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

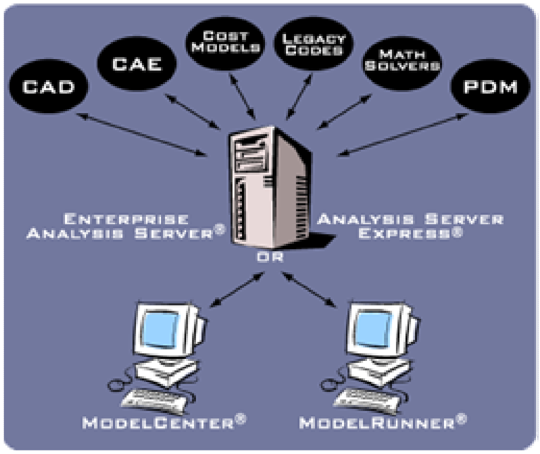
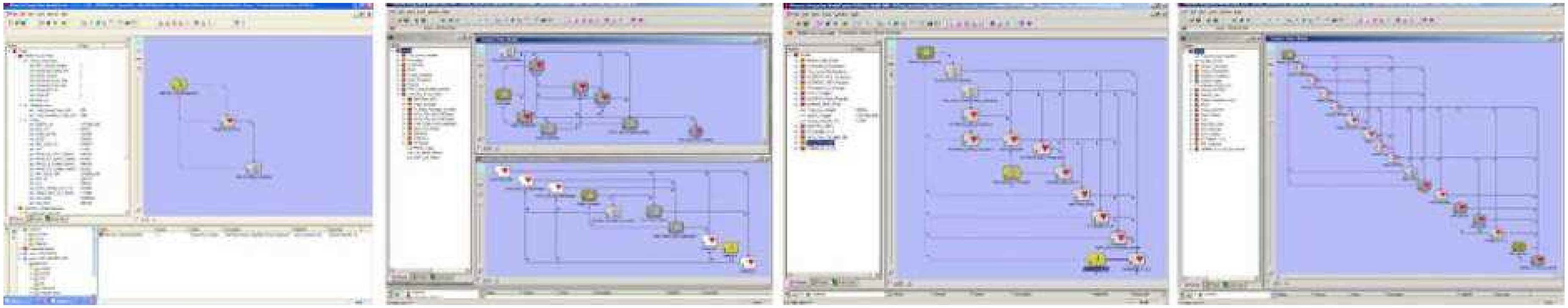


Image Source: Phoenix Integration Inc.
http://www.phoenix-int.com/products/index.html

"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


OptWorks: ModelCenter

COMPONENT NAME | CAPABILITY

SYSTEM REQUIREMENTS

ORDERING AND PRICING

OTHER PI BLUE SOFTWARE PRODUCTS

TRAINING AND CONSULTING

TECHNICAL SUPPORT

PiBlue

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

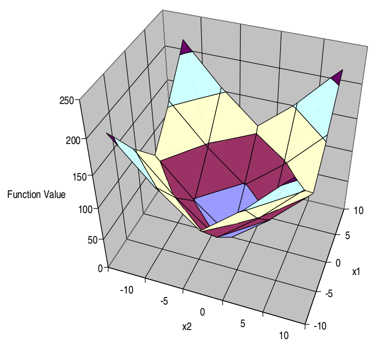
Mixed / discrete / integer variables

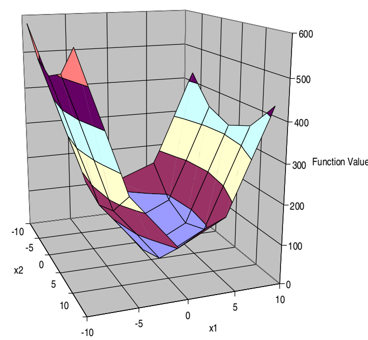
Multiple metrics

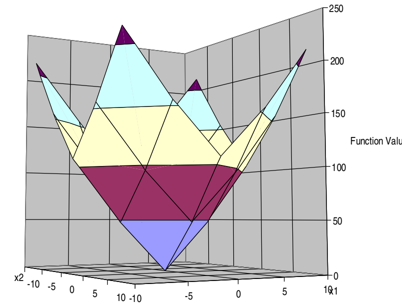
Vast design space

Multi-modal problems

Noisy gradient calculations

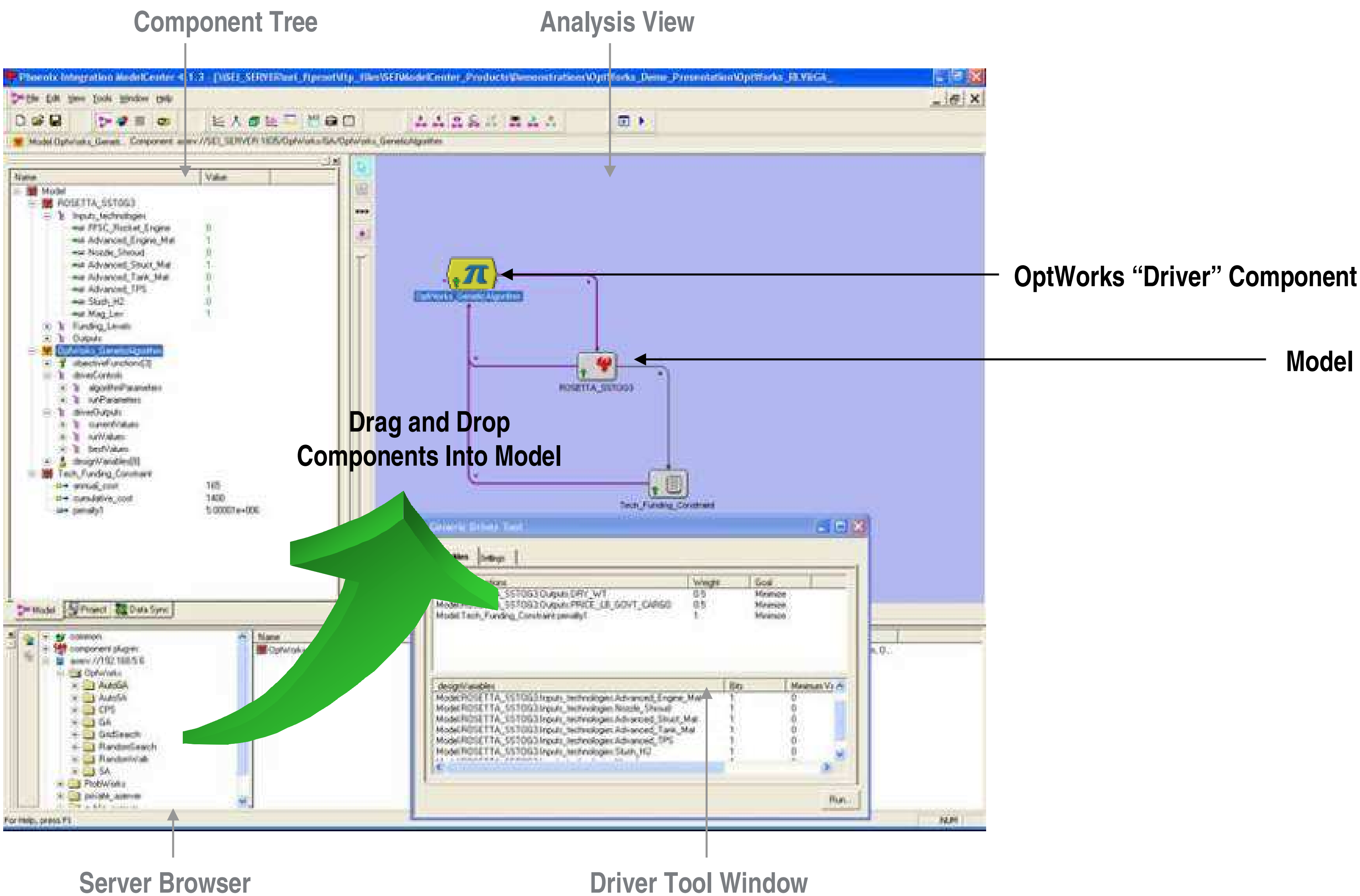




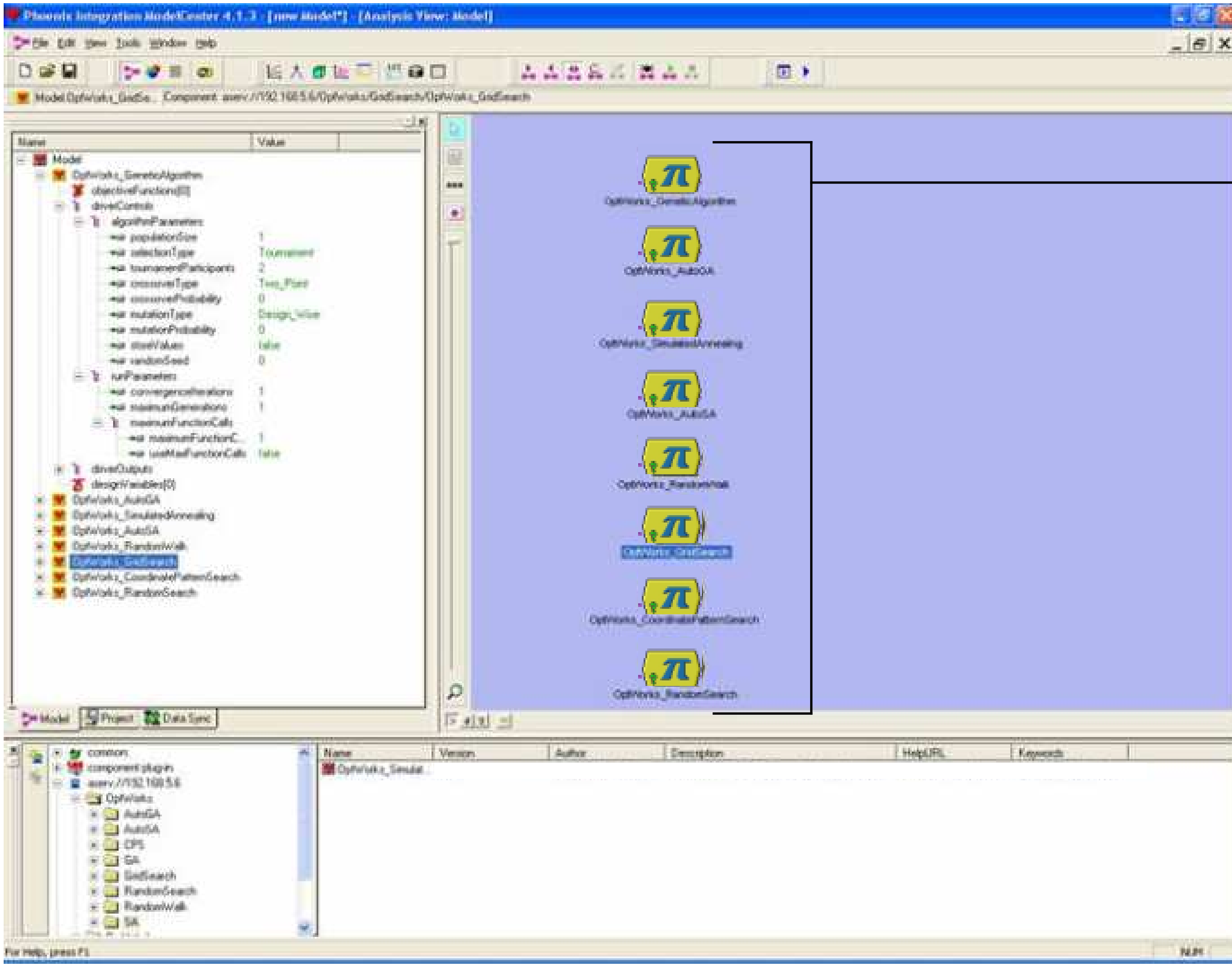


Why OptWorks?

Basic Functionality of an OptWorks Component Within ModelCenter©



OptWorks Components Available from Pi Blue Software, Inc.



OptWorks Suite

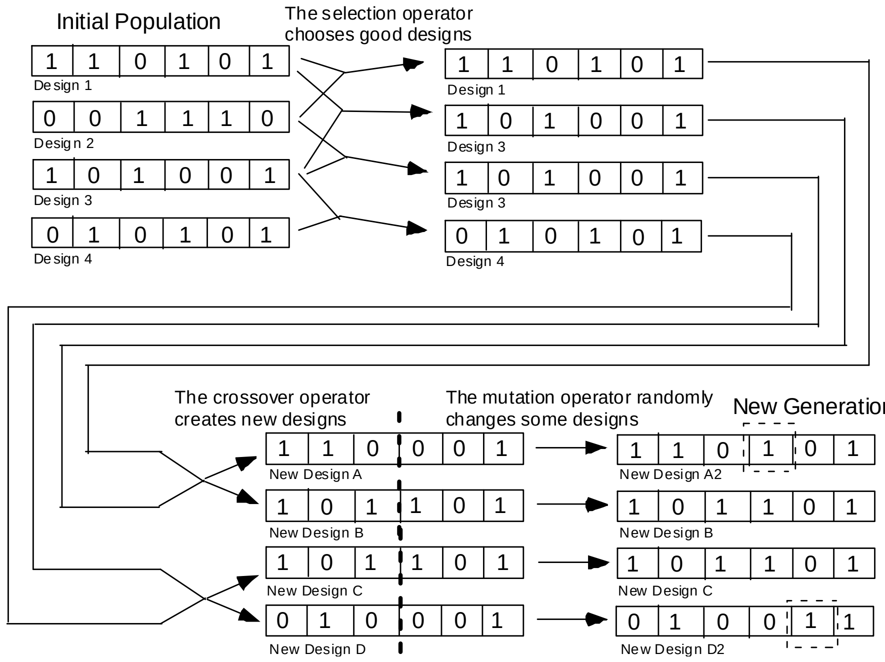
Genetic Algorithm (GA)
AutoGA
Simulated Annealing (SA)
AutoSA
RandomWalk
Coordinate Pattern Search (CPS)
RandomSearch
GridSearch

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

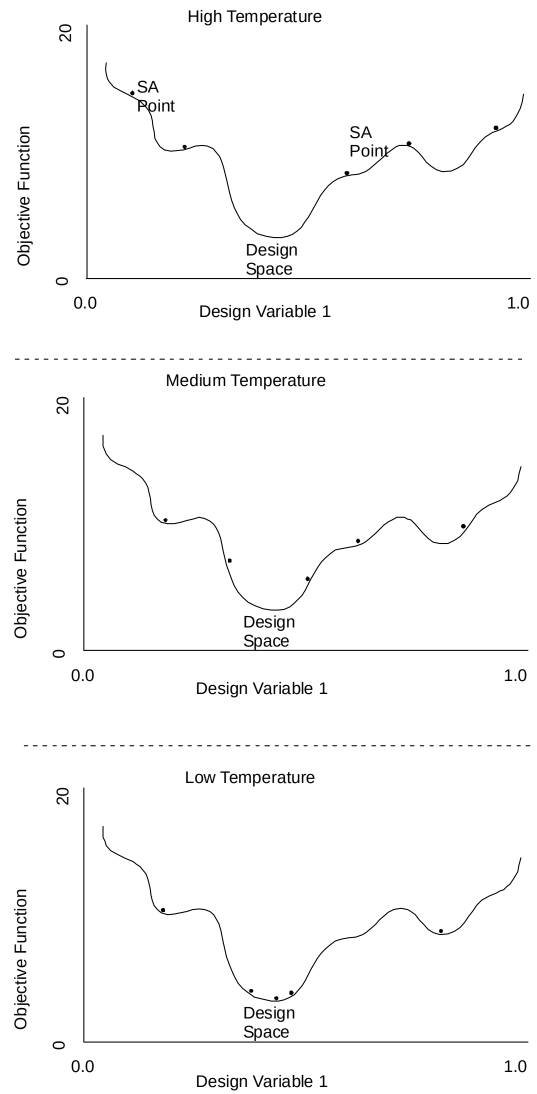
Genetic Algorithm (GA) and Auto GA

- **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**



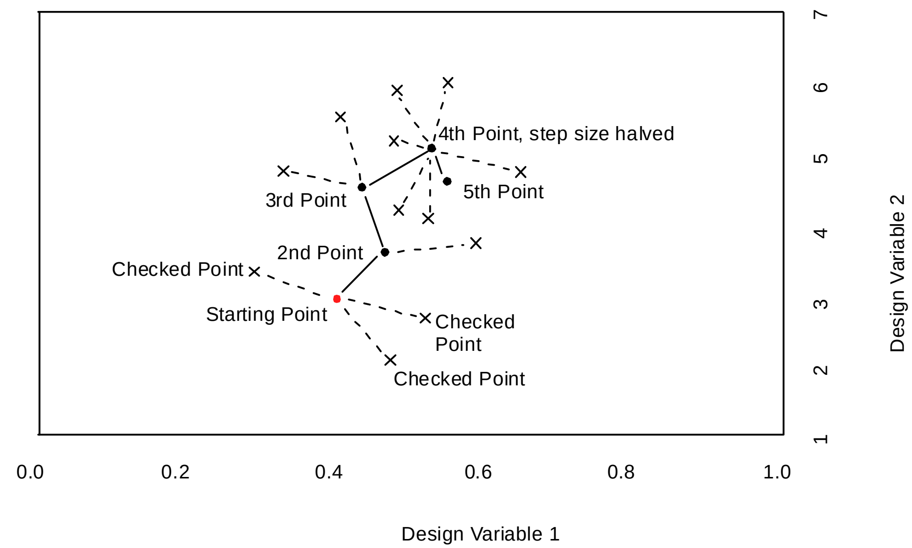
Simulated Annealing (SA) and Auto SA

- **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**



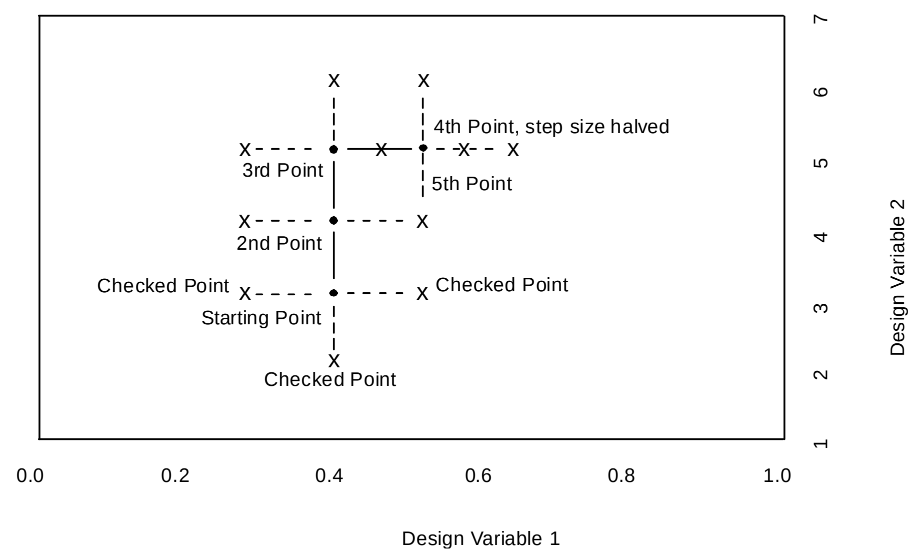
Random Walk

- 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



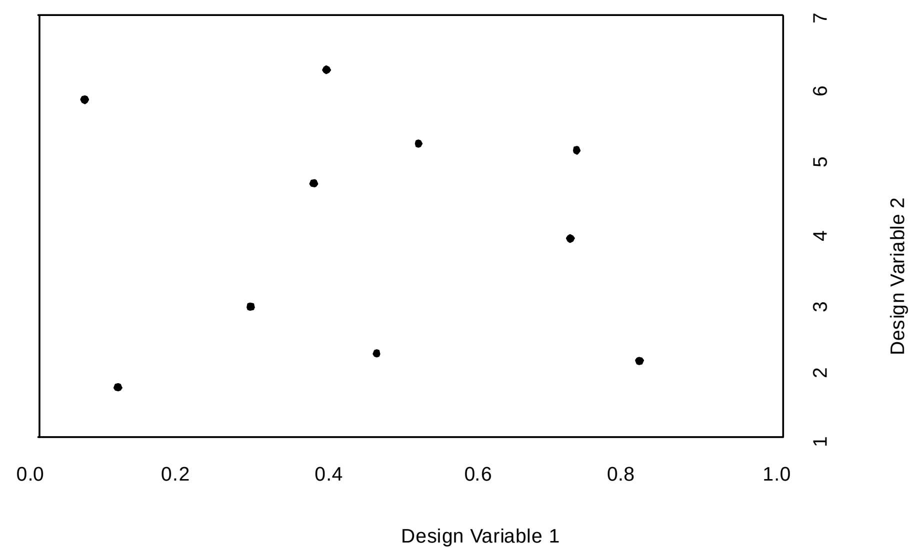
Coordinate Pattern Search (CPS)

- 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



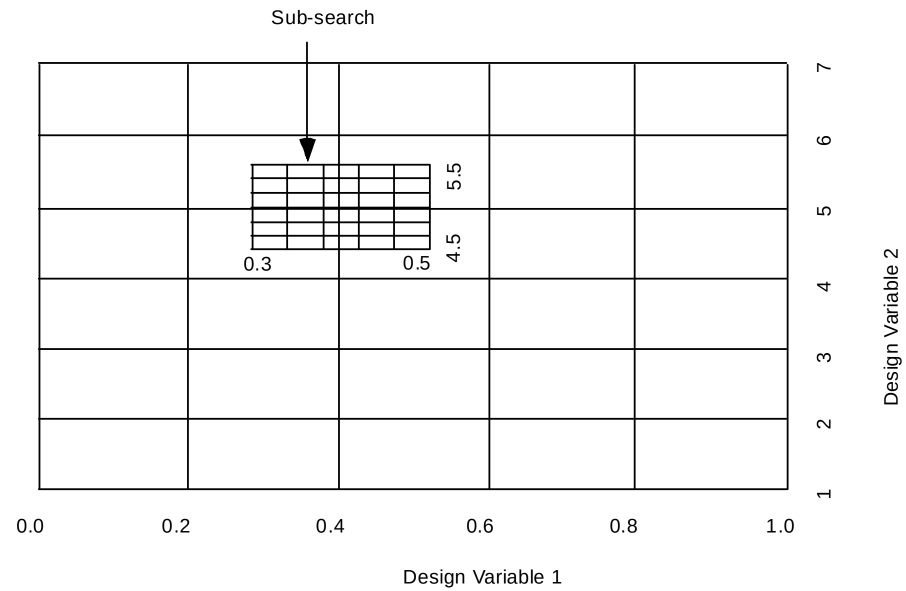
Random Search

- 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



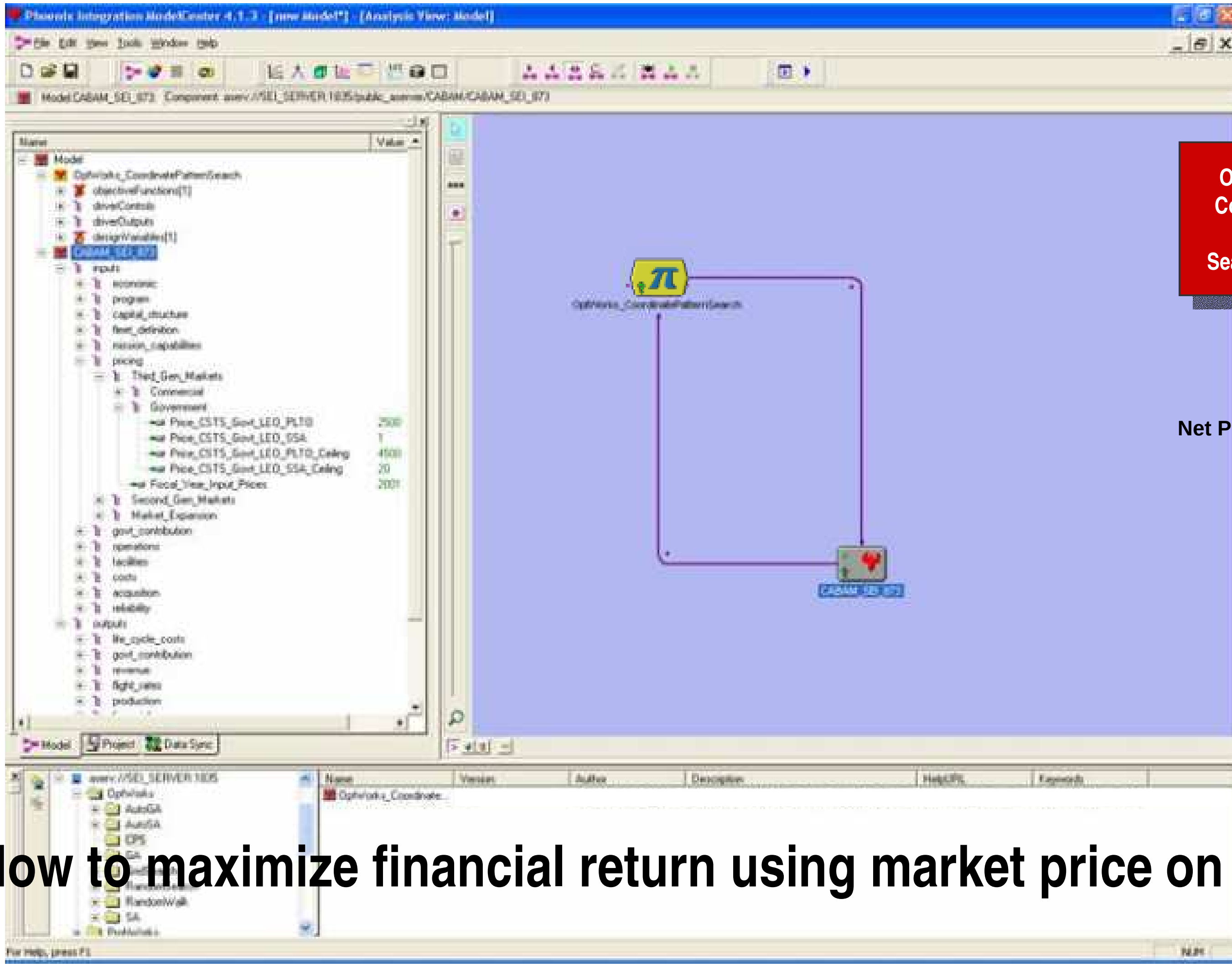
Grid Search

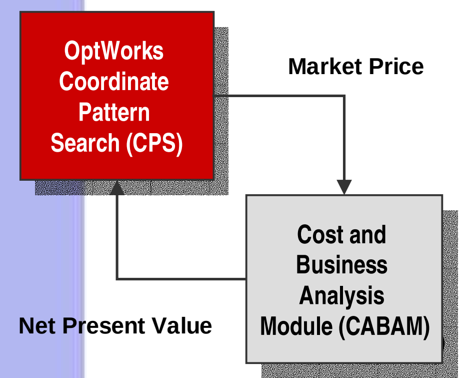
- Performs a basic grid search, checking all combinations of all design variables at specified intervals
- Useful for exploring design space or locating promising regions of space
- Not the most efficient at finding best value of objective
- Exactness (significant digit) of results is dependent upon 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



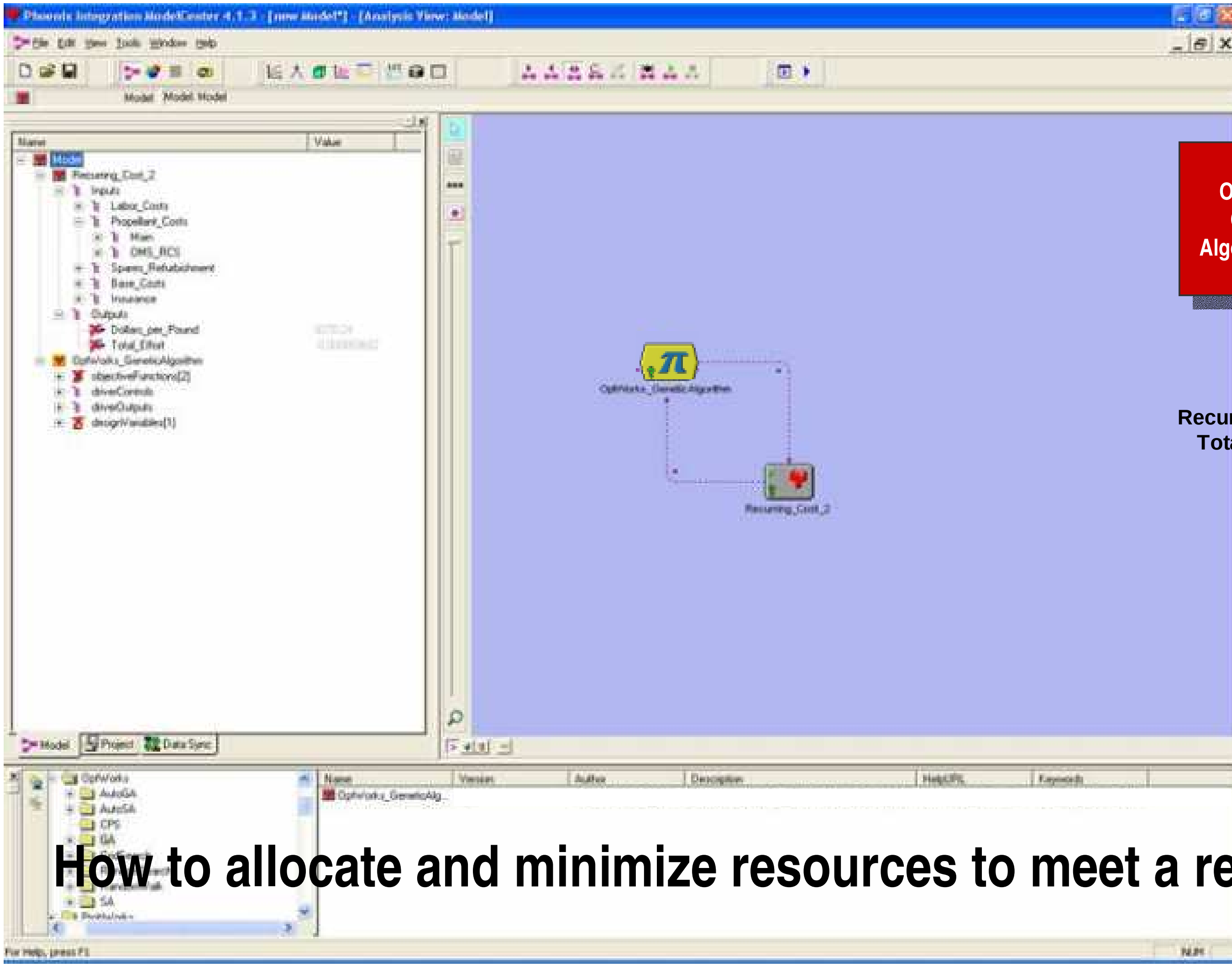


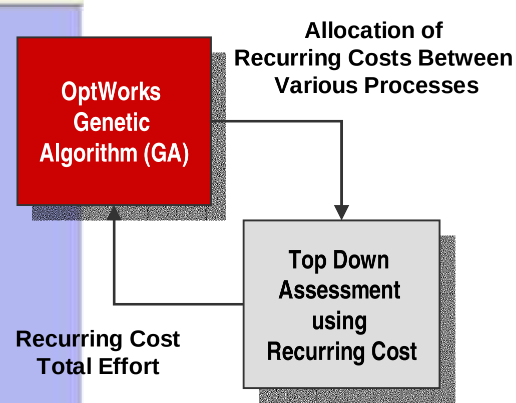
Why OptWorks?

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



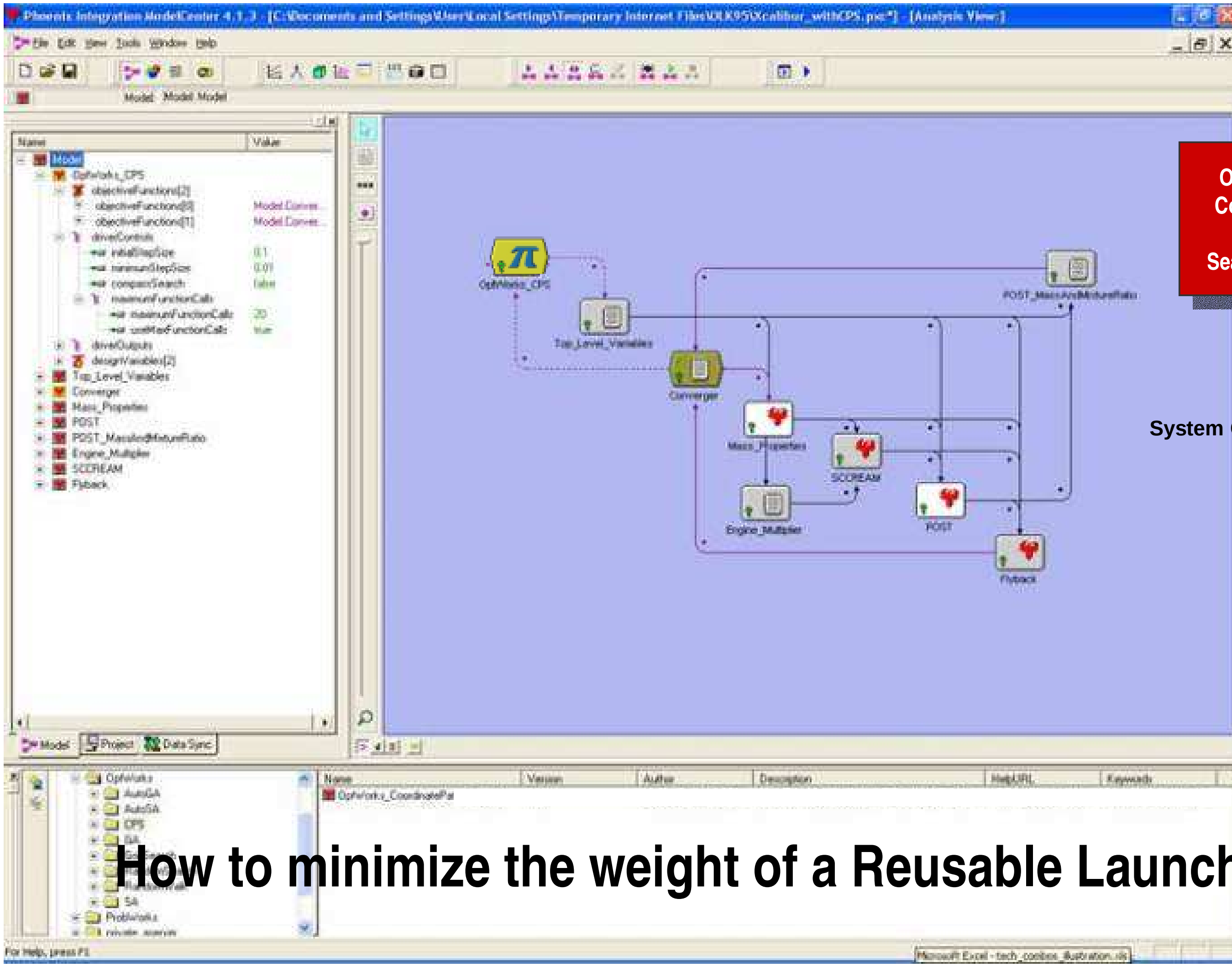


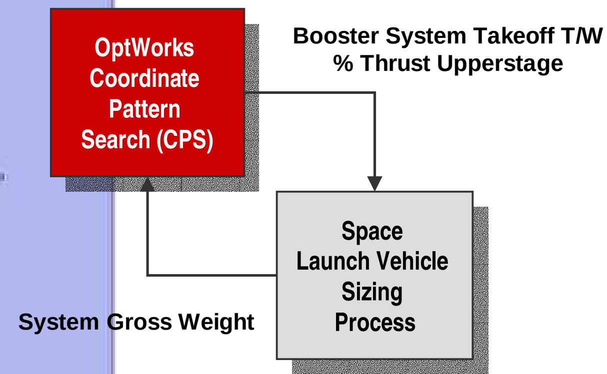
Why OptWorks?

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**

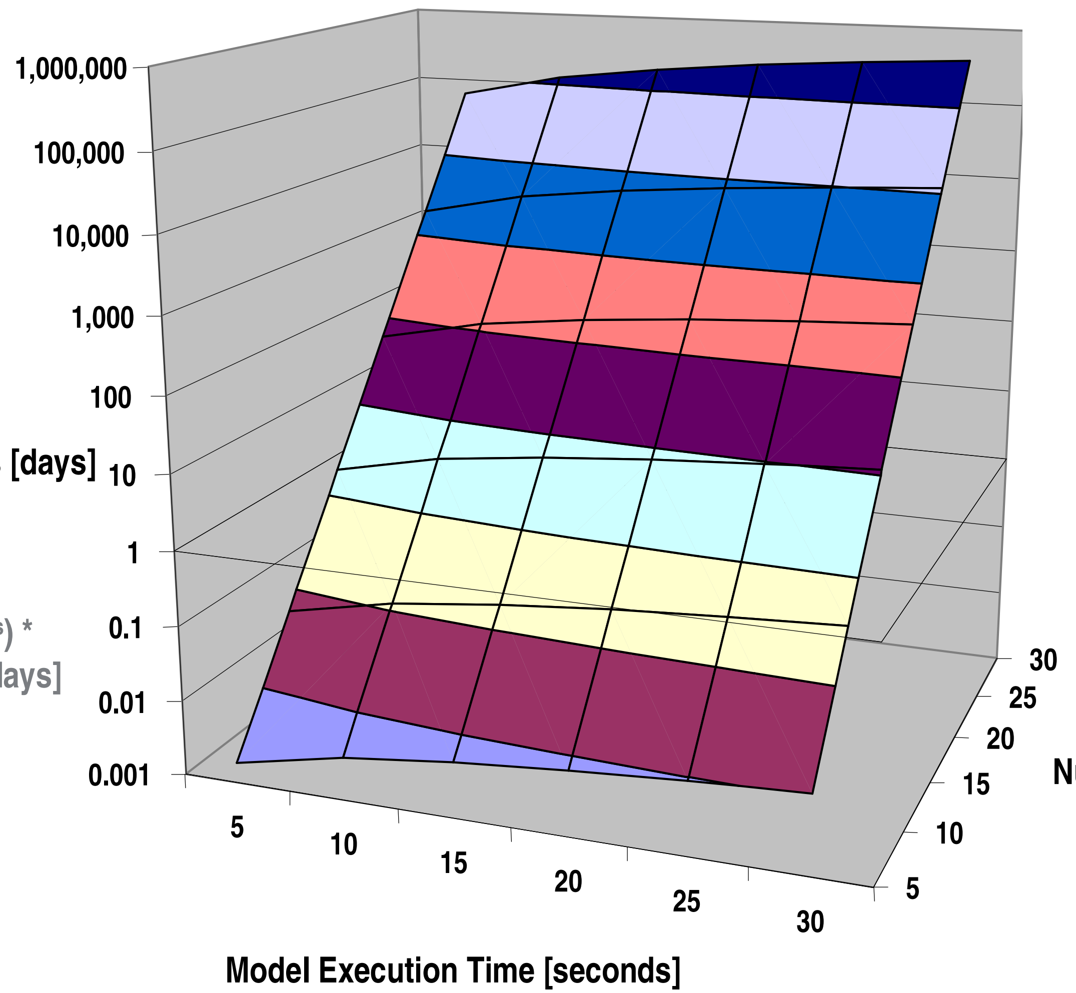
Technology Prioritization

Why Optimization Is Required

Total Run Time To Examine All Combinations [days]

=

($2^{\text{number of applied technologies}}$) * model execution time [days]



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

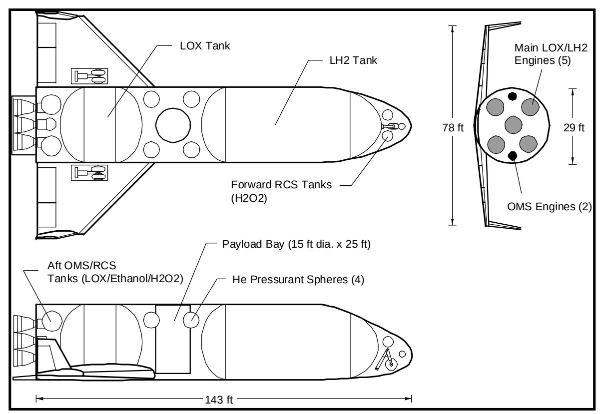
Optimization can dramatically speed up this search process

Prioritization of Enhancing Technologies Using a Genetic Algorithm (GA)

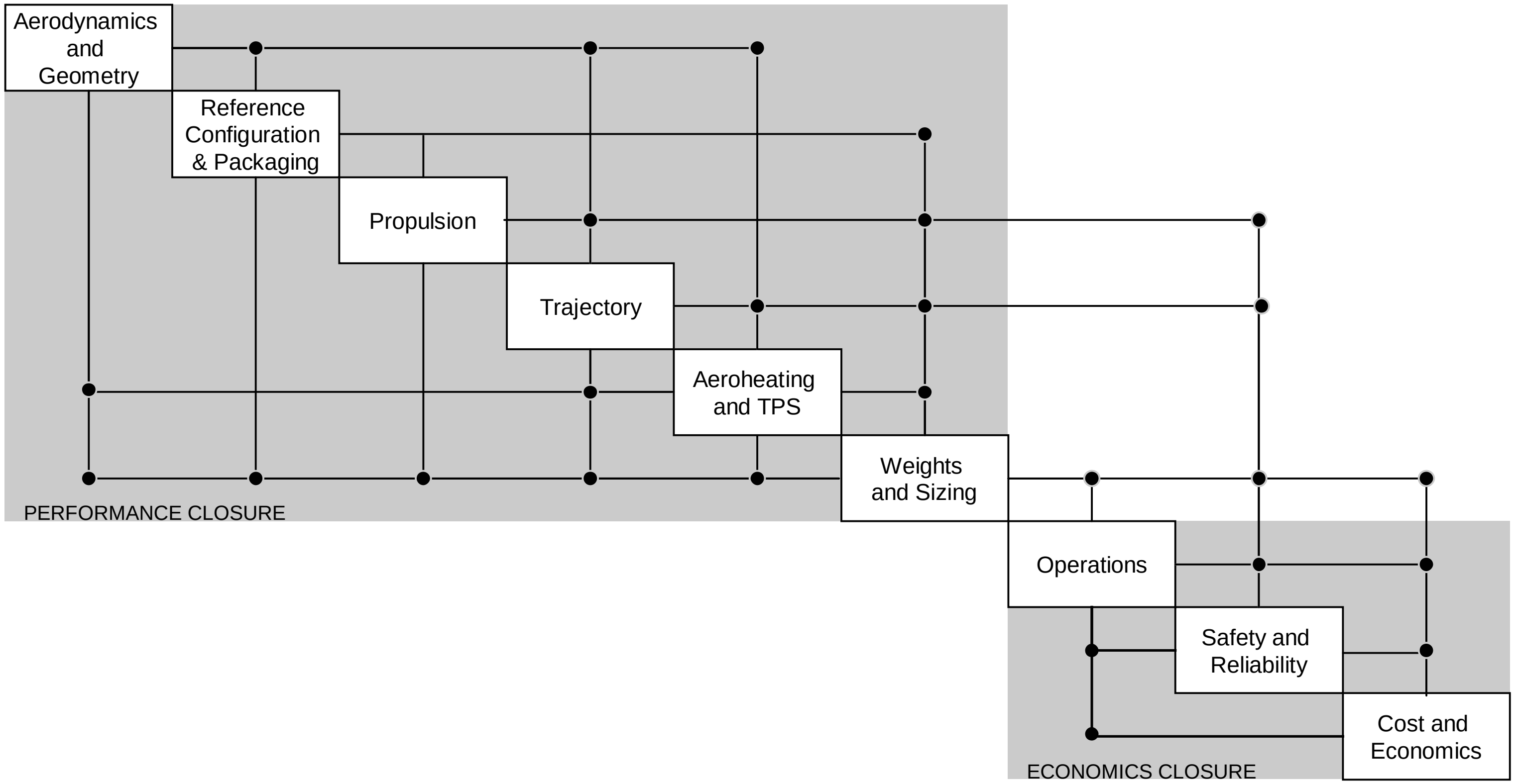
- Prioritize technologies based upon output metrics and funding levels to determine optimum portfolios of future technologies on which to pour investment dollars
- Simulate addition of various enhancing technologies upon the design of a future Reusable Launch Vehicle (RLV)
- Six engineering disciplines 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



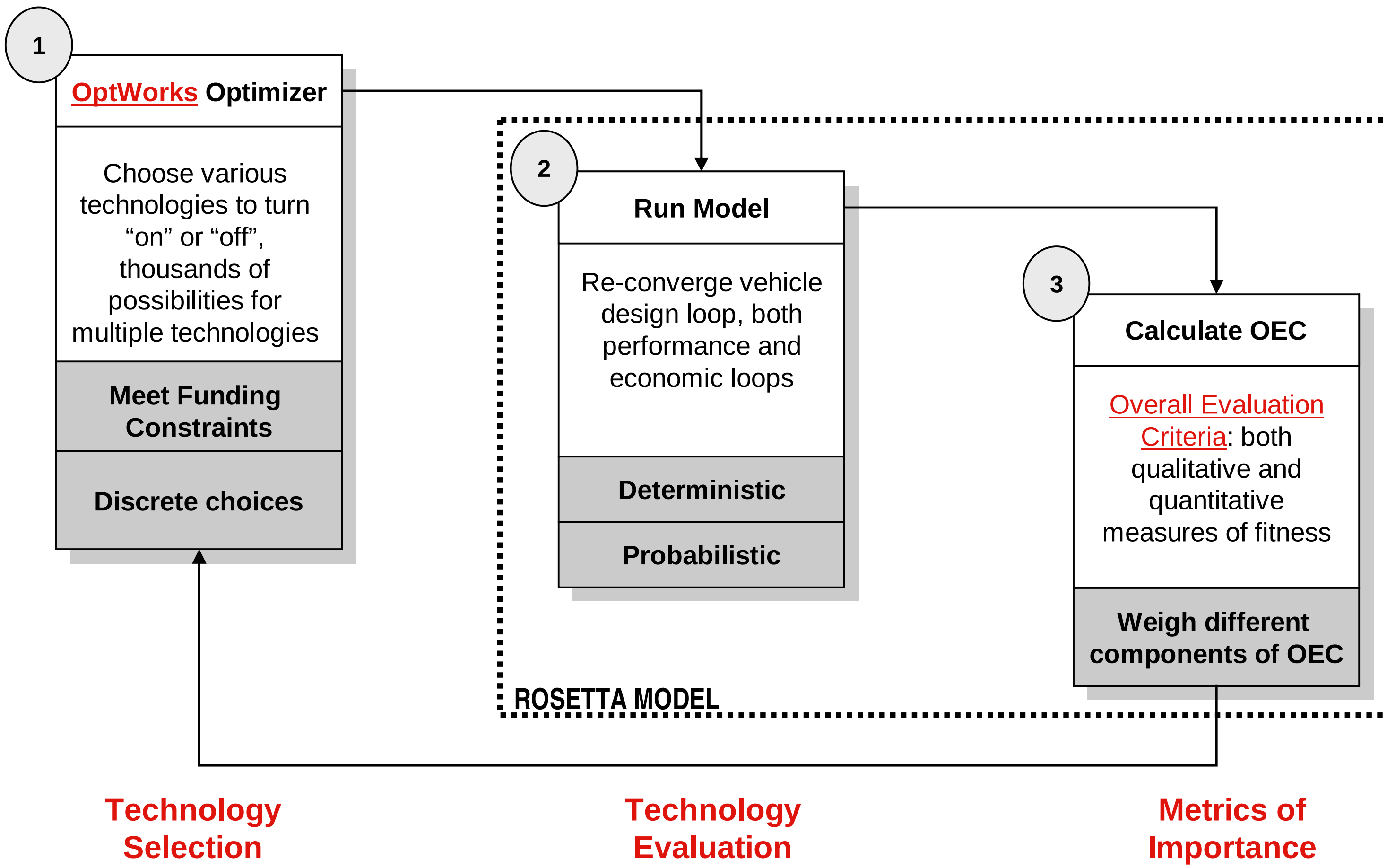
Typical Reusable Launch Vehicle (RLV) Design Structure Matrix (DSM)



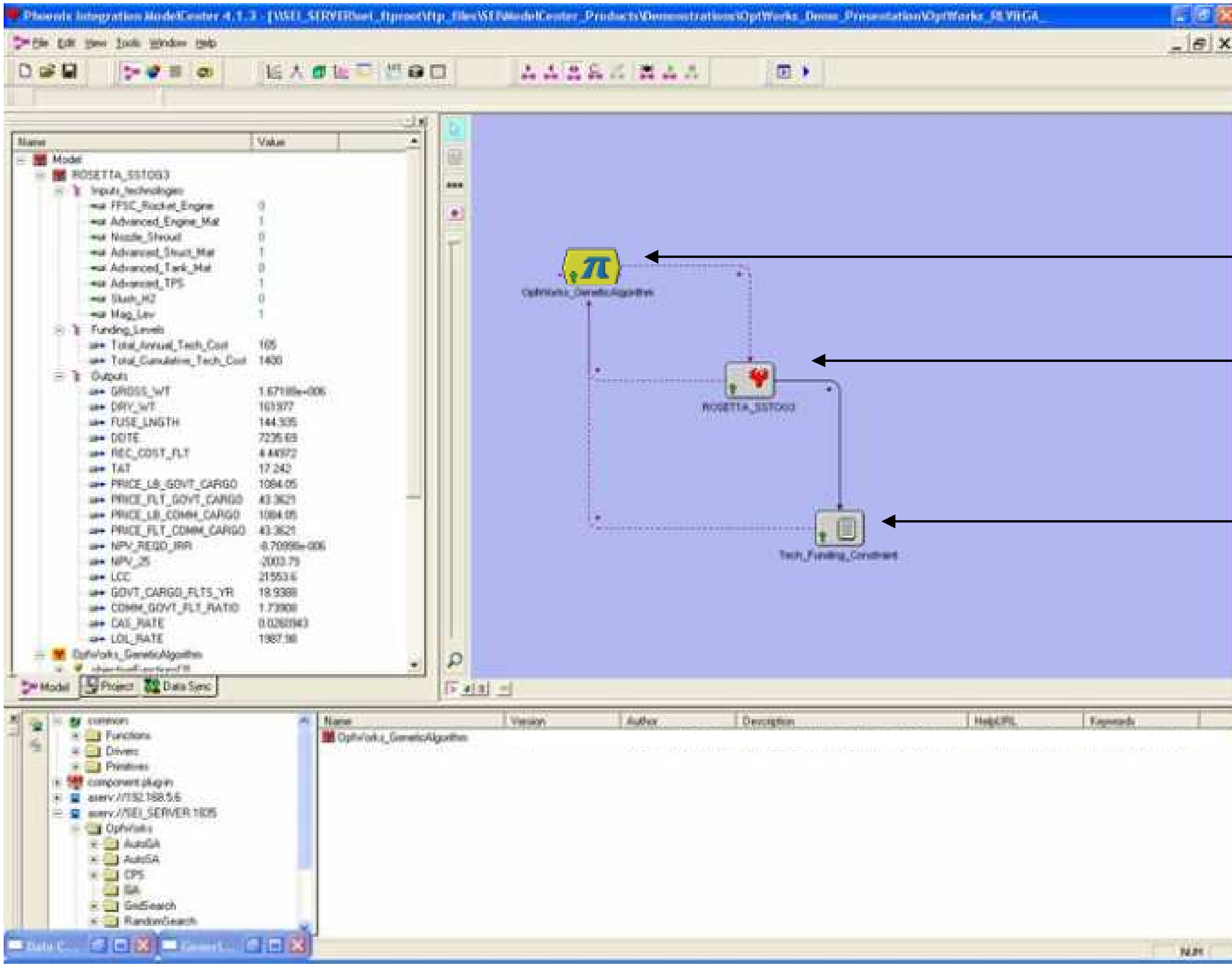
- **Reduced Order Simulation for Evaluation of Technologies and Transportation Architectures (ROSETTA)**
  - Spreadsheet-based meta-model representing design process for specific architecture
  - Traditional design discipline represented as contributing analysis

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)

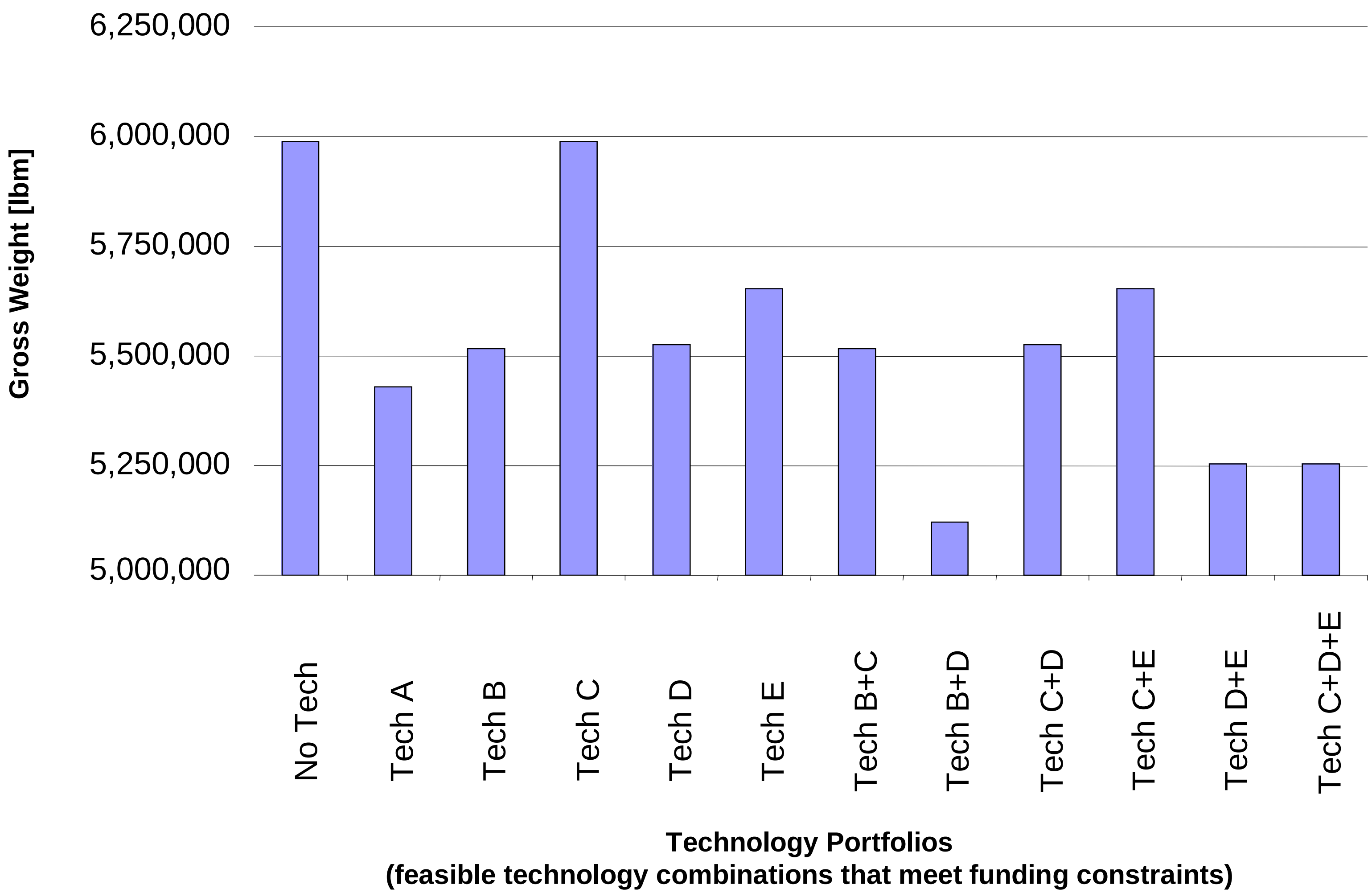
ROSETTA Model

Technology Investment Funding Constraint

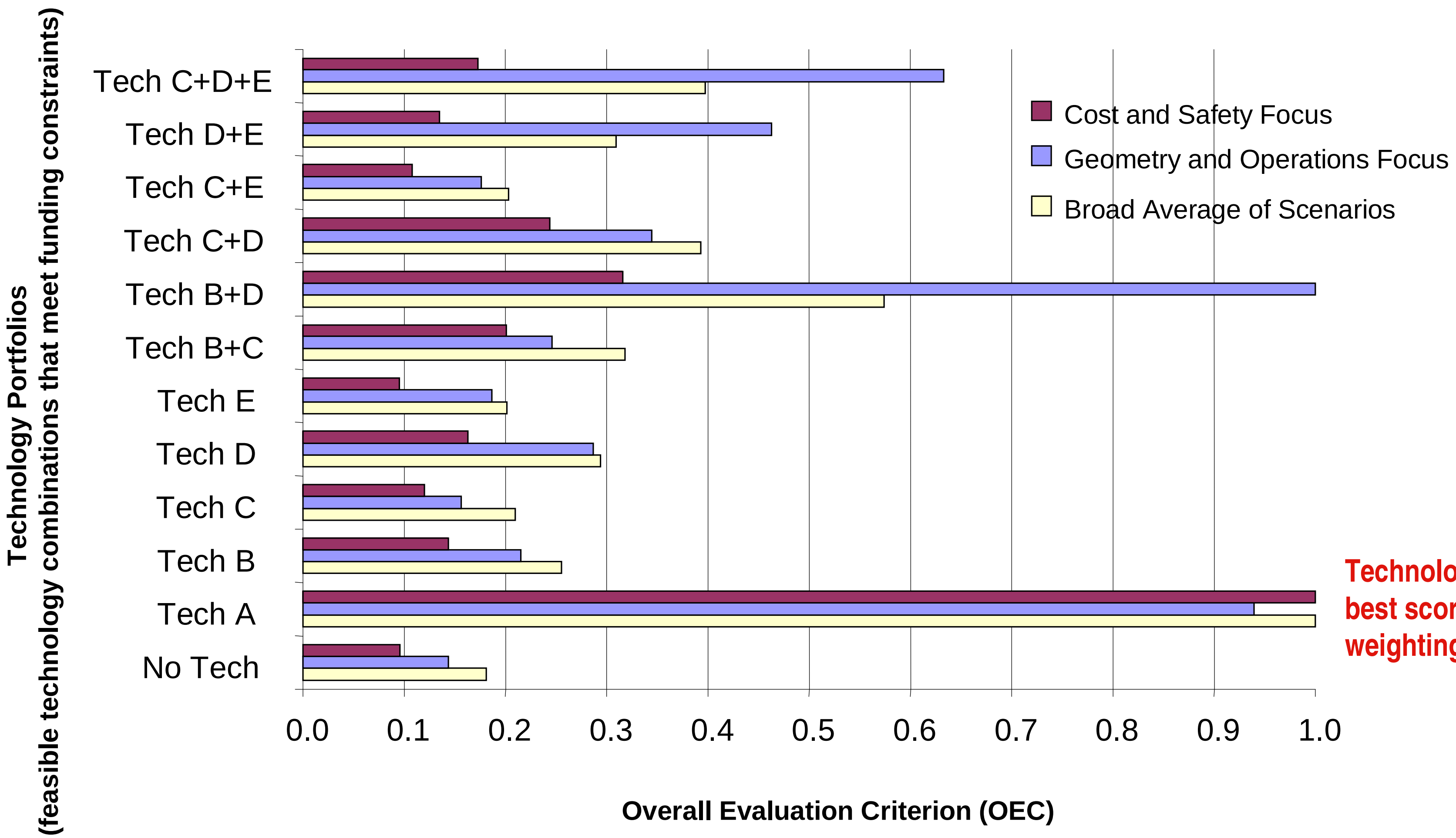
Why OptWorks?

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



Technology "A" has the best score over several weighting scenarios

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

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