Rapid Concept Evaluation with GT-POWER

Presented at the 2005 GT-SUITE User Conference in Dearborn, Michigan

Amer A. Amer and Roger K. Vick

Advanced Engine Engineering
Powertrain Product Team

Objective

- Present an innovative approach to 1D engine performance modeling which capitalizes on DoE techniques and computational power to develop statistical models for:
  - Rapid design analysis and/or optimization
  - Feature content and combination

Problem Complexity

- Strategy vision for a new engine program may include:
  - Application flexibility – Common design and adaptation
  - Technology – Leapfrog existing engines
    - Necessitate the capability to assess and wisely apply a wide variety and combination of features

- **Traditional Programs**
  - One engine / vehicle application
  - One engine adaptation
  - Single combination of valve events and manifold solution
  - Limited upgrade potential

- **Future engine programs**
  - Multiple engine / vehicle applications
  - Multiple engine adaptations
  - Multiple combinations of valve events and manifold solutions
  - Vast upgrade potential

- Result is too many degrees of freedom for a traditional sequential or linear approach to engine design and development

Alternate Modeling Approach

- Traditional Modeling Approach
  - Routine engineering is status quo - Performing the same task both repeatedly and consistently
    - "Good" solutions are identified and applied indefinitely
    - Unilateral optimization of design parameters (in series)
    - Use one computer

- Alternate Modeling Approach
  - Enabled by advancements in computing technology and software development
  - Use distributed computing and DoE techniques to rapidly develop statistical models for interactive interrogation
  - Optimize many design parameters simultaneously (interactions accounted for)
  - Deliverables include:
    - affordable parametric studies
    - alternative design evaluation
    - interactive "what-if" studies
    - reduced prototyping and cycle time reduction

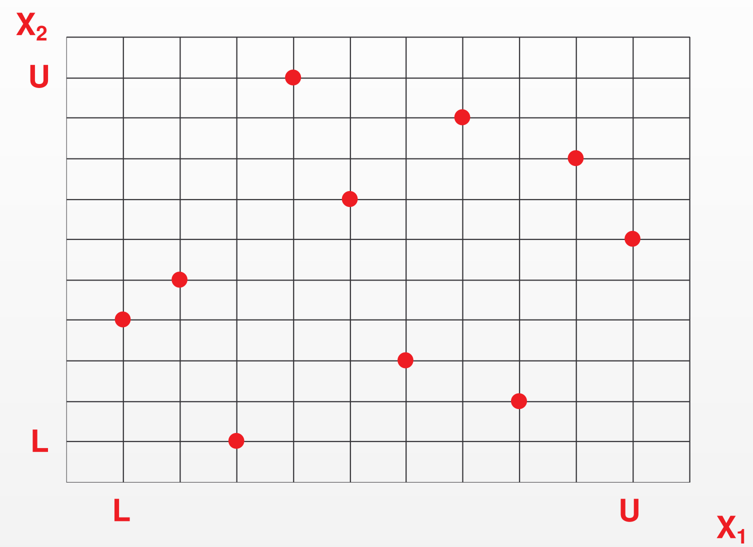
Approach Details

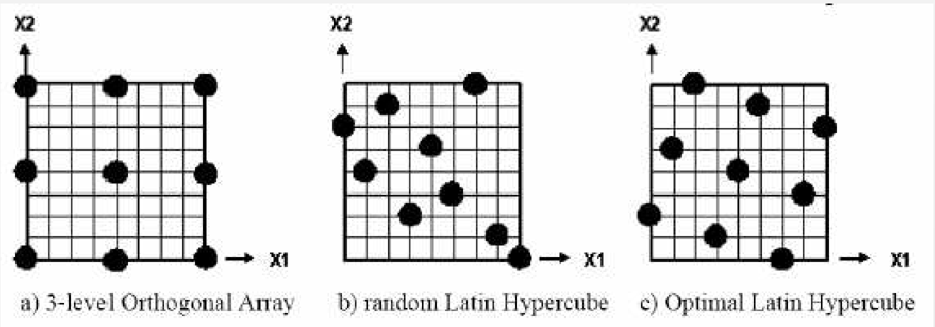
- Design space constructed such that only feasible alternatives are investigated with GT-POWER (e.g. with intake manifold and valvetrain design)
  - Specific valve motion strategies and tuning approaches considered
    - Intake manifold preliminary packaging studies conducted
    - Dynamically acceptable valve motions considered

- Design of Experiments (DoE)
  - Avoid full factorial
    - 3 Factors / 2 levels 2^3 = 8
    - 7 Factors / 2 levels 2^7 = 128
    - 7 Factors / 3 levels 3^7 = 2,187
    - 15 Factors / 2 levels 2^{15} = 32,768

Process Enabler – Latin Hypercube

- A "space-filling" technique where the design space for all factors is uniformly divided into levels
- Levels are then randomly combined to describe many experiments
  - each level is studied only once allowing for more points and more combinations to be interrogated
- Allows total freedom in selecting the number of designs (unlike orthogonal arrays)
- The smaller the number of experiments, the greater the chances of missing some regions in the design space
- If response surface is deemed statistically inadequate, appending of additional experiments is possible



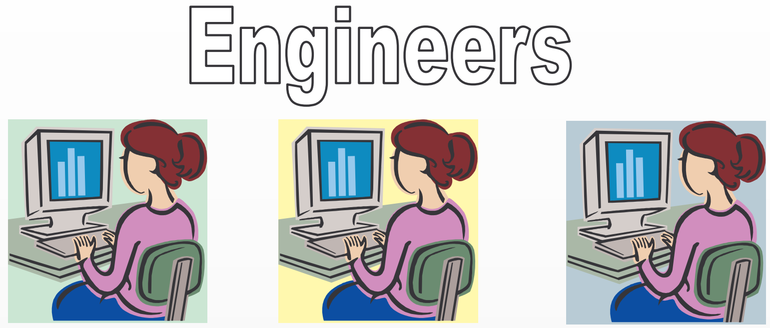


Reference: Therese Polito, "Practical Design Exploration by" at the Engineous User Conference , 2005

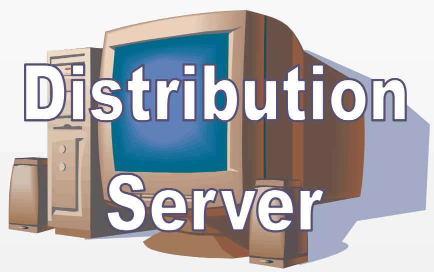
Process Enabler – Approximation Model

- Creates a mathematical model that approximates the response utilizing a number of deterministic analyses
  - Accuracy of the model is highly dependent on the number of experiments used for its construction along with the design space employed
- Advanced approximation techniques like Radial Basis Function (RBF) – available in GT-POWER and iSight
  - Type of neural network
  - Response surface passes through all data points
  - Uses a variable power spline
- The model can then be used for optimization and sensitivity studies with *minimal* computational expense

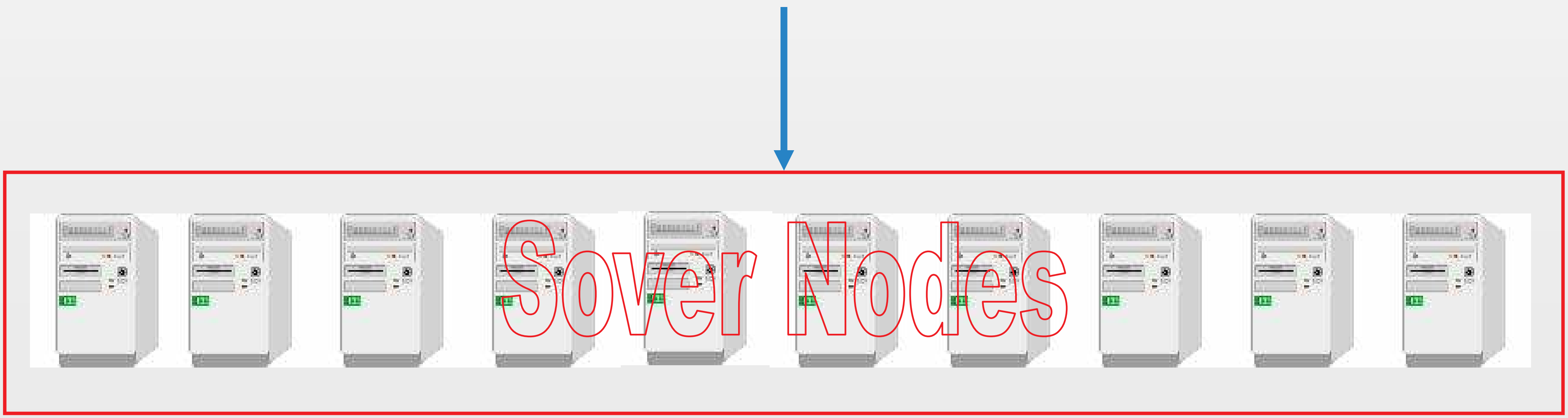
Process Enabler – Distributed Computing



Automatically, discretize multi-case simulation into several smaller packets, distribute across the network, and compile results upon completion.

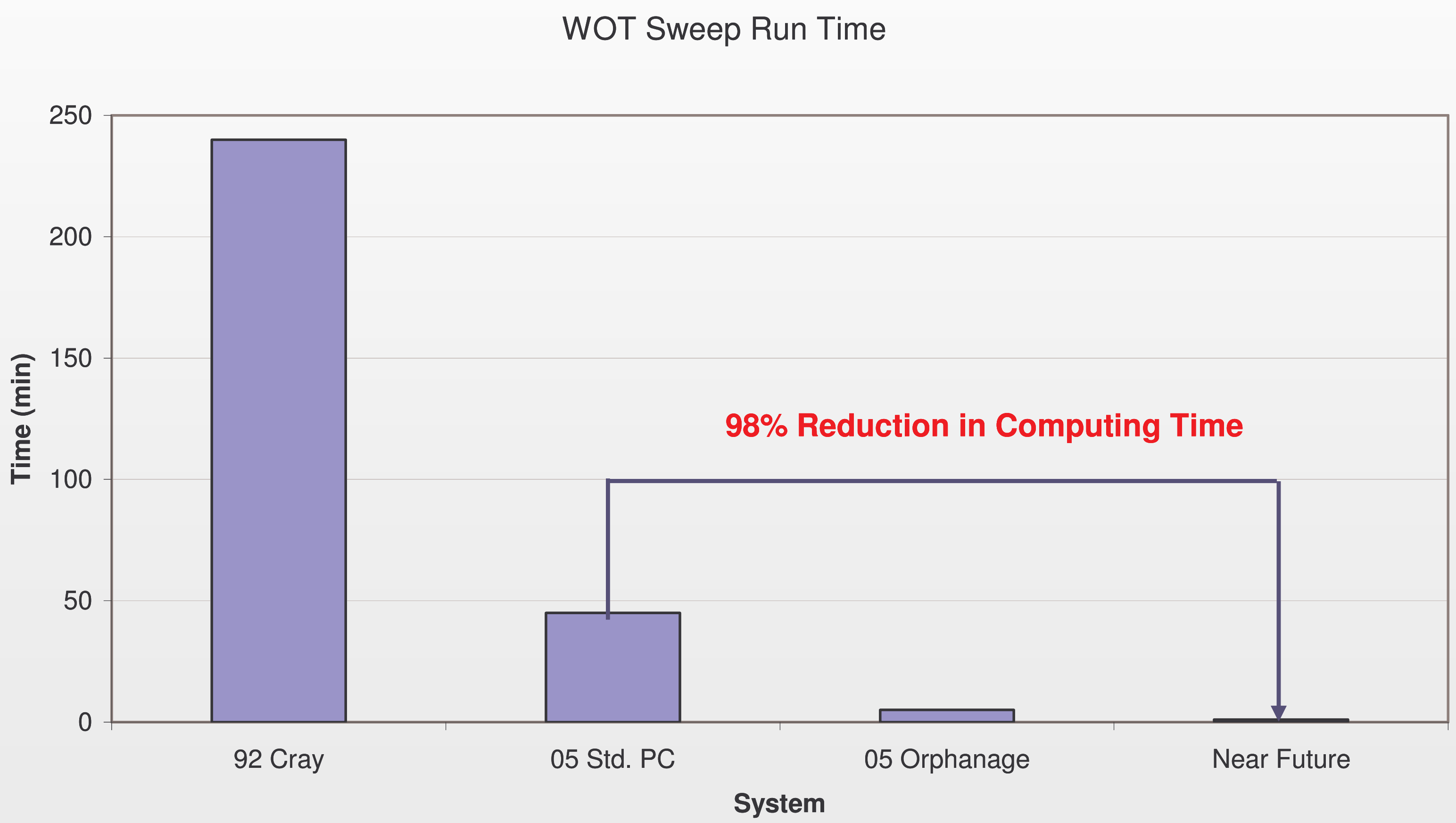


Load balancing algorithm takes into account: Solver node processor speed, availability, and user defined weighting.

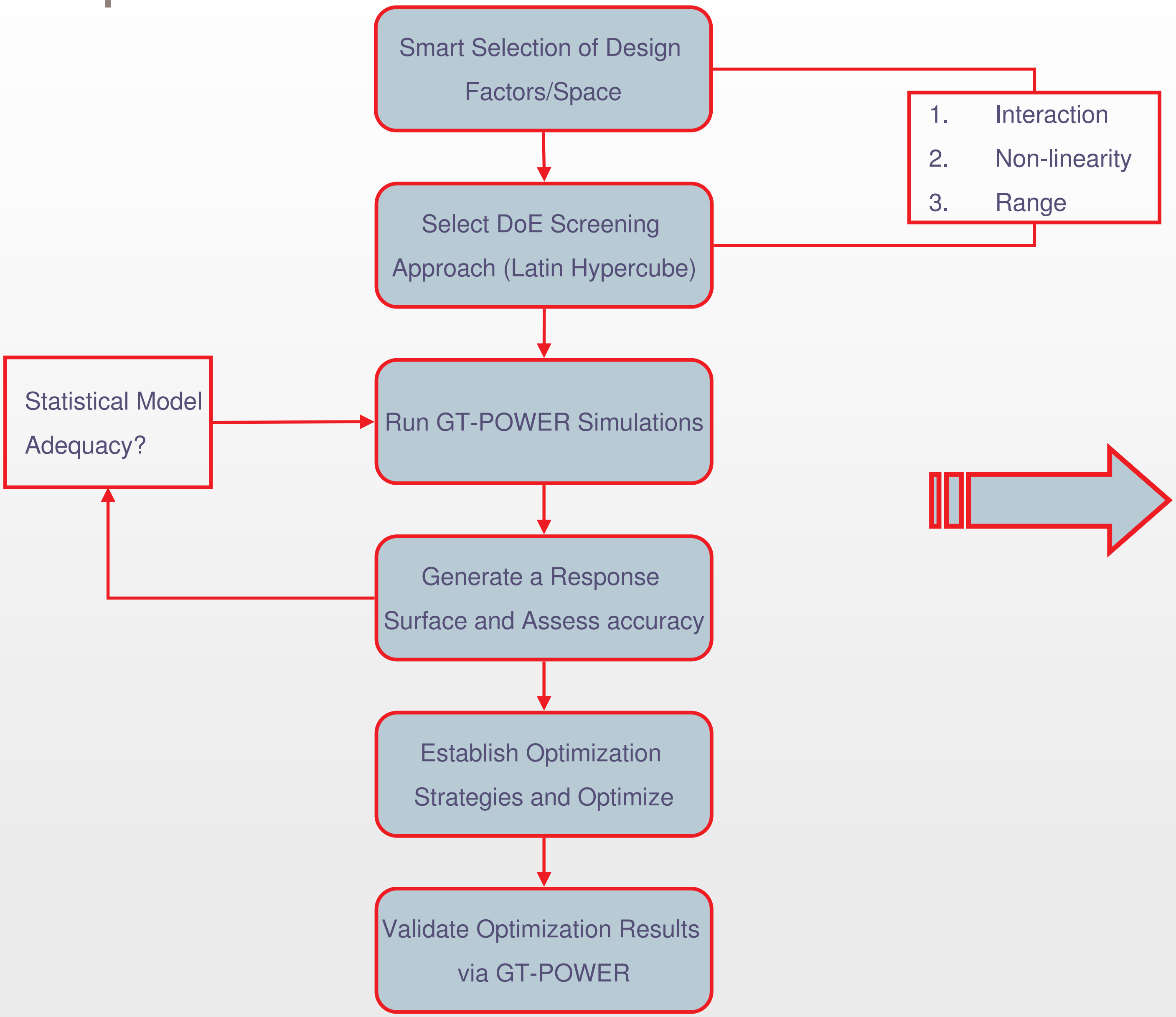


Distributed Computing at DCX

- "Borrowed" desktop computers from local users who also have laptops
- Setup Network "PC Orphanage" and demonstrated feasibility
- Migrated to HPC (Linux cluster with multiple CPUs)



Alternate Approach to 1D Modeling



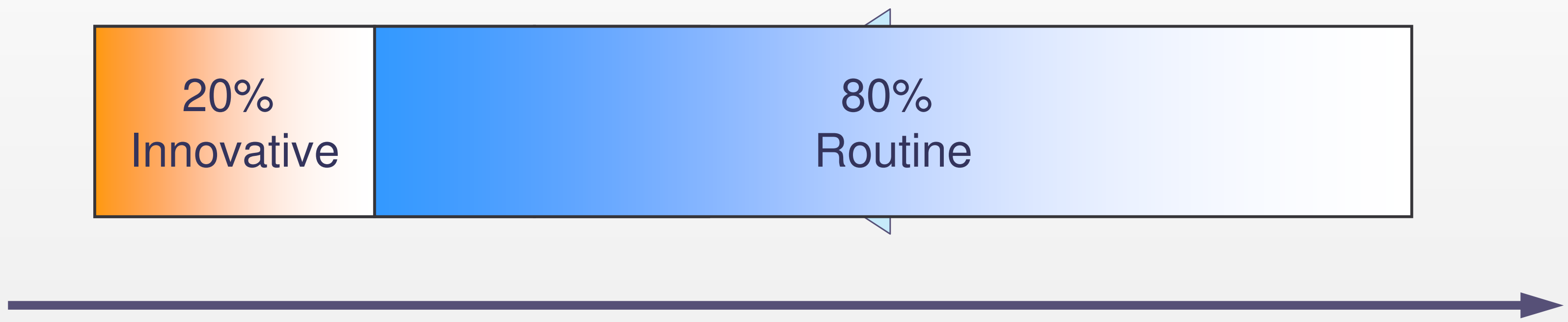
1. **Design space readily populated**
2. **Optimal solution for a given optimization strategy**
3. **Alternative solutions / Other designs satisfying an optimization strategy**
4. **"What if" questions answered instantly (customized Excel macros)**

Case Study

- Goal: Identify appropriate intake manifold geometry and valve timing strategies for various engine configurations utilizing several intake valve lift profiles and project their WOT performance potential
- Various engine configurations evaluated
  - Fixed valve events + Dual plenum intake manifold with MTV + Torque target at a specific engine speed + Power target at a specific engine speed
  - Variable Valve Events (Variable valve lift and/or Cam Phasing) + Active intake manifold (Dual Plenum with MTV and/or SRV) + Torque target at a specific engine speed + Power target at a specific engine speed
  - Identify solutions that address application flexibility (like intake manifold commonization, product differentiation, and price/feature compromise)
    - Multiple engine / vehicle applications
    - Multiple engine adaptations
    - Multiple combinations of valve events and manifold solutions
    - Vast upgrade potential
- DoE matrix construction
  - Eight independent design factors were evaluated
  - 10 DoEs (2 for each of the 5 intake valve lift profiles)
  - 300 runs for each DoE comprised of 18 cases (5400 cases)
  - Total for all DoEs was 3000 runs and 54000 cases (~ 5min./run)
- Response models utilizing Radial Basis Functions (RBF) were generated
  - Strategy: in so far as the torque and power targets could be met maximize low speed torque
- May not be able to realize the full torque potential due to knock limit considerations, particularly at low engine speeds
  - Volumetric efficiency monitored

Approximation Model Accuracy

Status vs. Now – 80/20 Rule



Final Thoughts

- The (Optimal) Latin Hypercube DoE screening approach was appropriate for such highly non-linear problem (assumes no particular model form)
- The RBF model, which passes through all data points, proved accurate for such highly non-linear problem
- The combination of Latin Hypercube DoE screening and RBF approximation model resulted in tremendous time savings, providing very many "what-if" answers - guiding the design
- Due to competition and challenging market demands, the product design and development cycle time is shrinking
  - Fortunately, this is accompanied by advancements in computing technology and power and software development
  - As a result, such computations are becoming essential and expected

Questions?

Thank You!