles
are modeled

Only
uncontrollable
factors are
modeled

Only final
outcomes
are
modeled

No
uncertainty
or variation
modeled

Anecdotal
data and
biased
samples



Overview of the Steps to Build PPMs

- Preparing to Develop PPMs

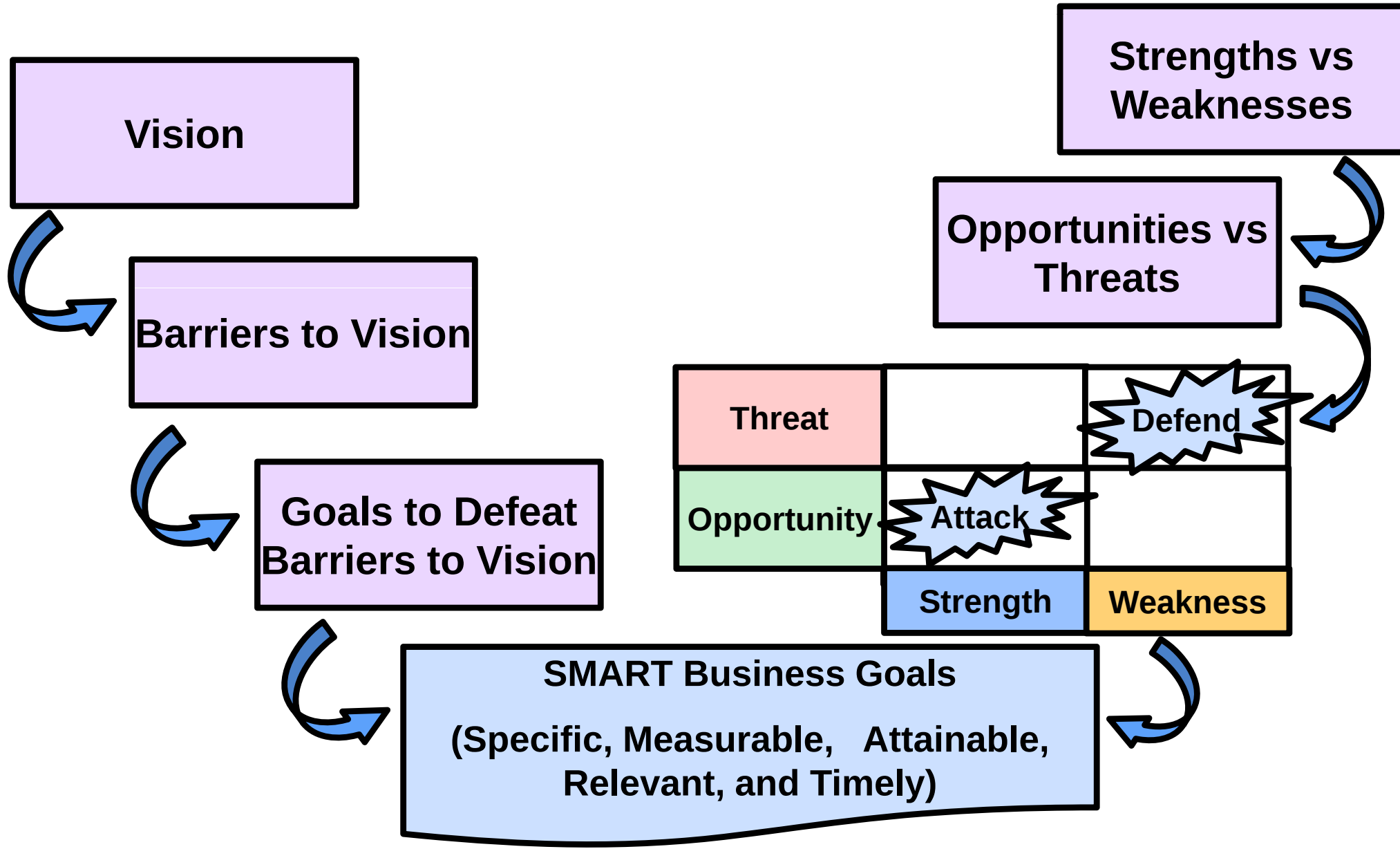


Preparing to Develop PPMs

1. **Initiating the development of process performance models from a context of the customer and Business goals**
2. **Using correct critical thinking and root cause analysis to identify the proper outcomes and drivers of the outcomes (including controllable and uncontrollable process factors)**
3. **Becoming sensitive to the types of issues and documentation needed during the development of the process performance models**
4. **Addressing issues related to data collection, measurement scale, data quality and integrity, outliers and measurement error**
5. **Identifying the data types involved with the outcomes and process drivers**
6. **Creating performance baselines of outcomes and process drivers**
7. **Forming a team to develop a process performance model**

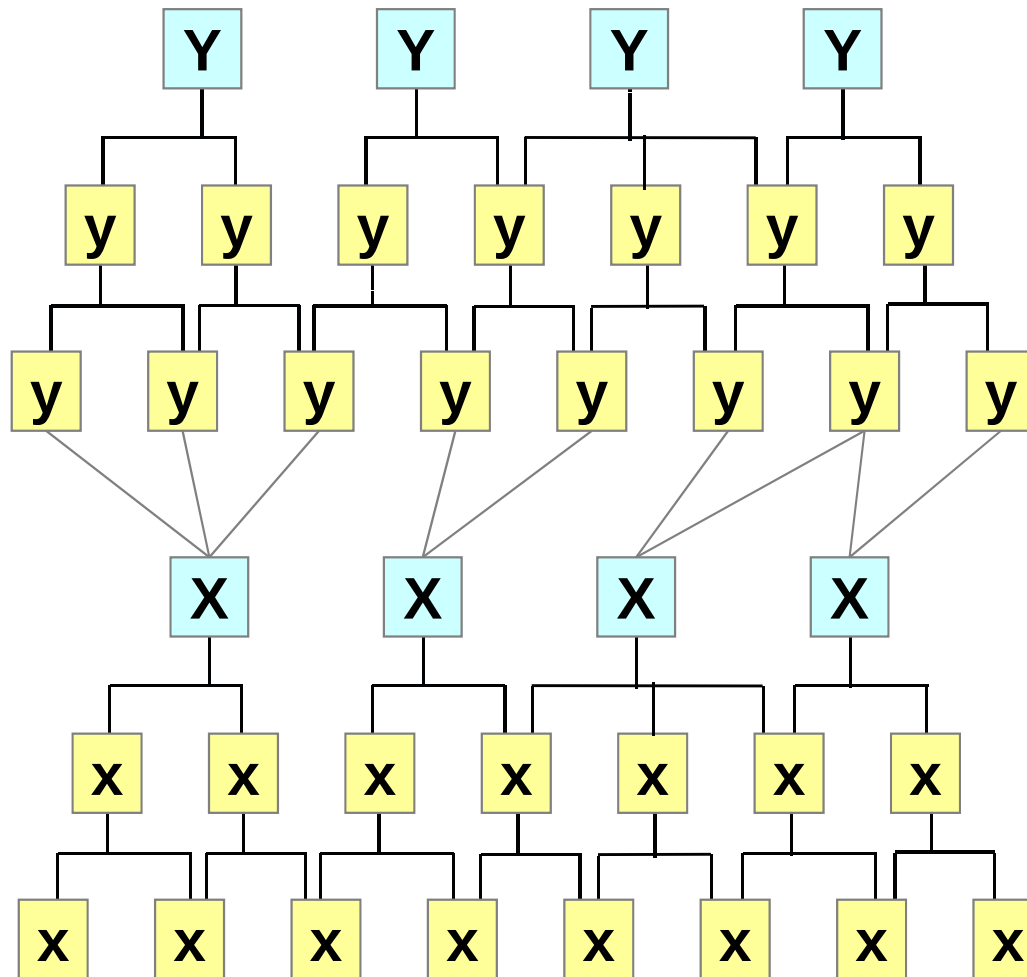


Step 1 - Identify or Reconfirm Business Goals



Step 1 - Business Goal Flowdown (Y-to-x)

Process-Agnostic
Process-Oriented



High Level Business Goals
(Balanced Scorecard)

Subordinate Business Goals
(e.g., \$ Buckets,
% Performance)

High Level Process
(e.g., Organizational Processes)

Subordinate Processes
(e.g., Down to a Vital x
sub-process to be
tackled by DMAIC team)



Questions

1. Are your senior leaders defining business goals rather than delegating goal definition to operational levels?
2. Do lower organizational levels redefine the higher level goals in operational terms or do they merely block copy and paste upper goals?
3. Are you organization's business goals SMART?
4. Has your organization ensured that process performance baselines and models are targeted at the most important issues and goals?



Step 2 - Identify the Sub-Process/Process

- Start with the Organization's Business Objectives
- Decompose to Quality and Process Performance Objectives (QPPOs)
- For the QPPOs that can be Measured Quantitatively
 - Perform Analysis to Determine which Sub-Process/Process Drives the Relevant Objective
 - Determine if Sufficient Data is Available or can be Obtained to Establish a Process Performance Baseline(s) and/or Build a Process Performance Model(s)



Step 2 - Identify the Sub-Process/Process Example

- Given Organizational Business Objectives:
 - Improve quality
 - Improve cycle time
 - Improve productivity
- Translate to measureable QPPOs
 - Post-delivery defect density of less than 0.5 Defects/KSLOC
 - Achieve 85% defect detection before System testing
 - Ensure requirements duration is within 15% of plan
 - Achieve a 5 % software productivity improvement



Step 2 - Examples of Outcomes

Escaped defects by phase*
 Task duration
 Task effort
 Task delay
 Earned Value Metrics (CPI, SPI)
 Req'ts Volatility*
 Customer Satisfaction
 Progress*
 "ilities" such as Reliability
 Difficulty*
 Productivity*
 Time to Market
 Injected Defects Volume by type
 Availability of resources*
 Cost Variance
 Latent defect content of artifact*
 Rework
 Cost of Poor Quality
 Warranty Costs
 Schedule Variance



Step 2 - Identify Controllable factors (x's) to Predict Outcome(s) - 1

“Controllable” implies that a project has direct or indirect influence over the factor prior to or during the project execution

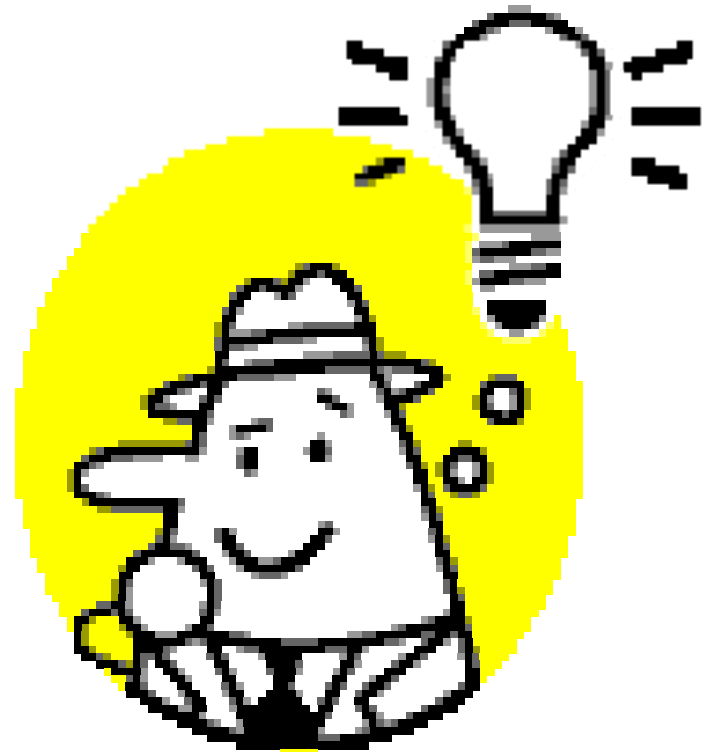
A common misconception is that factors are not controllable and thus disregarded from consideration for modeling. Requires out-of-the-box thinking to overcome this. Some organizations employ individuals known as “assumption busters”



Step 2 - Identify Controllable factors (x's) to Predict Outcome(s) - 2

As we view process holistically, controllable factors may be related, but not limited, to any of the following:

- People attributes
- Environmental factors
- Technology factors
- Tools (physical or software)
- Process factors
- Customers
- Suppliers
- Other Stakeholders



Step 2 - Examples of Controllable People x factors

Absolute performance of a task or topic
 Variability of performance of a task or topic
 Training
 Skills
 Traits
 Interruptions
 Degree of Mentoring and Coaching
 Staff Availability
 Experience Levels
 Degree of Multi-tasking
 Geographic dispersion of staff
 Diversity of staff
 Attitudes and Outlooks
 Communication Mechanisms
 Various Teaming Attributes
 Knowledge Sharing Mechanisms
 Degree of Cross Training
 Multi-capable staff
 Organizational Dynamics
 Nature of Leadership



Step 2 - Example of Controllable Environmental x Factors

Nature of work facilities

Access to breakout rooms

Proximity to team members

Access or proximity to customers

Access or proximity to suppliers

Access or proximity to management and other stakeholders

Other Visual or Audio Distractions

Degree of noise or distractions
External interferences including other organizations

Ergonomics

Temperature

Accommodations for specific needs

Available Training Rooms

Degree of Security Classification



Step 2 - Example of Controllable Technology x Factors



Step 2 - Example of Controllable Process x

Factors

Resolution time of technical inquiries

Efficiency of a work task

Compliance of a work task

Quality of a work task

Timeliness of a work task

Measures of bureaucracy

Resource contention between tasks

Difficulty of a work task

Number of people involved with a work task

Degree of Job Aids, Templates, Instructions

Peer Review Measures

Test Coverage
Measures

Modifications to how work
Tasks are performed

Choices of subprocesses

Quality of artifacts
(Input to or Output from
a work task)

Timeliness of Artifacts

Task Interdependence

Complexity of Artifacts

Readability of Artifacts

Any of the criteria for
good reqts statements

Any of the criteria for
good designs

Code measures
(Static and Dynamic)



Step 2 - Example of Controllable Customer, Supplier and Other Stakeholder x Factors

“Maturity” assessment
 Health of relationship
 Degree of communication
 Speed of feedback loops
 Trust
 Degree of oversight
 Degree of partnership, collaboration
 Geographic location
 Degree of access and participation
 Tradeoffs, Compromises, Optimization

Volatility of Staff
 Conflicts among Stakeholders
 Image and Perceptions
 Longevity of relationship
 Style
 Culture
 Domain Experience

Early Involvement
 Degree of Documentation of Expectations
 Complexity of relationship such as simultaneously a competitor and partner and supplier
 Bias on Quality vs Schedule
 Language



Step 2 - Identify Uncontrollable Factors

- Normally these are constraints placed by the customer or concrete terms of a contract or government regulation
- Can also be factors for which the project team truly has no direct nor indirect influence over
- Can be factors that are unchanging for a given project but can be changed for future projects
- Often includes external factors or factors related to other teams outside of the project



Questions

1. What is a critical, high risk, uncertain subprocess within your organization?
2. What is a potential outcome performance measure related to that subprocess?
3. What are 2-3 controllable factors directly influencing this outcome measure?
4. Do you believe there are any uncontrollable factors dominating this outcome measure?



Step 3 - Cost of Poor Data Quality to an Enterprise – Typical Issues and Impacts

Typical Issues

- Inaccurate data [1-5% of data fields are erred]
- Inconsistencies across databases
- Unavailable data necessary for certain operations or decisions

Typical Impacts

Operational	Tactical	Strategic
• Lowered customer satisfaction • Increased cost • Lowered employee satisfaction	• Poorer decision making & decisions take longer • More difficult to implement data warehouses • More difficult to engineer • Increased organizational mistrust	• More difficult to set strategy • More difficult to execute strategy • Contribute to issues of data ownership • Compromise ability to align organization • Divert management attention

Source: Redman, 1998



Step 3 - Impacts of Poor Data Quality

Inability to

- manage the quality and performance of software or application development
- Estimate and plan realistically

Ineffective

- process change instead of process improvement
- and inefficient testing causing issues with time to market, field quality and development costs

Products that are painful and costly to use within real-life usage profiles

Bad Information leading to Bad Decisions



Step 3 - Where do Measurement Errors come From₁

Data Entry Errors

- Manual data entry
- Lack of integrity checks

Differing Operational Definitions

- Project duration, defect severity or type, LOC definition, milestone completion

Not a priority for those generating or collecting data

- Complete the effort time sheet at the end of the month
- Inaccurate measurement at the source

Double Duty

- Effort data collection is for Accounting not Project Management
 - Overtime is not tracked
 - Effort is tracked only to highest level of WBS



Step 3 - Where do Measurement Errors come From₂

Dysfunctional Incentives

- Rewards for high productivity measured as LoC/Hr
- Dilbert-esque scenarios

Failure to provide resources and training

- Assume data collectors all understand goals and purpose
- Arduous manual tasks instead of automation

Lack of priority or interest

- No visible use or consequences associated with poor data collection or measurement
- No sustained management sponsorship

Missing data is reported as a valid value

- Can't distinguish 0 from missing when performing calculations



Step 3 - Documenting Measurement Objectives, Indicators, and Measures

Indicator Name/Title	_____	Date	_____
Objective	_____	Establish Measurement Objectives	_____
Questions	_____		_____
Visual Display	_____		_____
Communicate Results			
Perspective	_____	Specify Measures	_____
Input(s)	_____		_____
Data Elements	_____		_____
Definitions	_____	Specify Data Collection Procedures	_____
Data Collection	_____		_____
How	_____		_____
When/How Often	_____	Collect Data	_____
By Whom	_____		_____
Form(s)	_____		_____
Data Reporting	_____	Communicate Results	_____
Responsibility for Reporting	_____		_____
By/To Whom	_____		_____
How Often	_____	_____	_____

Data Storage	_____	Store Data & Results
Where	_____	
How	_____	
Security	_____	_____
Algorithm	_____	Specify Analysis Procedures
Assumptions	_____	
Interpretation	_____	
Probing Questions	_____	Analyze Data
Analysis	_____	
Evolution	_____	
Feedback Guidelines	_____	_____
X-reference	_____	_____



Step 4 - Identifying Outliers

Interquartile range description – A quantitative method for identifying possible outliers in a data set

Procedure

- Determine 1st and 3rd quartiles of data set: Q1, Q3
- Calculate the difference: interquartile range or IQR which equals Q3 minus Q1
- Lower outlier boundary = $Q1 - 1.5 \times IQR$
- Upper outlier boundary = $Q3 + 1.5 \times IQR$



Step 4 - Interquartile Range: Example

2

Interquartile Range
 $30 - 16 = 14$

Procedure

1. Determine 1st and 3rd quartiles of data set: Q1, Q3
2. Calculate the difference: interquartile range or IQR
3. Lower outlier boundary = $Q1 - 1.5 \cdot IQR$
4. Upper outlier boundary = $Q3 + 1.5 \cdot IQR$

1

	333
	50
	40
Q3 →	30
	27
	25
	22
	20
	18
Q1 →	16
	16
	13

4

Upper outlier boundary
 $30 + 1.5 \cdot 14 = 51$

3

Lower outlier boundary
 $16 - 1.5 \cdot 14 = -5$



Step 4 - Tips About Outliers

Outliers can be a clue to process understanding

If outliers lead you to measurement system problems,

- repair the erroneous data if possible
- if it cannot be repaired, delete it

Charts that are particularly effective to flag possible outliers include: box plots, distributions, scatter plots, and control charts

Rescale charts when an outlier reduces visibility into variation.

Be wary of influence of outliers on linear relationships



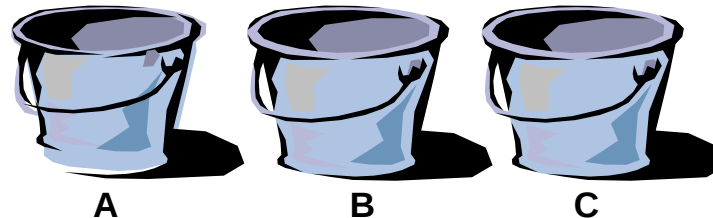


Step 5 - Types of Data

Nominal

Attribute
(aka categorized or discrete data)

Categorical data where the order of the categories is arbitrary



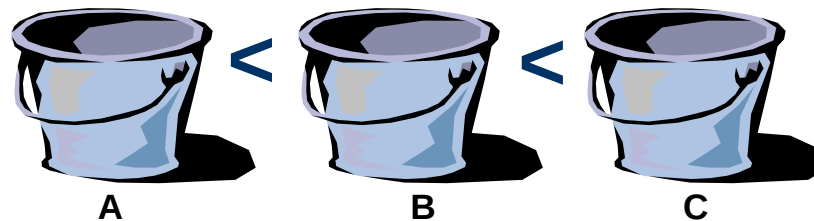
Examples

Defect types
Labor types
Languages

Ordinal

Increasing
information
content

Nominal data with an ordering; may have unequal intervals



Examples

Severity levels
Survey choices 1-5
Experience categories

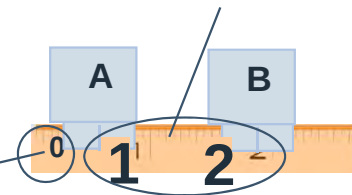
Interval

Continuous
(aka variables data)

Continuous data that has equal intervals; may have decimal values

Ratio

Interval data set that also has a true zero point



Examples

Defect densities
Labor rates
Productivity
Variance %'s
Code size SLOC



Questions

1. What data type is your outcome performance measure?
2. What data type is each of your controllable and uncontrollable x factors?



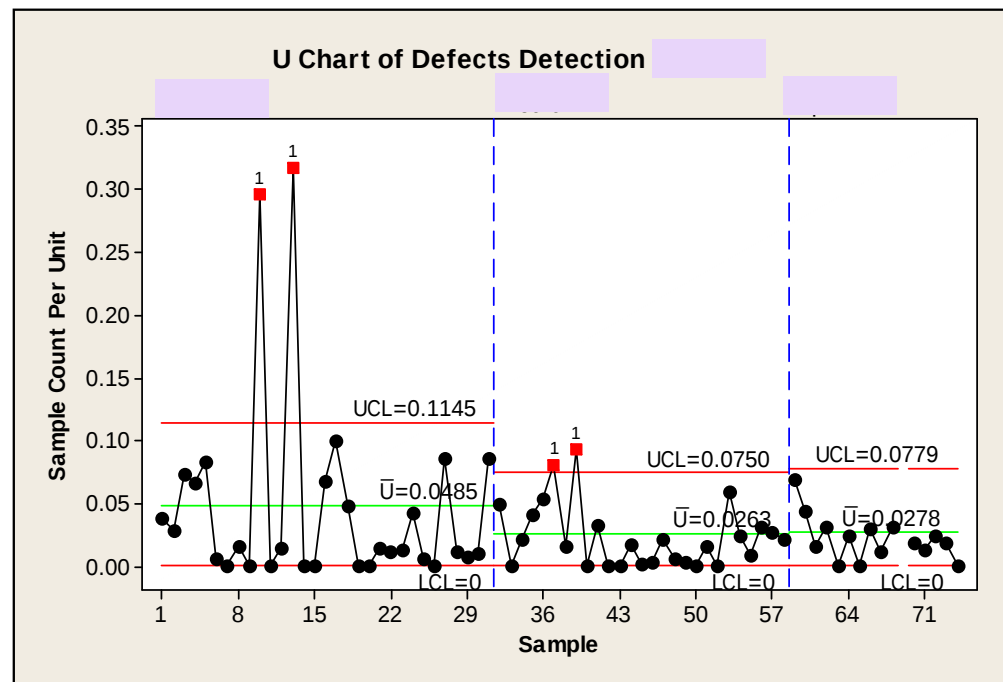
Step 6 - Creating Process Performance Baselines

- Definition: A Process Performance Baselines (PPB) is a documented characterization of the actual results achieved by following a process
- Therefore a PPB needs to reflect actual project performance
- CMMI-DEV OPP PA informative material:
 - Establish a quantitative understanding of the performance of the organization's set of standard processes in support of objectives
 - Select the processes that summarize the actual performance of processes in projects in the organization
- Alternatively Practical Software and Systems Measurement (PSM) recommends an organization follow three basic steps:
 - Identify organization needs
 - Select appropriate measures
 - Integrate measurement into the process



Step 6 - Creating Process Performance Baselines Example

- If we go back to our earlier example where we determined that the inspection sub-process should be statistically managed
- Collect data and Establish a PPB for the inspection sub-process



Step 6 - Appropriate Analysis: Types of Hypothesis Tests

Data Type		Interval or Ratio (Parametric Tests)		Ordinal (Non-Parametric Tests)		Nominal	Proportion
# Samples (Data groups)		Mean	Variance	Median	Variance / Fit	Similarity	Similarity
1 Sample		1-sample t test	1-sample Chi-Square test	1 sample Wilcoxon Signed Ranks test	Kolmogorov-Smirnov Goodness of Fit test	>2 cells Chi-Square Binomial Sign Test =2 cells	1 Proportions test
2 Samples		Independent 2-sample t test Paired t test Paired	Normal F test Levene test Not Normal	Independent Mann Whitney U test Wilcoxon matched Paired	= Medians Siegel-Tukey test Moses test ≠ Medians	Fisher Exact test (1-way ANOVA); Chi-Square test	2 Proportions test
3+ Samples		ANOVA (1 & 2 way ANOVA; Balanced ANOVA; GLM) MANOVA (General & Balanced)	Normal Bartlett test Levene test Not Normal	Independent Kruskal-Wallis 1-way ANOVA Friedman 2-way ANOVA Paired	Van der Waerden Normal scores test	Chi-Square test	ANOM (Analysis of Means)



Step 6 - Creating Process Performance Baselines Misconceptions

- We only need one baseline
- Once we establish the initial set of baselines we are done
- One data point constitutes a baseline
- We can't use the baseline until it is stable
- If the initial baseline is unstable we just remove the data points outside of the control limits and recompute the control limits until we get a plot that appears stable



Step 7 - Skills Needed to Develop PPMs

- Business Acumen
- Product Expertise
- Process Expertise
- Understanding of Measurement and Analysis Techniques
- Understanding of Advanced Statistical Techniques
- Understanding of Quantitative Management



Step 7 - Forming the PPM Development Team

Statistical Skills

- PPM builder needs a good understanding of statistics or Six Sigma Black Belt skill level or better
- PPM builder needs to be an expert user of the selected statistical tools
- User of PPMs needs to be an educated consumer

Process knowledge

- Build team needs to understand the process
- Build team needs to understand the context in which the PPMs will be used



Overview of the Steps to Build PPMs

- Creating PPMs



Creating PPMs

- 1. Identifying and using the correct analytical techniques for analyzing baselines, and creating process performance models**
- 2. Creating both confidence and prediction intervals with the models**
- 3. Validating and maintaining the process performance models including calibration and re-confirming with ongoing process and project data**
- 4. Confirming process performance models meet the established ingredients communicated by the SEI, either individually or as a whole**



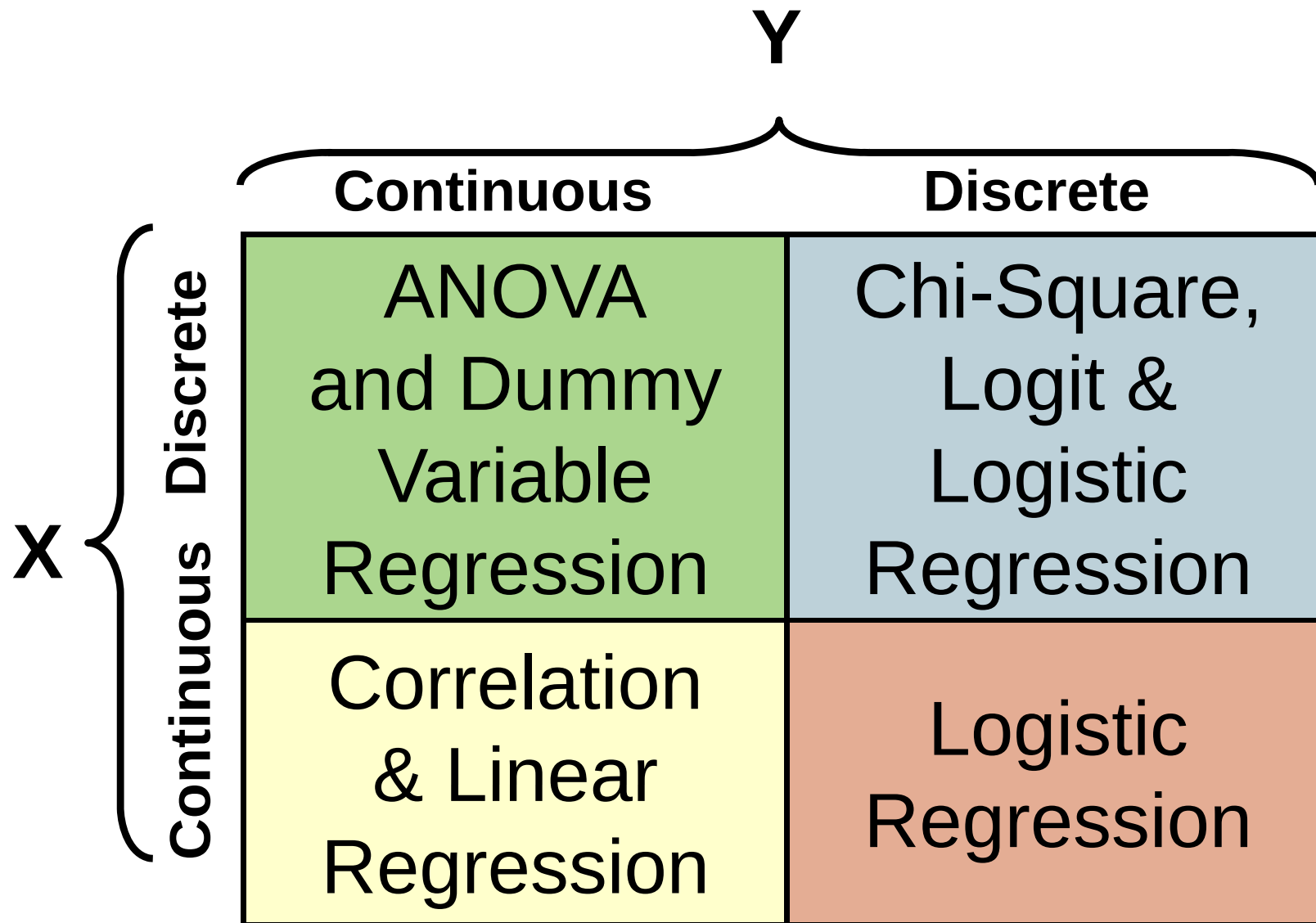
Step 1 - Select the Proper Analytical Model

Types of Modeling Techniques

- Statistical Modeling and Regression Equations
- Monte Carlo Simulation
- Probabilistic Modeling including Bayesian Belief Networks
- Discrete Event Process Simulation
- Other Advanced Modeling Techniques
 - Markov, Petri-net, Neural Nets, Systems Dynamics



Step 1 - Statistical Regression Analysis

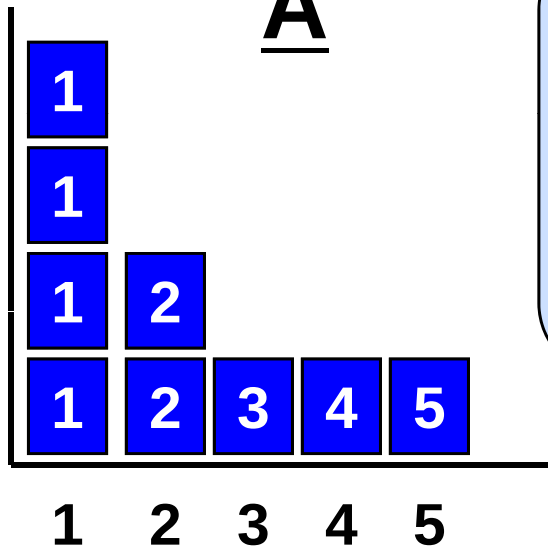


Step 1 - Why Use Monte Carlo Simulation?

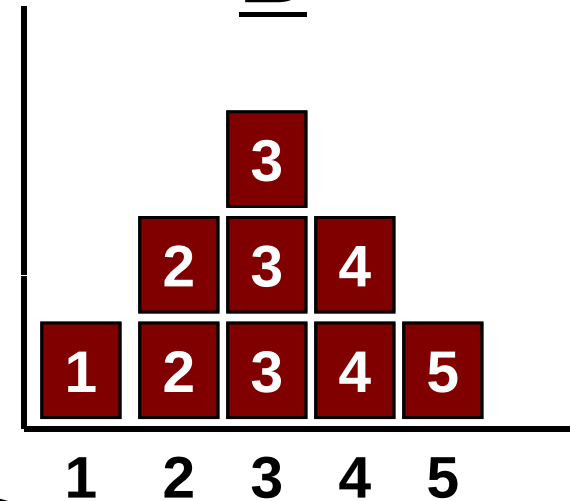
Use Monte Carlo simulation to do the following:

- Allow modeling of variables that are uncertain (e.g., put in a range of values instead of single value)
- Enable more accurate sensitivity analysis
- Analyze simultaneous effects of many different uncertain variables (e.g., more realistic)
- Aid buy-in and acceptance of modeling because user-provided values for uncertain variables are included in the analysis
- Provide a basis for confidence in a model output (e.g., supports risk management)
- Increase the usefulness of the model in predicting outcomes



A

Crystal Ball uses a random number generator to select values for A and B

B

A + B = C

C

Crystal Ball then allows the user to analyze and interpret the final distribution of C!

1 2 3 4 5 6 7 8 9 10

Crystal Ball causes Excel to recalculate all cells, and then it saves off the different results for C!



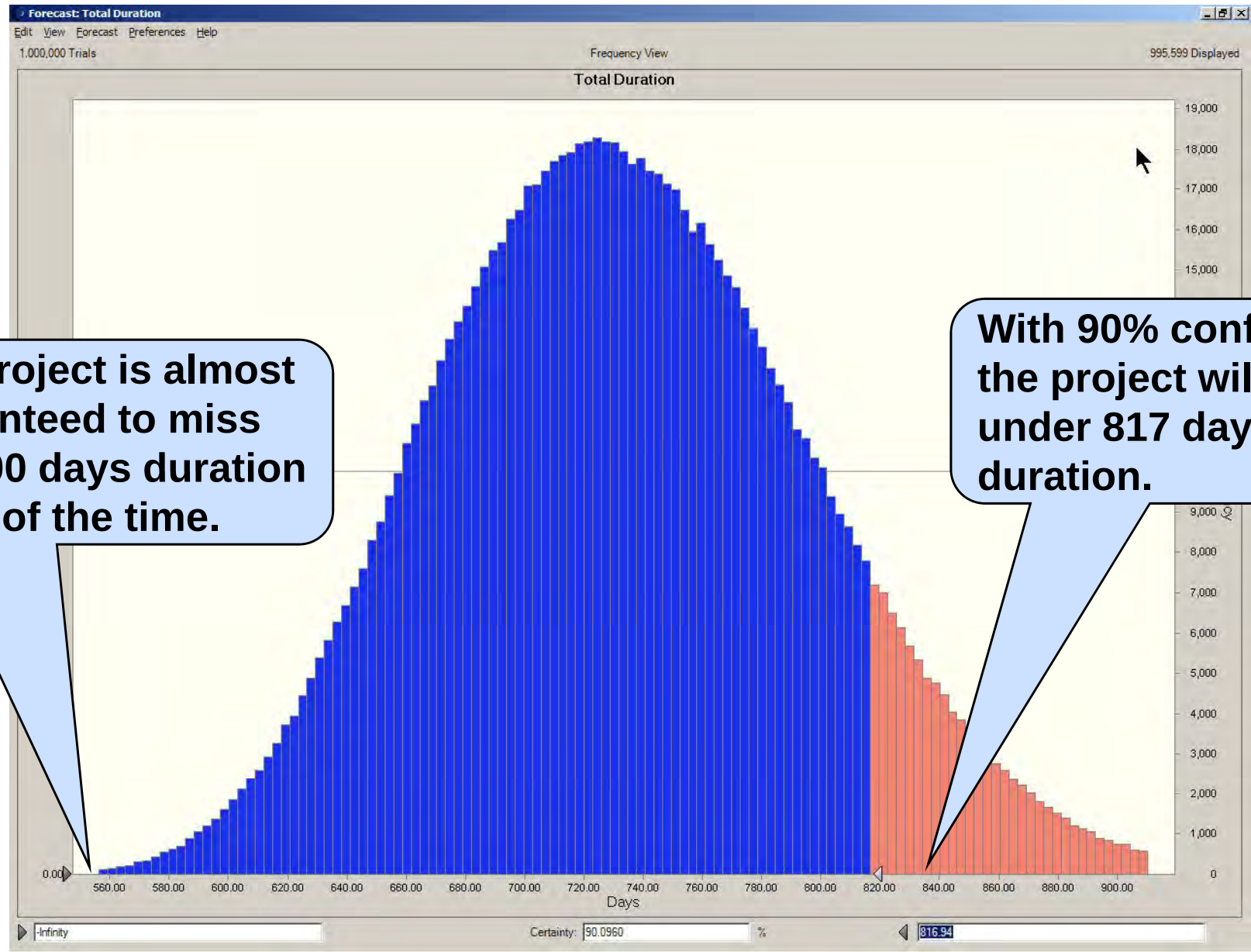
Example: Adding Reality to Schedules-1

Process	Durations		
Step	Best	Expected	Worst
1	27	30	75
2	45	50	125
3	72	80	200
4	45	50	125
5	81	90	225
6	23	25	63
7	32	35	88
8	41	45	113
9	63	70	175
10	23	25	63
		500	

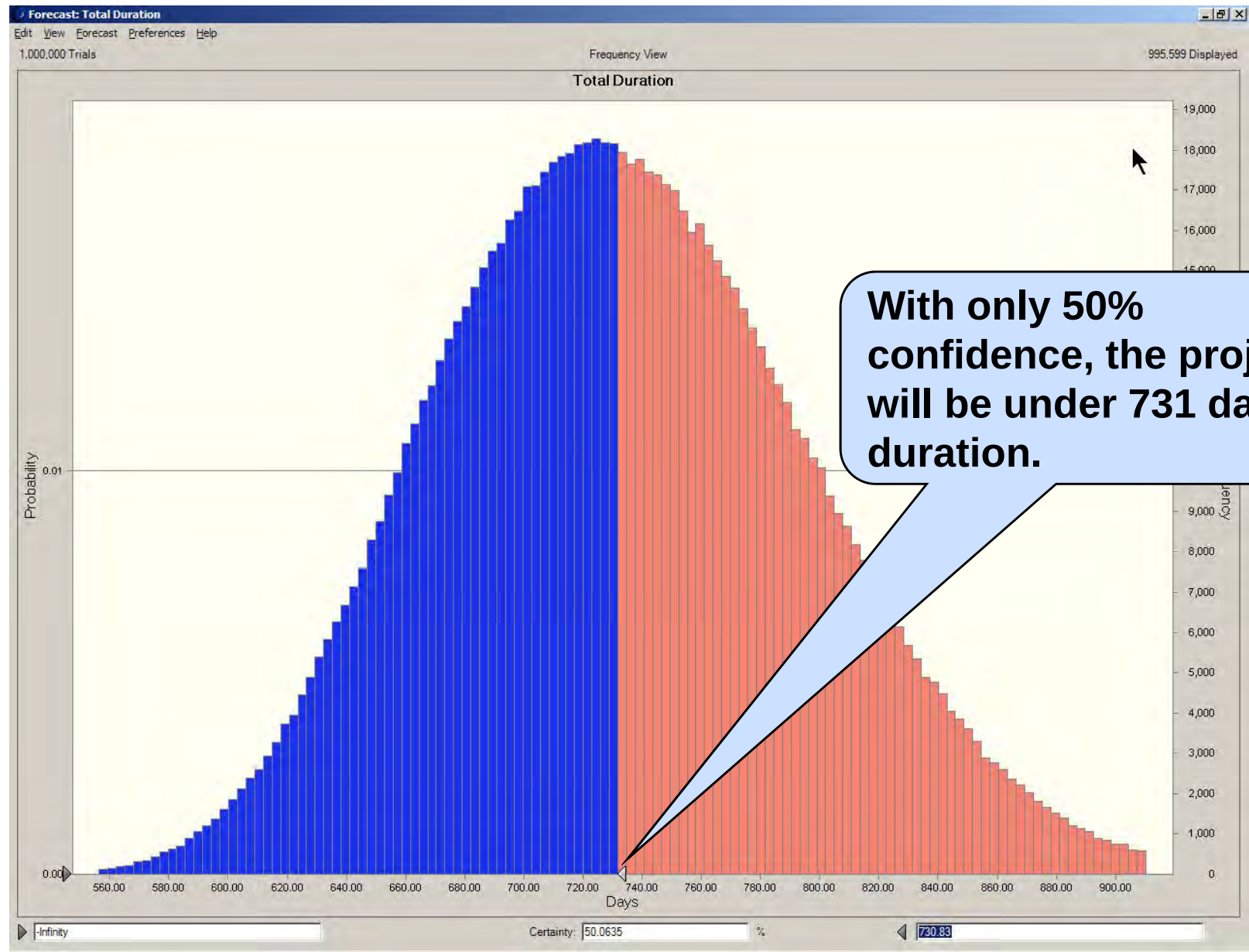
What would you forecast the schedule duration to be?



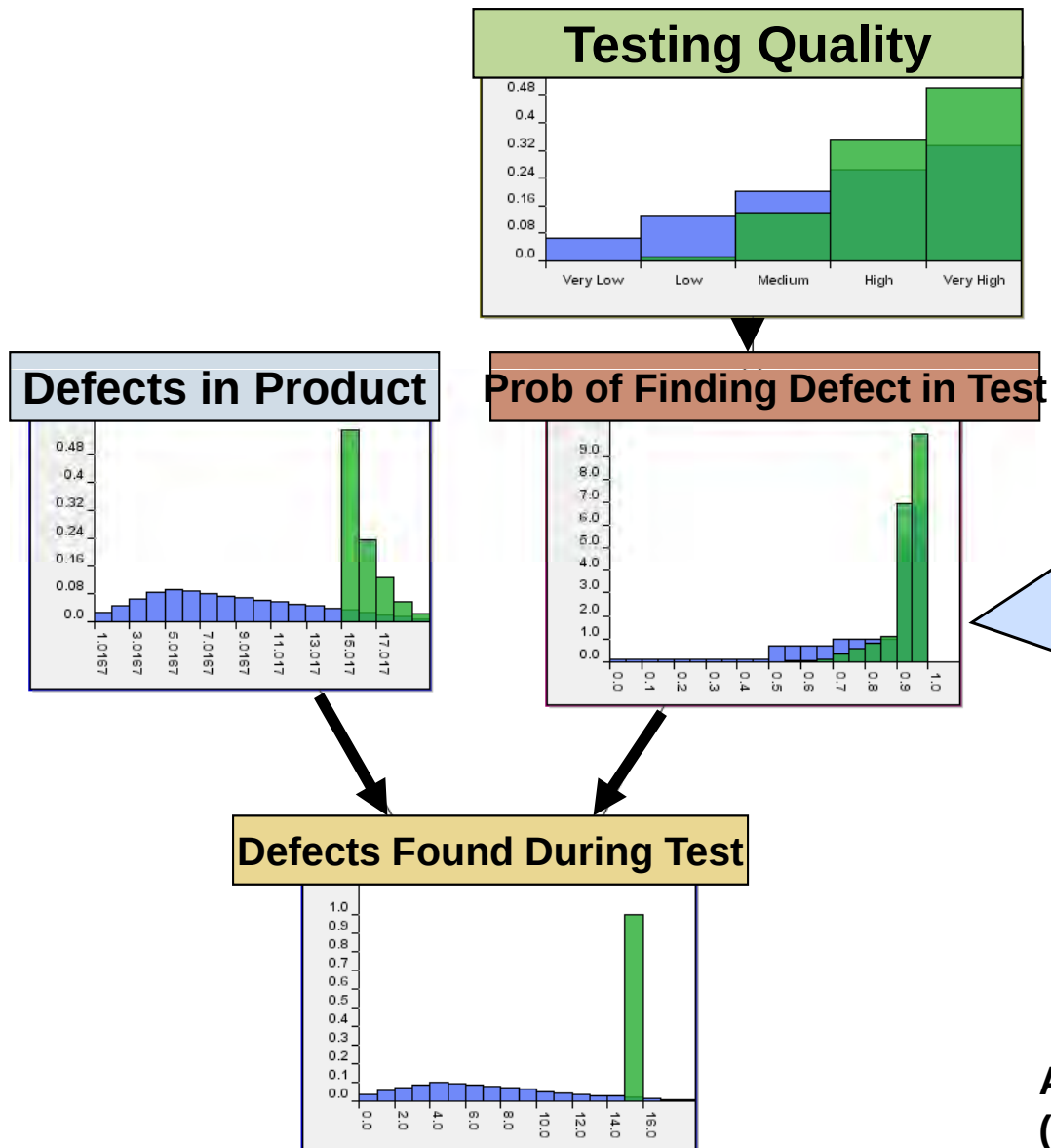
Adding Reality to Schedules-2



Adding Reality to Schedules-3



Example: BBN Quality Model



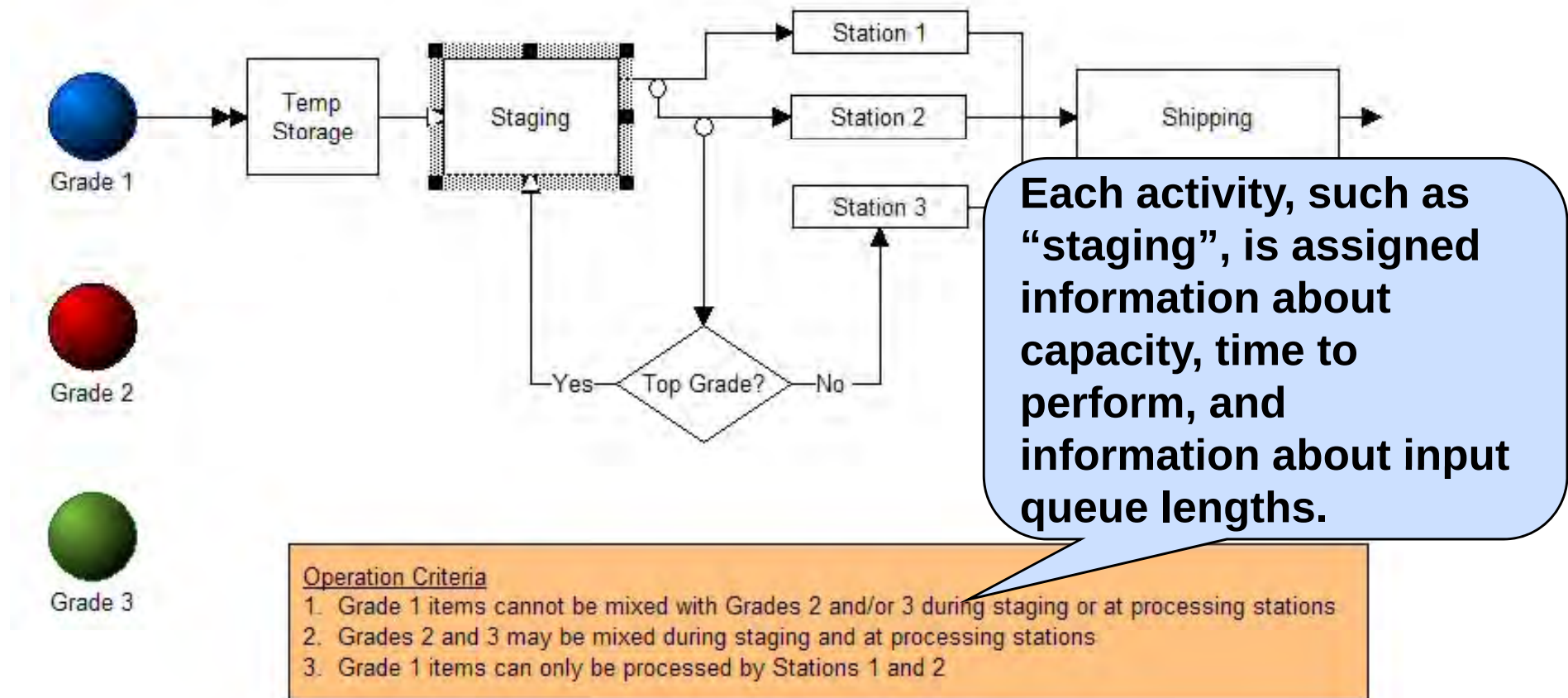
Predict the probability of finding a defect during a test by learning what the quality of testing is.

Predict defects found by learning more about the expected incoming defect level and the ability to find defects with testing.

AgenaRisk. <http://www.agenaco.uk>.
(URL valid as of April 2007)



Example: Discrete Event Process Simulation



Adapted from ProcessModel, Inc.
ProcessModel.

<http://www.processmodel.com>.

(URL valid as of April 2007)

Activity: Staging

General	Batching	Action	Cost	Shift	Submodel
Name:	Staging				Input Queue Cap.: 999 Undo
Capacity:	300	☒ Stats on	Output Queue Cap.: 99999 Help		
Time:	1	min	Object type:		Activity



Step 1 - Implement the Model in a Tool

Statistical Modeling: Example tools include Minitab, SAS
JMP

Monte Carlo Simulation: Example tools include Crystal Ball
and @Risk

Probabilistic Modeling: Example tools include AgenaRisk,
Netica, Hugin

Discrete Event Simulation: Example tools include
ProcessModel and Savvion



Step 1 - Example Statistical Package Tools

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Step 1 - Example Monte Carlo Simulation Tools

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Monmouth University's Dr. Roy

Conferences



 <http://www.oracle.com/crystalball/index.html>

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Oracle and Crystal Ball

As a result of its acquisition of Hyperion, Oracle

Crystal Ball software is a leading spreadsheet-t 500, Crystal Ball is used by customers from a bi schools worldwide for teaching risk analysis co

The diverse applications for Crystal Ball include Management, you can apply the power of Crysta



Software Engineering Institute

Carnegie Mellon

Robert Stoddard and Dave Zubrow
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Step 1 - Example Probabilistic Modeling Tools

“AGENARISK” <http://www.agena.co.uk/> “NETICA” <http://www.norsys.com/>



Bayesian Network and Simulation Software for Risk Analysis and Decision Support

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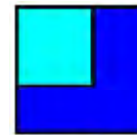
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more:

NEWS ITEM

Seminar



Software Engineering Institute

Carnegie Mellon

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Step 1 - Example Discrete Event Simulation Tools

<http://www.processmodel.com>

ProcessModel, Inc. - Business Process Improvement Solutions - Microsoft Internet Explorer

Address <http://www.processmodel.com/>

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NOVEMBER/DECEMBER 2006 IN THIS ISSUE

- » [Emerging Trends in BPM: What Happened in 2006, and What's Ahead in 2007](#)
- » [Savvion BusinessManager 7.0 is Here!](#)
- » [Successful Innovation Roadshow Offers BPM Proof Points](#)
- » [Introducing the First](#)

Emerging Trends in BPM: What Happened in 2006, and What's ahead in 2007

Guest contributor BPM consultant and blogger [Sandy Kemsley](#) shares an insider's look at the past year, and what we can expect in the year to come.

The BPM market continues to evolve, and although 2006 has seen some major events, there will be even more in 2007. This column takes a high-level view of four areas

WHAT'S AHEAD



Step 2 - Create Predictions with Both Confidence and Prediction Intervals-1

Because the central theme of CMMI High Maturity is understanding and controlling variation, PPMs produce statistical intervals of behavior for outcomes such that individual predicted values will have an associated confidence level

All of the Process Performance models discussed provide the ability to compute both the confidence and prediction intervals of the outcomes. These intervals are defined on the next slide



Step 2 - Create Predictions with Both Confidence and Prediction Intervals-2

Confidence Intervals: The statistical range of behavior of an average value computed from a sample of future data points

Prediction Intervals: The statistical range of behavior of individual future data points

Note: Prediction Intervals are almost always much wider than confidence intervals because averages don't experience the wide swings that individual data points can experience (similar to how individual grades in college compared to your grade point average)



Step 3 - Validating and Maintaining PPMs - 1

Initial estimation of a PPM typically yields

- Equation or function describing the relationship between independent variables (x's) and the dependent variable (y)
- An indication of the goodness-of-fit of the model to the data (e.g., R-square, Chi-square)

These do not necessarily indicate whether the model provides sufficient practical value

- Track and compare predictions with actual results
- Failure to meet business criteria (e.g., +/- 10%) indicates need to recalibrate (i.e, same variables with different data) or remodel (new variables and data)



Step 3 - Validating and Maintaining PPMs - 2

One strategy to jump start this process is to use half the data to estimate the model and the other half for validation (and other variations on this theme)

A second strategy is to accept that some period of time going forward will be needed to collect sample data by which to validate the PPM



Step 4 - Confirm the PPM Meets the Healthy Ingredients

PPMs can have the greatest business benefit when they meet all of the healthy ingredients

However, PPMs should not only be evaluated in isolation, but rather, as a collection of models enabling the organization and its projects to most likely exhibit superior results

That said, not every PPM has to exhibit each and every healthy ingredient to be considered as a member of the portfolio of PPMs serving the organization.



Tips - Barriers to Building PPMs

Lack of compelling outcomes to predict due to misalignment with critical business goals, usually caused by insufficient management sponsorship and involvement

Lack of a connection to a work process or sub-process such that direct changes in that process or sub-process can help cause changes in predicted outcomes

Insufficient process and domain knowledge which is necessary to identify the probable x factors to predict the outcome

Insufficient training and practice with modeling techniques



Tips - Documentation Needed when Building PPMs-1

Similar to the existing SEI Indicator Template but with some additional information content:

1. Identity of associated processes and subprocesses
2. Identity of the outcome measure (y) and the x factors
3. Data type of all outcome (y) and x factors
4. Statistical evidence that the x factors are significant (e.g. p values of individual x factors)
5. Statistical evidence of the strength of the model (e.g. the adjusted R-squared value)
6. The actual prediction equation for the outcome (y)
7. The performance baselines of the x factors



Tips - Documentation Needed when Building PPMs-2

Similar to the existing SEI Indicator Template but with some additional information content (continued):

- 8.The resulting confidence interval of the predicted outcome
- 9.The resulting prediction interval of the predicted outcome
- 10.Use case scenarios of how the PPM is intended to be used by different audiences for specific decisions
- 11.Description of how often the PPM is updated, validated, and calibrated
- 12.Description of how often the PPM is used to make predictions with results shown to decision-makers
- 13.Description of which organizational segment of projects the PPM applies to



Overview of the Steps to Build PPMs

- Using PPMs



Using PPMs

Use these models to assist with statistical management of critical subprocesses

Use the predictions of these models to make decisions and take preventive and mitigative action

Use these models to help with CAR and OID

Coach audiences on how to understand, interpret and draw conclusions from process performance models



Take Action Based on Results of PPM Predictions

If a PPM model predicts an unacceptable range of values for a particular outcome, then early action can influence a more desirable range of outcome

Once a PPM model predicts a range of values for a particular outcome, then actual values can be compared to the range. If the actual values fall outside the range, it may be treated similarly to a point on a control chart falling outside of the control limits

Use PPM predictions to help inform process composition decisions so that business goals may be optimized



How PPMs Assist CAR

- Aid impact, benefit, and ROI predictions for
 - Selecting defects for analysis
 - Selecting action proposals for implementation
- Use PPMs to identify potential sources of the problem or defect
- Use PPMs to understand the interactions among selected improvements; and the combined predicted impacts, costs, and benefits of the improvements (considered as a set)
- Compare the result versus the original PPM-based prediction



How PPMs Assist OI

- Select process improvement proposals for implementation by aiding impact, benefit, and ROI predictions
- Identify opportunities for improvement
- Use PPMs to understand the interactions among selected improvements; and the combined predicted impacts, costs, and benefits of the improvements (considered as a set)
- Prioritize improvements based on ROI, cost, risk, etc.
- Confirm the prediction (provides input to maintaining PPMs)



What is Sub-optimization and how can PPMs help?

Sub-optimization is where one parameter is optimized at the expense of other(s)

- Reduce delivered defects, but are late and over budget
- Meet the cost goal but don't deliver desired functionality

PPMs allow you to

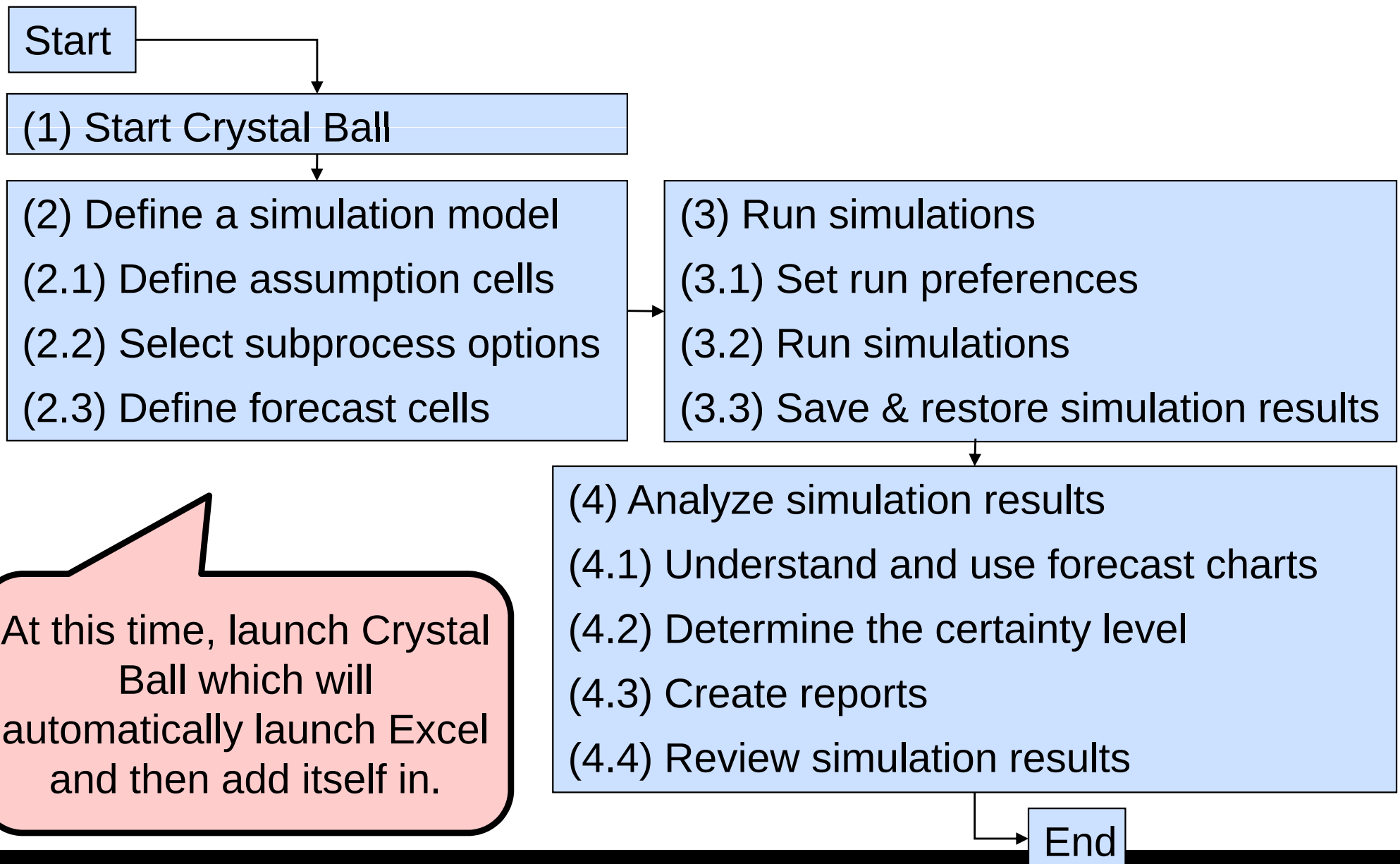
- Gauge the trade-offs amongst multiple goals
- Gauge the effects of changes to multiple parameters



PPM Exercise 1: Constructing a Product Business Case with Monte Carlo Simulation and Optimization



Monte Carlo Simulation Steps with Crystal Ball



Crystal Ball Toolbar

SSTC 2010

Define decision

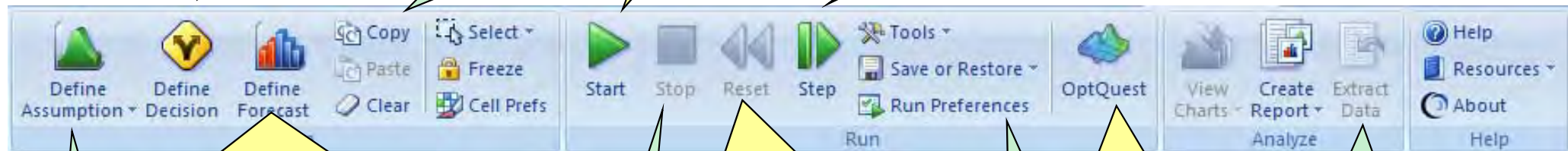
(Lets you identify a cell as a decision cell to be used in Optimization Modeling)

You can copy, paste and clear Crystal Ball identities to save time

Start simulation
(Start simulation once all settings are made)

Single step
(Lets you run the simulation step by step. Normally used to debug issues with simulation)

Create report
(Creates standardized reports of the simulation)



Define forecast

(Lets you identify a cell as an outcome that you want to study)

Reset simulation
(Restart simulation and erase previous results)

Optquest
(Begin optimization)

Extract data
(Allows the capture and saving of the actual simulation data from all the runs)

Define assumption

(Lets you identify a cell as an uncertain cell with a distribution)

Stop simulation
(You can stop the simulation midstream)

Run preferences
(Enables the settings of how long the simulation runs, etc...)



Benefits of Using Optimization Modeling

Monte Carlo simulation models can only provide a range of possible outcomes for any situation. They do not identify ways to **control** the situation to achieve the **best** outcome.

Optimization modeling

- automates tens of thousands of decision “what-ifs” from a Monte Carlo simulation to determine the best possible solution
- is easy to use, not tedious and time consuming like many other analytical methods
- uses state-of-the-art algorithms for confidently finding optimal solutions
- supports decision making in situations where significant resources, costs, or revenues are at stake



Steps for Optimization Using Crystal Ball

SSTC 2010

(1) Create a simulation model of the problem.



(2) Define decision variables cells.



(3) Select the objective for the optimization.



(4) Identify additional requirements.



(5) Confirm settings for decision variables.



(6) Specify constraints for decision variables.



(7) Identify Optimization Parameters.



(8) Run the Optimization.



(9) Interpret the Results.



Business Case Example for Feature Inclusion Decision in Upcoming Hospital Records Software Project

Business Case Monte Carlo Optimization-v010.xls file

4	Develop Feature?	Feature ID	Feature Description
5	1	1	Online Web Access
6	1	2	Real-time Updating of Information
7	0	3	Shared User Information
8	0	4	Report Historical Usage
9	0	5	Conduct Security Check
10	0	6	Confirm Transactions
11	0	7	Cross Check Different Patients Information
12	0	8	Trace Prescriptions Used
13	0	9	Trace Assigned Doctor
14	0	10	Trace Hospital
15	1	11	Conduct Periodic Audit
16	1	12	Check for Corrupt Data
17	0	13	Provide Conflict Warning
18	0	14	Identify Incomplete Records
19	1	15	Compute Cycle Times on Value Stream
20	1	16	Enable cross hospital sharing of data
21	0	17	Provide Security Encryption for Sensitive Data
22	1	18	Enable workflow automation messages
23	1	19	Require peer review of critical data inputs
24	1	20	Provide for automated archival of information

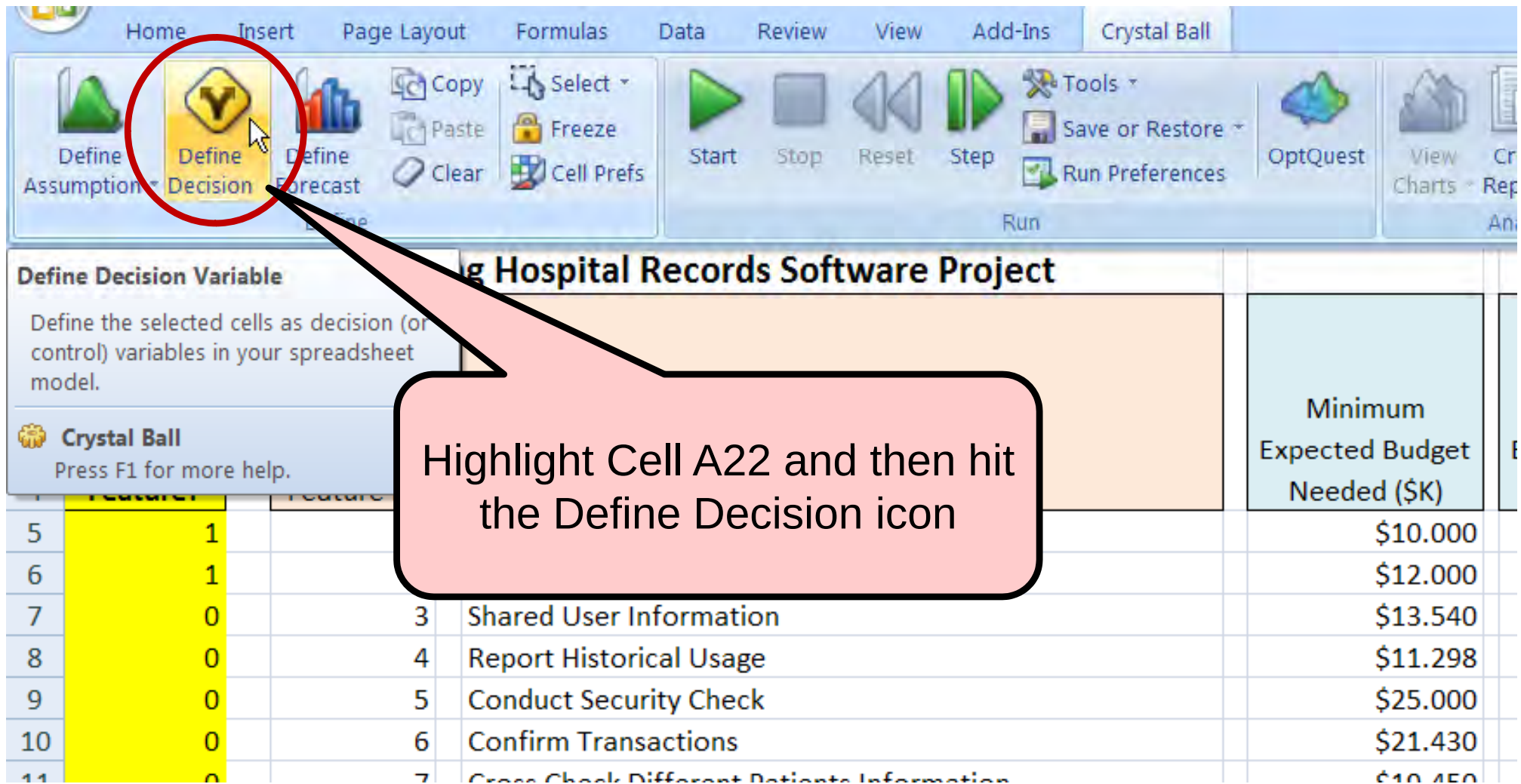


Minimum Expected Budget Needed (\$K)	Most Likely Expected Budget Needed (\$K)	Maximum Expected Budget Needed (\$K)	Simulated Budget (\$K)	Budget Used in Simulation Feature Scenario (\$K)
\$10.000	\$12.000	\$29.260	\$0.000	\$0.000
\$12.000	\$14.400	\$21.870	\$0.000	\$0.000
\$13.540	\$16.248	\$27.420	\$0.000	\$0.000
\$11.298	\$13.558	\$19.880	\$0.000	\$0.000
\$25.000	\$30.000	\$35.290	\$0.000	\$0.000
\$21.430	\$25.716	\$29.830	\$0.000	\$0.000
\$19.450	\$23.340	\$39.750	\$0.000	\$0.000
\$18.390	\$22.068	\$38.234	\$0.000	\$0.000
\$17.420	\$20.904	\$29.774	\$0.000	\$0.000
\$29.170	\$35.004	\$51.960	\$0.000	\$0.000
\$26.290	\$31.548	\$62.948	\$0.000	\$0.000
\$21.290	\$25.548	\$39.497	\$0.000	\$0.000
\$21.990	\$26.388	\$34.659	\$0.000	\$0.000
\$27.990	\$33.588	\$39.774	\$0.000	\$0.000
\$39.230	\$47.076	\$57.849	\$0.000	\$0.000
\$41.090	\$49.308	\$72.895	\$0.000	\$0.000
\$38.210	\$45.852	\$67.391	\$0.000	\$0.000
\$31.280	\$37.536	\$47.324	\$0.000	\$0.000
\$31.670	\$38.004	\$49.846	\$0.000	\$0.000
\$27.720	\$33.264	\$39.888	\$0.000	\$0.000
	\$581.350			
		Total Budget >>>>>>>>>>>>		\$0.000

	Minimum Expected Calendar Days Needed	Most Likely Expected Calendar Days Needed	Maximum Expected Calendar Days Needed	Simulated Calendar Days	Calendar Days used in Simulation Feature Scenario
	15	20	30	0	0
	10	18	36	0	0
	12	15	56	0	0
	25	38	49	0	0
	30	38	75	0	0
	26	30	48	0	0
	18	29	62	0	0
	15	22	36	0	0
	19	26	39	0	0
	7	14	31	0	0
	28	37	45	0	0
	22	29	49	0	0
	26	40	67	0	0
	33	40	78	0	0
	18	26	40	0	0
	17	21	38	0	0
	26	29	37	0	0
	21	35	59	0	0
	22	29	51	0	0
	26	30	47	0	0
		Total Calendar Days >>>>>>>>>>>>			0

Expected Senior Resource Needed	Actual Senior Resource Used in Simulation	Relative Customer Value	Customer Value in Simulation
0	0	1.00	1.00
0.2	0.2	2.00	2.00
0.3	0	1.20	0.00
0	0	1.50	0.00
0.12	0	1.80	0.00
0.15	0	0.90	0.00
0.19	0	0.30	0.00
0.25	0	0.80	0.00
0	0	1.70	0.00
0	0	1.20	0.00
0	0	1.90	1.90
0.65	0.65	2.40	2.40
0.34	0	2.70	0.00
0.29	0	3.00	0.00
0.21	0.21	2.20	2.20
0.17	0.17	1.70	1.70
0	0	1.95	0.00
0	0	2.67	2.67
0	0	4.00	4.00
0	0	2.39	2.39
Total Resource>>	1.23	Value>>>	20.26





Define Decision Variable

Define the selected cells as decision (or control) variables in your spreadsheet model.

Crystal Ball
Press F1 for more help.

Highlight Cell A22 and then hit the Define Decision icon

Feature	Shared User Information	Report Historical Usage	Conduct Security Check	Confirm Transactions	Cross Check Different Patients Information	Expected Budget Needed (\$K)
5	1					\$10.000
6	1					\$12.000
7	0	3				\$13.540
8	0	4				\$11.298
9	0	5				\$25.000
10	0	6				\$21.430
11	0	7				\$10.450



Highlight Cell A23 next and
then hit the Define
Decision icon

Define Decision Variable: Cell A22

Name:

Bounds

Lower: Upper:

Type

☐ Continuous

☒ Discrete

Step:



Highlight Cell A24 next and
then hit the Define
Decision icon

Define Decision Variable: Cell A23

Name:

Bounds

Lower: Upper:

Type

☐ Continuous

☒ Discrete

Step:



Define Decision Variable: Cell A24

Name:

Bounds

Lower: Upper:

Type

☐ Continuous

☒ Discrete

Step:



Business Case Monte Carlo Optimization-

Home Insert Page Layout Formulas Data Review View Add-Ins Crystal Ball

Define Assumption Define Decision Define Forecast

Copy Paste Clear Select Freeze Cell Prefs

Start Stop Reset Step Tools Save or Restore Run Preferences OptQu

Run

Define Assumption

Define the selected cells as assumption by choosing from a gallery of probability distributions types.

Assumptions are the uncertain variables in your spreadsheet model.

Crystal Ball
Press F1 for more help.

Highlight Cell M22 next and then hit the Define Assumption icon

Project

Feature Description		Min	Expected	Need
7	Online Web Access	0		
8	Real-time Updating of Information	0		
9	Shared User Information	0		
10	Report Historical Usage	0		
	Conduct Security Check			
	Confirm Transactions			



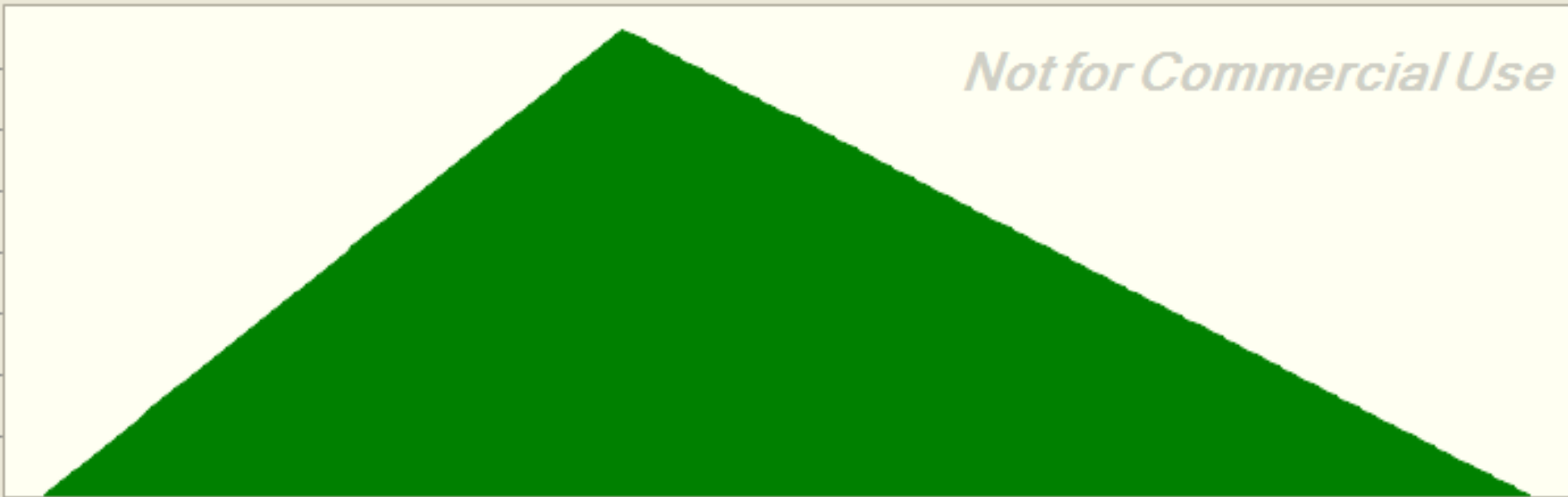
Define Assumption: Cell M22

Edit View Parameters Preferences Help

Name:

Triangular Distribution

Not for Commercial Use

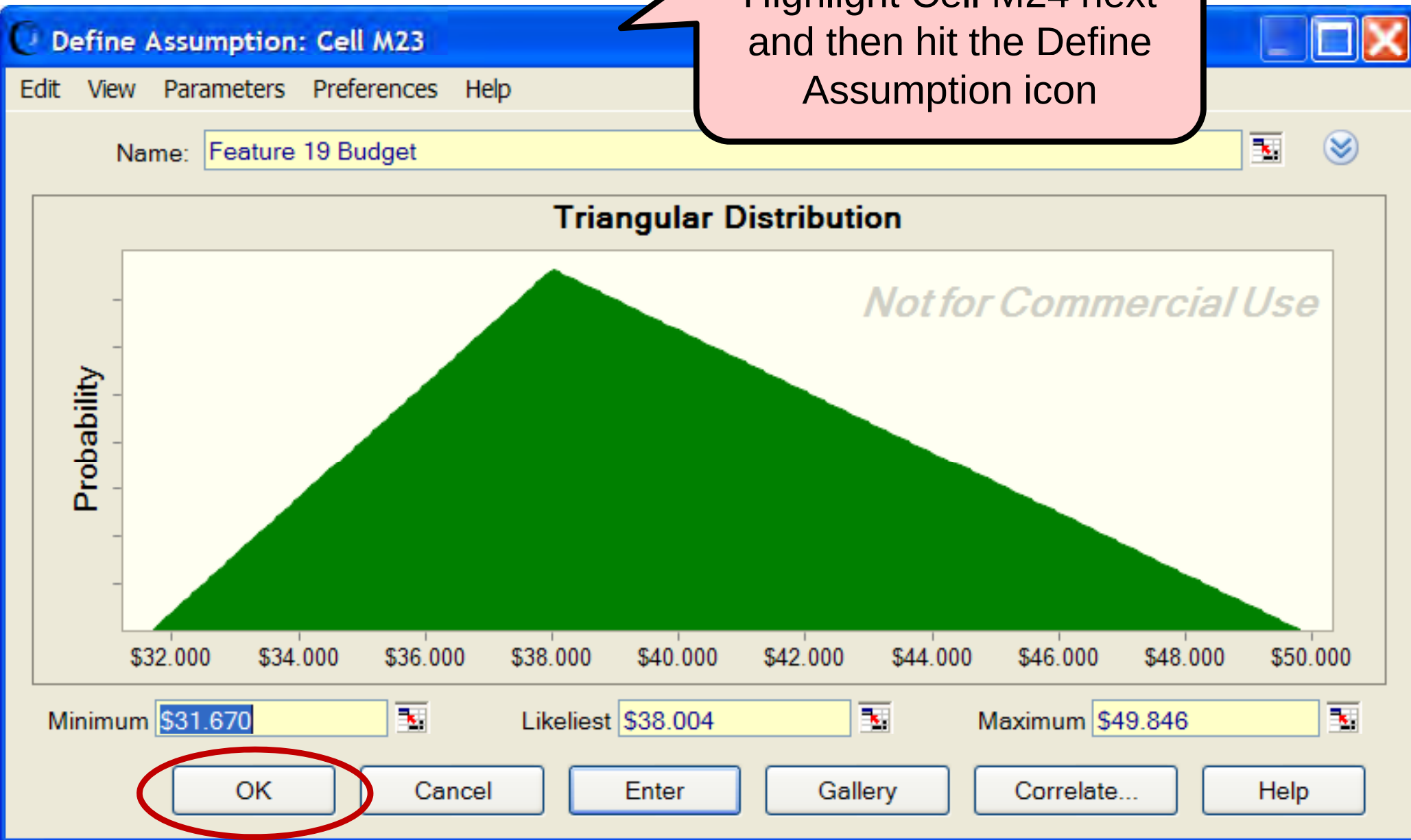


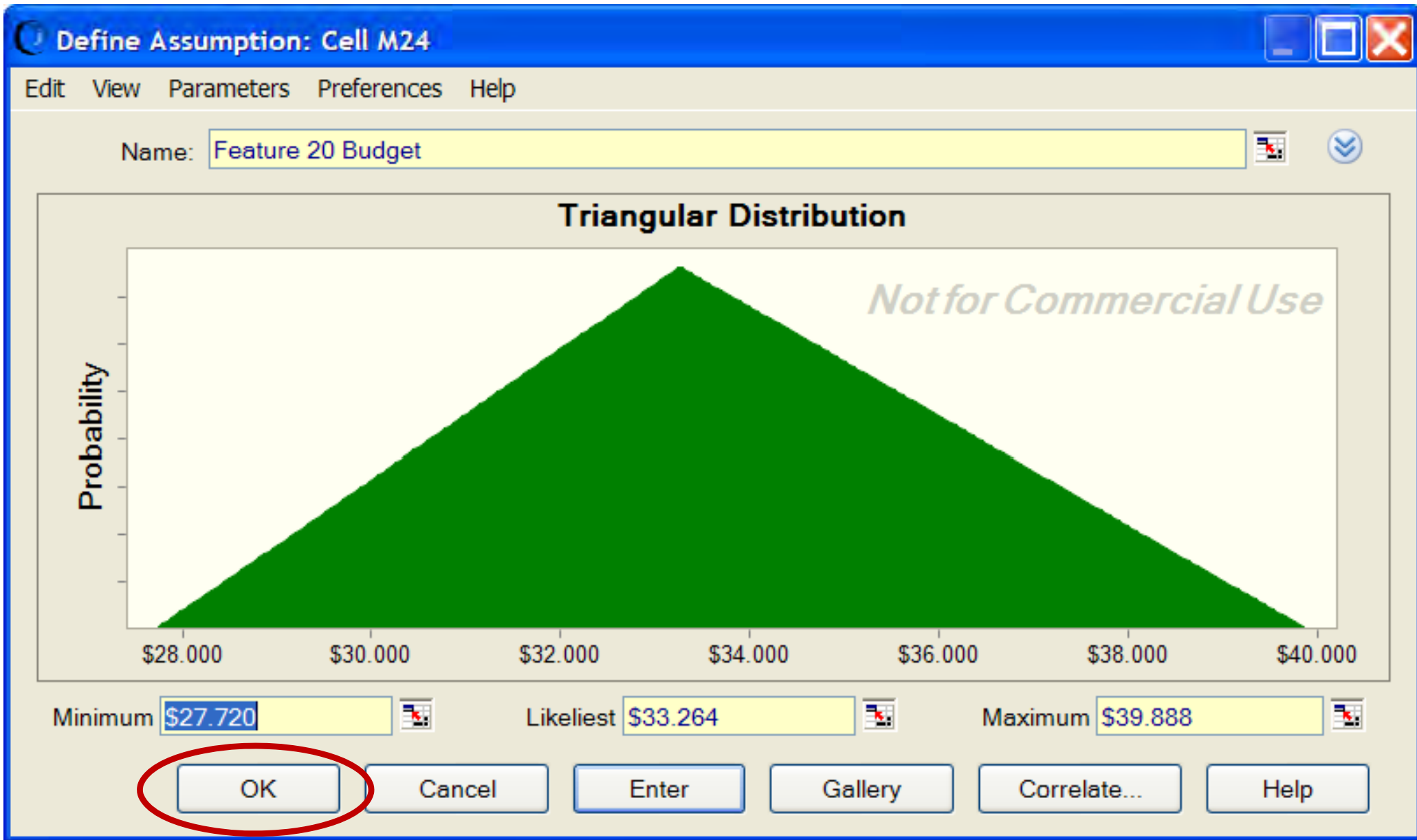
Minimum Likeliest Maximum

Highlight Cell M23 next
and then hit the Define
Assumption icon



Highlight Cell M24 next
and then hit the Define
Assumption icon





Business Case Monte Carlo C

Home Insert Page Layout Formulas Data Review View Add-Ins Crystal I

Define Assumption ▾ Define Decision Define Forecast Define

Copy Paste Clear Select ▾ Freeze Cell Prefs

Start Stop Reset Step Tools ▾ Save or Res Run Prefere

Run

Define Forecast

Define the selected cells as output variables of interest in your spreadsheet model.

 **Crystal Ball**
Press F1 for more help.

Highlight Cell O26 and then hit the Define Forecast icon

	Feature ID	Feature Description	Minim Expected Needed
5	1	Online Web Access	\$
6	2	Real-time Updating of Information	\$
7	3	Shared User Information	\$
8	4	Report Historical Usage	\$
9	5	Conduct Security Check	\$



Define Forecast: Cell O26

Name:

Units:

LSL: USL:

Target:

Forecast Window Precision Filter Auto Extract

View:

☐ Split view

Window

☒ Show automatically

☒ While running simulation

☐ When simulation stops

Fit distribution

☐ Fit a probability distribution to the forecast

After hitting OK, Highlight Cell Y26 next and then hit the Define Forecast icon



Define Forecast: Cell Y26

Name:

Units:

LSL: USL:

Target:

Forecast Window Precision Filter Auto Extract

View:

☐ Split view

Window

☒ Show automatically

☒ While running simulation

☐ When simulation stops

Fit distribution

☐ Fit a probability distribution to the forecast

After hitting OK, Highlight Cell AC26 next and then hit the Define Forecast icon



Define Forecast: Cell AC26

Name:

Units:

LSL: USL:

Target:

Forecast Window Precision Filter Auto Extract

View:

☐ Split view

Window

☒ Show automatically

☒ While running simulation

☐ When simulation stops

Fit distribution

☐ Fit a probability distribution to the forecast

After hitting OK, Highlight Cell AG26 next and then hit the Define Forecast icon



Define Forecast: Cell AG26

Name:

Units:

LSL: USL:

Target:

Forecast Window Precision Filter Auto Extract

View:

☐ Split view

Window

☒ Show automatically

☒ While running simulation

☐ When simulation stops

Fit distribution

☐ Fit a probability distribution to the forecast



Business Case Monte Carlo Optimization-v010 - Micro

Home Insert Page Layout Formulas Data Review View Add-Ins Crystal Ball

Define Assumption ▾ Define Decision Define Forecast Copy Paste Clear Select ▾ Freeze Cell Prefs

Start Stop Reset Step Tools ▾ Save or Restore Run Preferences

OptQuest View Charts ▾

OptQuest
Search for and find optimal solutions to your simulation models.
Crystal Ball
Press F1 for more help.

in Upcoming Hospital Records System				Minimum Expected Budget Needed (\$K)
Develop Feature?	Feature ID	Feature Description		
1	1	Online Web Access		\$10.000
1	2	Real-time Updating of Information		\$12.000
0	3	Shared User Information		\$13.540
0	4	Report Historical Usage		\$11.298
0	5	Conduct Security Check		\$25.000
0	6	Confirm Transactions		\$21.430



Select an objective and optionally specify requirements



Primary workbook: Business Case Monte Carlo Optimiz

Objectives: ?

Exclude

Maximize the 5% Percentile of Total Customer Value

☐

Minimize the 95% Percentile of Total Budget

☒

Exclude

☐☐☐

Hit the Add Objective button to enter the first objective seen on this screen.

Add Objective

Add Requirement

Efficient Frontier

Import...

Delete



Select an objective and optionally specify requirements



Then, Hit the Add Requirement button 3 times to enter the three Requirements seen on this screen.

Requirements: ?	Exclude
The <u>95% Percentile</u> of <u>Total Senior Resource</u> must be <u>less than 2.10</u>	☐
The <u>95% Percentile</u> of <u>Total Days</u> must be <u>less than 300.00</u>	☐
The <u>95% Percentile</u> of <u>Total Budget</u> must be <u>less than \$400,000</u>	☐

Add Objective

Add Requirement

Efficient Frontier

Import...

Delete



Select an objective and optionally specify requirements

Primary workbook: Business Case Monte Carlo Optimiz

Objectives: ? Exclude

Maximize the 5% Percentile of Total Customer Value	☐
Minimize the 95% Percentile of Total Budget	☒

Requirements: ? Exclude

The 95% Percentile of Total Senior Resource must be less than 2.10	☐
The 95% Percentile of Total Days must be less than 300.00	☐
The 95% Percentile of Total Budget must be less than \$400.000	☐

Add Objective Add Requirement Efficient Frontier Import... Delete

< Back Next > Run Close Help



OptQuest

Welcome

Objectives

Decision Variable

Constraints

Options

Review decision variables and change properties as necessary

☐ Show cell locations

Decision Variables	Lower B...	Base Ca...	Upper B...	Type	St...	Fre...
Feature 1 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 10 Decision	0.00	0.00	1.00	Discrete	1.00	☐
Feature 11 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 12 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 13 Decision	0.00	0.00	1.00	Discrete	1.00	☐
Feature 14 Decision	0.00	0.00	1.00	Discrete	1.00	☐
Feature 15 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 16 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 17 Decision	0.00	0.00	1.00	Discrete	1.00	☐
Feature 18 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 19 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 2 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 20 Decision	0.00	1.00	1.00	Discrete	1.00	☐
Feature 3 Decision	0.00	0.00	1.00	Discrete	1.00	☐
Feature 4 Decision	0.00	0.00	1.00	Discrete	1.00	☐
Feature 5 Decision	0.00	0.00	1.00	Discrete	1.00	☐
Feature 6 Decision	0.00	0.00	1.00	Discrete	1.00	☐
Feature 7 Decision	0.00	0.00	1.00	Discrete	1.00	☐

Enter 0 for each of the Base case values. This is the starting solution where the optimization will begin looking.

< Back Next > Run Close Help



OptQuest

Welcome
Objectives
Decision Variabl
Constraints
Options

Optionally, specify constraints on the decision variables

☐ Advanced entry

Constraints ?	Type	Exclude
> optional constraints on decision variables)		☐

Add Constraint Add Comment... Efficient Frontier Delete

< Back Next > Run Close Help



OptQuest

Welcome
Objectives
Decision Variabl
Constraints
Options

Choose your options and run the optimization

Optimization control

☐ Run for 100000 simulations

☒ Run for 10 minutes

Simulation: [Run Preferences...](#)

Type of optimization

☒ With simulation (stochastic)

☐ Without simulation (deterministic)

While running

☒ Show chart windows as defined

☐ Show only target forecast windows

☒ Update only for new best solutions

Decision variable cells

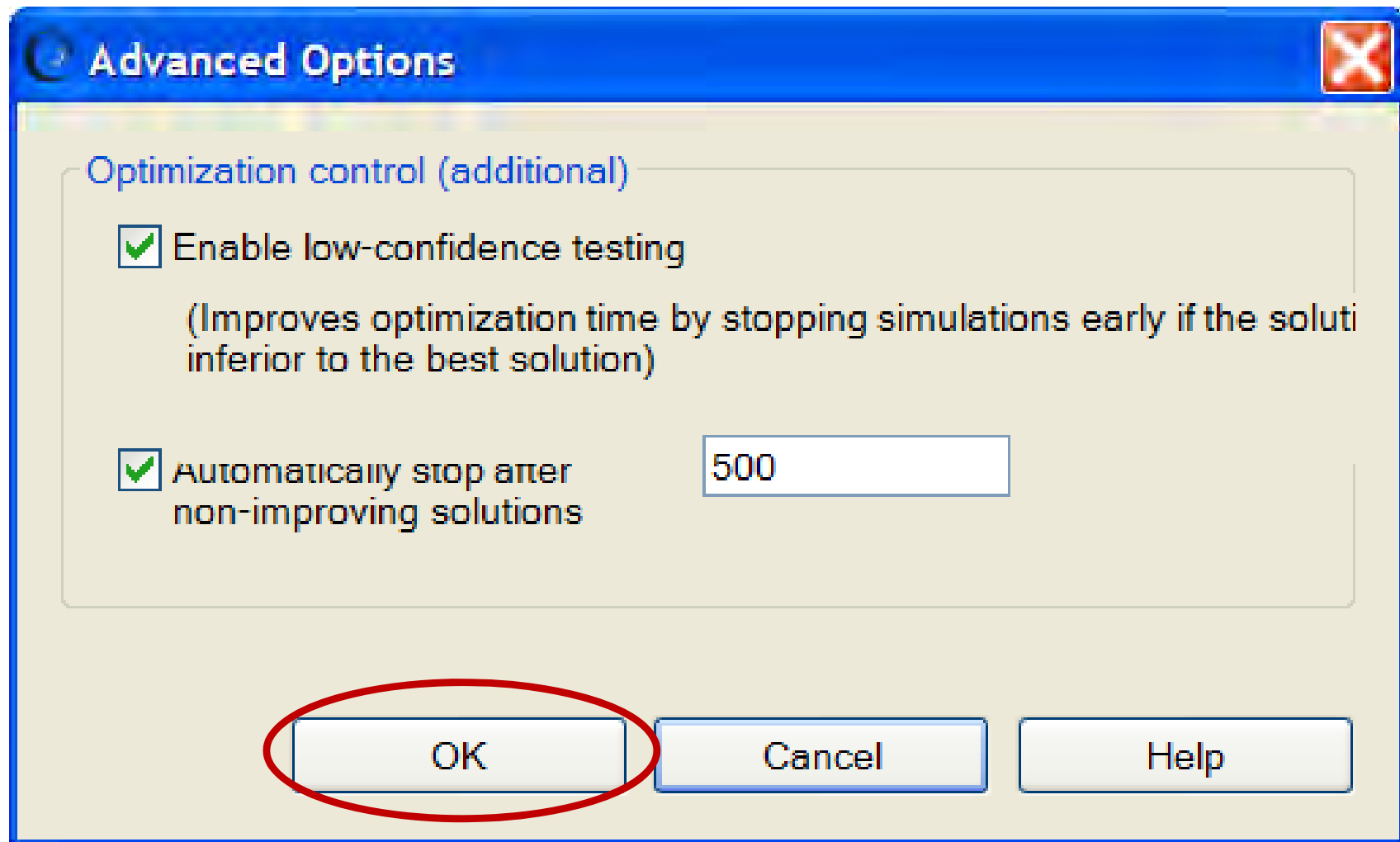
☐ Leave set to original values

☒ Automatically set to best solution

[Advanced Options...](#)

< Back Next > Run Close Help





OptQuest

Welcome
Objectives
Decision Variabl
Constraints
Options

Choose your options and run the optimization

Optimization control

☐ Run for 100000 simulations

☒ Run for 10 minutes

Simulation: **Run Preferences...**

Type of optimization

☒ With simulation (stochastic)

☐ Without simulation (deterministic)

While running

☒ Show chart windows as defined

☐ Show only target forecast windows

☒ Update only for new best solutions

Decision variable cells

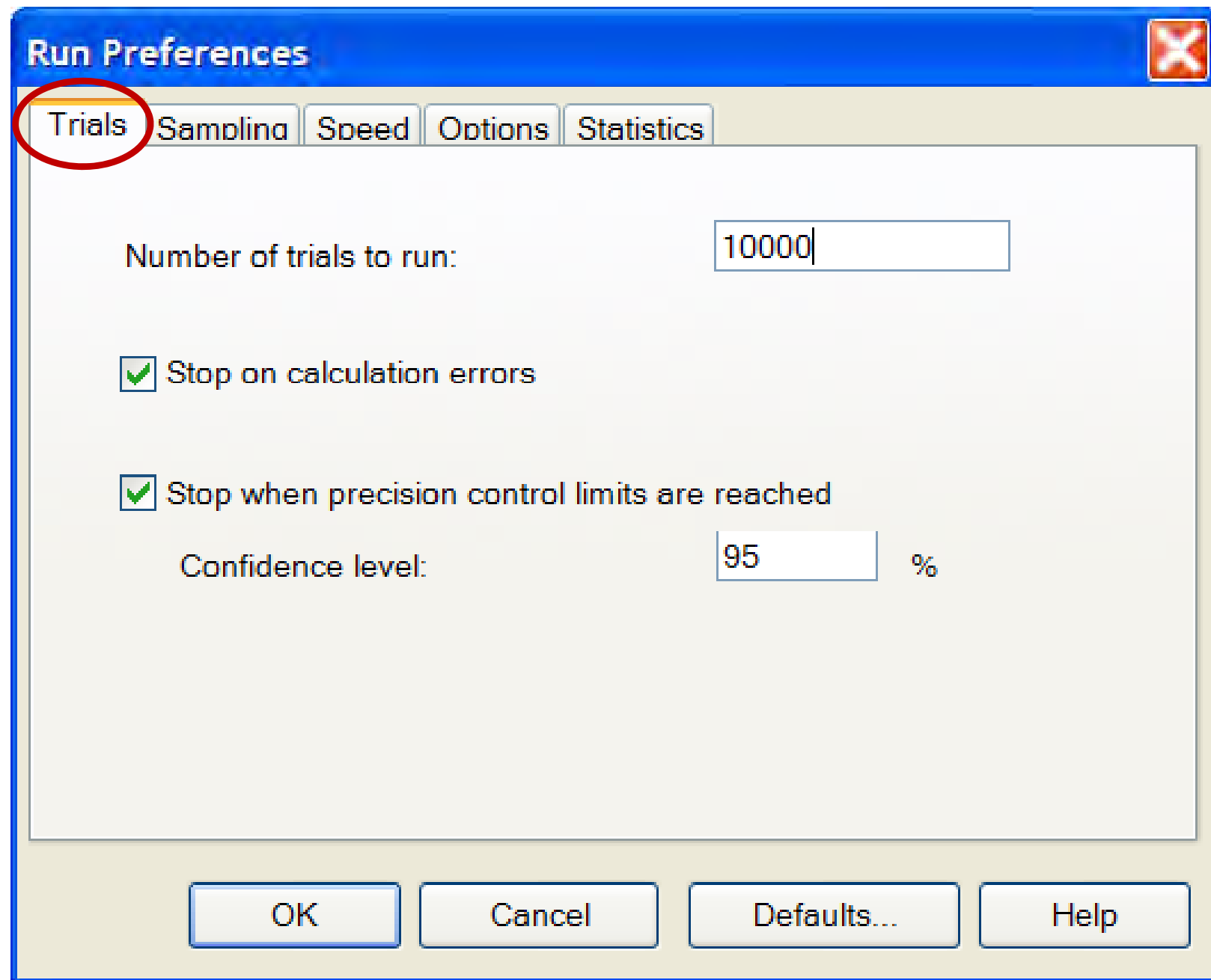
☐ Leave set to original values

☒ Automatically set to best solution

Advanced Options...

< Back Next > Run Close Help





The image shows a 'Run Preferences' dialog box with a blue title bar and a red 'X' close button. It has five tabs: 'Trials' (highlighted with a red circle), 'Sampling', 'Speed', 'Options', and 'Statistics'. The 'Trials' tab contains the following settings:

- 'Number of trials to run:' with a text box containing '10000'.
- A checked checkbox for 'Stop on calculation errors'.
- A checked checkbox for 'Stop when precision control limits are reached'.
- 'Confidence level:' with a text box containing '95' and a '%' symbol.

At the bottom are four buttons: 'OK', 'Cancel', 'Defaults...', and 'Help'.



Run Preferences

Trial**s** **Sampling** Speed Options Statistics

Random number generation

☐ Use same sequence of random numbers

Initial seed value:

Sampling method

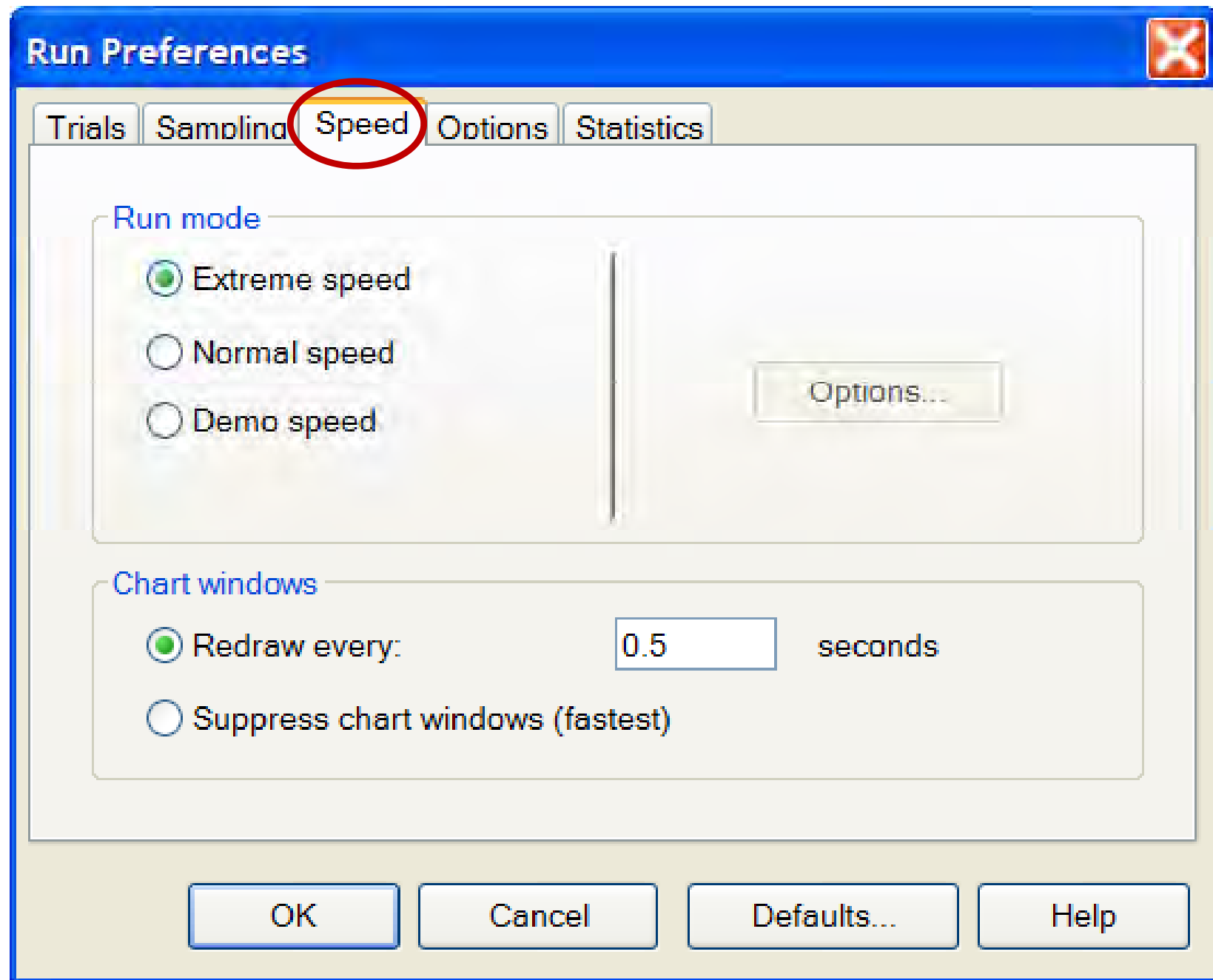
☒ Monte Carlo (more random)

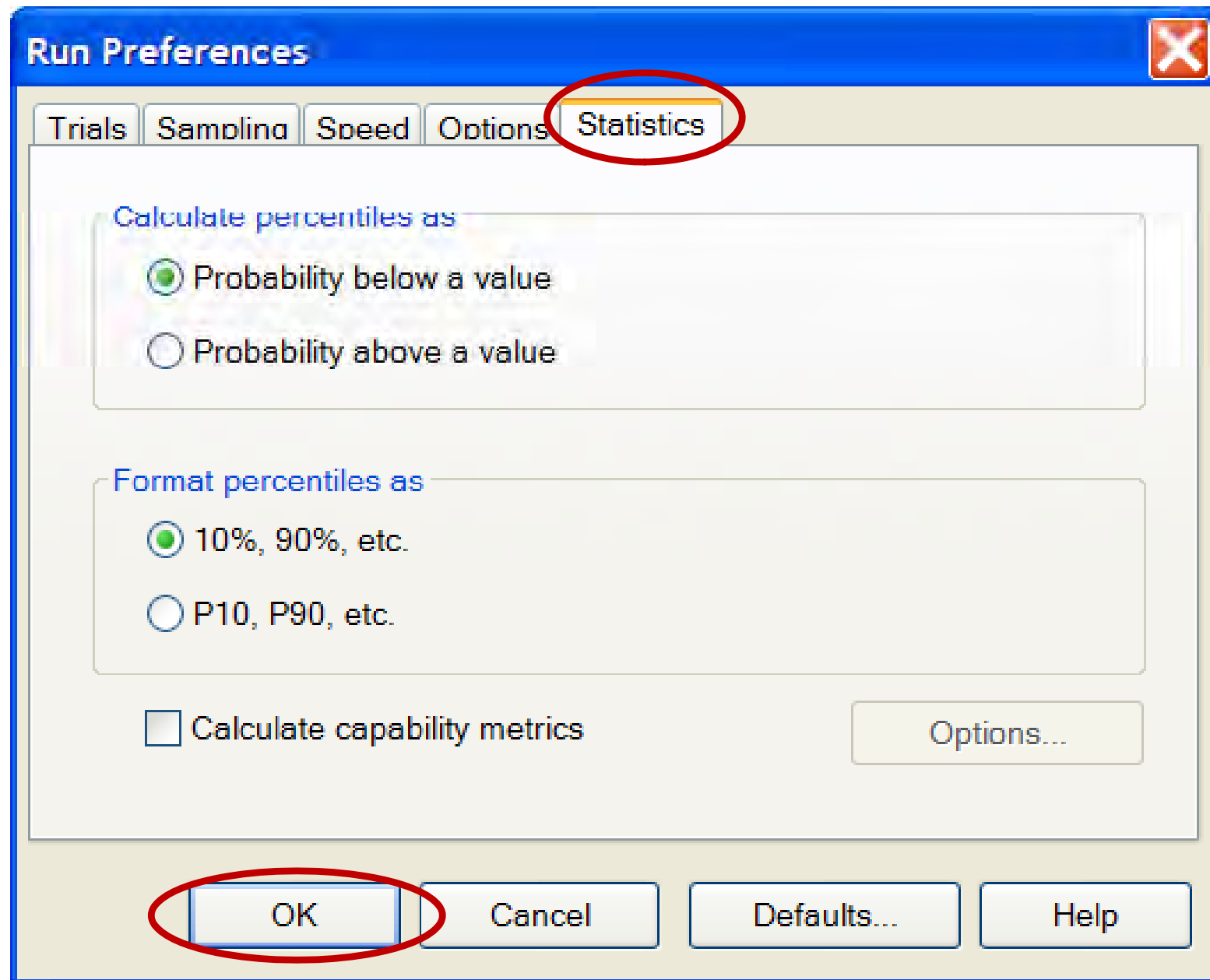
☐ Latin Hypercube (more even)

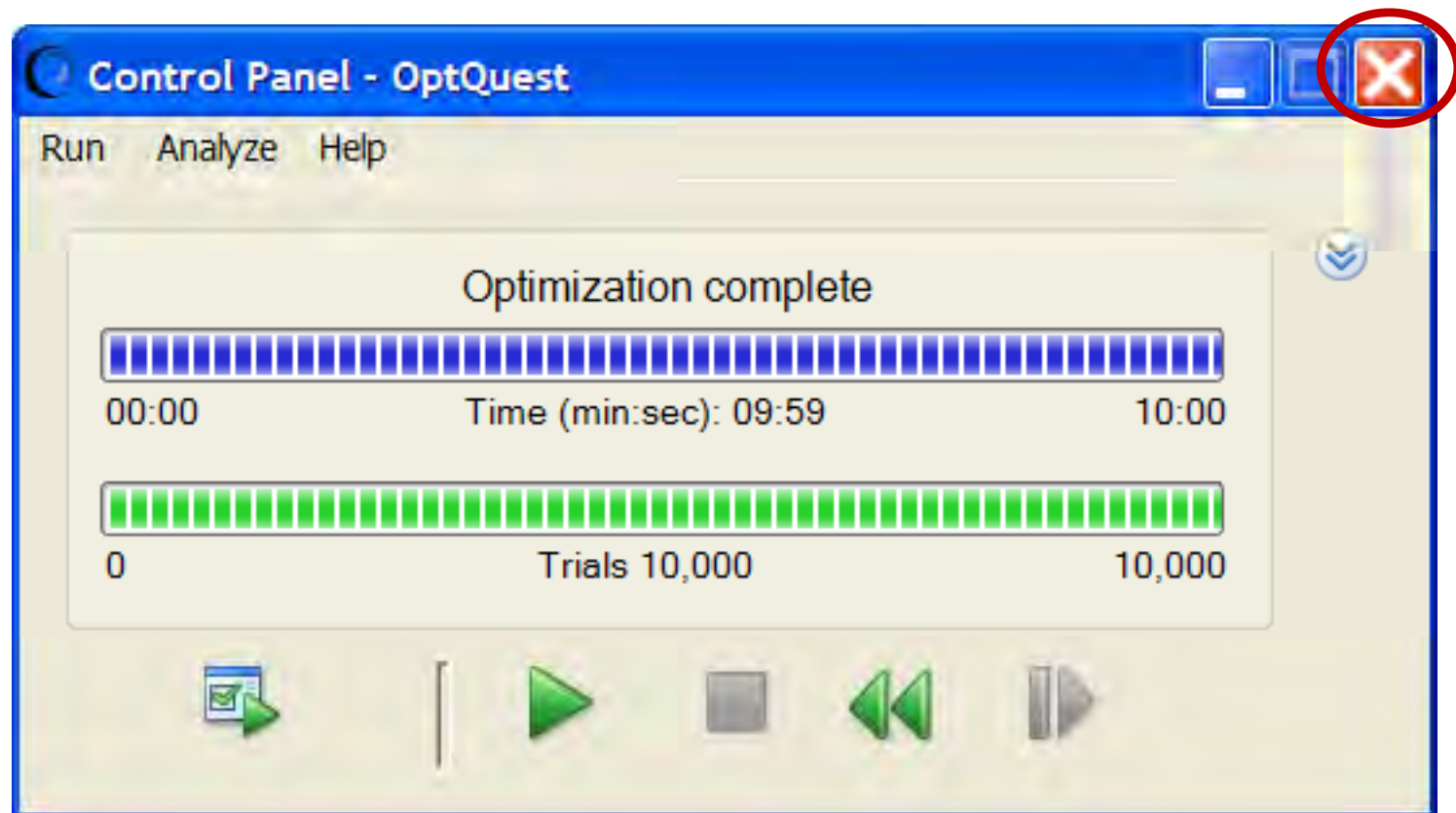
Sample size:

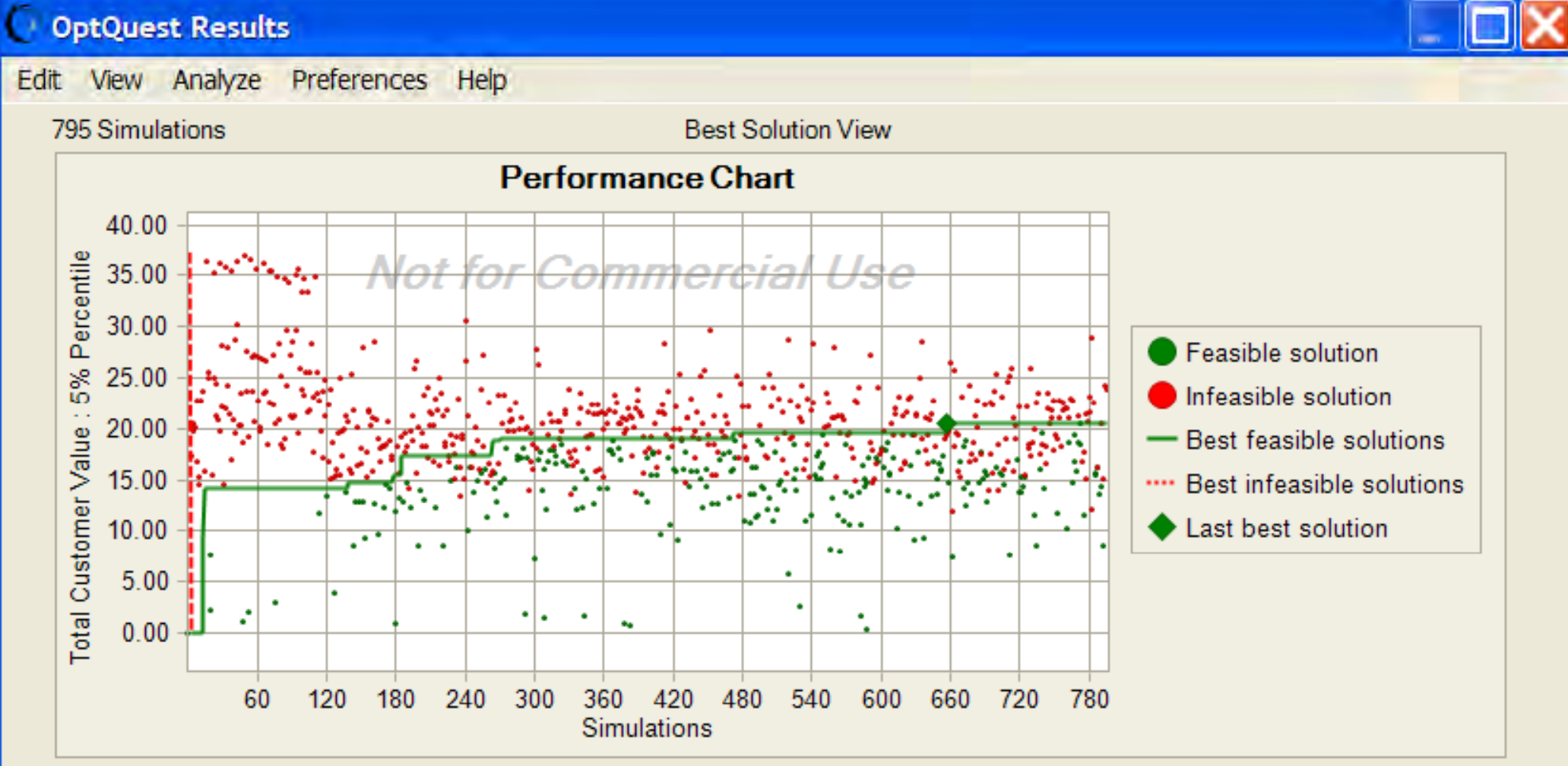
OK Cancel Defaults... Help











Best Solution:

Simulation # 656

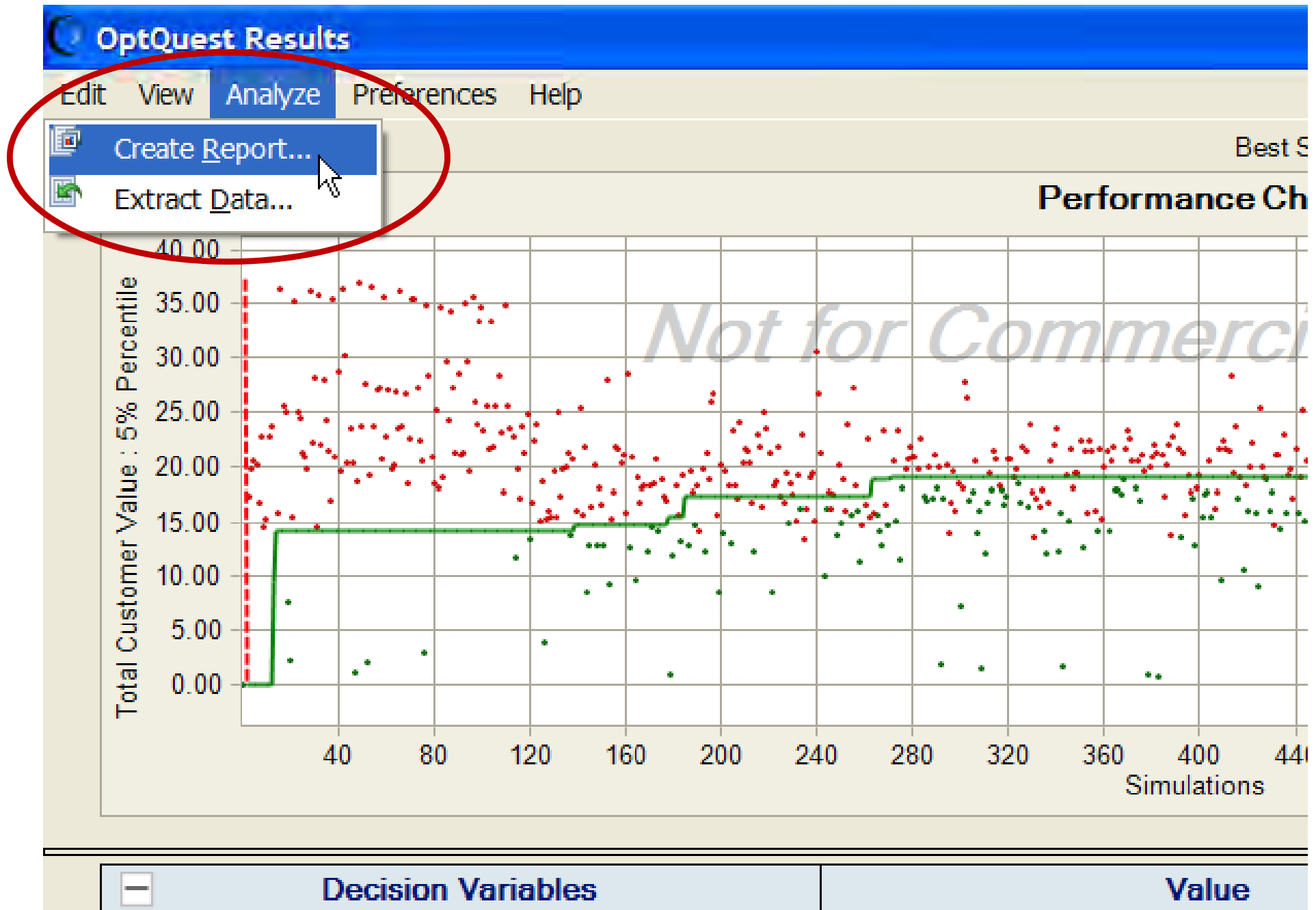
Objectives	Value
Maximize the 5% Percentile of Total Customer Value	20.54

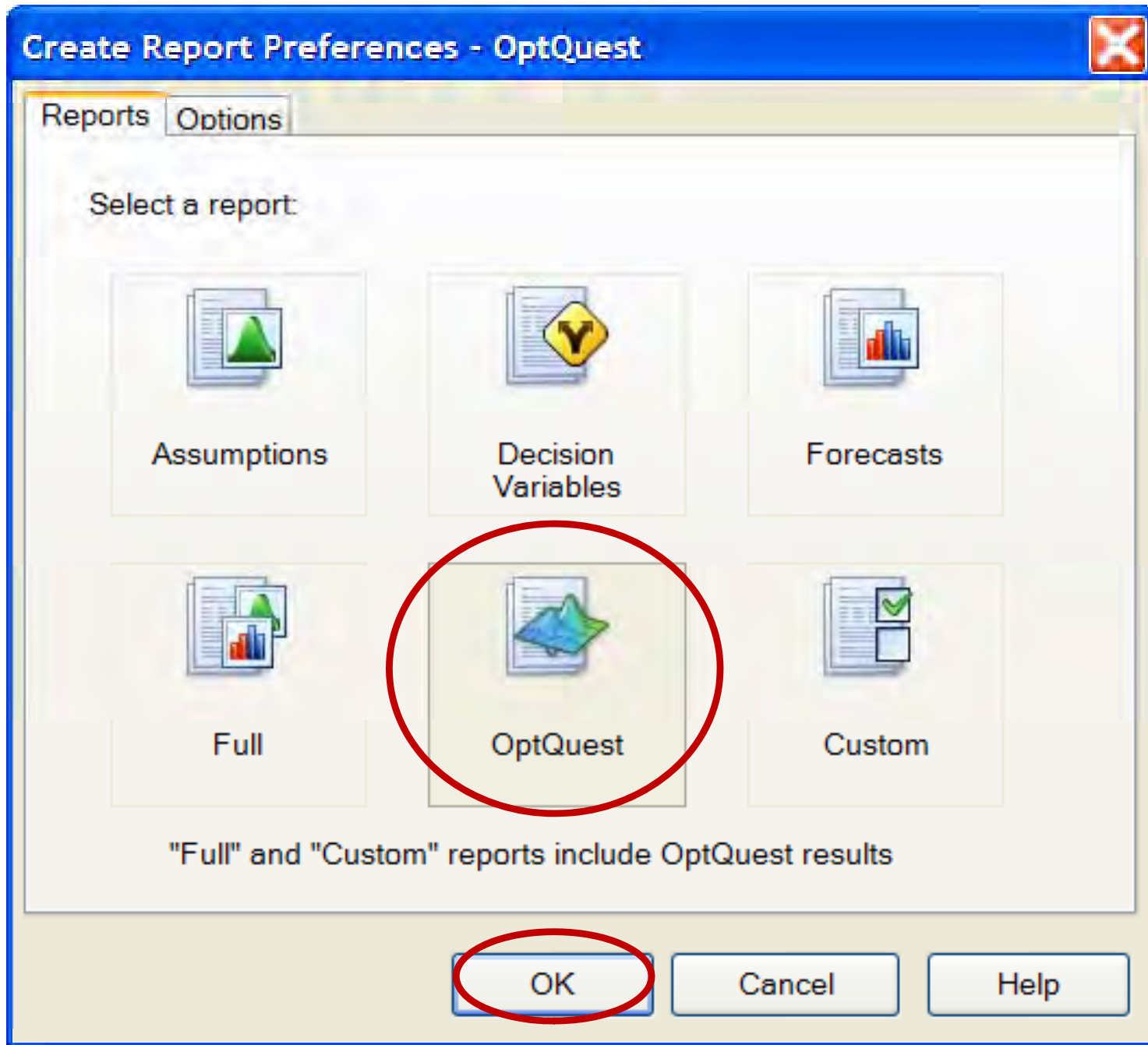
 Requirements	Value
The 95% Percentile of Total Senior Resource must b...	1.57
The 95% Percentile of Total Days must be less than ...	296.10
The 95% Percentile of Total Budget must be less tha...	\$359.952



 Decision Variables	Value
Feature 1 Decision	0.00
Feature 10 Decision ☒	1.00
Feature 11 Decision	0.00
Feature 12 Decision ☒	1.00
Feature 13 Decision ☒	1.00
Feature 14 Decision	0.00
Feature 15 Decision ☒	1.00
Feature 16 Decision ☒	1.00
Feature 17 Decision ☒	1.00
Feature 18 Decision	0.00
Feature 19 Decision ☒	1.00
Feature 2 Decision ☒	1.00
Feature 20 Decision ☒	1.00
Feature 3 Decision	0.00
Feature 4 Decision	0.00
Feature 5 Decision	0.00
Feature 6 Decision	0.00
Feature 7 Decision	0.00
Feature 8 Decision	0.00
Feature 9 Decision	0.00









Crystal Ball Report - OptQuest

Optimization started on 8/21/2009 at 9:20:35

Optimization stopped on 8/21/2009 at 9:30:36

Run preferences:

Stochastic optimization (with simulation)

Low-confidence testing on

Maximum trials per simulation 10,000

Monte Carlo

Random seed

Precision control on

Confidence level 95.00%

Run statistics:

Total optimization time (min:sec) 10:01

Number of simulations 795

Stopped by

Trials limit reached 406

Precision control 0

Low-confidence testing 389

Infeasible constraints 0

Simulation/second (average) 1

Other statistics:

Number of infeasible solutions 537

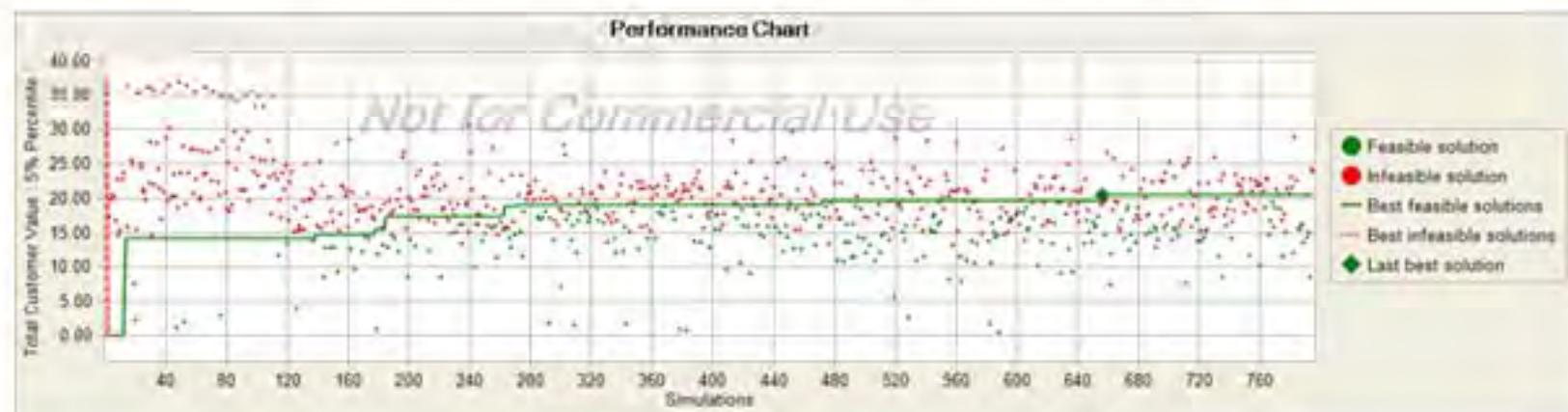
Due to requirements 537

Due to non-linear constraints 0



Summary:

After 795 solutions were evaluated in 10 minutes and 1 second,
the 5% Percentile of Total Customer Value was improved to 20.54



Objectives

Maximize the 5% Percentile of Total Customer Value

20.54

Cell: AG26

Best Solution:

Requirements

The 95% Percentile of Total Senior Resource must be less than 2.10

1.57

Cell: AC26

The 95% Percentile of Total Days must be less than 300.00

296.10

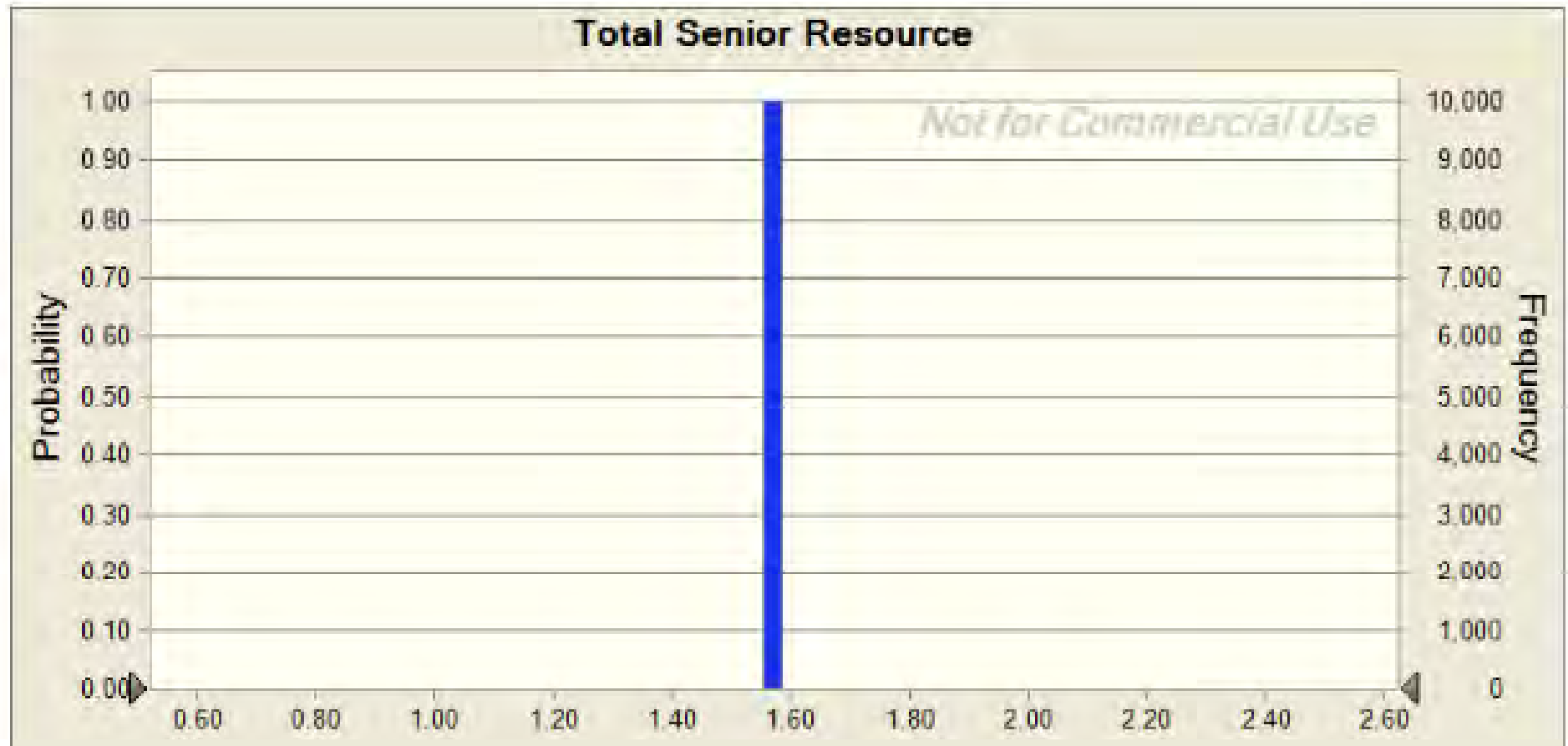
Cell: Y26

The 95% Percentile of Total Budget must be less than \$400.000

\$359.952

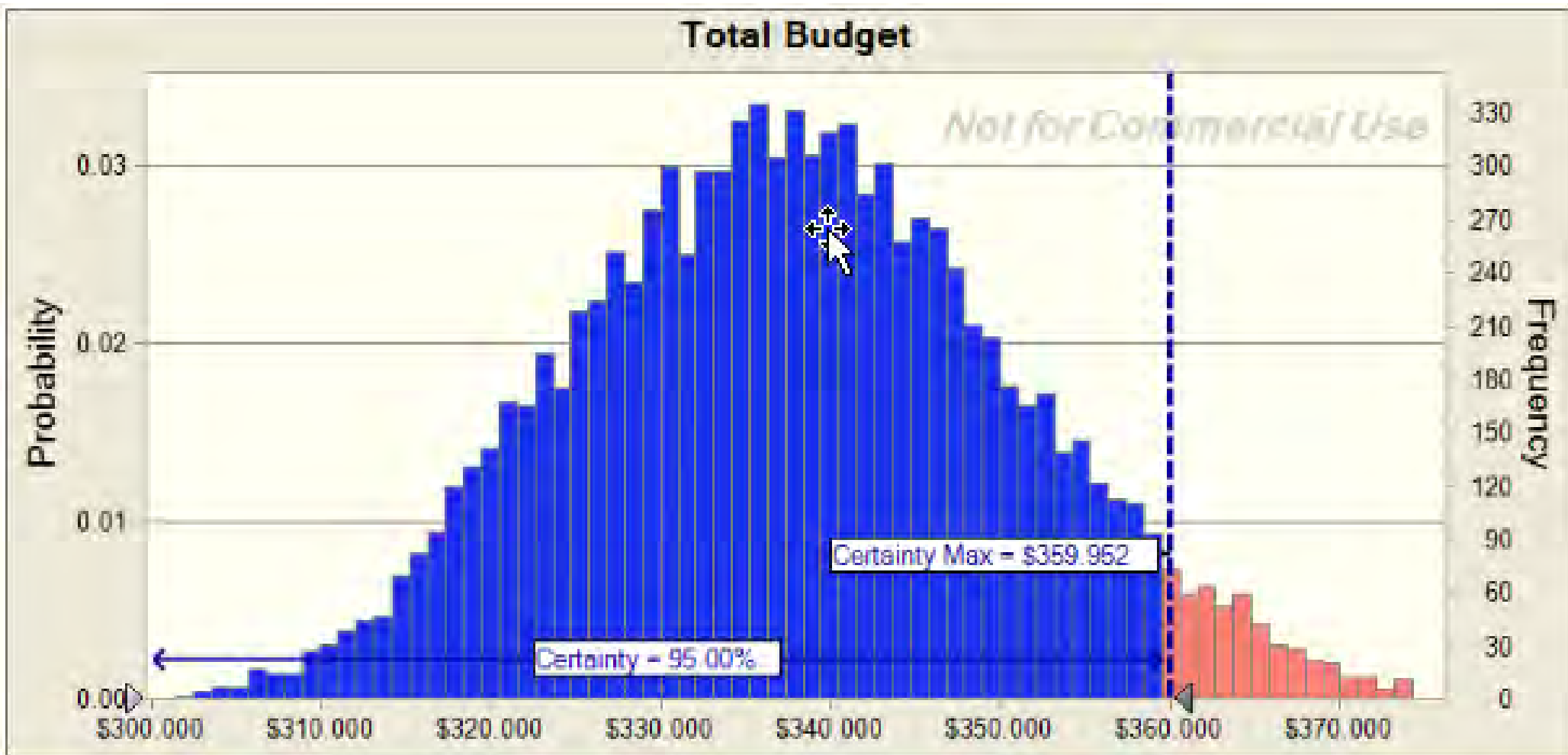
Cell: Q26

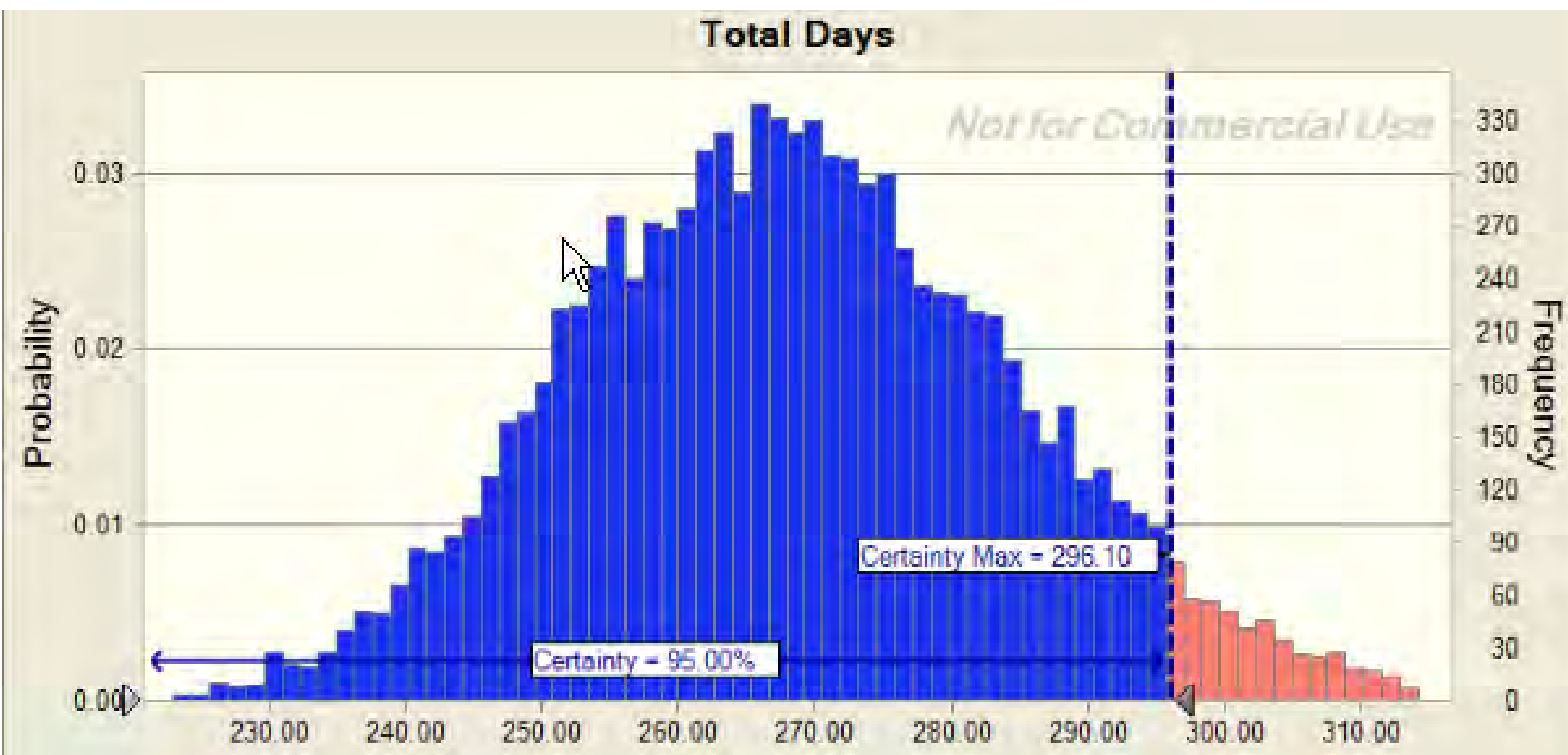


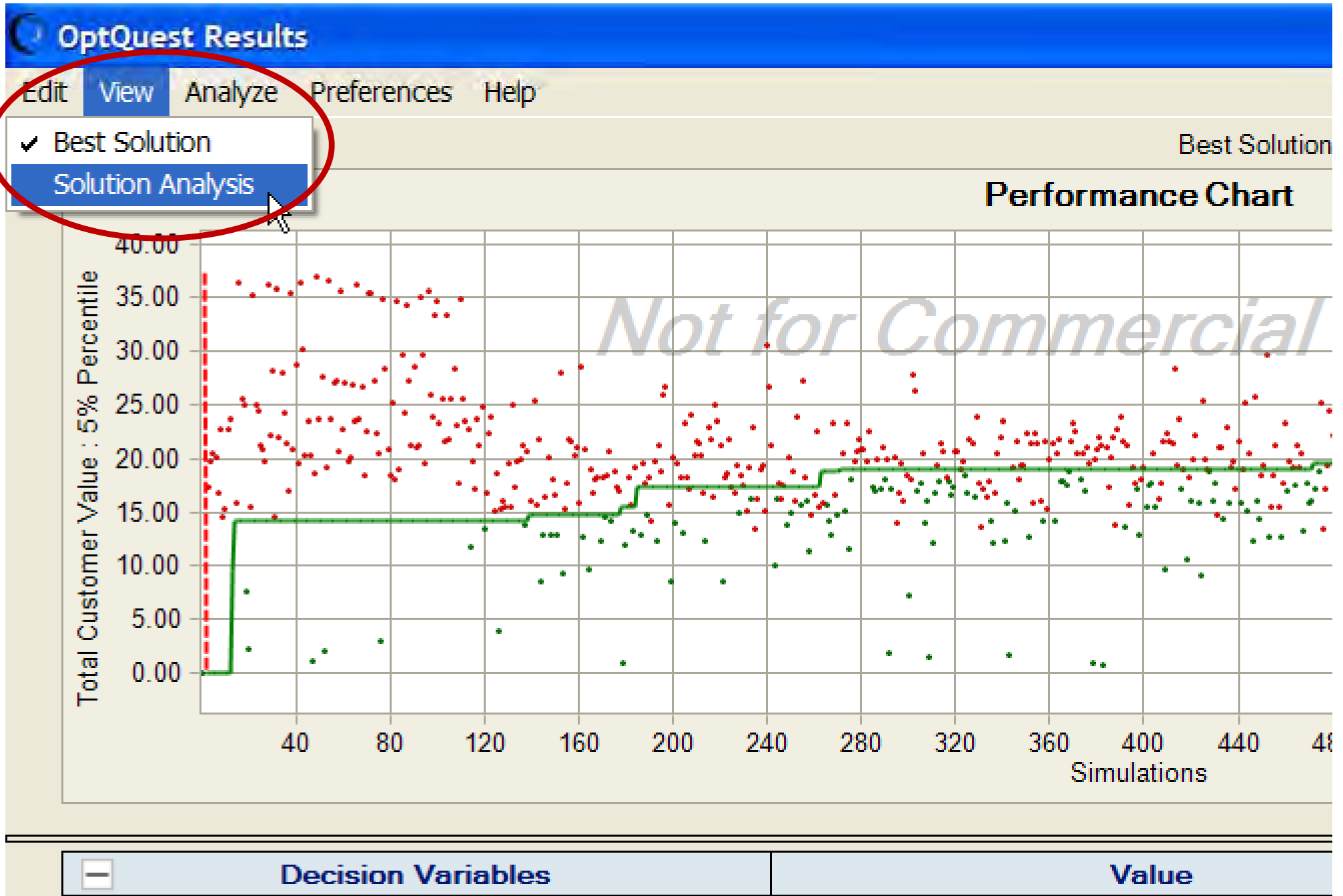
**Statistics:****Forecast values**

Trials	10,000
Mean	1.57
Median	1.57
Mode	1.57









795 Total Solutions

Solution Analysis View

258 Displayed

		Objective	Requirements			Decision Value
Rank	Solution #	Maximize 5% Percentile Total Customer Value	95% Percentile < 2.10 Total Senior Resource	95% Percentile < 300.00 Total Days	95% Percentile < \$400,000 Total Budget	Feature 1 Decision
1	656	20.54	1.57	296.10	\$359.952	0
2	772	20.51	1.23	289.29	\$371.264	0
3	489	19.64	1.65	295.60	\$329.433	0
4	740	19.64	1.48	296.89	\$286.605	0
5	472	19.59	1.57	287.43	\$325.140	1
6	627	19.39	1.65	293.52	\$299.642	0
7	768	19.36	1.48	283.53	\$345.677	0
8	549	19.31	1.19	282.13	\$292.331	0
9	284	19.09	1.70	294.06	\$286.844	1
10	271	19.04	1.36	283.31	\$316.881	0
11	673	18.91	0.83	279.33	\$369.156	0
12	368	18.89	1.82	286.77	\$291.631	0
13	428	18.84	1.06	272.43	\$316.042	1
14	494	18.84	1.40	270.26	\$301.929	0
15	263	18.79	1.55	296.84	\$293.061	1
16	474	18.79	1.67	297.46	\$328.196	1

Statistics: † - Low-confidence solution (values are approx.)

Minimum		0.00	0.00	0.00	\$0.000	0.00
Mean		13.98	1.06	238.17	\$248.456	0.35
Maximum		20.54	2.06	299.12	\$371.264	1.00
Std. Dev.		4.18	0.45	59.66	\$70.477	0.48

Show the best

- ☐ 15 solutions
☐ 10 % of solutions
☒ All feasible solutions (258)
☐ New best solutions (12)

Include

- ☒ Feasible solutions (258)
☐ Infeasible solutions (537)



Objectives

Best Solution:

Maximize the 5% Percentile of Total Customer Value

20.01

Cell: AG26



Requirements

The 95% Percentile of Total Senior Resource must be less than 1.00

0.41

Cell: AC26

The 95% Percentile of Total Days must be less than 300.00

293.86

Cell: Y26

The 95% Percentile of Total Budget must be less than \$400.000

\$351.343

Cell: O26



Decision variables

Feature 1 Decision	
Feature 10 Decision	☒
Feature 11 Decision	☒
Feature 12 Decision	
Feature 13 Decision	
Feature 14 Decision	
Feature 15 Decision	☒
Feature 16 Decision	
Feature 17 Decision	☒
Feature 18 Decision	☒
Feature 19 Decision	☒
Feature 2 Decision	☒
Feature 20 Decision	☒
Feature 3 Decision	
Feature 4 Decision	
Feature 5 Decision	
Feature 6 Decision	
Feature 7 Decision	
Feature 8 Decision	
Feature 9 Decision	☒

Best Solution:

0.00	Cell: A5
1.00	Cell: A14
1.00	Cell: A15
0.00	Cell: A16
0.00	Cell: A17
0.00	Cell: A18
1.00	Cell: A19
0.00	Cell: A20
1.00	Cell: A21
1.00	Cell: A22
1.00	Cell: A23
1.00	Cell: A6
1.00	Cell: A24
0.00	Cell: A7
0.00	Cell: A8
0.00	Cell: A9
0.00	Cell: A10
0.00	Cell: A11
0.00	Cell: A12
1.00	Cell: A13



PPM Exercise 2: Scheduling Projects with Monte Carlo Simulation and Optimization



Scheduling With Monte Carlo Optimization-v010.xls file

Example of Using Monte Carlo Simulation and Optimization to Make Decisions Regarding the Work Activities and Schedule for the Hospital Records Information System (HRIS)

(NOTE: The following choices are independent decisions)

Critical Path Tasks	Task Description	Choice One			Choice Two			Decision Variable for Choices	Value Used in Given Decision Scenario	Simulation Value Choice 1	Simulation Value Choice 2
		Minimum Days	Most Likely Days	Maximum Days	Minimum Days	Most Likely Days	Maximum Days				
1	Reqs Development	Traditional Spec Driven			Prototype with Customer First			1	0	0	0
		32	40	50	70	90	120				
2	Architecture/Design	All New Code			Major Reuse of Code			2	0	0	0
		55	70	90	8	10	15				
3	Code	All New Code			Major Reuse of Code			2	0	0	0
		43	50	62	17	20	28				
4	Unit/Integration Test	Informally Performed			Formally Performed			1	0	0	0
		100	110	125	140	150	185				
5	Acceptance Test	Only Choice						1	0	0	
		19	30	39							
Total Critical Path Days >>									0		



Scheduling with Monte Carlo Optimization-v010 - Microsoft Excel

Crystal Ball

OptQuest

Start Stop Reset Step Tools Save or Restore Run Preferences View Charts Create Report Extract Data Analyze

(NOTE: The following choices are based on the following assumptions: Choice One)

Minimum Days	Most Likely Days	Maximum Days	Minimum Days	Most Likely Days	Maximum Days	Simulation Variable for Choices	Value Used in Given Decision Scenario	Simulation Value Choice 1	Simulation Value Choice 2
Traditional Spec Driven			Prototype with Customer First						
32	40	50	70	90	120	1	0	0	0
All New Code			Major Reuse of Code						
55	70	90	8	10	15	2	0	0	0
All New Code			Major Reuse of Code						
43	50	62	17	20	28	2	0	0	0
Informally Performed			Formally Performed						
100	110	125	140	150	185	1	0	0	0

OptQuest
Search for and find optimal solutions to your simulation models.

Crystal Ball
Press F1 for more help.



OptQuest

Welcome

Objectives

Decision Variabl

Constraints

Options

Select an objective and optionally specify requirements

Primary workbook: Scheduling with Monte Carlo Optim

Objectives: ? Exclude

Minimize the 95% Percentile of TotalCriticalPathDays ☐

Requirements: ? Exclude

(optional requirements on forecasts) ☐

Hit the Add Objective button to enter the objective seen on this screen. Then hit the Next button.

Add Objective Add Requirement Efficient Frontier Import... Delete

< Back Next > Run Close Help



OptQuest

Welcome
Objectives
Decision Variables
Constraints
Options

Review decision variables and change properties as necessary

☐ Show cell locations

Decision Variables	Lower B...	Base Ca...	Upper B...	Type	St...	Fre...
ArchDesignChoice	1.00	0.00	2.00	Discrete	1.00	☐
CodeChoice	1.00	0.00	2.00	Discrete	1.00	☐
ReqtChoice	1.00	0.00	2.00	Discrete	1.00	☐
UnitITChoice	1.00	0.00	2.00	Discrete	1.00	☐

Enter 0 for each of the base case values. This is the starting point from which the optimization routine will begin. Then hit Next.

< Back **Next >** Run Close Help



OptQuest

Welcome
Objectives
Decision Variabl
Constraints
Options

Optionally, specify constraints on the decision variables

☐ Advanced entry

Constraints ?	Type	Exclude
> optional constraints on decision variables)		☐

Add Constraint Add Comment... Efficient Frontier Delete

< Back Next > Run Close Help



OptQuest

Welcome
Objectives
Decision Variabl
Constraints
Options

Choose your options and run the optimization

Optimization control

☐ Run for 100000 simulations

☒ Run for 10 minutes

Simulation: [Run Preferences...](#)

Type of optimization

☒ With simulation (stochastic)

☐ Without simulation (deterministic)

While running

☒ Show chart windows as defined

☐ Show only target forecast windows

☒ Update only for new best solutions

Decision variable cells

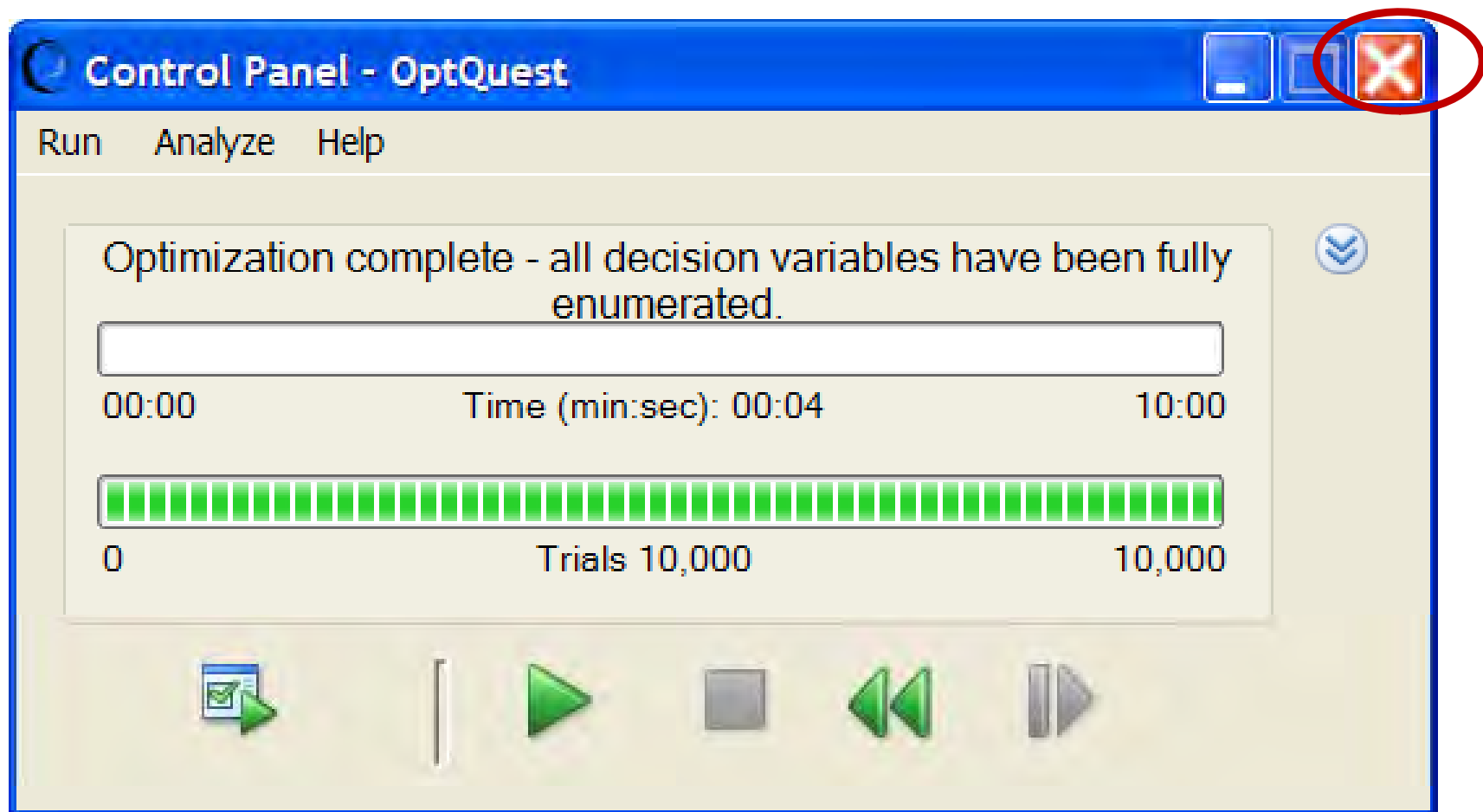
☐ Leave set to original values

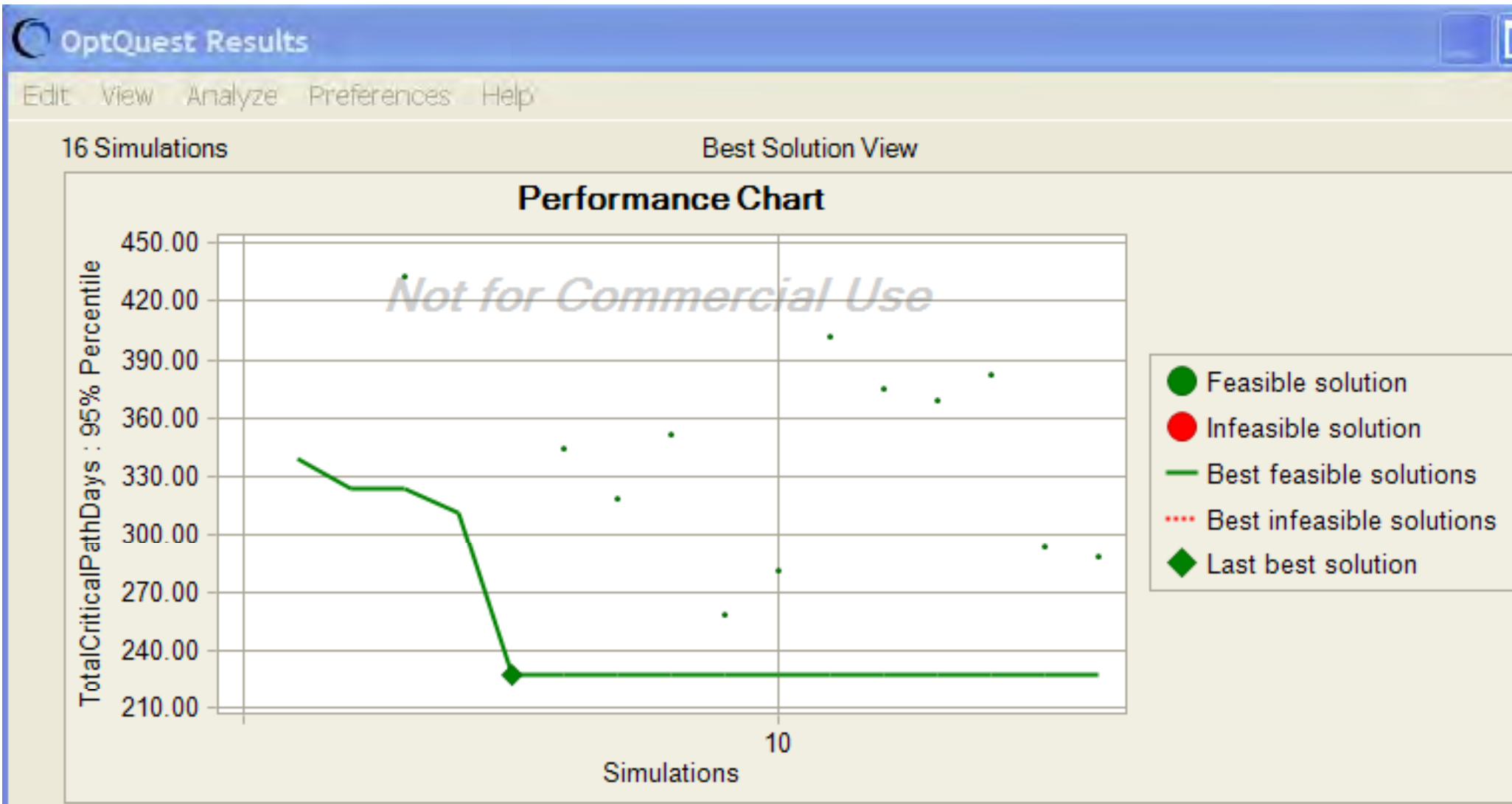
☒ Automatically set to best solution

[Advanced Options...](#)

[< Back](#) [Next >](#) [Run](#) [Close](#) [Help](#)







Best Solution:

Simulation # 5

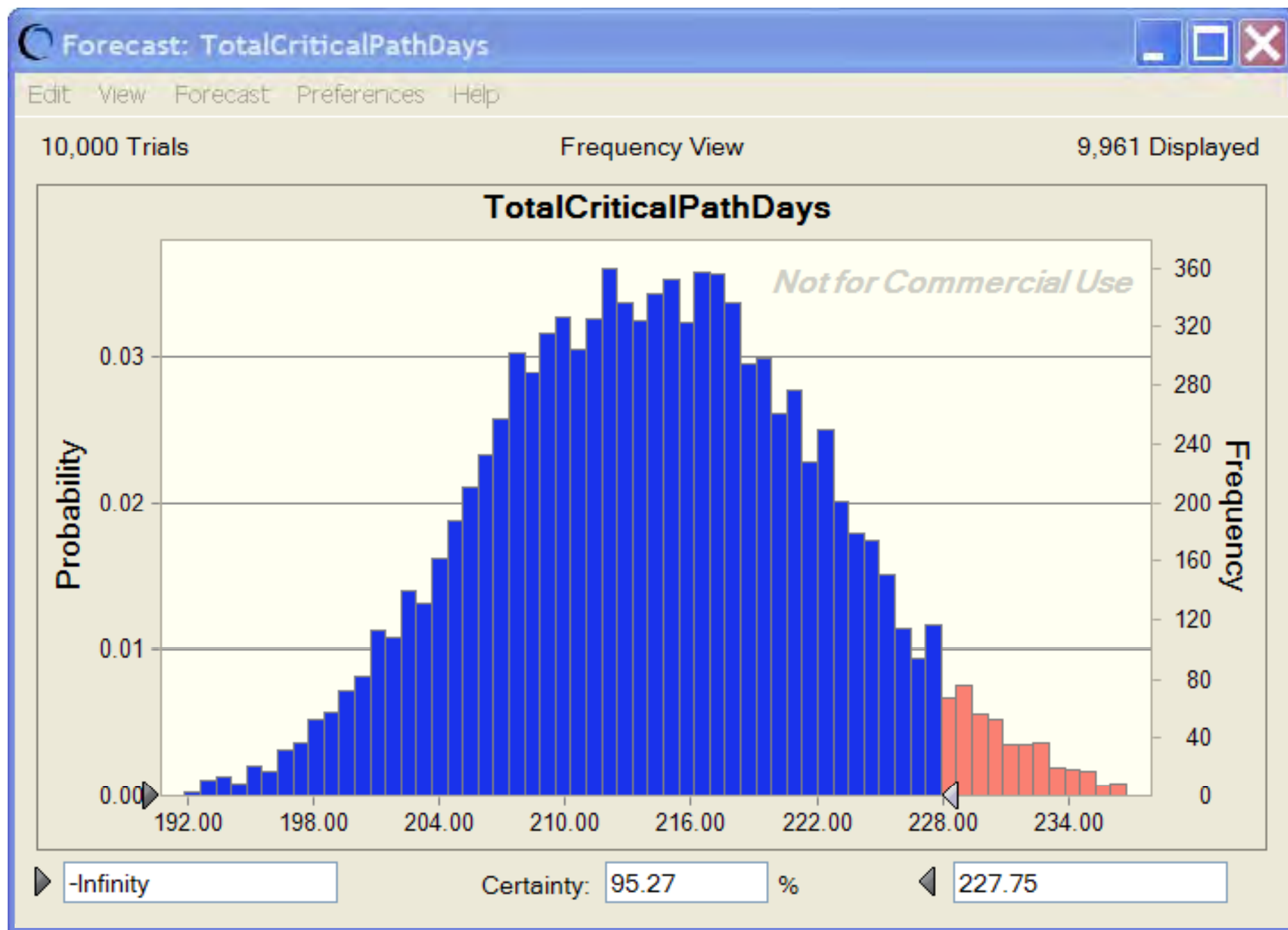
Objectives	Value
Minimize the 95% Percentile of TotalCriticalPathDays	227.59

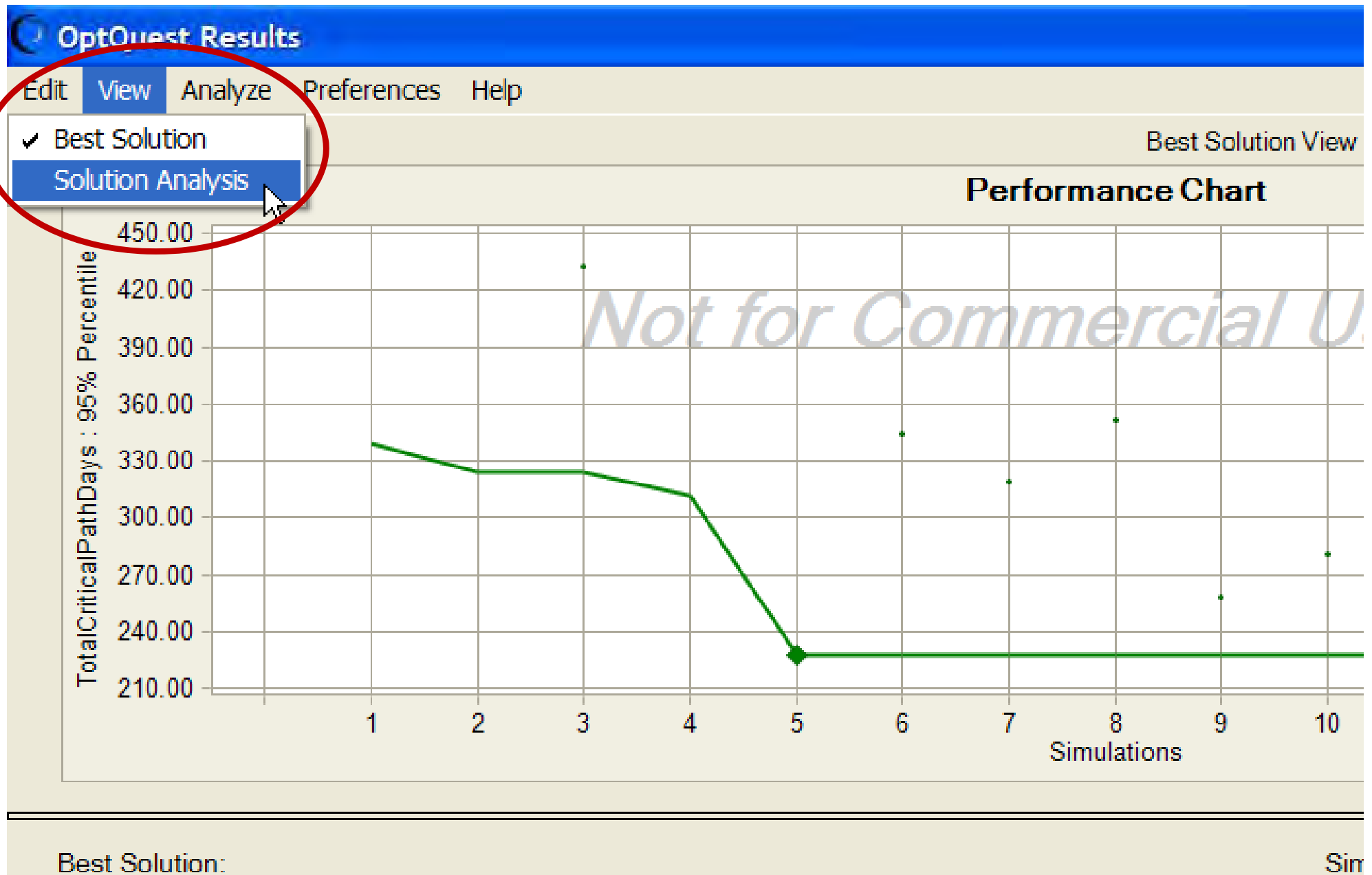
Requirements	Value
--------------	-------

Constraints	Left Side		Right Side
-------------	-----------	--	------------

 Decision Variables	Value
ArchDesignChoice	2.00
CodeChoice	2.00
ReqsChoice	1.00
UnitITChoice	1.00







16 Total Solutions

Solution Analysis View

		Objective	Decision Variables			
Rank ▲	Solution #	Minimize 95% Percentile TotalCriticalPathDays	ArchDesignChoice	CodeChoice	ReqsChoice	UnitITChoice
1	5	227.59	2.00	2.00	1.00	1.00
2	9	258.40	2.00	1.00	1.00	1.00
3	10	280.93	2.00	2.00	1.00	2.00
4	16	288.51	2.00	2.00	2.00	1.00
5	15	293.13	1.00	2.00	1.00	1.00
6	4	311.57	2.00	1.00	1.00	2.00
7	7	318.81	2.00	1.00	2.00	1.00
8	2	323.84	1.00	1.00	1.00	1.00
9	1	339.05	2.00	2.00	2.00	2.00
10	6	344.50	1.00	2.00	1.00	2.00
11	8	352.16	1.00	2.00	2.00	1.00
12	13	369.57	2.00	1.00	2.00	2.00
13	12	374.86	1.00	1.00	1.00	2.00
14	14	382.32	1.00	1.00	2.00	1.00
15	11	402.05	1.00	2.00	2.00	2.00
16	3	432.65	1.00	1.00	2.00	2.00



PPM Exercise 3: Predicting Product Requirements Change with Linear Regression



Statistical Regression Landscape

The purpose of regression is to perform the basic task of ANOVA by determining whether there is significant prediction of dependent (y) variable(s) using knowledge of independent (x) variable(s).

- **Example:** Can the defects by release (y) be predicted using knowledge of one or more independent variables (x)s?
- **Some types of regression** (all y's & x's continuous unless noted as discrete):

Simple linear	1 "y" & 1 "x"
Multiple linear	1 "y" & multiple "x"s
Multivariate	multiple "y"s & 1+ "x"
Nonlinear	nonlinear version of the above types
Logistic	1 discrete "y" & 1+ "x"s



p value Summary

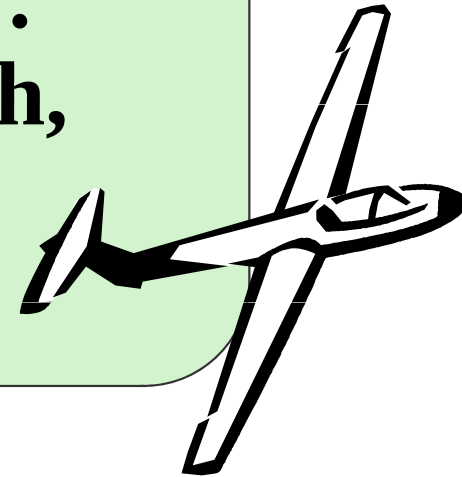
Method	Null	Alternative	$P < 0.05$	$P > 0.05$
Hypothesis Tests	No difference exists; no associations	Two items are different; association exists	Accept alternative	Accept null
Tests for Normality	Data follows Normal Distribution	Data does not follow Normal Distribution	Accept alternative	Accept null
ANOVA	No difference of Y across levels of x	Difference of Y exists between 1+ levels of x	Accept alternative	Accept null
Regression	x factor does not add value to model	X factor adds value to model	Accept alternative	Accept null
Chi-Square	Two discrete variables are not associated	Two discrete variables are associated	Accept alternative	Accept null
Logistic Regression	x factor does not add value; model has no significant x's	X factor adds value to model; model has 1+ significant x's	Accept alternative	Accept null



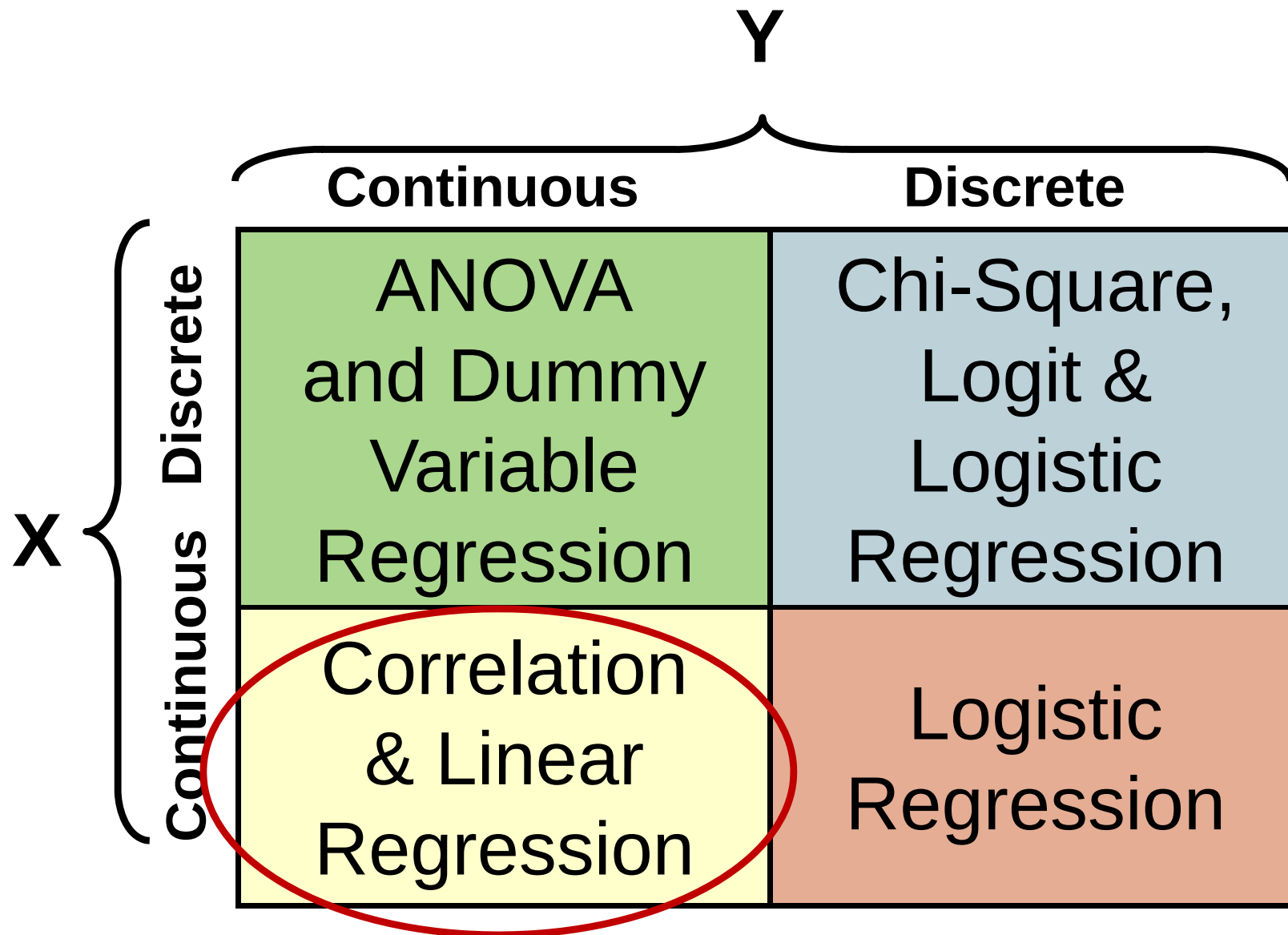
Slogan to Remember p Interpretation



**“When the p is low,
the null must go...
When the p is high,
the null must fly”**



Statistical Regression Analysis



Open the ReqtsChangeLinearRegression.jmp file

	ExpectedReqtChanges	CustomerRelationshipAge	ReadingLevel	AgeOfReqt	ReqtAnalystExperience	TimeSinceCustStaffChange
1	0.56	31.65	7.29	9.23	48.55	8.36
2	0.45	26.34	6.76	8.77	55.68	7.4
3	0.76	11.78	8.68	7.85	46	8.29
4	0.57	44.99	7.73	9.21	47.29	7.94
5	0.9	37.07	9.39	8.45	45.4	7.74
6	0.81	22.81	8.64	8.38	43.48	7.54
7	0.65	32.65	8.8	9.23	46.12	8.45
8	1.01	2.79	9.72	10.04	43.76	6.75
9	0.88	15.25	9.47	9.5	46.32	8.1
10	0.55	31.22	6.5	8.77	44.72	7.43
11	0.85	26.19	8.77	9.25	57.85	8.25
12	0.78	18.77	8.56	10.2	47	8.54
13	0.79	31.5	8.05	11.29	51.52	6.88
14	1.09	11.21	9.58	8.9	47.65	7.1
15	0.69	48.57	7.85	9.56	51.15	7.91
16	1.13	48.99	11.45	13.2	44.78	7.59
17	0.76	28.75	8.56	7.98	46.34	7.2
18	0.86	39.62	8.92	13.11	43.24	7.88
19	0.79	22.55	8.67	11.76	41.81	7.09
20	0.66	19.34	7.94	11.57	53.48	8.14
21	0.71	48.31	8.35	9.65	46.11	8.85
22	0.77	17.15	8.75	8.25	53.25	7.62



Factor	Role	Data Type	Description
ExpectedReqtChanges	Y Outcome	Continuous	The number of expected changes that will occur during product development with a given product requirement
CustomerRelationshipAge	X1 Factor	Continuous	At the time of requirement formulation, the age in months of the relationship with the customer of the product development
ReadingLevel	X2 Factor	Continuous	The reading level (grade level) computed for the requirement statement (sentence or paragraph)
AgeOfReqt	X3 Factor	Continuous	The age in months of the product requirement at the point the requirement is identified for this product
ReqtAnalystExperience	X4 Factor	Continuous	The experience level in months of the Requirements Analyst
TimeSinceCustStaffChange	X5 Factor	Continuous	At the time of requirement formulation, the number of months since the last customer staff change



The screenshot shows the JMP software interface. The title bar reads "JMP - [ReqtChangeLinearRegression]". The menu bar includes File, Edit, Tables, Rows, Cols, DOE, Analyze, Graph, Tools, View, and Window. The "Analyze" menu is open, showing options: Distribution, Fit Y by X, Matched Pairs, Fit Model (highlighted with a mouse cursor), Modeling, Multivariate Methods, and Reliability and Survival. The background displays a data table with columns "ExpectedReqtChanges" and "CustomerRelationshipAge".

	ExpectedReqtChanges	CustomerRelationshipAge
1	0.56	
2	0.45	
3	0.76	
4	0.57	
5	0.9	
6	0.81	
7	0.65	
8	1.01	
9	0.88	
10	0.55	
11	0.85	



Fit Model

Model Specification

Select Columns

- ExpectedReqtCh
- CustomerRelatio
- ReadingLevel
- AgeOfReqt
- ReqtAnalystExpe
- TimeSinceCustS

Pick Role Variables

ExpectedReqtCl
optional

optional numeric

optional numeric

optional

Personality: Standard Least Squares ▾

Emphasis: Effect Leverage ▾

Construct Model Effects

Macros ▾

Degree

Attributes ☒

Transform ☒

☐ No Intercept

CustomerRelationshipAge
ReadingLevel
AgeOfReqt
ReqtAnalystExperience
TimeSinceCustStaffChange



Summary of Fit

RSquare	0.903713
RSquare Adj	0.902491
Root Mean Square Error	0.003318
Mean of Response	0.844075
Observations (or Sum Wgts)	400

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	14.825457	2.96509	739.5833
Error	394	1.579600	0.00401	Prob > F
C. Total	399	16.405058		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	0.0811043	0.064497	1.26	0.2093
CustomerRelationshipAge	-0.000144	0.000262	-0.55	0.5833
ReadingLevel	0.1574728	0.002647	59.49	<.0001*
AgeOfReq	0.0004456	0.001195	0.37	0.7094
ReqAnalystExperience	-0.003763	0.000862	-4.37	<.0001*
TimeSinceCustStaffChange	-0.058817	0.005759	-10.21	<.0001*



Fit Model

Model Specification

Select Columns

- ExpectedReqtCh
- CustomerRelatio
- ReadingLevel
- AgeOfReqt
- ReqtAnalystExpe
- TimeSinceCustS

Pick Role Variables

Y: ExpectedReqtCl
optional

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help Run Model

Recall

Remove

Construct Model Effects

Add

Cross

Nest

Macros

Degree 2

Attributes

Transform

No Intercept

CustomerRelationshipAge

ReadingLevel

AgeOfReqt

ReqtAnalystExperience

TimeSinceCustStaffChange



Fit Model

Model Specification

Select Columns

- ExpectedReqtCh
- CustomerRelatio
- ReadingLevel
- AgeOfReqt
- ReqtAnalystExpe
- TimeSinceCustS

Pick Role Variables

Y: ExpectedReqtCh *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help Run Model Recall Remove

Construct Model Effects

Add Cross Nest Macros

CustomerRelationshipAge
ReadingLevel
ReqtAnalystExperience
TimeSinceCustStaffChange

Degree 2

Attributes ☒

Transform ☒

☐ No Intercept



Summary of Fit

RSquare	0.903679
RSquare Adj	0.902703
Root Mean Square Error	0.063249
Mean of Response	0.844075
Observations (or Sum Wgts)	400

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	14.824900	3.70623	926.4638
Error	395	1.580158	0.00400	Prob > F
C. Total	399	16.405058		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	0.0835877	0.064082	1.30	0.1929
CustomerRelationshipAge	-0.000137	0.000261	-0.53	0.5998
ReadingLevel	0.1575641	0.002633	59.85	<.0001*
ReqtAnalystExperience	-0.003748	0.00086	-4.36	<.0001*
TimeSinceCustStaffChange	-0.058785	0.005752	-10.22	<.0001*



Fit Model

Model Specification

Select Columns

- ExpectedReqtCh
- CustomerRelatio
- ReadingLevel
- AgeOfReqt
- ReqtAnalystExpe
- TimeSinceCustS

Pick Role Variables

Y: ExpectedReqtCl
optional

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help Run Model

Recall

Remove

Construct Model Effects

Add

Cross

Nest

Macros

Degree 2

Attributes

Transform

No Intercept

CustomerRelationshipAge

ReadingLevel

ReqtAnalystExperience

TimeSinceCustStaffChange



Fit Model

Model Specification

Select Columns

- ExpectedReqtCr
- CustomerRelatio
- ReadingLevel
- AgeOfReqt
- ReqtAnalystExpe
- TimeSinceCustS

Pick Role Variables

Y: ExpectedReqtCl *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help

Run Model

Recall

Remove

Construct Model Effects

Add

Cross

Nest

Macros

Degree: 2

Attributes

Transform

No Intercept

ReadingLevel
ReqtAnalystExperience
TimeSinceCustStaffChange



Summary of Fit

RSquare	0.903611
RSquare Adj	0.902881
Root Mean Square Error	0.063191
Mean of Response	0.844075
Observations (or Sum Wgts)	400

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	14.823797	4.94127	1237.457
Error	396	1.581261	0.00399	Prob > F
C. Total	399	16.405058		<.0001*

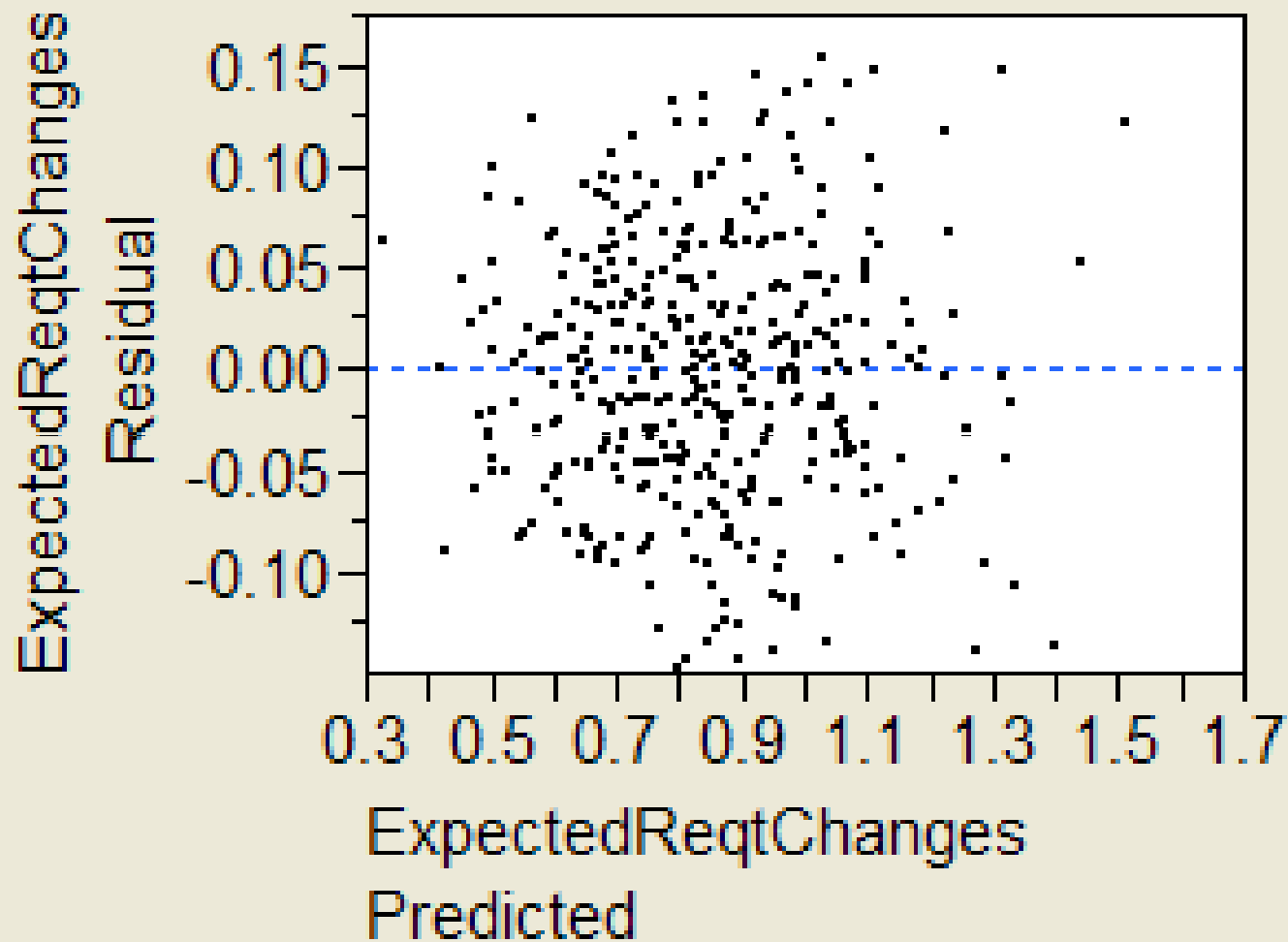
Parameter Estimates

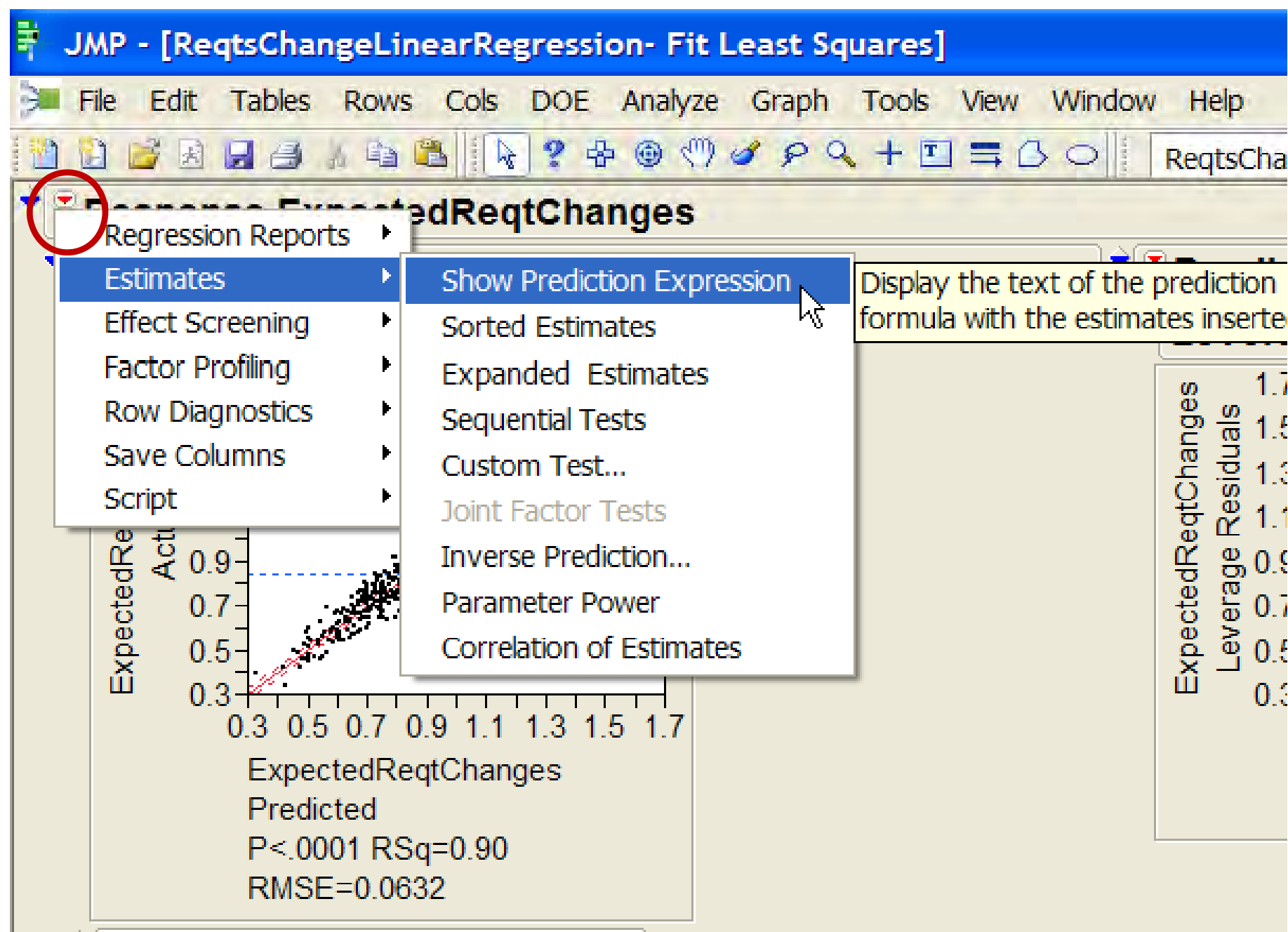
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	0.079986	0.063656	1.26	0.2097
ReadingLevel	0.1576274	0.002628	59.99	<.0001*
ReqtAnalystExperience	-0.003749	0.000859	-4.36	<.0001*
TimeSinceCustStaffChange	-0.058869	0.005745	-10.25	<.0001*





Residual by Predicted Plot

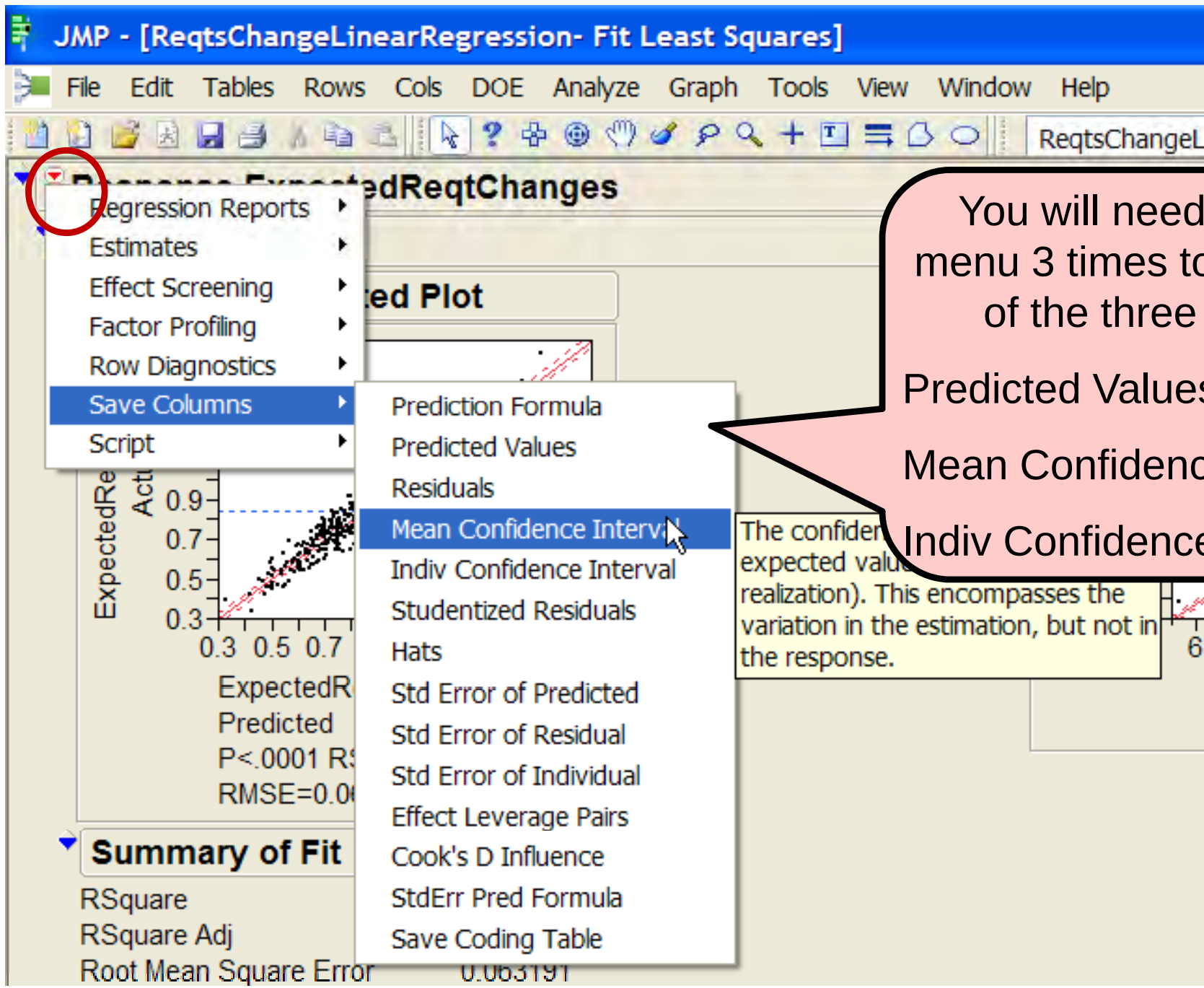




▼ Prediction Expression

```
0.079986016248  
+ 0.15762743466752 * ReadingLevel  
+ -0.0037486144177  
+ * ReqtAnalystExperience  
+ -0.0588691875889  
+ * TimeSinceCustStaffChange
```





	Predicted ExpectedReqtChan...	Lower 95% Mean ExpectedReqtChanges	Upper 95% Mean ExpectedReqtChanges	Lower 95% Indiv ExpectedReqtChanges	Upper 95% Indiv ExpectedReqtChanges
1	0.55494838	0.54354212	0.56635463	0.43019439	0.67970237
2	0.50119264	0.48071519	0.52167008	0.37528481	0.62710046
3	0.78773032	0.77996762	0.79549302	0.66325657	0.91220407
4	0.65375276	0.64466949	0.66283604	0.52918968	0.77831584
5	0.93427302	0.92589222	0.94265383	0.80975919	1.05878685
6	0.83502362	0.82398931	0.84605794	0.71030309	0.95974416
7	0.79677671	0.78830532	0.8052481	0.67225675	0.92129667
8	1.0507183	1.0333979	1.06803869	0.92528524	1.17615135
9	0.92224158	0.91497575	0.92950742	0.79779783	1.04668534
10	0.49952824	0.48310202	0.51595446	0.37421553	0.62484096
11	0.75985048	0.74183342	0.77786753	0.63431933	0.88538163
12	0.75034912	0.7414727	0.75922554	0.62580095	0.87489729
13	0.75073824	0.7338668	0.76760968	0.62536639	0.87611009
14	0.99346413	0.98080803	1.00612023	0.86858966	1.1183386
15	0.65996448	0.64952963	0.67039932	0.53529555	0.78463341
16	1.27014006	1.25421652	1.28606359	1.14489224	1.39538787
17	0.83170791	0.82004771	0.84336812	0.70693045	0.95648538
18	0.86004345	0.84999154	0.87009535	0.73540599	0.98468091
19	0.87250377	0.85688522	0.88812231	0.74729436	0.99771317
20	0.65187676	0.6392197	0.66453382	0.5270022	0.77675133
21	0.70233417	0.69025672	0.71441163	0.57751703	0.82715132
22	0.81102914	0.7987054	0.82335289	0.68618792	0.93587036



PPM Exercise 4: Predicting Delivered Defects with Dummy Variable Regression

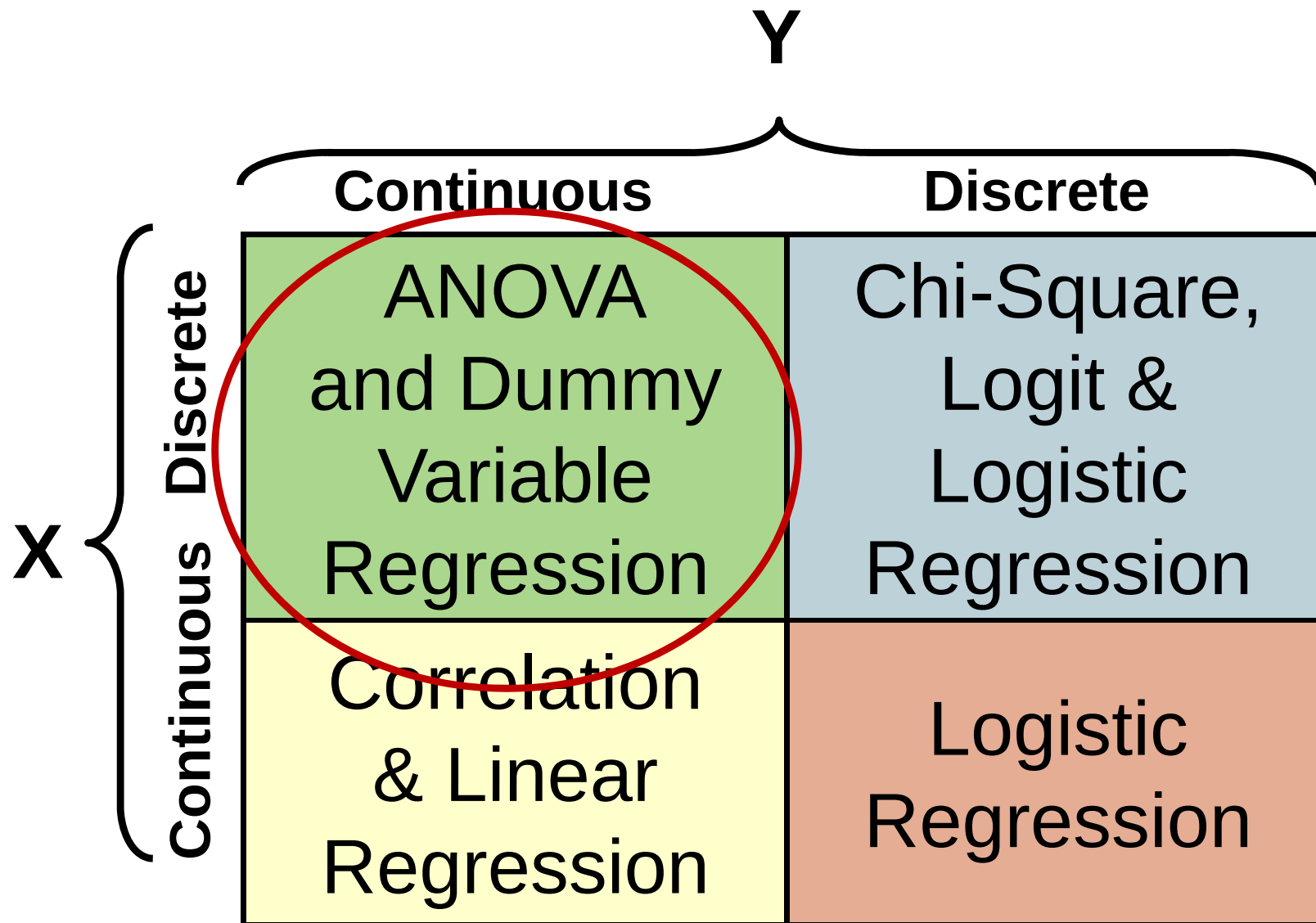


Dummy Variable Regression

The purpose of Dummy Variable Regression is to predict a continuous Y outcome using a combination of continuous and discrete x factors.



Statistical Regression Analysis



Open the DeliveredDefectsDummyVariableRegression.jmp file

DeliveredDefects	InspectionDefects	InspectionCoverage	InspectionTeamExperience	PercentNewCode	InspectionType	UnitTestType
0.52	7.21	81.46	52.55	75.18	0	0
0.56	6.95	81.77	46.76	76.68	0	0
0.58	9.69	81.94	48.12	77.43	0	0
0.32	7.27	90.75	36.93	75.45	1	0
0.6	6.1	74.11	36.5	77.59	0	0
0.54	6.53	76.42	45.37	78	0	0
0.41	5.72	79.52	31.42	78.35	0	1
0.45	6.94	88.68	48.64	81.13	0	0
0.59	6.54	70.69	27.42	76.8	0	0
0.6	6.3	78.14	22.48	75.93	0	0
0.55	6.52	76.01	33.9	82.39	0	0
0.6	9.67	77	49.69	80.04	0	0
0.66	6.54	65.28	45.86	76.84	1	0
0.6	8.45	79.48	40.3	80.81	0	0
0.53	5.77	77.15	38.23	78.51	0	0
0.52	5.77	78.98	39.47	79.84	0	0
0.55	5.68	73.57	29.03	80.74	0	0
0.41	8.57	80.08	24.82	76.55	0	1
0.45	8.99	85.46	34.95	80.09	0	1
0.55	6.38	76.66	27.05	82.46	0	0
0.43	5.83	80.14	33.77	78.74	1	1



Factor	Role	Data Type	Description
DeliveredDefects	Y Outcome	Continuous	Delivered Defect Density normalized to KSLOC for a given feature
InspectionDefects	X1 Factor	Continuous	Inspection Defect Density normalized to KSLOC for a given feature
InspectionCoverage	X2 Factor	Continuous	The percentage of inspection criteria implemented across the code files for a given feature
InspectionTeamExperience	X3 Factor	Continuous	The average domain experience in months of the participants of the peer review of the feature
PercentNewCode	X4 Factor	Continuous	The percent of new code within the feature
InspectionType	X5 Factor	Nominal	A factor which reflects whether an informal peer review (0) vs a formal inspection (1) occurred for the feature
UnitTestType	X6 Factor	Nominal	A factor which reflects whether informal unit testing (0) vs formal unit testing (1) occurred for the feature



JMP - DeliveredDefectsDummyVariableRegression

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window H

DeliveredD

DeliveredDefe

Distribution
Fit Y by X
Matched Pairs
Fit Model
Modeling
Multivariate Methods
Reliability and Survival

Defects	InspectionDefects	Inspe
0.52	7.21	
0.56	6.95	
0.58	9.69	
0.32	7.27	
0.6	6.1	
0.54	6.53	
0.41	5.72	
0.45	6.94	
0.59	6.54	



Fit Model

Model Specification

Select Columns

- DeliveredDefects
- InspectionDefect
- InspectionCovera
- InspectionTeamE
- PercentNewCode
- InspectionType
- UnitTestType

Pick Role Variables

Y: DeliveredDefect *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help

Run Model

Recall

Remove

Construct Model Effects

Add

Cross

Nest

Macros

Degree: 2

Attributes

Transform

☐ No Intercept

InspectionDefects
InspectionCoverage
InspectionTeamExperience
PercentNewCode
InspectionType
UnitTestType



Summary of Fit

RSquare	0.846337
RSquare Adj	0.844753
Root Mean Square Error	0.033605
Mean of Response	0.483701
Observations (or Sum Wgts)	589

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	3.6198962	0.603316	534.2531
Error	582	0.6572352	0.001129	Prob > F
C. Total	588	4.2771314		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	1.0617488	0.061206	17.35	<.0001*
InspectionDefects	0.0098332	0.001301	7.56	<.0001*
InspectionCoverage	-0.009272	0.000278	-33.39	<.0001*
InspectionTeamExperience	-0.000149	0.000132	-1.13	0.2588
PercentNewCode	0.0009154	0.000705	1.30	0.1947
InspectionType[0]	0.023847	0.001518	15.71	<.0001*
UnitTestType[0]	0.0609747	0.00147	41.47	<.0001*



Fit Model

Model Specification

Select Columns

- DeliveredDefects
- InspectionDefect
- InspectionCovera
- InspectionTeamE
- PercentNewCode
- InspectionType
- UnitTestType

Pick Role Variables

Y: DeliveredDefect *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help

Run Model

Recall

Remove

Construct Model Effects

Add

Cross

Nest

Macros

Degree: 2

Attributes

Transform

No Intercept

InspectionDefects

InspectionCoverage

InspectionTeamExperience

PercentNewCode

InspectionType

UnitTestType



Fit Model

Model Specification

Select Columns

- DeliveredDefects
- InspectionDefect
- InspectionCovera
- InspectionTeamE
- PercentNewCode
- InspectionType
- UnitTestType

Pick Role Variables

Y: DeliveredDefect *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help

Recall

Remove

Run Model

Construct Model Effects

Add

Cross

Nest

Macros

Degree: 2

Attributes

Transform

No Intercept

InspectionDefects

InspectionCoverage

PercentNewCode

InspectionType

UnitTestType



Summary of Fit

RSquare	0.846
RSquare Adj	0.844679
Root Mean Square Error	0.033613
Mean of Response	0.483701
Observations (or Sum Wgts)	589

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	3.6184537	0.723691	640.5434
Error	583	0.6586777	0.001130	Prob > F
C. Total	588	4.2771314		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	1.0562782	0.061028	17.31	<.0001*
InspectionDefects	0.009816	0.001302	7.54	<.0001*
InspectionCoverage	-0.009266	0.000278	-33.37	<.0001*
PercentNewCode	0.0009039	0.000705	1.28	0.2004
InspectionType[0]	0.0239018	0.001518	15.75	<.0001*
UnitTestType[0]	0.0609821	0.00147	41.47	<.0001*



Fit Model

Model Specification

Select Columns

- DeliveredDefects
- InspectionDefect
- InspectionCoverage
- InspectionTeamEffort
- PercentNewCode
- InspectionType
- UnitTestType

Pick Role Variables

Y: DeliveredDefect *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help Run Model Recall Remove

Construct Model Effects

Add Cross Nest Macros

Degree: 2

Attributes: ☐

Transform: ☐

☐ No Intercept

InspectionDefects
InspectionCoverage
PercentNewCode
InspectionType
UnitTestType



Fit Model

Model Specification

Select Columns

- DeliveredDefects
- InspectionDefect
- InspectionCovera
- InspectionTeamE
- PercentNewCode
- InspectionType
- UnitTestType

Pick Role Variables

Y: DeliveredDefect *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Standard Least Squares

Emphasis: Effect Leverage

Help

Run Model

Recall

Remove

Construct Model Effects

Add

Cross

Nest

Macros

Degree: 2

Attributes

Transform

No Intercept

InspectionDefects

InspectionCoverage

InspectionType

UnitTestType



Summary of Fit

RSquare	0.845566
RSquare Adj	0.844508
Root Mean Square Error	0.033631
Mean of Response	0.483701
Observations (or Sum Wgts)	589

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	3.6165970	0.904149	799.3879
Error	584	0.6605344	0.001131	Prob > F
C. Total	588	4.2771314		<.0001*

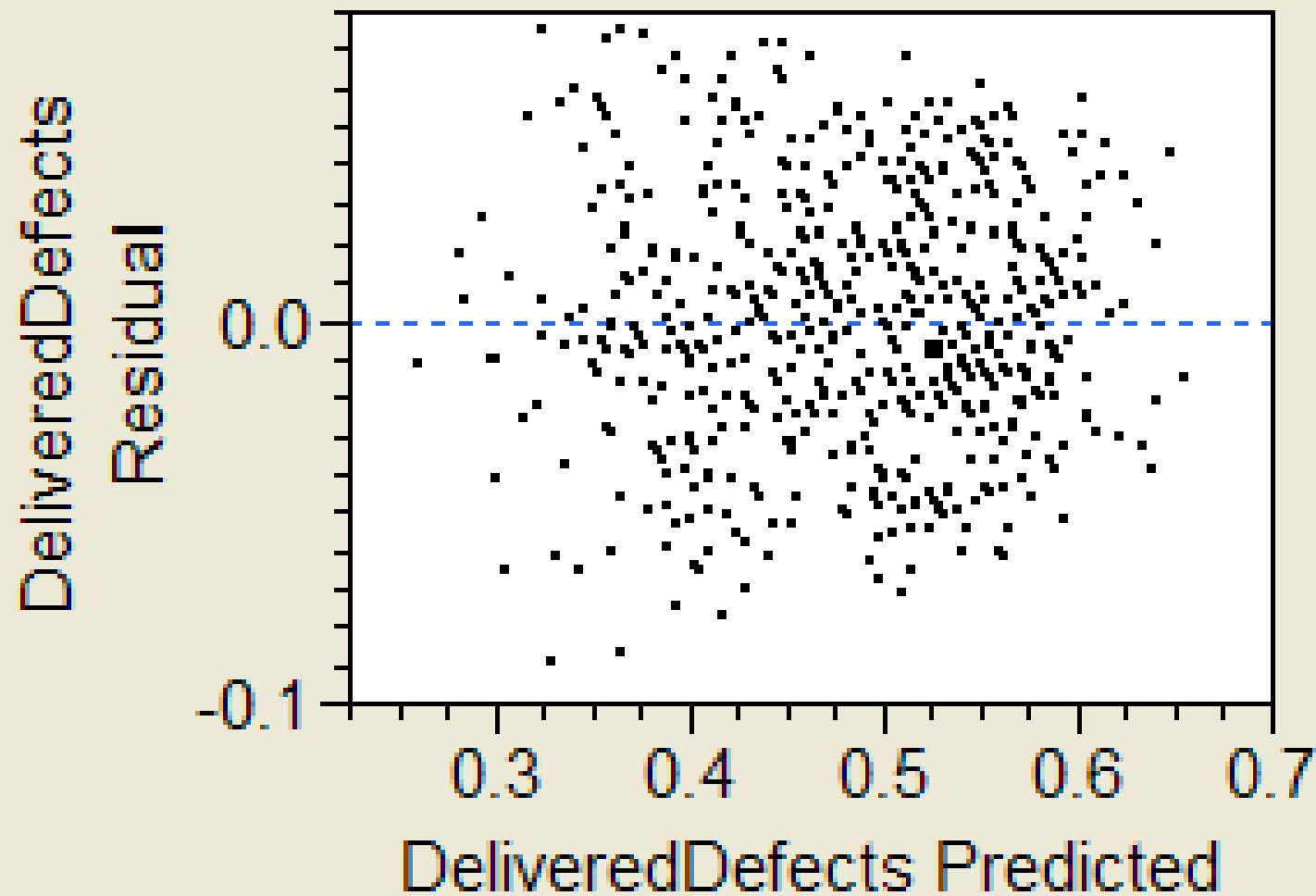
Parameter Estimates

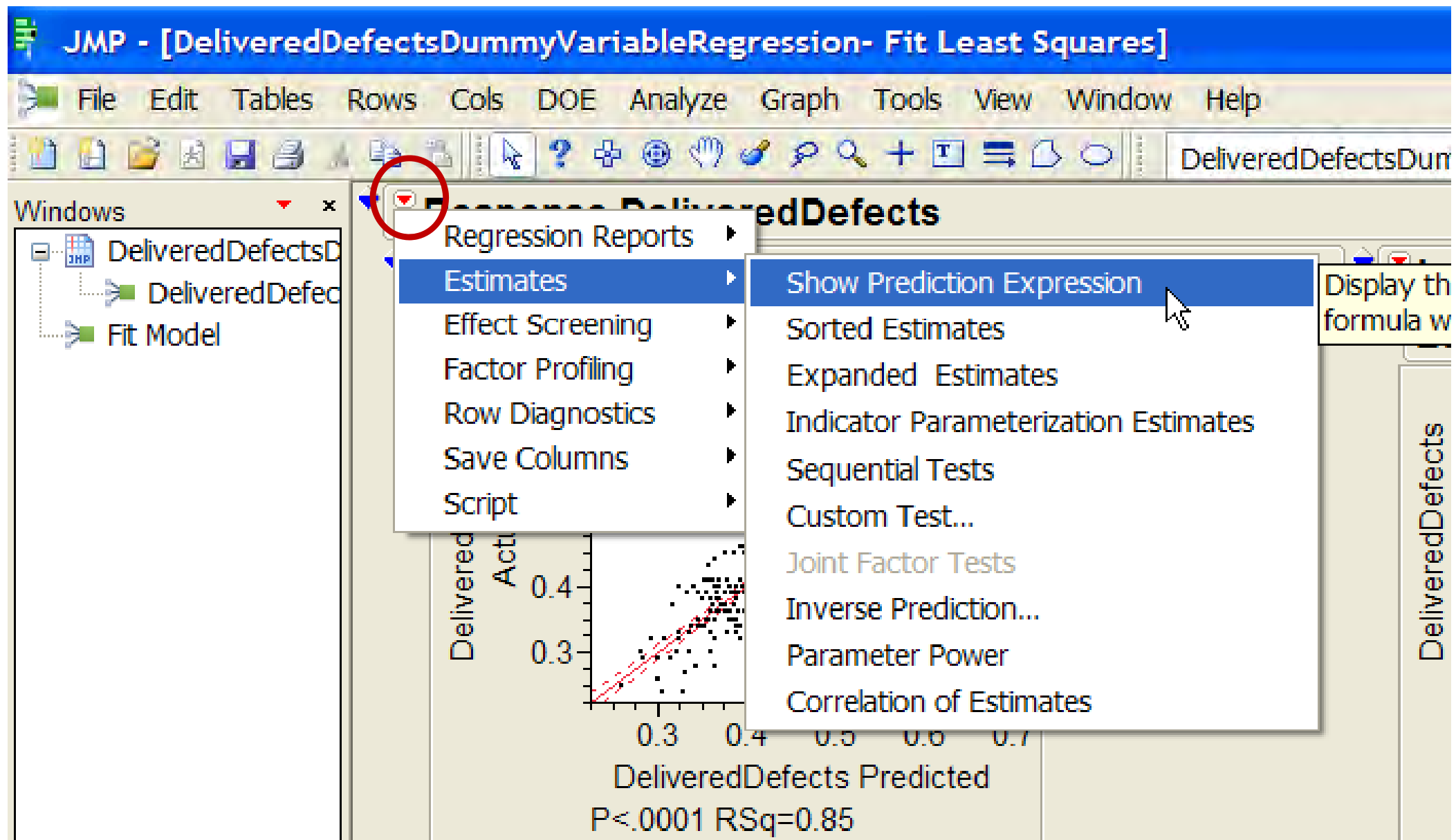
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	1.1279627	0.024456	46.12	<.0001*
InspectionDefects	0.0097196	0.0013	7.48	<.0001*
InspectionCoverage	-0.00927	0.000278	-33.36	<.0001*
InspectionType[0]	0.023858	0.001518	15.71	<.0001*
UnitTestType[0]	0.0608499	0.001468	41.46	<.0001*





Residual by Predicted Plot





▼ Prediction Expression

$$\begin{aligned}
 &1.12796274699737 \\
 &+ 0.00971961664 * \text{InspectionDefects} \\
 &- 0.0092698591556 \\
 &+ * \text{InspectionCoverage} \\
 &+ \text{Match} [\text{InspectionType}] \left[\begin{array}{ll} 0 & \Rightarrow 0.02385799899818 \\ 1 & \Rightarrow -0.0238579989982 \\ \text{else} & \Rightarrow . \end{array} \right] \\
 &+ \text{Match} [\text{UnitTestType}] \left[\begin{array}{ll} 0 & \Rightarrow 0.06084988884934 \\ 1 & \Rightarrow -0.0608498888493 \\ \text{else} & \Rightarrow . \end{array} \right]
 \end{aligned}$$



The screenshot shows the JMP software interface with the title bar 'JMP - [DeliveredDefectsDummyVariableRegression- Fit Least Squares]'. The menu bar includes File, Edit, Tables, Rows, Cols, DOE, Analyze, Graph, Tools, View, Window, and Help. The 'Analyze' menu is open, and the 'Save Columns' option is highlighted. A red circle is drawn around the 'Save Columns' option in the 'Analyze' menu. A secondary menu is open, showing options like Prediction Formula, Predicted Values, Residuals, Mean Confidence Interval, and Indiv Confidence Interval. A mouse cursor is pointing at 'Mean Confidence Interval'. A pink speech bubble contains text explaining the process of selecting these options three times.

Windows

- DeliveredDefectsD
- DeliveredDefec
- Fit Model

Analyze

- Regression Reports
- Estimates
- Effect Screening
- Factor Profiling
- Row Diagnostics
- Save Columns**
- Script

Save Columns

- Prediction Formula
- Predicted Values
- Residuals
- Mean Confidence Interval**
- Indiv Confidence Interval
- Studentized Residuals
- Hats
- Std Error of Predicted
- Std Error of Residual
- Std Error of Individual
- Effect Leverage Pairs
- Cook's D Influence
- StdErr Pred Formula
- Save Coding Table

DeliveredDefects

Delivered Plot

The confiden
expected va
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variation in t
the respons

Root Mean Square Error

You will need to do this menu 3 times to make each of the three choices:

- Predicted Values
- Mean Confidence Intervals
- Indiv Confidence Intervals



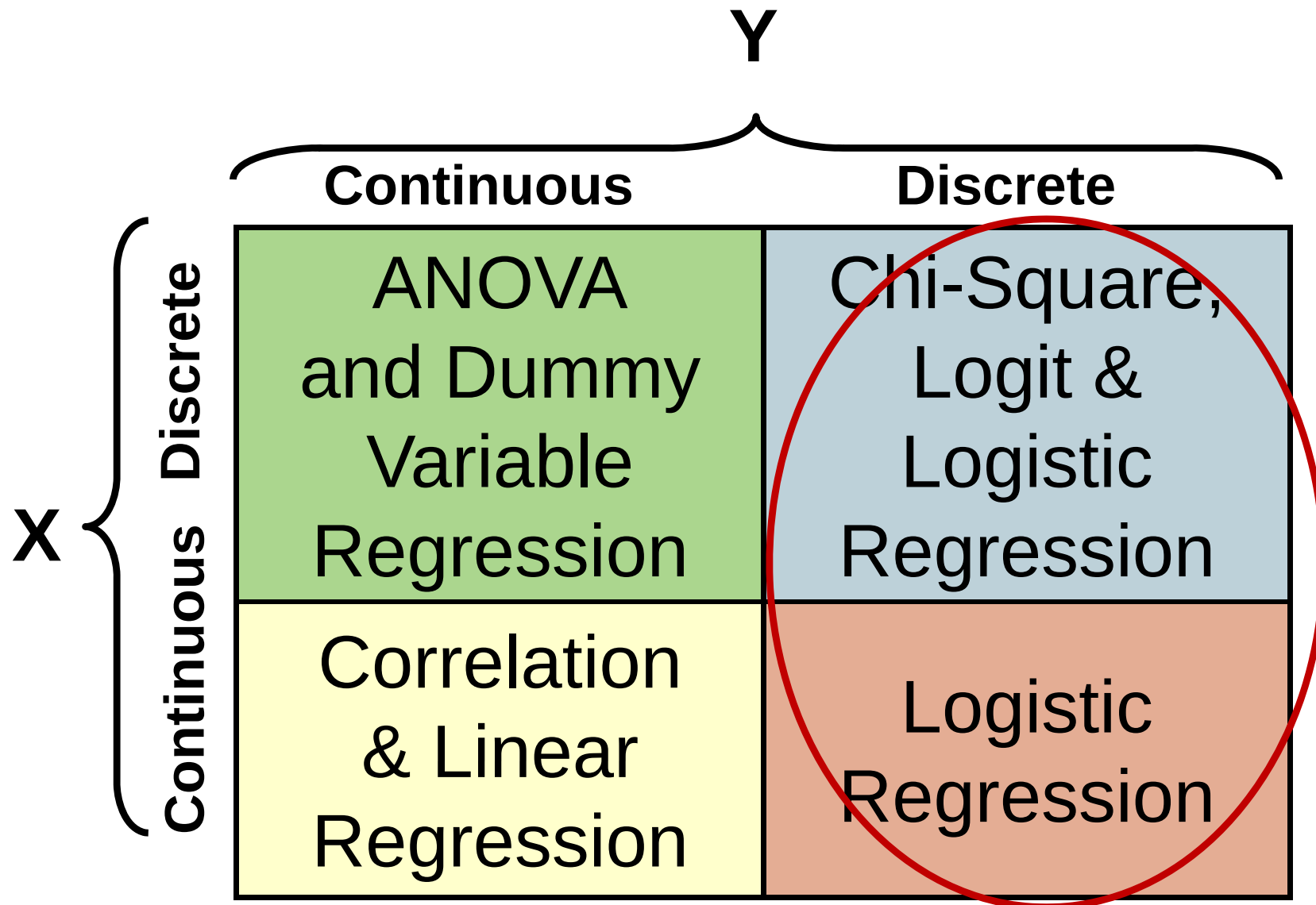
Predicted DeliveredDefect...	Lower 95% Mean DeliveredDefects	Upper 95% Mean DeliveredDefects	Lower 95% Indiv DeliveredDefects	Upper 95% Indiv DeliveredDefects
0.52762634	0.52375953	0.53149316	0.46146059	0.5937921
0.52222559	0.5183626	0.52608858	0.45606005	0.58839112
0.54728146	0.53935391	0.55520901	0.48075477	0.61380816
0.39437653	0.38606592	0.40268715	0.3278031	0.46094996
0.58497103	0.57942818	0.59051389	0.51868621	0.65125586
0.56773709	0.5632922	0.57218199	0.50153504	0.63393915
0.40942786	0.40306404	0.41579169	0.34306934	0.47578639
0.45807366	0.45207219	0.46407514	0.39174891	0.52439842
0.62095058	0.61444472	0.62745645	0.55457829	0.68732288
0.54955743	0.54524504	0.55386981	0.48336413	0.61575072
0.57144054	0.56688035	0.57600073	0.50523064	0.63765044
0.59288017	0.58499115	0.6007692	0.52635806	0.65940229
0.62338452	0.6138448	0.63292425	0.55664652	0.69012253
0.55803299	0.55276691	0.56329907	0.49177073	0.62429525
0.55358319	0.54838539	0.55878099	0.48732632	0.61984005
0.53661935	0.53166763	0.54157106	0.47038133	0.60285736
0.58589452	0.57962983	0.59215921	0.51954543	0.65224361
0.43193765	0.42581413	0.43806118	0.36560174	0.49827356
0.38614805	0.37870953	0.39358656	0.31967785	0.45261824
0.56405439	0.5595407	0.56856808	0.49784768	0.6302611
0.35703371	0.35012345	0.36394397	0.29062056	0.42344686
0.43740385	0.43126051	0.4435472	0.37106611	0.50374159
0.39756646	0.39207934	0.40305357	0.33128627	0.46384665



PPM Exercise 5: Predicting Customer Satisfaction using Ordinal Logistic Regression



Statistical Regression Analysis



Logistic Regression

The purpose of logistic regression is to predict a discrete (attribute) Y outcome using continuous X factors.

Logistic regression belongs to the class of models generally referred to as log-linear models.

Types of logistic regression analysis include the following:

- **nominal** – a nominal Y is predicted (e.g., categorical without ordering)
- **ordinal** – an ordinal Y is predicted (e.g., categorical with ordering)
- **binary** – a binomial Y is predicted (e.g., Y is categorical with only two possible values)



CustomerSatisfactionExerciseWithOrdinalLogisticRegression.jmp file

PredictedCustomerSat	AvgAgeUnresolvedCust QuestionsAtCoding	AvgAgeUnresolvedDev QuestionsAtCoding	AvgWeeklyInPerson Meetings	AvgWeekly Telecons
1	20.27	49.02	0.15	4.91
3	19.86	47.53	0.99	4.15
4	19.52	51.5	3.57	3.14
2	18.56	49.02	0.59	4.58
3	20.45	46.22	1.34	2.48
3	20.4	48.22	2.49	0.84
3	19.42	45.43	0.41	4.02
4	19.85	48.03	1.81	4.69
4	19.98	47.25	3.13	3.95
2	19.99	48.93	1.39	1.67
3	19.11	47.92	1.52	1.76
3	20.95	47.93	0.69	5.17
3	19.5	41.1	2.8	5.31
3	19.72	42.94	1.44	4.18
3	20.69	44.88	1.27	2.53
2	18.95	50.49	0.31	6.12



ReqtsElicitation Method	UnresolvedCustQuestions AtCoding	UnresolvedDevQuestions AtCoding
1.00	28.8	36.33
2.00	30.88	41.15
1.00	23.74	47.75
1.00	26.16	49.61
2.00	32.35	43.4
1.00	27.56	42.92
3.00	25.53	45.85
2.00	26.22	47.87
1.00	31.26	42.48
1.00	31.62	41.47
1.00	26.34	46.71
2.00	31.38	51.41
1.00	24.47	45.12
1.00	30.6	44.8
2.00	27.59	47.24
1.00	27.6	48.9
1.00	29.18	42.58



Factor	Role	Data Type	Description
PredictedCustomerSat	Y Outcome	Ordinal	Very Low=1; Low=2; Medium=3; High=4; Very High=5
AvgAgeUnresolvedCustQuestionsAtCoding	X1 Factor	Continuous	Average Age in Work Days of Unresolved Questions From Customer at the Beginning of Coding Phase
AvgAgeUnresolvedDevQuestionsAtCoding	X2 Factor	Continuous	Average Age in Work Days of Unresolved Questions From Developer Team at the Beginning of Coding Phase
AvgWeeklyInPersonMeetings	X3 Factor	Continuous	Average Number of Face to Face meetings per week between the Development Team and the Customer
AvgWeeklyTelecons	X4 Factor	Continuous	Average Number of Teleconference Calls held each Week between the Development Team and the Customer
ReqsElicitationMethod	X5 Factor	Nominal	Strictly Spec Driven=1; Interview=2; Prototyping=3
UnResolvedCustQuestionsAtCoding	X6 Factor	Continuous	Number of Unresolved Questions From Customer at the Beginning of Coding Phase
UnResolvedDevQuestionsAtCoding	X7 Factor	Continuous	Number of Unresolved Questions From Developer Team at the Beginning of Coding Phase



JMP - [CustomerSatisfactionExerciseWithOrdinalLogisticRegression]

File Edit Tables Rows Cols DOE **Analyze** Graph Tools View Window Help

Windows

CustomerSatisf

Analyze menu options:

- Distribution
- Fit Y by X
- Matched Pairs
- Fit Model**
- Modeling
- Multivariate Methods
- Reliability and Survival

Columns (8/1)

- PredictedCustomerSat
- AvgAgeUnresolvedCust
- AvgAgeUnresolvedDev
- AvgWeeklyInPersonMe

	PredictedCustomerSat	AvgAgeUnresolvedCust
1	1	
2	3	
3	4	
4	2	
5	3	
6	3	
7	3	
8	4	
9	4	
10	2	
11	3	
12	3	
13	3	
14	3	



Fit Model

Model Specification

Select Columns

- PredictedCustor
- AvgAgeUnresolve
- AvgAgeUnresolve
- AvgWeeklyInPers
- AvgWeeklyTelec
- ReqtElicitationM
- UnresolvedCustC
- UnresolvedDevQ

Pick Role Variables

Y: PredictedCustor *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Ordinal Logistic

Help

Run Model

Recall

Remove

Construct Model Effects

Add

Cross

Nest

Macros

Degree: 2

Attributes

Transform

☐ No Intercept

AvgAgeUnresolvedCustQuestionsAtC

AvgAgeUnresolvedDevQuestionsAtCc

AvgWeeklyInPersonMeetings

AvgWeeklyTelecons

ReqtElicitationMethod

UnresolvedCustQuestionsAtCoding

UnresolvedDevQuestionsAtCoding



Ordinal Logistic Fit for PredictedCustomerSat

Iteration History

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	100.56109	8	201.1222	<.0001*
Full	8.84501			
Reduced	109.40610			
RSquare (U)		0.9192		
Observations (or Sum Wgts)		90		

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	348	8.8450140	17.69003
Saturated	356	0.0000000	Prob>ChiSq
Fitted	8	8.8450140	1.0000



Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept[1]	92.9334278	51.810259	3.22	0.0729
Intercept[2]	148.597425	71.058627	4.37	0.0365*
Intercept[3]	203.99553	92.369135	4.88	0.0272*
Intercept[4]	254.214635	112.83919	5.08	0.0243*
AvgAgeUnresolvedCustQuestionsAtCoding	1.96123574	1.0437171	3.53	0.0602
AvgAgeUnresolvedDevQuestionsAtCoding	-0.4579541	0.5633572	0.66	0.4163
AvgWeeklyInPersonMeetings	-35.583689	15.138283	5.53	0.0187*
AvgWeeklyTelecons	-0.7033199	0.8018375	0.77	0.3804
ReqsElicitationMethod[1.00]	31.0735426	13.061873	5.66	0.0174*
ReqsElicitationMethod[2.00]	-4.398162	2.3425233	3.53	0.0604
UnresolvedCustQuestionsAtCoding	-1.7209171	0.7953154	4.68	0.0305*
UnresolvedDevQuestionsAtCoding	-2.152774	0.8611309	6.25	0.0124*



Fit Model

Model Specification

Select Columns

- PredictedCustor
- AvgAgeUnresolve
- AvgAgeUnresolve
- AvgWeeklyInPers
- AvgWeeklyTelec
- ReqtsElicitationM
- UnresolvedCustC
- UnresolvedDevQ

Pick Role Variables

Y: PredictedCustor *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Ordinal Logistic

Help Run Model Recall Remove

Construct Model Effects

Add Cross Nest Macros

Degree: 2

Attributes: ☐

Transform: ☐

☐ No Intercept

AvgAgeUnresolvedCustQuestionsAtC
AvgAgeUnresolvedDevQuestionsAtCo
AvgWeeklyInPersonMeetings
AvgWeeklyTelecons
ReqtsElicitationMethod
UnresolvedCustQuestionsAtCoding
UnresolvedDevQuestionsAtCoding



Fit Model

Model Specification

Select Columns

- PredictedCuston
- AvgAgeUnresolve
- AvgAgeUnresolve
- AvgWeeklyInPers
- AvgWeeklyTelec
- ReqtsElicitationM
- UnresolvedCustC
- UnresolvedDevQ

Pick Role Variables

Y: PredictedCustor *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Ordinal Logistic

Help Run Model Recall Remove

Construct Model Effects

Add Cross Nest Macros

AvgAgeUnresolvedCustQuestionsAtC
AvgWeeklyInPersonMeetings
AvgWeeklyTelecons
ReqtsElicitationMethod
UnresolvedCustQuestionsAtCoding
UnresolvedDevQuestionsAtCoding

Degree: 2

Attributes: ☒

Transform: ☒

☐ No Intercept



Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept[1]	62.129936	27.6369	5.05	0.0246*
Intercept[2]	110.845603	40.444952	7.51	0.0061*
Intercept[3]	160.156478	58.481434	7.50	0.0062*
Intercept[4]	203.407054	74.122921	7.53	0.0061*
AvgAgeUnresolvedCustQuestionsAtCoding	1.66957142	0.8736435	3.65	0.0560
AvgWeeklyInPersonMeetings	-31.445747	12.098374	6.76	0.0093*
AvgWeeklyTelecons	-0.5290472	0.7016369	0.57	0.4508
ReqsElicitationMethod[1.00]	27.4484984	10.472716	6.87	0.0088*
ReqsElicitationMethod[2.00]	-3.9627567	2.0628873	3.69	0.0547
UnresolvedCustQuestionsAtCoding	-1.4306074	0.5823547	6.03	0.0140*
UnresolvedDevQuestionsAtCoding	-1.908446	0.6884446	7.68	0.0056*



Fit Model

Model Specification

Select Columns

- PredictedCustor
- AvgAgeUnresolve
- AvgAgeUnresolve
- AvgWeeklyInPers
- AvgWeeklyTelec
- ReqtsElicitationM
- UnresolvedCustC
- UnresolvedDevQ

Pick Role Variables

Y: PredictedCustor *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Ordinal Logistic

Help Run Model Recall Remove

Construct Model Effects

Add Cross Nest Macros

Degree: 2

Attributes

Transform

No Intercept

AvgAgeUnresolvedCustQuestionsAtC

AvgWeeklyInPersonMeetings

AvgWeeklyTelecons

ReqtsElicitationMethod

UnresolvedCustQuestionsAtCoding

UnresolvedDevQuestionsAtCoding



Fit Model

Model Specification

Select Columns

- PredictedCustom
- AvgAgeUnresolve
- AvgAgeUnresolve
- AvgWeeklyInPers
- AvgWeeklyTelec
- ReptsElicitationM
- UnresolvedCustC
- UnresolvedDevQ

Pick Role Variables

Y: PredictedCustor *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Ordinal Logistic

Help Run Model Recall Remove

Construct Model Effects

Add Cross Nest Macros

AvgAgeUnresolvedCustQuestionsAtC
AvgWeeklyInPersonMeetings
ReptsElicitationMethod
UnresolvedCustQuestionsAtCoding
UnresolvedDevQuestionsAtCoding

Degree 2

Attributes

Transform

☐ No Intercept



Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept[1]	54.9797203	24.345705	5.10	0.0239*
Intercept[2]	100.794188	33.940026	8.82	0.0030*
Intercept[3]	145.703314	48.287961	9.10	0.0025*
Intercept[4]	186.096476	61.562511	9.14	0.0025*
AvgAgeUnresolvedCustQuestionsAtCoding	1.56135331	0.768001	4.13	0.0421*
AvgWeeklyInPersonMeetings	-28.947564	10.104355	8.21	0.0042*
ReqsElicitationMethod[1.00]	25.2121153	8.6077178	8.58	0.0034*
ReqsElicitationMethod[2.00]	-3.5025523	1.7280995	4.11	0.0427*
UnresolvedCustQuestionsAtCoding	-1.2619774	0.4359331	8.38	0.0038*
UnresolvedDevQuestionsAtCoding	-1.8034997	0.6076278	8.81	0.0030*



Whole Model Test				
Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	99.82037	6	199.6407	<.0001*
Full	9.58574			
Reduced	109.40610			
RSquare (U)	0.9124			
Observations (or Sum Wgts)		90		
Converged by Gradient				



JMP - [CustomerSatisfactionExerciseWithOrdinalLogisticRegression- Fit Ordinal

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CustomerS

Windows

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CustomerSatisf
Fit Model

Ordinal Logistic Fit for PredictedCustomerSat

- ✓ Likelihood Ratio Tests
- Wald Tests
- Confidence Intervals
- ROC Curve
- Lift Curve
- Profiler**
- Save
- Script

DF ChiSquare Prob>Chi

6 199.6407 <.000

0.9124

Observations (or Sum Wgts) 90

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	350	9.5857356	19.17147
Saturated	356	0.0000000	Prob>ChiSq



Parameter Estimates

Sensitivity Indicator

Desirability Functions

Maximize Desirability

Maximization Options

Maximize for each Grid Point

Save Desirabilities

Set Desirabilities

Save Desirability Formula

Reset Factor Grid

Factor Settings

Output Grid Table

Output Random Table

Alter Linear Constraints

Save Linear Constraints

Default N Levels

Interaction Profiler

	Estimate	Std Error	ChiSquare	Prob>ChiSq
	54.9797203	24.345705	5.10	0.0239
	100.794188	33.940026	8.82	0.0030
	145.703314	48.287961	9.10	0.0029
	186.096476	61.562511	9.14	0.0029
ding	1.56135331	0.768001	4.13	0.0421
	-28.947564	10.104355	8.21	0.0042
	25.2121153	8.6077178	8.58	0.0034
	-3.5025523	1.7280995	4.11	0.0427
	-1.2619774	0.4359331	8.38	0.0038
	-1.8034997	0.6076278	8.81	0.0030

	L-R			
	Nparm	DF	ChiSquare	Prob>ChiSq
ding	1	1	6.09880179	0.0135*
	1	1	151.868665	<.0001*
	2	2	111.379472	<.0001*
	1	1	29.1823898	<.0001*
	1	1	49.204595	<.0001*

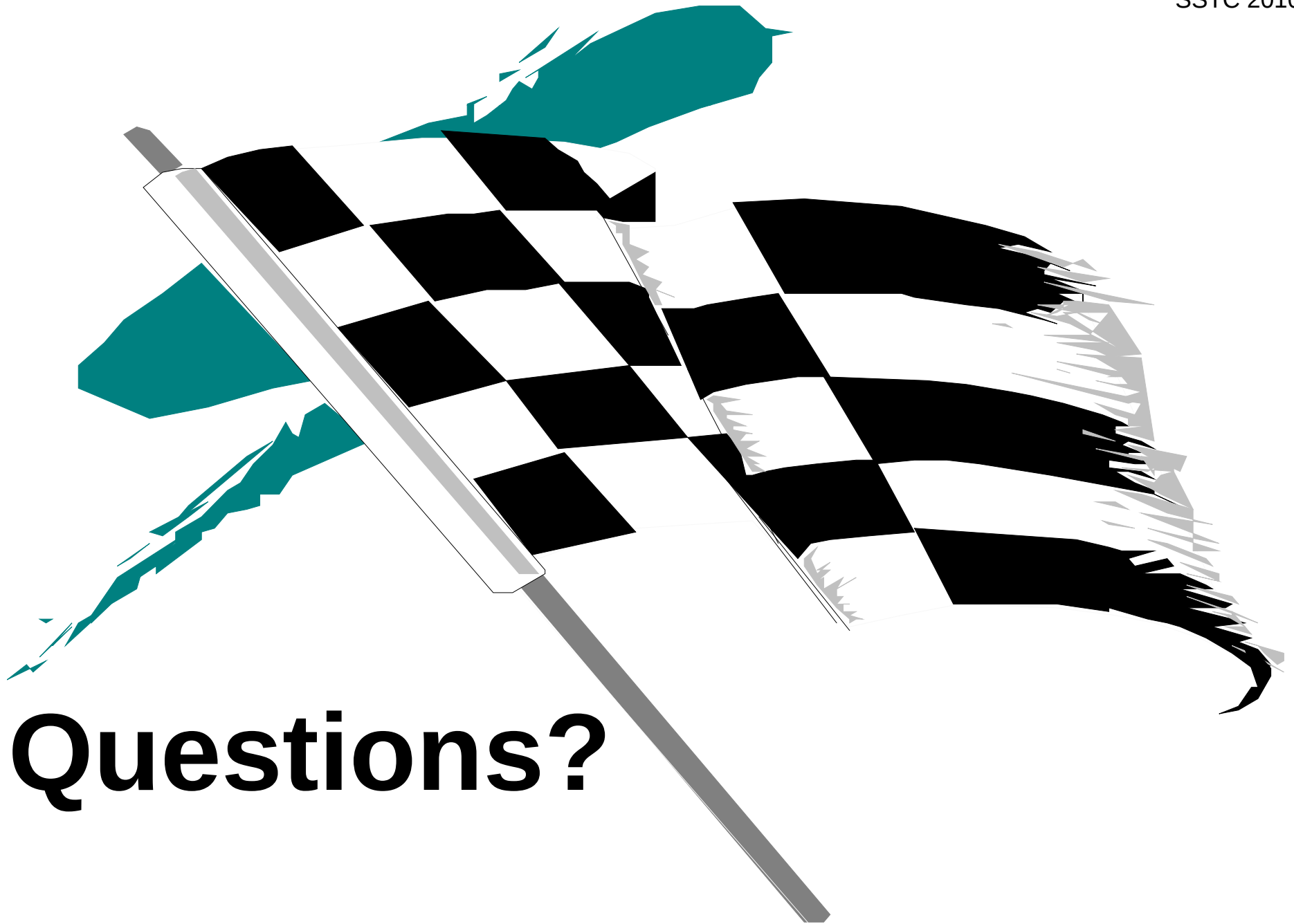


AvgAgeUnresolvedCustQ uestionsAtCoding	AvgWeeklyInPers onMeetings	ReqtsElicitati onMethod	UnresolvedCustQues tionsAtCoding	UnresolvedDevQues tionsAtCoding
17.39	0.11	1.00	22.63	36.33
17.39	0.11	1.00	22.63	40.585
17.39	0.11	1.00	22.63	44.84
17.39	0.11	1.00	22.63	49.095
17.39	0.11	1.00	22.63	53.35
17.39	0.11	1.00	25.7125	36.33
17.39	0.11	1.00	25.7125	40.585
17.39	0.11	1.00	25.7125	44.84
17.39	0.11	1.00	25.7125	49.095
17.39	0.11	1.00	25.7125	53.35
17.39	0.11	1.00	28.795	36.33
17.39	0.11	1.00	28.795	40.585
17.39	0.11	1.00	28.795	44.84
17.39	0.11	1.00	28.795	49.095
17.39	0.11	1.00	28.795	53.35
17.39	0.11	1.00	31.8775	36.33
17.39	0.11	1.00	31.8775	40.585
17.39	0.11	1.00	31.8775	44.84
17.39	0.11	1.00	31.8775	49.095
17.39	0.11	1.00	31.8775	53.35



	Probability(Predicted CustomerSat=1)	Probability(Predicted CustomerSat=2)	Probability(Predicted CustomerSat=3)	Probability(Predicted CustomerSat=4)	Probability(Predicted CustomerSat=5)
1	0.99995809	4.19142e-5	0	0	0
2	0.91728006	0.08271994	0	0	0
3	0.00512779	0.99487221	0	0	0
4	2.39571e-6	0.9999976	5.3291e-15	0	0
5	1.11354e-9	1	1.1385e-11	0	0
6	0.99795395	0.00204605	0	0	0
7	0.18480994	0.81519006	0	0	0
8	0.00010536	0.99989464	2.2204e-16	0	0
9	4.89789e-8	0.99999995	2.589e-13	0	0
10	2.2766e-11	1	5.5686e-10	0	0
11	0.90885654	0.09114346	0	0	0
12	0.00461353	0.99538647	0	0	0
13	2.15433e-6	0.99999785	5.9952e-15	0	0
14	1.00135e-9	1	1.266e-11	0	0
15	4.6543e-13	0.99999997	2.72379e-8	0	0
16	0.16934269	0.83065731	0	0	0
17	0.00009475	0.99990525	2.2204e-16	0	0
18	4.4044e-8	0.99999996	2.8777e-13	0	0
19	2.0472e-11	1	6.1926e-10	0	0
20	9.5155e-15	0.99999867	1.33229e-6	0	0
21	0.00415062	0.99584938	0	0	0





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