

Pi Blue Software, Inc.

Non-Gradient Based Optimization Using ModelCenter and OptWorks

March 2003



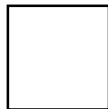
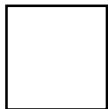
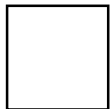
Introduction to the Firm

Overview of OptWorks: ModelCenter

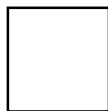
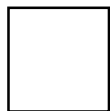
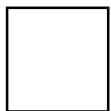
OptWorks: ModelCenter Case Studies

OptWorks: ModelCenter Demonstration

Summary



Agenda

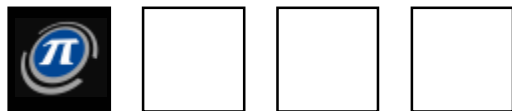


Introduction to the Firm

About



Pi Blue Software, Inc. (Pi Blue) specializes in developing easy-to-use software products for advanced numerical analysis, risk/uncertainty assessment, and optimization. Our flagship products are OptWorks: ModelCenter[®] and ProbWorks: ModelCenter[®]. Pi Blue's products provide powerful numerical simulation and probabilistic design capabilities for users of all skill levels, from professionals to students.



Overview of OptWorks: ModelCenter

ModelCenter[®] Collaborative Environment

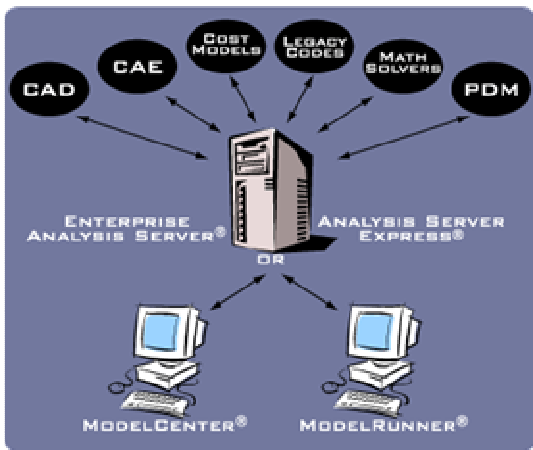
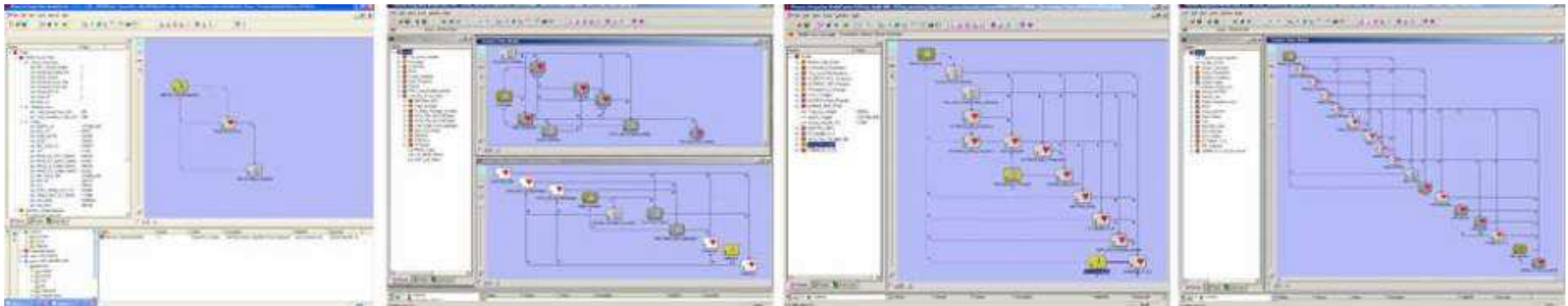


Image Source: Phoenix Integration Inc.
<http://www.phoenix-int.com/products/index.html>

“Phoenix Integration allows manufacturing companies to integrate and automate numerous software tools, remote locations, and different computing platforms into a cohesive environment for systems design...

...Our client software and back-end server software products help you build an integrated process for your engineering design team.”

Phoenix Integration Inc.
<http://www.phoenix-int.com>



Overview of Optimization

- ▶ Optimizers attempt to **minimize or maximize an objective function**, formed from multiple specified outputs from other models, by manipulating design variables that are inputs to those models
- ▶ The user specifies each objective function and its weighting value:

$$Overall_Objective = \sum objectiveFunctions[i] * weight[i]$$

- ▶ In general more design variables, objective functions, or complexity will result in more function calls needed to find an optimal solution



Pi Blue Software, Inc. introduces a new suite of **optimization** tools for incorporation with Phoenix Integration's ModelCenter[®] collaborative design environment.

Entitled OptWorks: ModelCenter[®], this suite consists of **eight non-gradient based optimizers** each implemented as Java-based components which can function on any platform running Phoenix Integration's ModelCenter[®] or Analysis Server[®].



OptWorks: ModelCenter

COMPONENT NAME	CAPABILITY
Optimize_ConvexAlgorithm	Global gradient of sub-problem based in hierarchical solution
Optimize_Linear	Using an interior point or primal-dual type algorithms for convex cases
Optimize_SimplexAlgorithm	Simplex algorithm used in method based upon multi-phase processes
Optimize_NLP	Based on global search pre-processed with a gradient based for convex cases
Optimize_QuasiNewton	Based on using a memory sub-problem procedure for local minimization
Optimize_TrustRegion	Trust region search with a multi-dimensional set of trust region local minima
Optimize_LevenbergMarquardt	Trust region search with a multi-dimensional set of trust region local minima
Optimize_QuasiNewton	Trust region search with a multi-dimensional set of trust region local minima

SYSTEM REQUIREMENTS
OptWorks: ModelCenter® does not require any special hardware or software. It runs on Windows® 95, 98, or 2000.

ORDERING AND PRICING
OptWorks: ModelCenter, Inc. is the primary supplier for Pi Blue Software, ModelCenter® and ModelCenter® products. For sales and pricing information, please contact Pi Blue Software, Inc. at 1-800-353-1144. Individual and development licenses are available with annual maintenance plans as available. Individual user licenses are priced at \$1,995 (US) including charge.

OTHER PIBLUE SOFTWARE PRODUCTS
Pi Blue Software, Inc. develops software products targeted at professionals and students in the engineering, financial, accounting, logistics, scientific, mathematical, and physical fields. Our current products include the OptWorks suite of domain-specific optimization algorithms and the ProModel suite of tools for real-time optimization.

TRAINING AND CONSULTING
Pi Blue Software, Inc. offers specialized training related to ModelCenter® and other Pi Blue software products as well as consulting services for subsequent application to business engineering and optimization.

TECHNICAL SUPPORT
Pi Blue Software, Inc. offers customer service technical support for all products. These include FAQs, white papers, and an online support center.

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PiBlue
Pi Blue Software, Inc.
11111 Main Street, Suite 100, Houston, TX 77055
www.piblue.com | www.piblue.com

These tools enhance the current gradient based optimization tools in ModelCenter® to allow **solution of previously intractable problems.**

Characteristics of these sets of applications include the capability to handle problems with high dimensionality, discrete or mixed variables (continuous and discrete), and multi-modal solutions spaces.

This package is currently available for purchase through **individual/group site licenses.** The full product suite includes optimizers in Java byte code, documentation with case study examples, and selected online support.



OptWorks: ModelCenter Capabilities

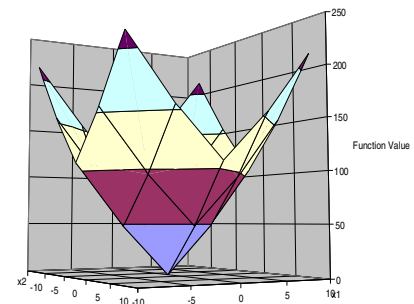
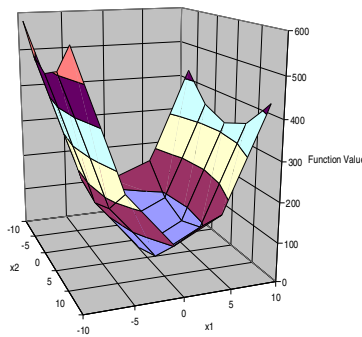
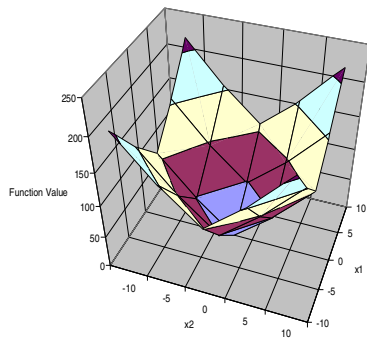
Mixed / discrete / integer variables

Multiple metrics

Vast design space

Multi-modal problems

Noisy gradient calculations



Why OptWorks?

Basic Functionality of an OptWorks Component Within ModelCenter®

The screenshot displays the ModelCenter software interface with several key components labeled:

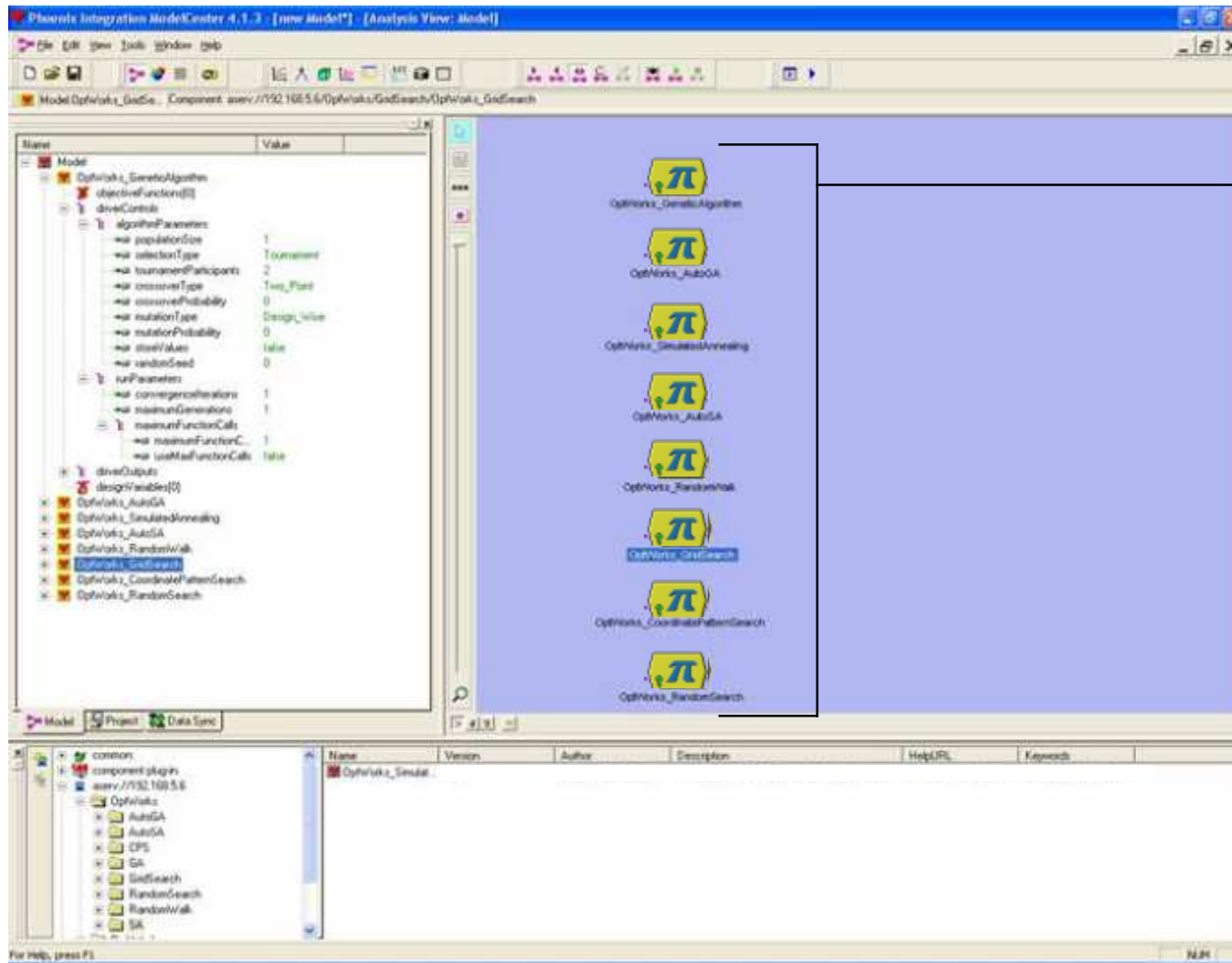
- Component Tree:** A hierarchical tree view on the left side of the window, listing various model components and their values.
- Analysis View:** The central workspace showing a flow diagram of the model. It includes an OptWorks "Driver" Component (represented by a Pi symbol), a Model component (ROSETTA_SST003), and a Tech_Funding_Constraint component.
- Drag and Drop Components Into Model:** A large green arrow pointing from the Server Browser to the Analysis View, indicating the process of adding components to the model.
- Server Browser:** A tree view at the bottom left showing the file structure of the server.
- Driver Tool Window:** A window at the bottom right showing a table of model parameters and their values.

Component	Value
Model	
ROSETTA_SST003	
Inputs/technologies	
Advanced_Engine_Mat	0
Advanced_Engine_Mat	1
Nozzle_Shroud	0
Advanced_Struct_Mat	1
Advanced_Tank_Mat	0
Advanced_TPS	1
Stack_H2	0
Mag_Ler	1
Funding_Level	
Funding_Level	1
Outputs	
ObjectiveFunctionG	
DriverControl	
AlgorithmParameters	
RunParameters	
DriverOutputs	
RunResults	
RunValues	
TechValues	
StorageVariables	
Tech_Funding_Constraint	
annual_cost	100
cumulative_cost	1400
penalty	5.0000E+006

Component	Weight	Goal
Model:ROSETTA_SST003:Outputs:DRY_WT	0.5	Minimize
Model:ROSETTA_SST003:Outputs:PRICE_LE_GOVY_CARIGD	0.5	Minimize
Model:Tech_Funding_Constraint:penalty	1	Minimize

Component	Run	Minimum Value
Model:ROSETTA_SST003:Inputs/technologies/Advanced_Engine_Mat	1	0
Model:ROSETTA_SST003:Inputs/technologies/Nozzle_Shroud	1	0
Model:ROSETTA_SST003:Inputs/technologies/Advanced_Struct_Mat	1	0
Model:ROSETTA_SST003:Inputs/technologies/Advanced_Tank_Mat	1	0
Model:ROSETTA_SST003:Inputs/technologies/Advanced_TPS	1	0
Model:ROSETTA_SST003:Inputs/technologies/Stack_H2	1	0

OptWorks Components Available from Pi Blue Software, Inc.



OptWorks Suite

Genetic Algorithm (GA)

AutoGA

Simulated Annealing (SA)

AutoSA

RandomWalk

Coordinate Pattern Search (CPS)

RandomSearch

GridSearch

Genetic Algorithm (GA) Utilizes properties of natural selection found in biological evolution

AutoGA Same as GA but with heuristically-based optimizer setup parameters

Simulated Annealing (SA) Search method based upon metallurgical processes

AutoSA Same as SA but with heuristically-based optimizer setup parameters

RandomWalk Search through random determination of direction for next movement

Coordinate Pattern Search (CPS) N-orthogonal search able to handle discontinuities but not multiple local minima

RandomSearch Random determination of analysis point within design space

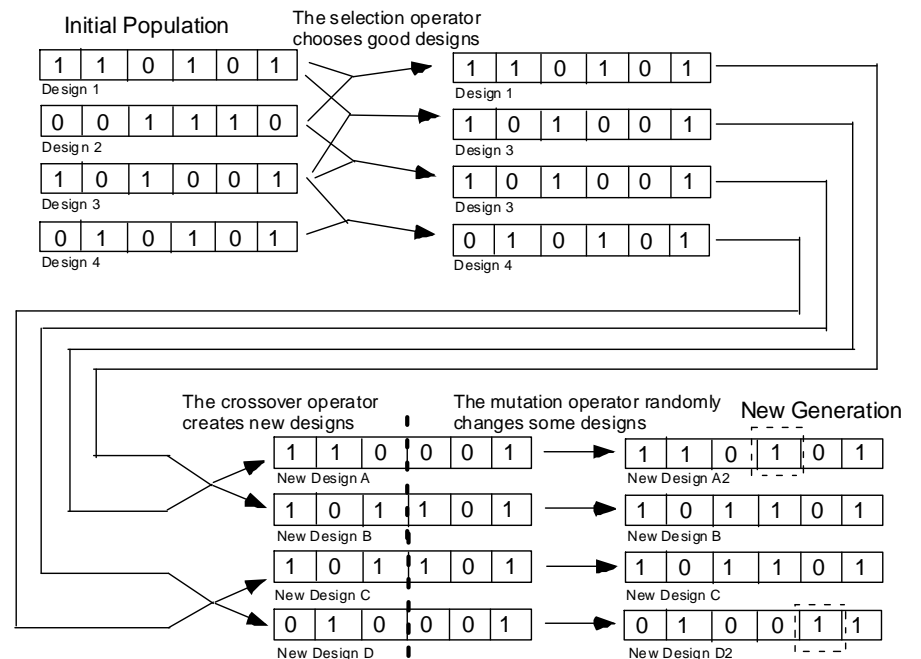
GridSearch Area searching with analysis at various refinement levels



OptWorks Suite of Components

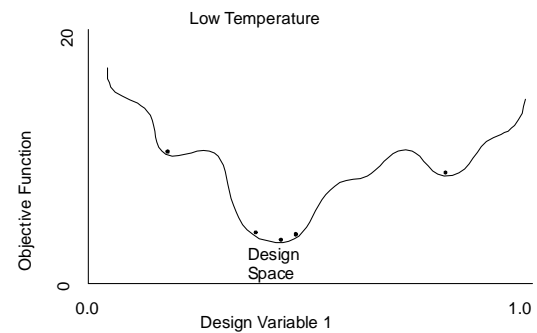
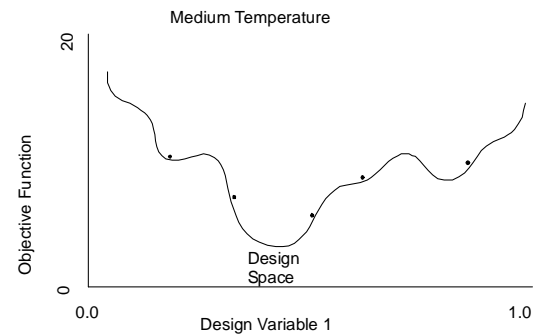
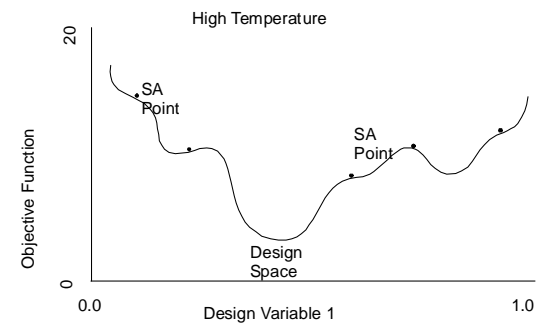
Genetic Algorithm (GA) and Auto GA

- ▶ **Genetic Algorithm (GA) operates similar to natural evolution**
- ▶ **Bit string genes represent designs and better designs are selected to reproduce**
- ▶ **Reproduction crosses over parent genes to create children with similar properties**
- ▶ **Process continues for specified number of generations or until no improvement found in the objective function over a certain number of generations**
- ▶ **GA good for design space exploration, solving problems with high dimensionality, and solving multi-modal spaces**
- ▶ **Requires more function calls than a simpler algorithm, such as coordinate pattern search, but can solve many types of problems**
- ▶ **Automated Genetic Algorithm (AutoGA) has reduced input complexity, intended for novice users**



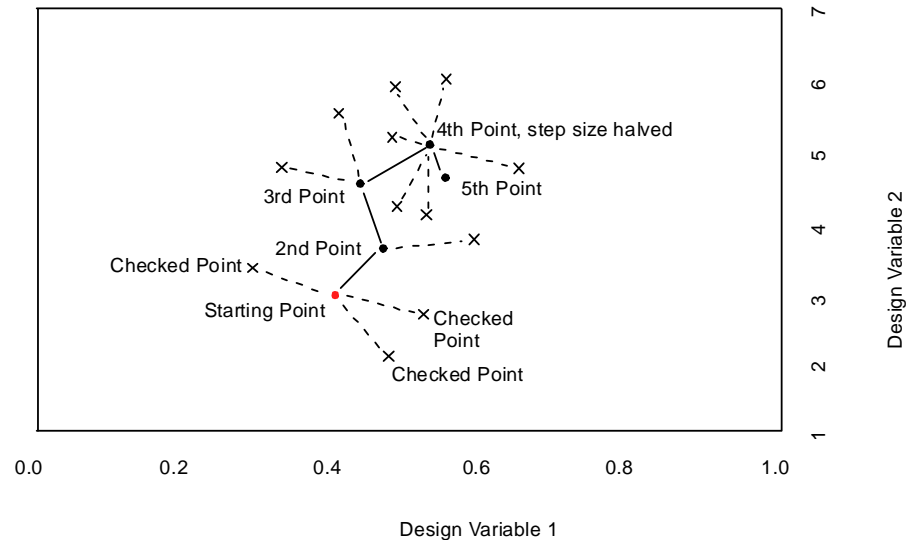
Simulated Annealing (SA) and Auto SA

- ▶ Mimic metallurgical process in which material is heated to high temperature and cooled
- ▶ At high temperatures the SA's points can move to higher objective function values, but as the temperature decreases the ability to move uphill is also reduced
- ▶ Causes the points to become located in good regions of the design space and allows the possibility of finding a global minimum among many local minima
- ▶ Automated Simulated Annealing (AutoSA) has reduced input complexity, intended for novice users



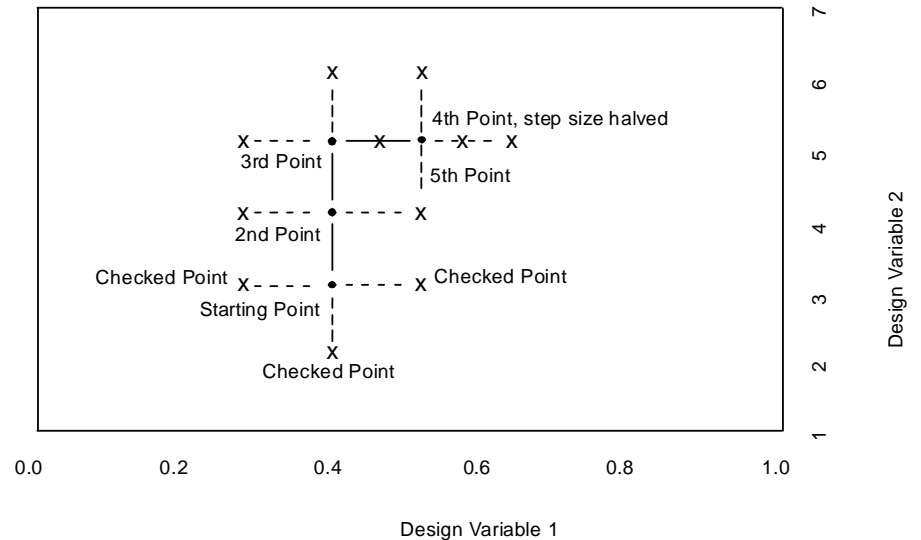
Random Walk

- ▶ Takes steps while searching for better objective function values
- ▶ Direction of these steps is random rather than fixed
- ▶ Algorithm continues until fails to improve on best results, then halves step size and repeats process until specified minimum step size obtained
- ▶ Appropriate for many of the same problems that a coordinate pattern search
- ▶ More function calls than a coordinate pattern search, but with random search direction can be more robust



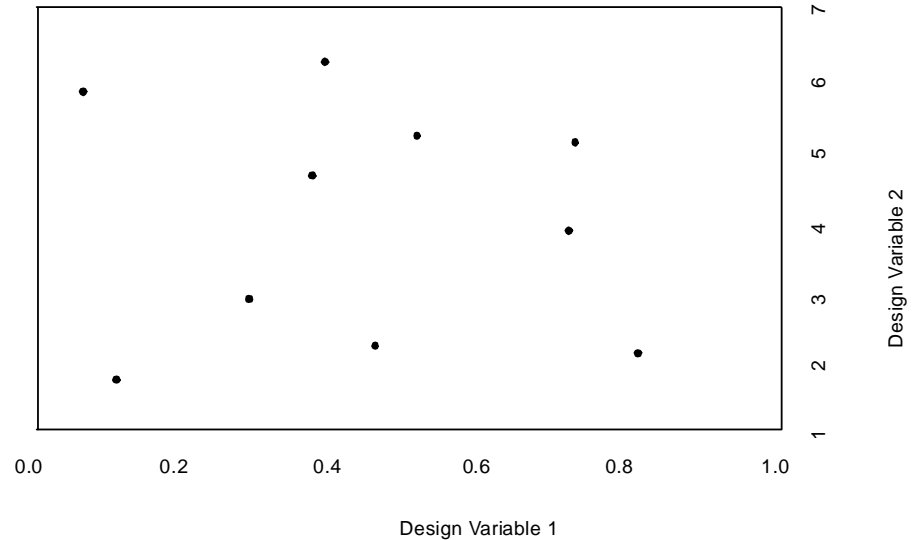
Coordinate Pattern Search (CPS)

- ▶ **Steps specified distance along each positive and negative univariate direction individually**
- ▶ **Finds best direction from all variables, then moves there and begins again**
- ▶ **When cannot find better objective value than current one, cuts step size in half and continues until some minimum step size is reached**
- ▶ **Tends to have very good performance and will generally find the value of objective closest to starting point with relatively few function calls**
- ▶ **Good choice for spaces with only one minimum but discontinuous or discrete variables**



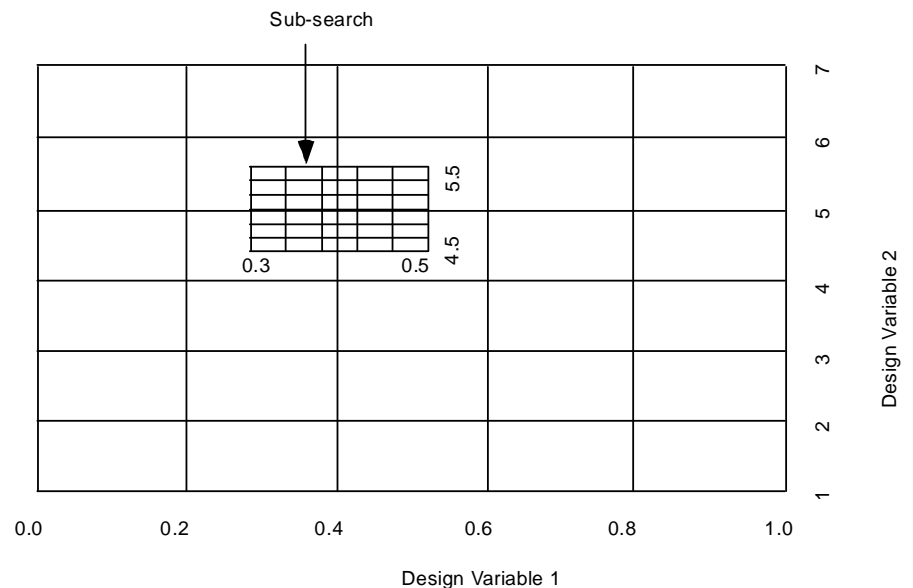
Random Search

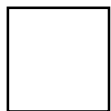
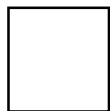
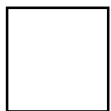
- ▶ Performs a completely random search of design space and records the best value found
- ▶ Useful for design space exploration and finding best value of objective in space where other optimizers may find difficulty in traversing space
- ▶ Can find local minima but is not particularly efficient for this task



Grid Search

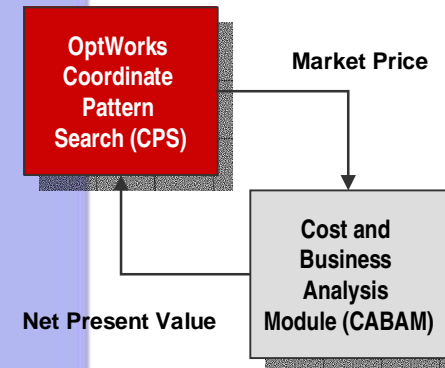
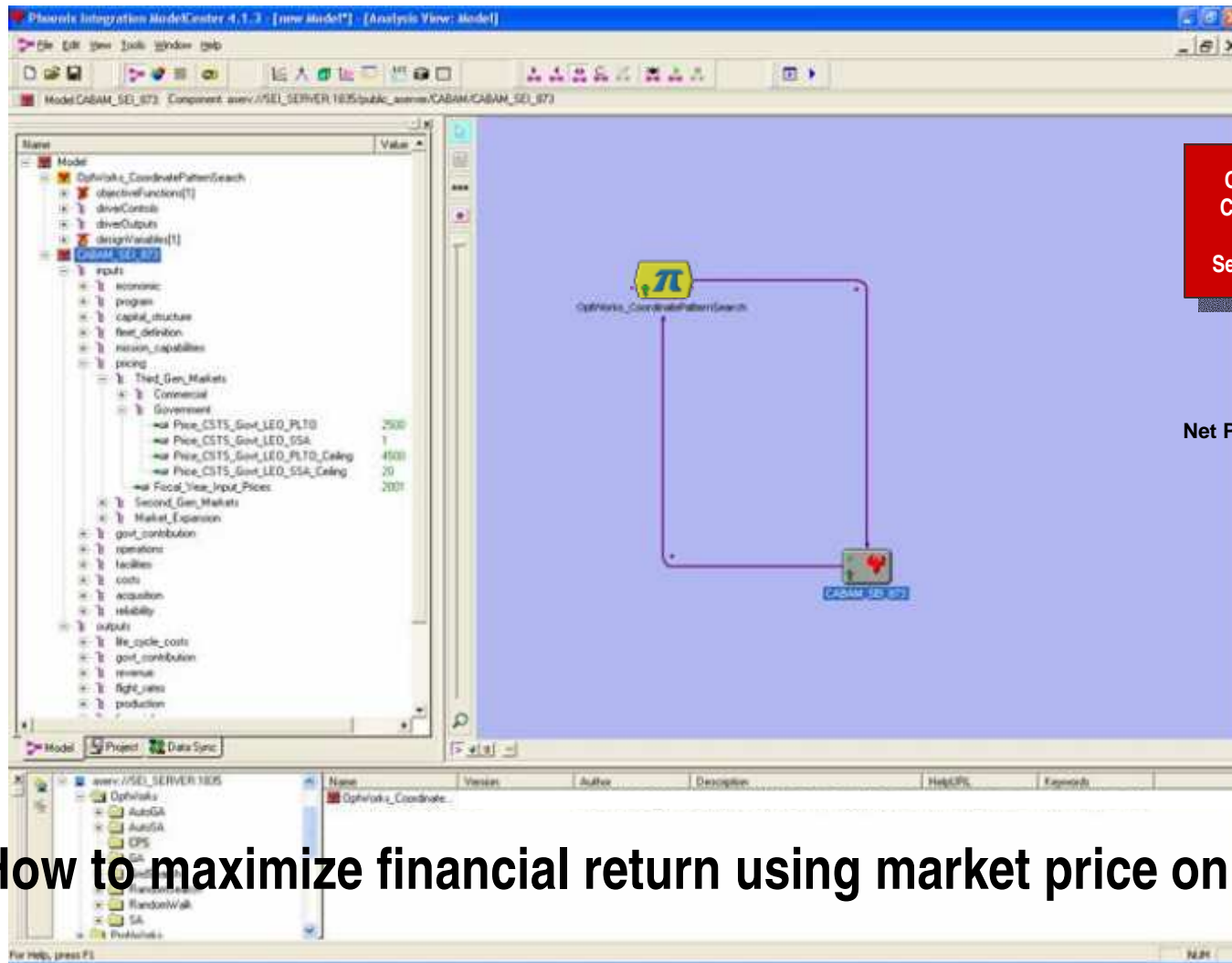
- ▶ Performs a basic grid search, checking all combinations of all design variables at specified intervals
- ▶ Useful for exploring design space or locating promising regions of space
- ▶ Not the most efficient at finding best value of objective
- ▶ Exactness (significant digit) of results is dependent upon grid resolution
- ▶ Can find several minima and therefore can be used on multi-modal problems
- ▶ Because it searches every combination of every setting of every design variable, requires many function calls for problems with many design variables





OptWorks Case Studies

Case Study: Economic Optimization

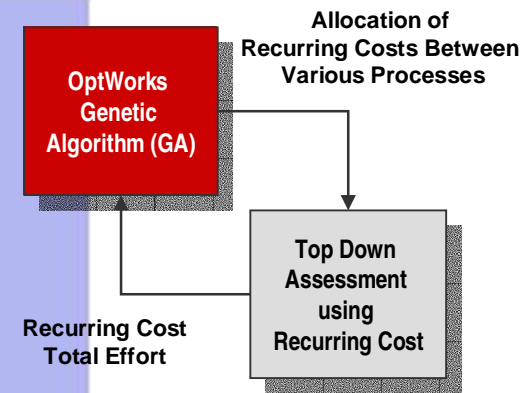
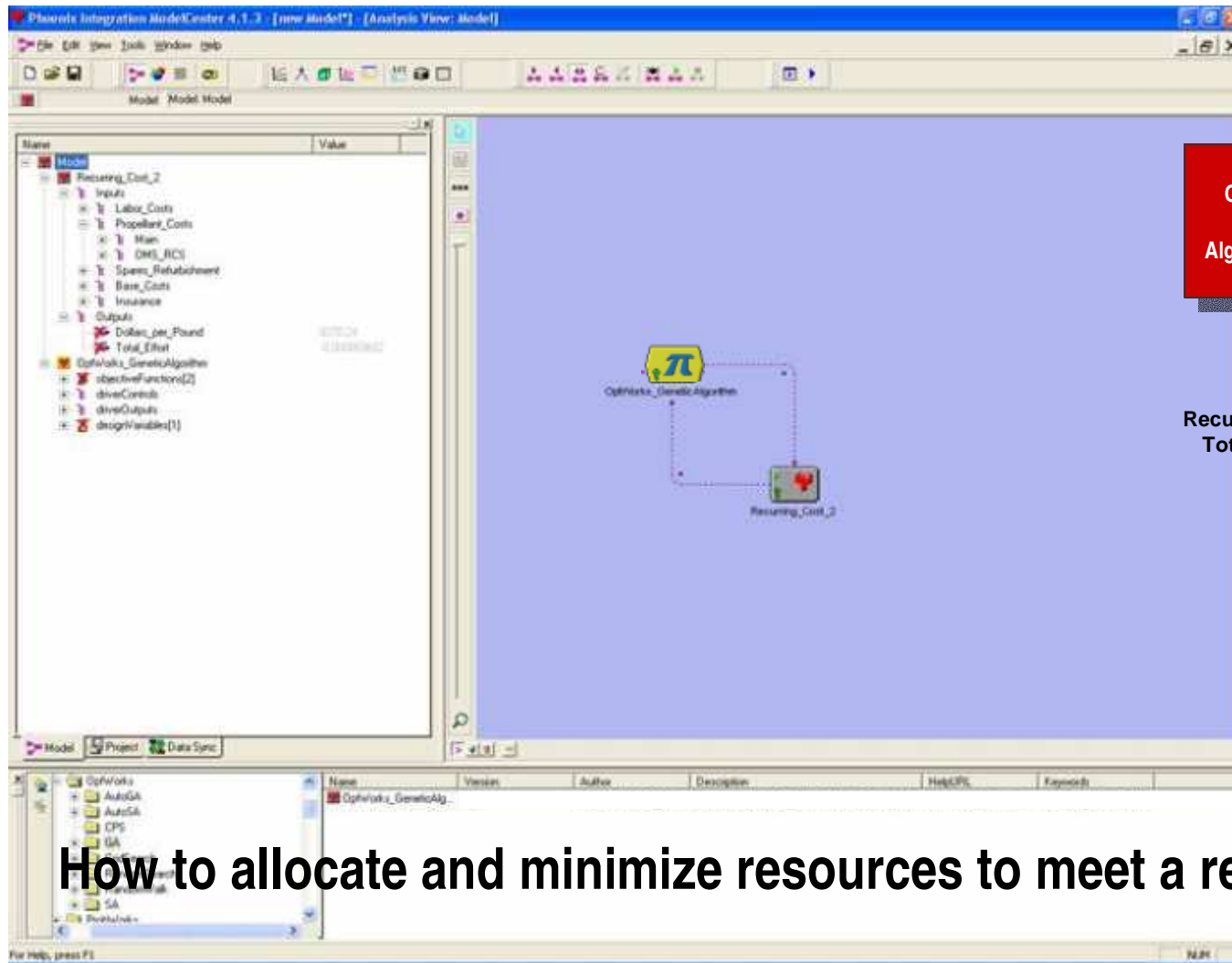


Why OptWorks?

Multi-modal problem
Discrete jumps in objective

How to maximize financial return using market price on an economics model

Case Study: Top Down Assessment of a Goal

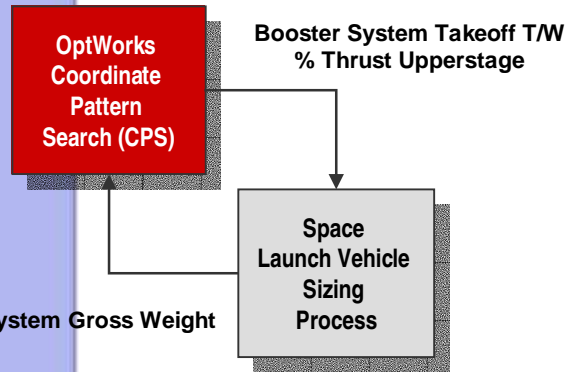
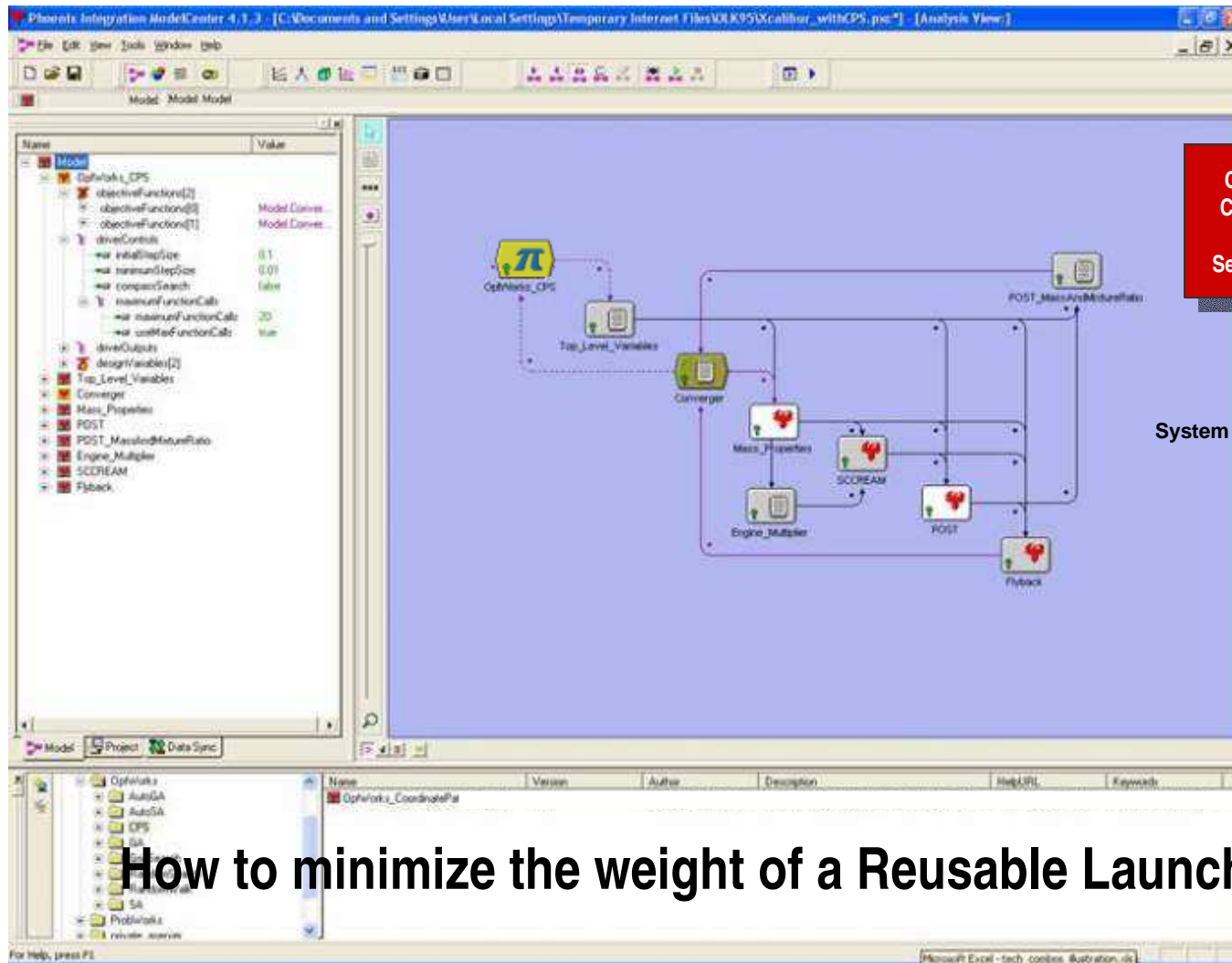


Why OptWorks?

Vast design space
Multi-modal problem

How to allocate and minimize resources to meet a recurring cost goal

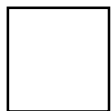
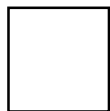
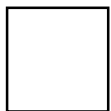
Case Study: Vehicle Sizing



Why OptWorks?

Expensive function calls
Noisy gradient calculations

How to minimize the weight of a Reusable Launch Vehicle (RLV)



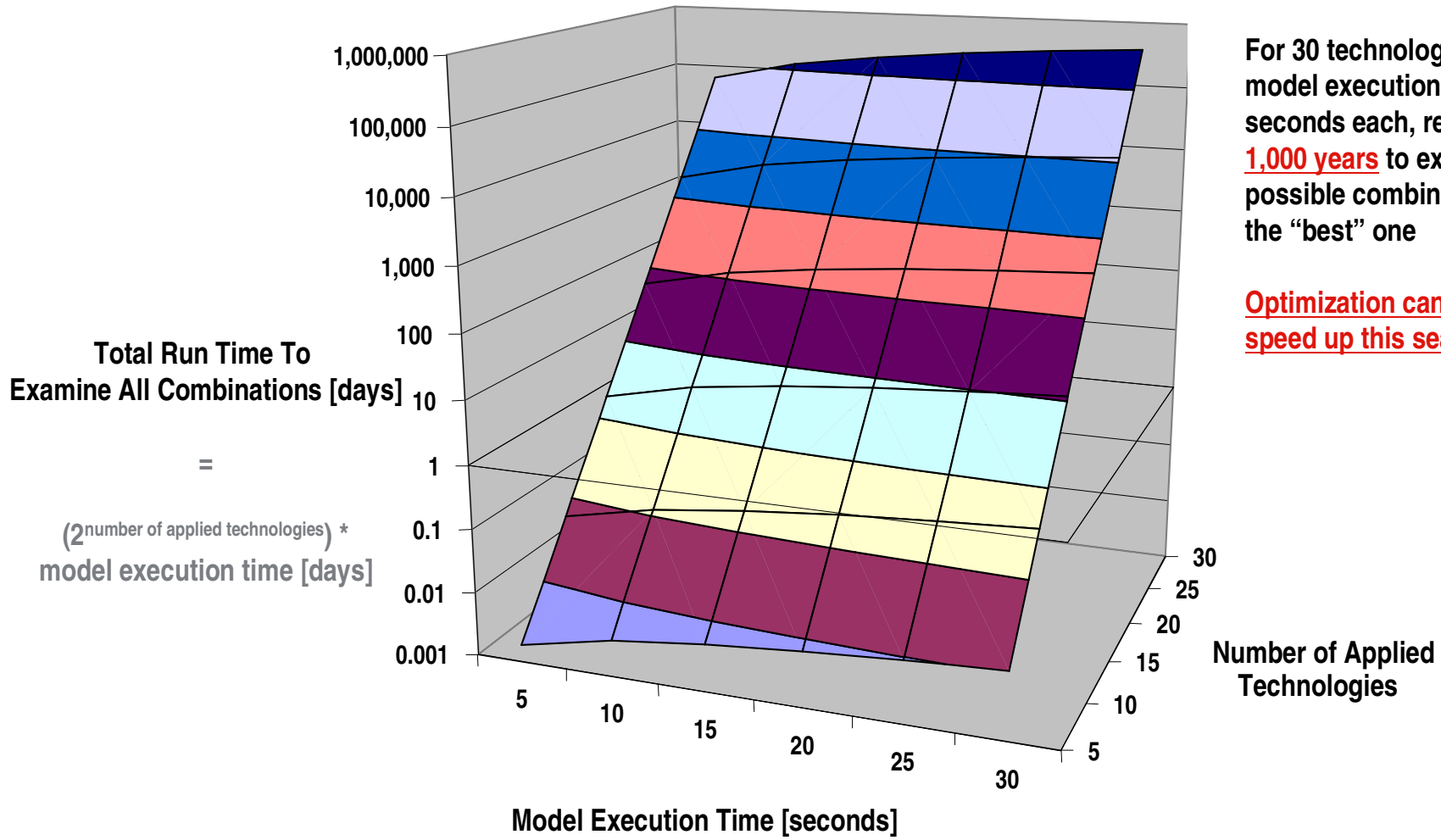
OptWorks Demonstration

- Future?** - **Ubiquitous Space Transportation Systems**
- Need?** - **Revolutionary Improvements in Enabling and Enhancing Technologies**
- Mechanisms?** - **Technology Maturation**
- Resources?** - **Limited Public and Private Outlays**
- Techniques?** - **Knowledge Inherent in Engineering Models**



Technology Prioritization

Why Optimization Is Required



For 30 technologies at a model execution time of 30 seconds each, requires over **1,000 years** to examine all possible combinations to find the “best” one

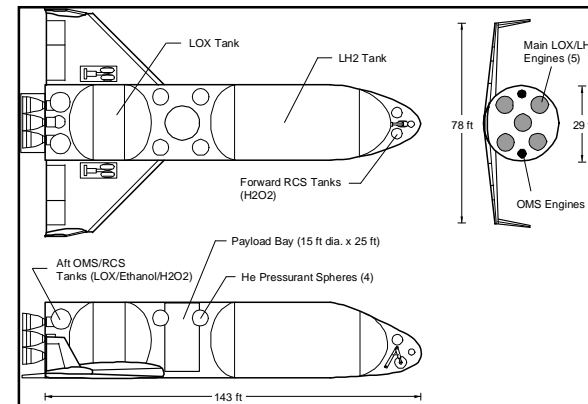
Optimization can dramatically speed up this search process

Prioritization of Enhancing Technologies Using a Genetic Algorithm (GA)

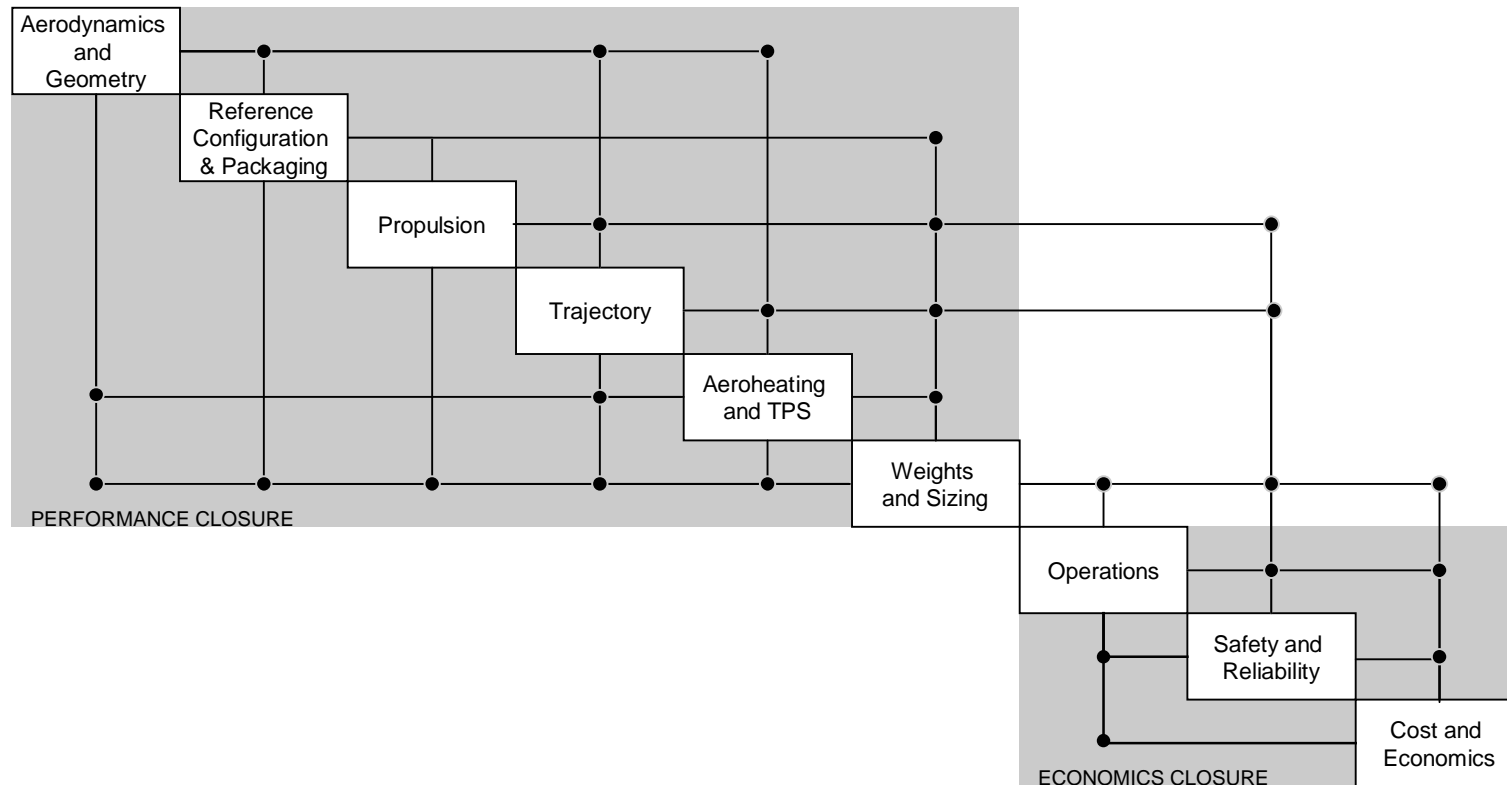
- ▶ Prioritize technologies based upon output metrics and funding levels to determine optimum portfolios of future technologies on which to pour investment dollars
- ▶ Simulate addition of various enhancing technologies upon the design of a future Reusable Launch Vehicle (RLV)
- ▶ Six engineering disciplines using ROSETTA model used to simulate life cycle performance and metrics assessment
- ▶ Genetic Algorithm (GA) optimizer utilizes properties of natural selection found in biological evolution (GA from OptWorks software suite)
- ▶ GA selects enhancing technology portfolios that do not exceed funding levels
- ▶ Prioritization performed in Phoenix Integration's ModelCenter© collaborative design environment

Design Study: ACRE-92 Reusable Launch Vehicle (RLV)

Item	Characteristics
Concept	Single-Stage-To-Orbit (SSTO) Vertical Take-Off Horizontal Landing (VTHL) Earth-To-Orbit (ETO) Reusable Launch Vehicle (RLV); commercial focus with initial flight capable in 2025, technology freeze date of 2018
Reference Mission	Payload: 40k lbs. (100 nmi. @ 28.5 degrees inclination from KSC), Cargo delivery or passenger delivery and return
Propulsion	Engines: 5 Advanced Staged Combustion Engines (Pc 4000 psi, mixture ratio 6.9) Propellants: NBP LOX and NBP LH2 T/We: ~92
Sizing	GLOW: 2.3M lbs. (system), Dry Wt.: 224k lbs Length: 163 ft
Analyses Performed	Creation of ROSETTA analysis model for probabilistic examination; modeled in ModelCenter distributed framework with eight disciplines



Typical Reusable Launch Vehicle (RLV) Design Structure Matrix (DSM)

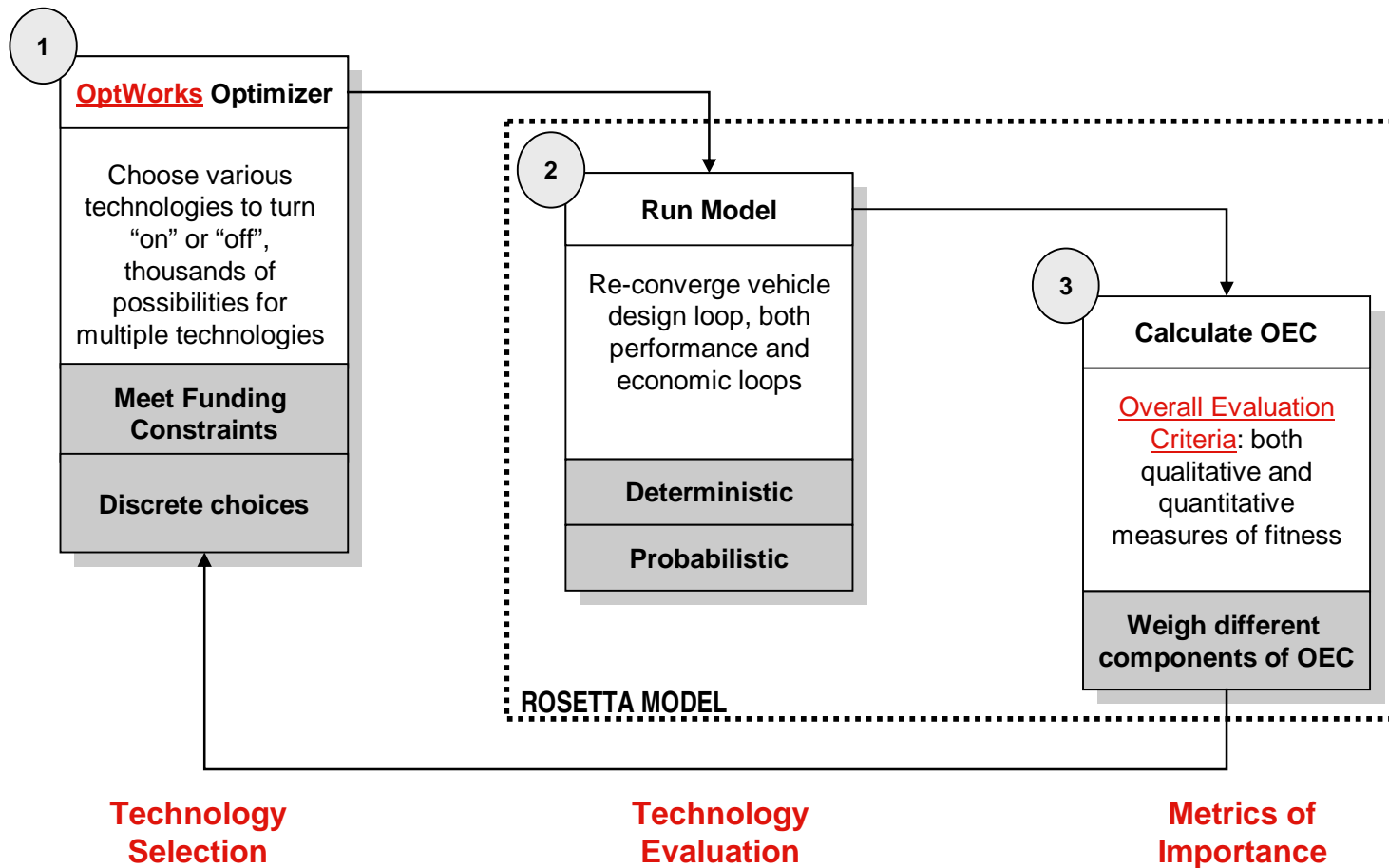


▶ Reduced Order Simulation for Evaluation of Technologies and Transportation Architectures (ROSETTA)

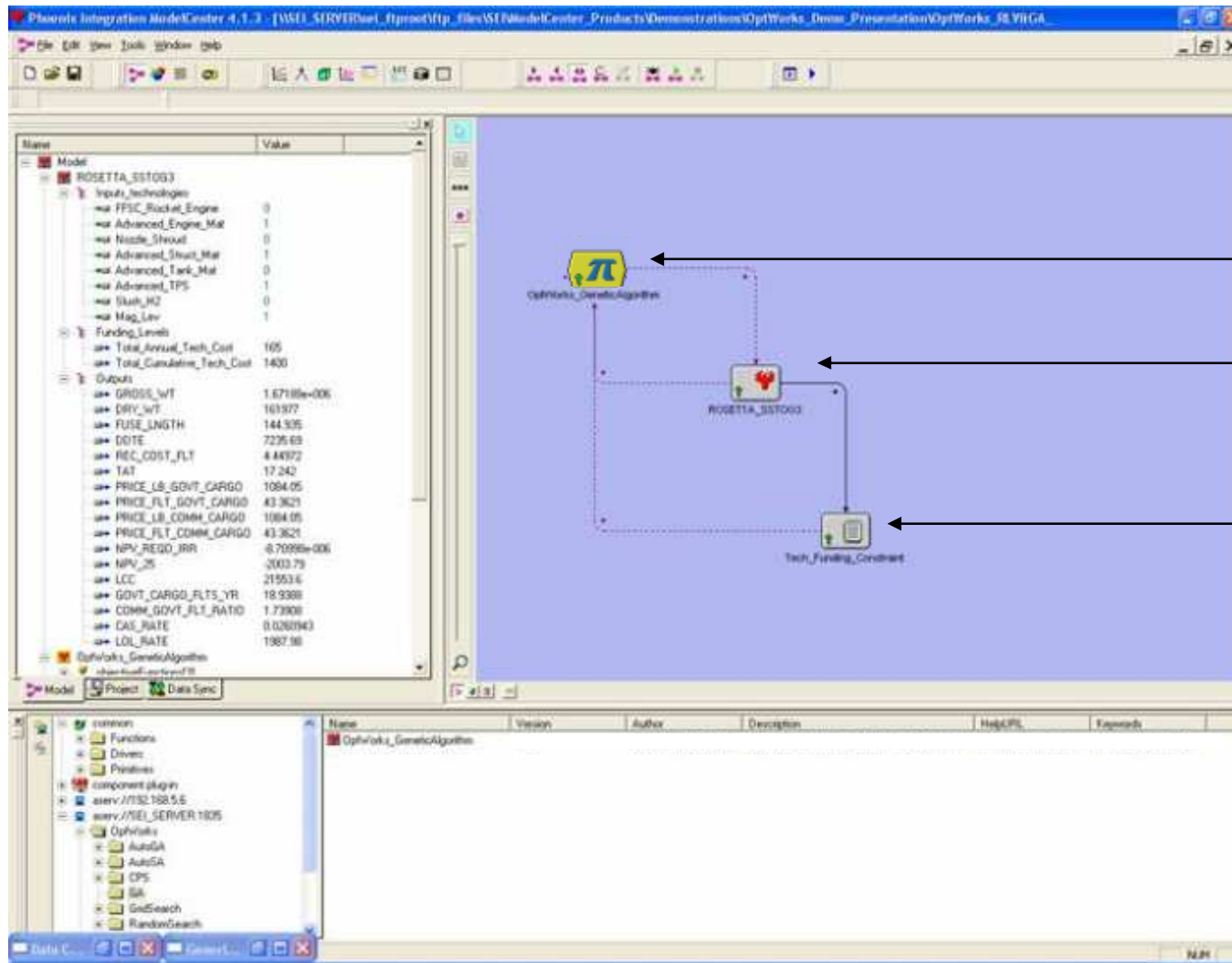
- Spreadsheet-based meta-model representing design process for specific architecture
- Traditional design discipline represented as contributing analysis

Optimization of Project Metrics Using Enhancing Technologies

What are the optimum combination of technologies that maximize the OEC?



OptWorks Demonstration in ModelCenter® Environment



OptWorks Genetic Algorithm (GA)

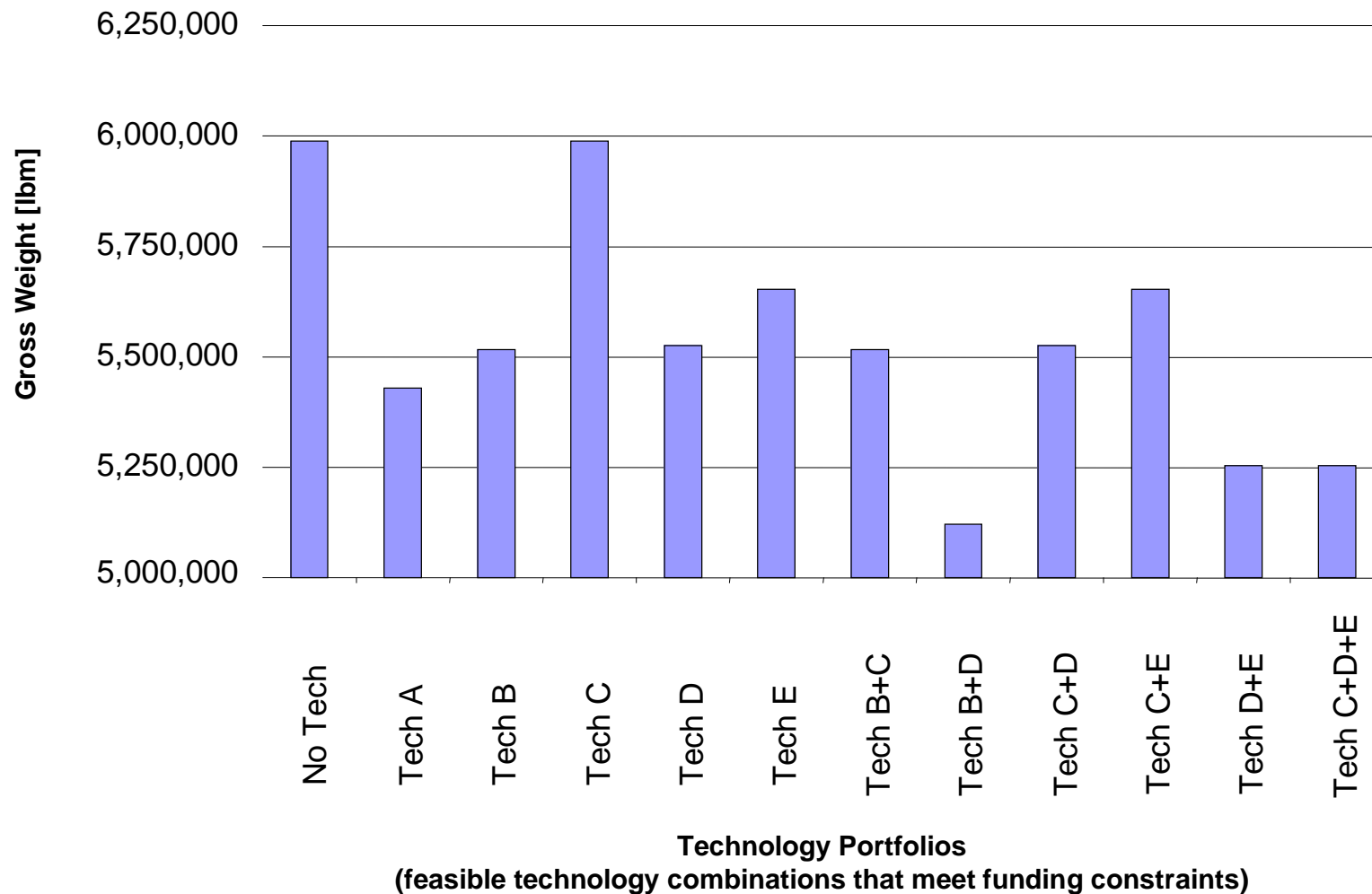
ROSETTA Model

Technology Investment Funding Constraint

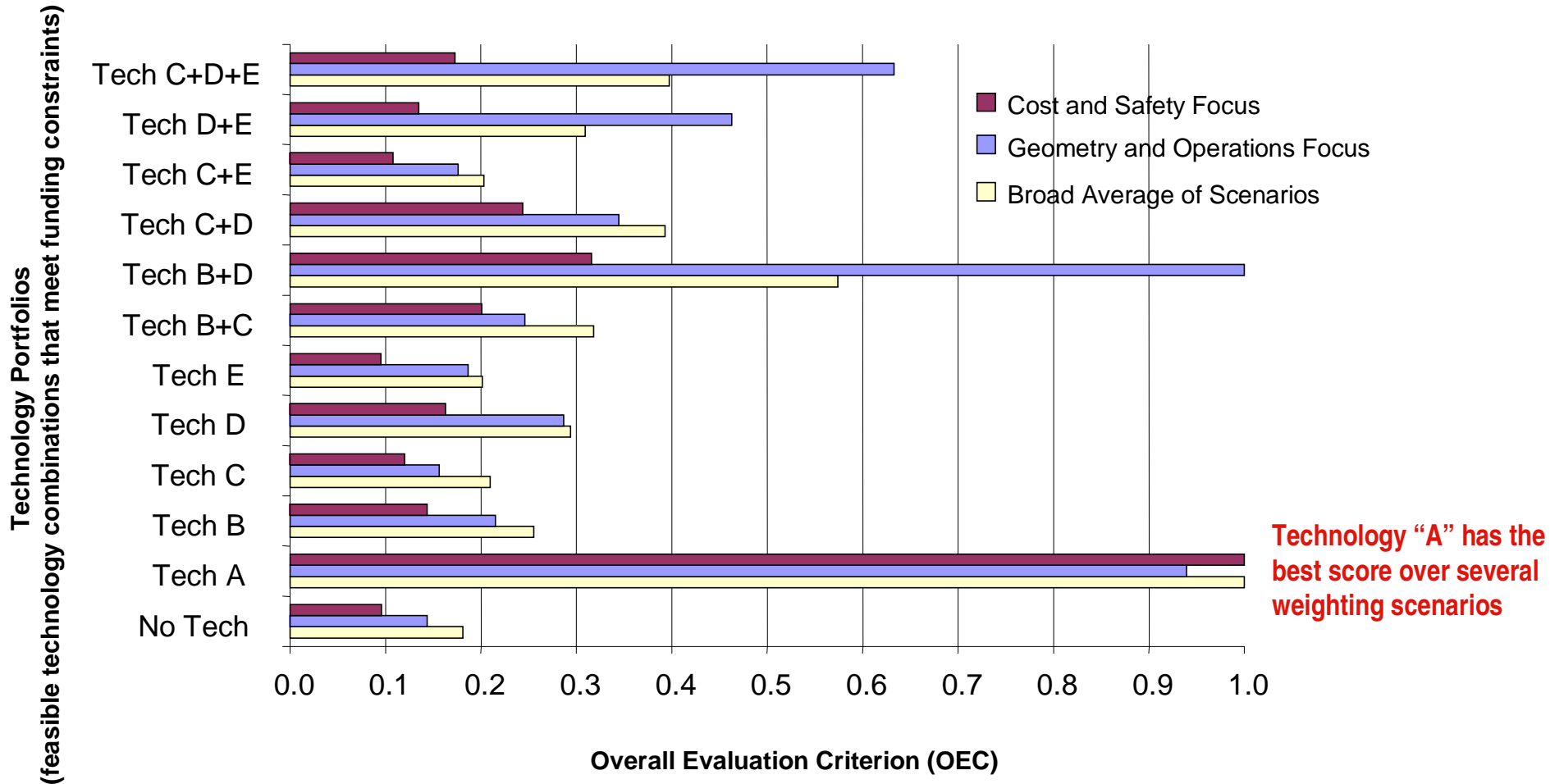
Why OptWorks?

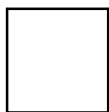
- Discrete variables
- Vast design space
- Multi-modal problem

Outputs from the Process: Technology Selection Using One Metric



Outputs from the Process: Technology Selection Using Multiple Metrics





Summary



OptWorks: ModelCenter[®], suite consists of **eight non-gradient based optimizers** implemented as Java-based components which can function on any platform running Phoenix Integration's ModelCenter[®] or Analysis Server[®]. OptWorks: ModelCenter[®], easy to implement as drag-and-drop components for harder to solve problems where traditional (gradient-based) methods are not useful.

Phoenix-Integration, Inc. serves as the primary reseller for Pi Blue's Optworks: ModelCenter[®], and ProbWorks: ModelCenter[®], products. For sales and pricing info, please contact sales@phoenix-int.com or call Phoenix Integration at 1.800.500.1936. Individual and discounted division-wide licenses with annual maintenance plans are available. Individual-user licenses are priced at \$1999.00 (one-time charge).



Conclusion



Pi Blue Software, Inc. introduces a new suite of uncertainty and sensitivity analysis tools for use with Phoenix Integration's ModelCenter[®] collaborative design environment.

Entitled ProbWorks: ModelCenter[®], this suite consists of four tools to help employ uncertainty analysis techniques, each implemented as a Java-based component which can function on any platform running Phoenix Integration's ModelCenter[®] and Analysis Server[®].



ProbWorks: ModelCenter

ProbWorks: ModelCenter
version 1.1

ProbWorks: ModelCenter® is a suite of probabilistic analysis tools for use with Ptolemy Integration Optimizer® probabilistic optimization framework. Each main component has a PURPOSE listed at the top of a different page of products. The capabilities capabilities in the ProbWorks suite component are listed in the table below. The suite is used when trying to maximize the computational speed for Monte Carlo simulation. The suite enables the better DPOMD results influence as well as faster results approximation through Response Surface Approximation (RSA). Each of the capabilities in the suite is listed as a table component and can be toggled on/off only a transactional model for a user in some design cases.

COMPONENT NAME	CAPABILITY
ProbWorks_MonteCarlo	Performs Monte Carlo analysis simulation using random numbers to create distributions normal, lognormal, Weibull, etc. on input parameters based on the known sample average, mean, standard deviation, etc. to be simulated in running.
ProbWorks_DPOMD	Implements the Efficient Probability Output Method (EPOMD) technique that generates an approximation of the output distribution for a given number of iterations. When simulation is completed, the output is a small number of iterations.
ProbWorks_ResponseSurface	Determines the correlation of variables of each model input with respect to each selected output with appropriate fitting of continuous, discrete of discrete Pareto results in RSA form.
ProbWorks_RiskAnalysis	Performs probabilistic regression analysis to approximate the results of the simulation. Generates a set of polynomial response surface equations (RSEs) and Pareto sensitivity analysis.

SYSTEM REQUIREMENTS:
ProbWorks: ModelCenter® does not require any hardware that supports Ptolemy Integration Optimizer, version 2.0 or greater.

ORDERING AND PRICING:
Ptolemy Integration, Inc. is the primary supplier for Pi Blue Software, ModelCenter® and ProbWorks: ModelCenter® products. For sales and pricing info, please contact sales@piblue.com or call Ptolemy Integration at 1-800-353-1144. Individual and development licenses are available with volume discounts. Prices are available. Individual user licenses are priced at \$1,995 US (excluding charge).

OTHER PI BLUE SOFTWARE PRODUCTS:
Pi Blue Software, Inc. develops software products targeted at professionals and students in the engineering, financial, accounting, logistics, materials, mathematics, and robotics fields. Our current product includes the iQWorks suite of domain spanning optimization algorithms and the ProbWorks suite of tools for risk based analysis.

TRAINING AND CONSULTING:
Pi Blue Software, Inc. offers specialized training related to ModelCenter® and suite of the suite of components as well as consulting services for subsequent application to systems engineering and optimization.

TECHNICAL SUPPORT:
Pi Blue Software, Inc. offers customer service technical support for all products. These include FAQs, white papers, and an online support center.

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11111 Main Street, Suite 100, Houston, TX 77055
www.piblue.com

The ProbWorks: ModelCenter®, suite is aimed at users who must treat **uncertainty and risk** in their product designs. The direct Monte Carlo driver and the faster DPOMD approximation driver propagate uncertainty in input parameters to assess statistical parameters such as mean, standard deviation, certainty level, and skewness. Supporting tools allow for the generation of fast-acting polynomial response surface equations (RSEs) and Pareto sensitivity analysis.

This package is currently available for purchase through **individual/group site licenses**. The full product suite includes optimizers in Java byte code, documentation with case study examples, and selected online support.



ProbWorks: ModelCenter Capabilities

Pi Blue Software, Inc.

Contact Information

Business Address:

Pi Blue Software, Inc.
170 Park Creek Drive
Alpharetta, GA 30005 U.S.A.

Internet:

WWW: www.piblue.com
E-mail: sales@piblue.com