Tool Development for NIRPS Industrial Base Analysis
PropSIMA
(Propulsion Supplier Integrated Modeling and Analysis)

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Agenda and Outline

- Time Management
  - *Presentation: 25 min.*
  - *Database demonstration: 20 min*
  - *Questions: 5 min*
- Task Overview
- Supply Chain Model and Analysis Approach
- Results Summary
- Database Visualization Demonstration

PropSIMA (Propulsion Supplier Integrated Modeling and Analysis)

- The Aerospace Corporation is assisting NIRPS with the development of rocket engine and solid motor supply chain database analytical capabilities
  - *Conduct a bottom- up analyses of how launch vehicle and engine procurement selections affect rocket engine industrial base (suppliers and engine manufacturers)*
  - *Prototype Tool developed with following analytical capabilities*
    - Visualize data for a detailed supplier level database
    - Identify supplier interdependencies, critical & high risk suppliers, etc.
    - Conduct industry related trade studies for engine demand scenarios
- NIRPS collaborated with NASA's Space Launch System (SLS) Program on a pilot project to guide capability development
  - *Evaluate potential impacts of SLS Exploration Upper Stage (EUS) engine options on propulsion industrial base*
  - *Compare to the J-2X baseline*

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PropSIMA (Propulsion Supplier Integrated Modeling and Analysis)

What the Tool Does

- *Models Propulsion Industry-Wide Participation for Launch Vehicle Demand*
- *Allows High-Level Trade Studies between Different Engine Demand Scenarios*
- *Tracks Suppliers and Prime Involvement in rocket engine production*
- *Accounts for Engine Demand Uncertainty using Discrete Event Simulation tool*
- *Book-keeps Suppliers and How They are Shared Across the Industrial Base*
- *Book-keeps Relative Part Value for what Supplier Provides to Primes*
- *Stores metadata associated suppliers: parts produced, location, estimated financial health and dependency of prime*
- *Allows Several Types of Visualization for Industry-Wide Supply Chains*

What the Tool Does NOT Do

- *Model Business Metrics on a Supplier Scale*
- *Model Process Flow for Engine Production*
  - Currently does not identify bottlenecks but could be incorporated
- *Track Every Sub-Tier Supplier*
  - Trade high level accuracy (complexity/time) for ease of performing demand scenario trade studies
- *Model Supplier Uncertainty or Future Diversification*

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PropSIMA (Propulsion Supplier Integrated Modeling and Analysis)

Launch Vehicle Scenario

Launch vehicle demand driven by assumed procurement scenario and determines engine and motor demand

Engine and Motor Demand

Prime and Supplier Involvement

- One supplier may make several parts on an engine
- Each part supplied creates a single supplier "touch"
- Metadata stored in database tracks the value of each "touch" (Described later)
- Allows tracking of the value of hardware provided by each supplier

Value of Touches per Engine

The value of the prime contractors integration and manufacturing is tracked as well

Relative Value of Touches Compared to baseline scenario

- Engine relative cost is incorporated to adjust the value of the supplier and prime "touches"
- "Valuized" touches are bookept in terms of "cumulative benefit" with a value of 1 equating to the value of 1% of subtier supplier hardware used on the baseline

Trade Results for Launch Vehicle Scenarios

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PropSIMA Supplier Data

- Major suppliers for engines and motors used for US expendable launch vehicles have been identified and the parts they supply to major subsystems
- Metadata recorded for the supplier include the best estimate
  - *Supplied Commodity*
  - *Alternative Suppliers*
  - *Financial health*
  - *Dependency on engine prime contractor*
  - *Relative value of parts supplied*
  - *Location (City, State, Country)*

Subassembly	Sub-subassembly	Part(s)	Supplier	Category	Commodity	Location	Financials (1-5)	Dependency (1-5)	Alternatives (Y/N)	Net Sales/Employment	Data Source
Fuel Turbopump		Thick Shaft	Company Private	Machining & Fabrications	Turbopump Machining	Company Private	3	2	Y	$35M; 110 emp	InsideView
		Crossover		Raw Materials, Castings, Forgings	Casting		1	1	Y	$57.7B; 218,000 emp ($30M; 375 emp MN unit)	Morningstar, http://
				Machining & Fabrications	Machining		3	3	Y	$10M-$49.9M; 100-249 emp	http://free.salesfue
		Pump Inlet		Raw Materials, Castings, Forgings	Casting		3	1	Y	$10M-$49.9M; 100-249 emp	http://free.salesfue
				Machining & Fabrications	Machining		3	3	Y	$10M-$49.9M; 100-249 emp	http://free.salesfue
		Pump Inducer		Machining & Fabrications	Machining		3	2	Y	$40M; <200 emp	therm.com & http://
		1st Stage Impeller		Machining & Fabrications	Turbopump Machining		3	2	Y	$35M; 110 emp	InsideView
		2nd Stage Impeller		Machining & Fabrications	Turbopump Machining		3	2	Y	$35M; 110 emp	InsideView
		Turbine Exhaust Housing		Raw Materials, Castings, Forgings	Casting		1	2	Y	$24B; 61,000 emp	Morningstar
				Machining & Fabrications	Machining		3	3	Y	$10M-$49.9M; 100-249 emp	http://free.salesfue
		Turbine Manifold		Raw Materials, Castings, Forgings	Casting		1	2	Y	$24B; 61,000 emp	Morningstar
				Machining & Fabrications	Machining		3	3	Y	$10M-$49.9M; 100-249 emp	http://free.salesfue
		Turbine Blisks		Machining & Fabrications	Turbopump Machining		3	2	Y	$35M; 110 emp	InsideView
				Raw Materials, Castings, Forgings	Forging		1	1	Y	300 emp,	manta.com

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Supply Chain Details

- Fraction of engine cost between prime contractor and suppliers is estimated:

	Development	Production
Prime	60%	67%
Suppliers	30%	25%

- Initial analysis using this tool focused on prime and first-tier suppliers, but the database and discrete event simulation tools are highly scalable
- Top 15-20 suppliers make up 80% of the material cost for an engine
- Supplier "touches" (single unit purchase) do not represent every touch needed to produce a single engine – focus on big ticket items
- Some suppliers provide multiple parts and others just one
- A value of "importancy" has been assigned to the suppliers

$$Importancy = \frac{Percentage\ of\ Hardware\ Cost\ for\ Engine}{Number\ of\ supplier's\ touches\ in\ our\ database}$$

- Multiplying the number of "touches" for a supplier by the importance allows the analysis to recover the percentage of hardware cost

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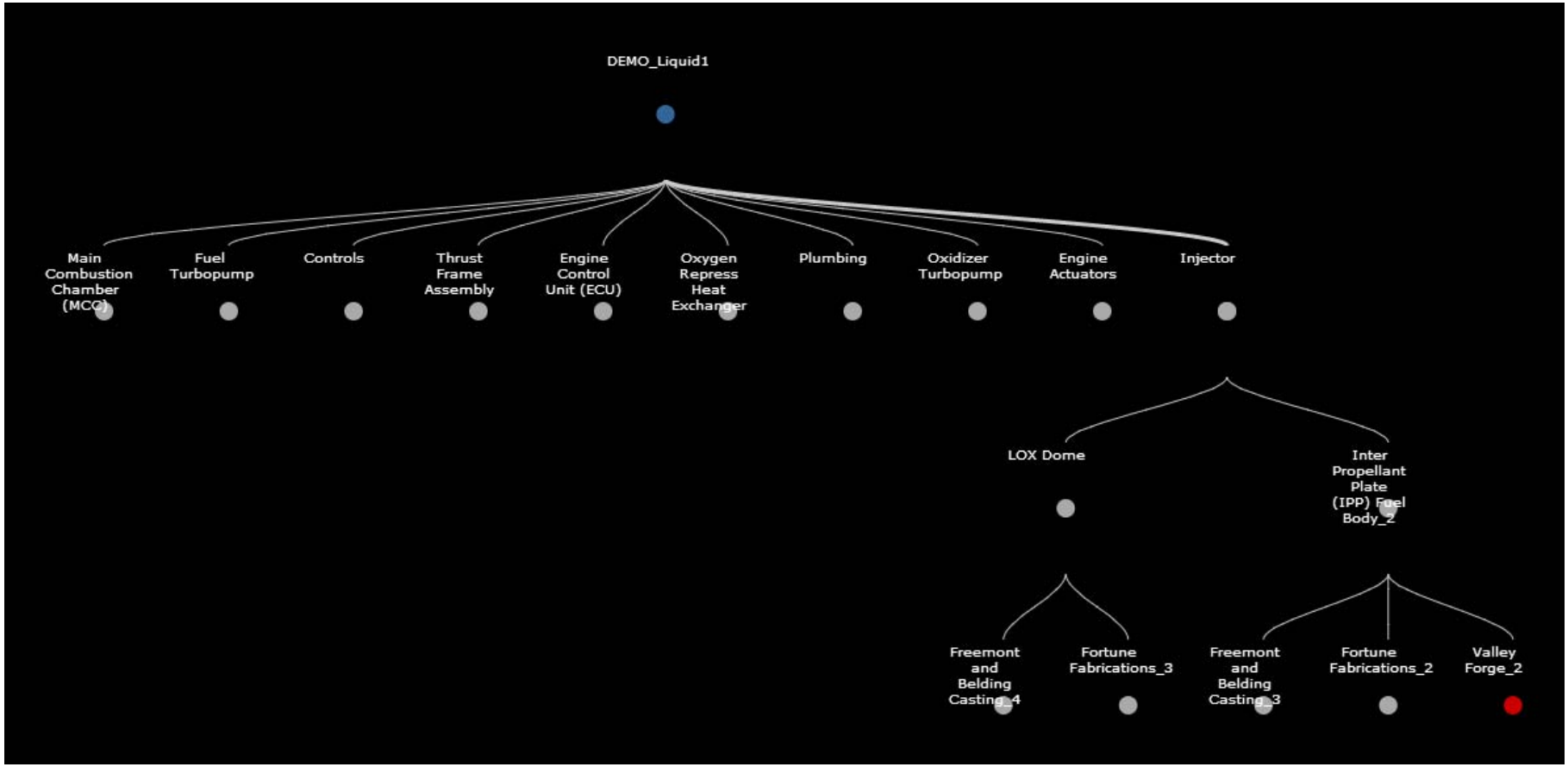
Demo Liquid Engine Model Database



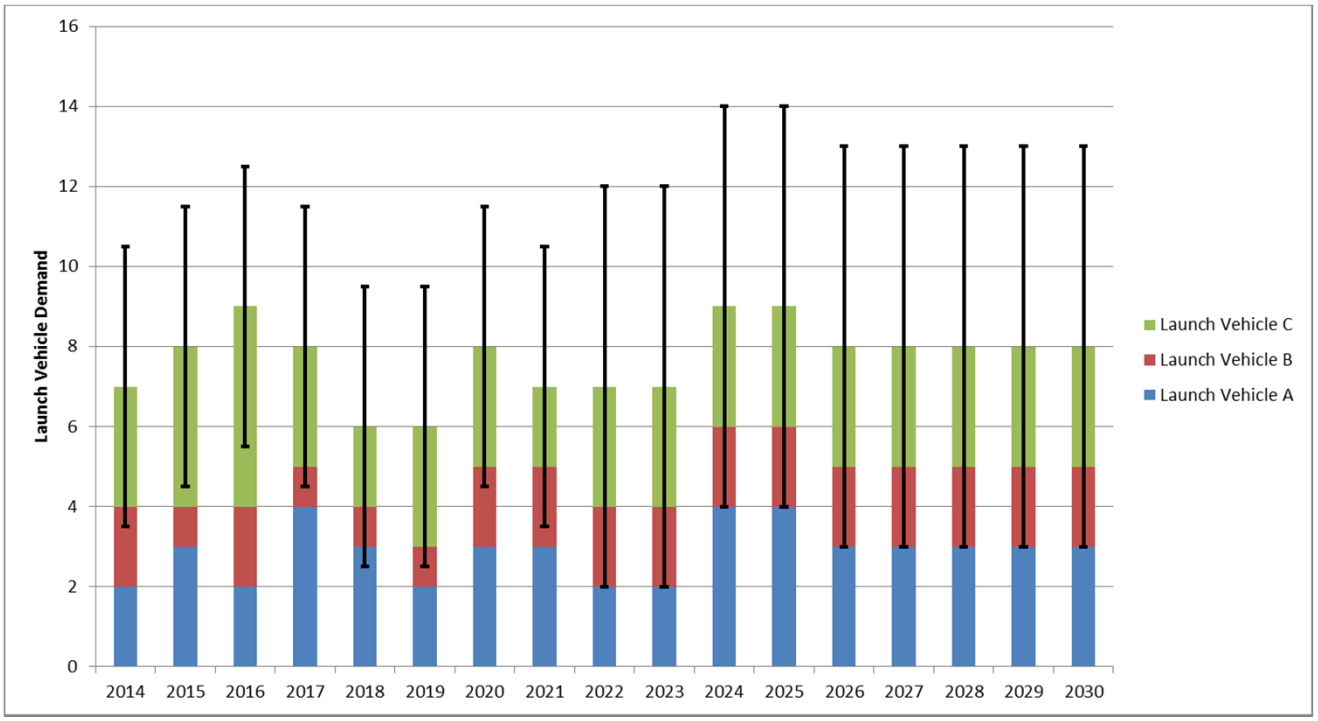
- Database Type: JavaScript Object Notation (JSON) Datafile
- Scripts generate large Möbius Descrete Event Models from JSON databases

Launch Vehicle Scenarios: Engine Demand

- Baseline engine demand constructed from current launch manifests that impact the U.S. industrial base, combined with projections for future
  - *EELV*
    - DoD
    - NASA LSP
    - Commercial EELV
  - *NASA Human Spaceflight*
    - Commercial Crew Launch
    - SLS (booster, core, and EUS options)
- Variation in engine demand included to reflect uncertainty in future years
  - *Uncertainty captures events such as launch date slips or mission cancellation*
- Alternative Scenarios represent a fundamental change to launch vehicle demand due to higher level decisions
  - *Payloads moving from one existing launch vehicle to another*
  - *New launch vehicle enters market*
  - *New propulsion system developed for an existing launch vehicle*

Baseline Demand Model

- Launch vehicle demand model determines production rates for all engines
  - *Vehicle demand and propulsion configuration are inputs to kick-off engine level supply chain model (Möbius)*
- Monte Carlo method used to sample a production rate for all engines for each year considered for analysis
  - *Triangular distribution applied in the Monte Carlo simulation*

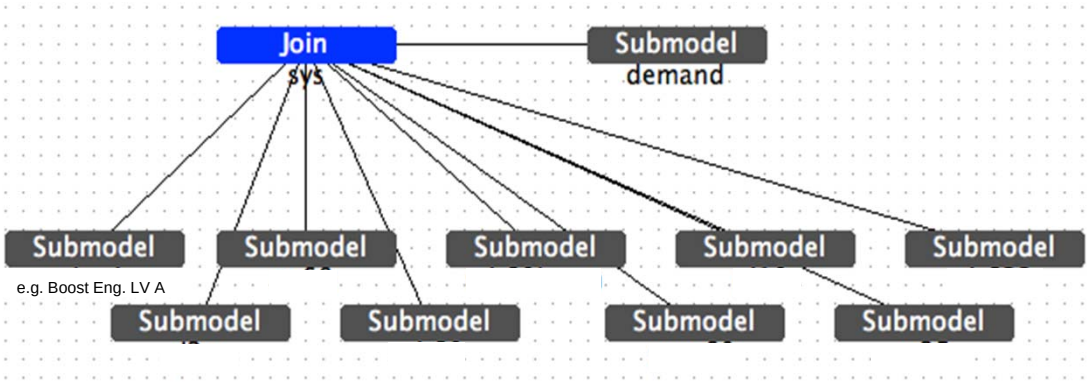


Möbius Overview

- Möbius: Model-Based Environment for Validation of System Reliability, Availability, Security, and Performance
  - *Software tool for modeling the behavior of complex systems*
  - *Developed by the University of Illinois*
- **Distributed discrete-event simulation**: Evaluates the custom measures using efficient simulation algorithms to repeatedly execute the system, either on the local machine or in a distributed fashion across a cluster of machines, and gather statistical results of the measures.*
  - *Current models execute on a 30-core cluster; several hours to complete simulation*
- The Aerospace Reliability and Statistics Department (RSD) has applied Möbius to a number of programs:
  - *Audit of a commercial satellite constellation reliability model*
  - *Augmentation of replenishment modeling capabilities*
  - *Process/Schedule analysis*

*https://www.mobius.illinois.edu/

Trade Study Analysis for Competing Scenarios



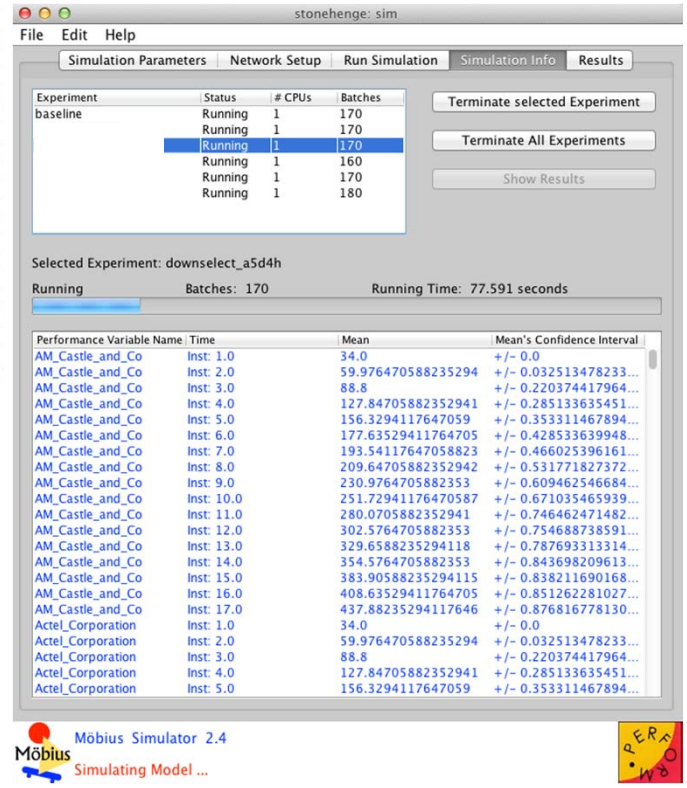
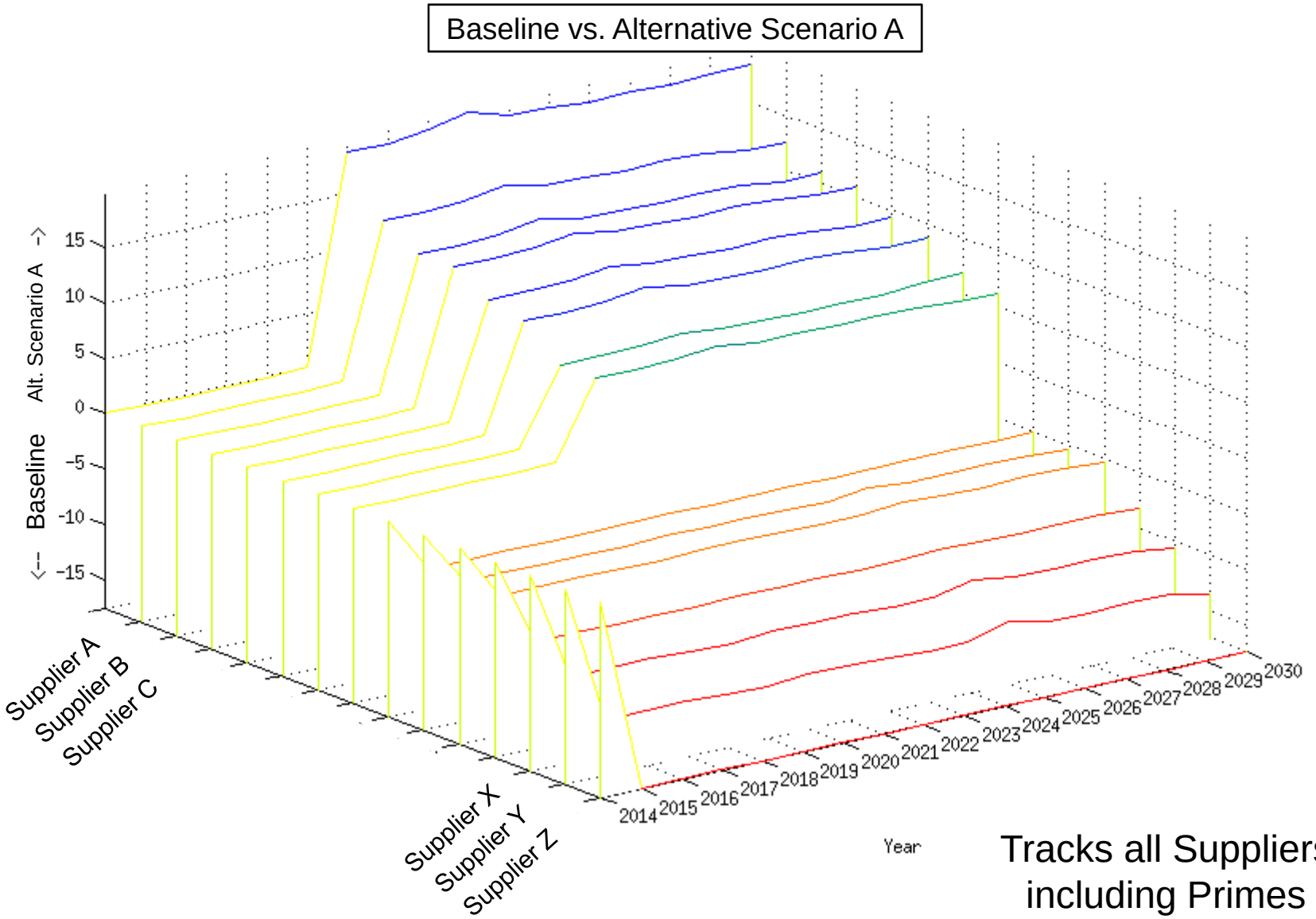


Figure courtesy of https://www.mobius.illinois.edu/

- A “composed” Möbius model ties together engine models and identifies shared suppliers
- Monte Carlo simulation performed for each alternative scenario
- Results of each alternative scenario traded
- Cumulative supplier benefit (mean value and distribution)

Supplier Disruption Alternative Scenario Analysis



Tracks all Suppliers including Primes

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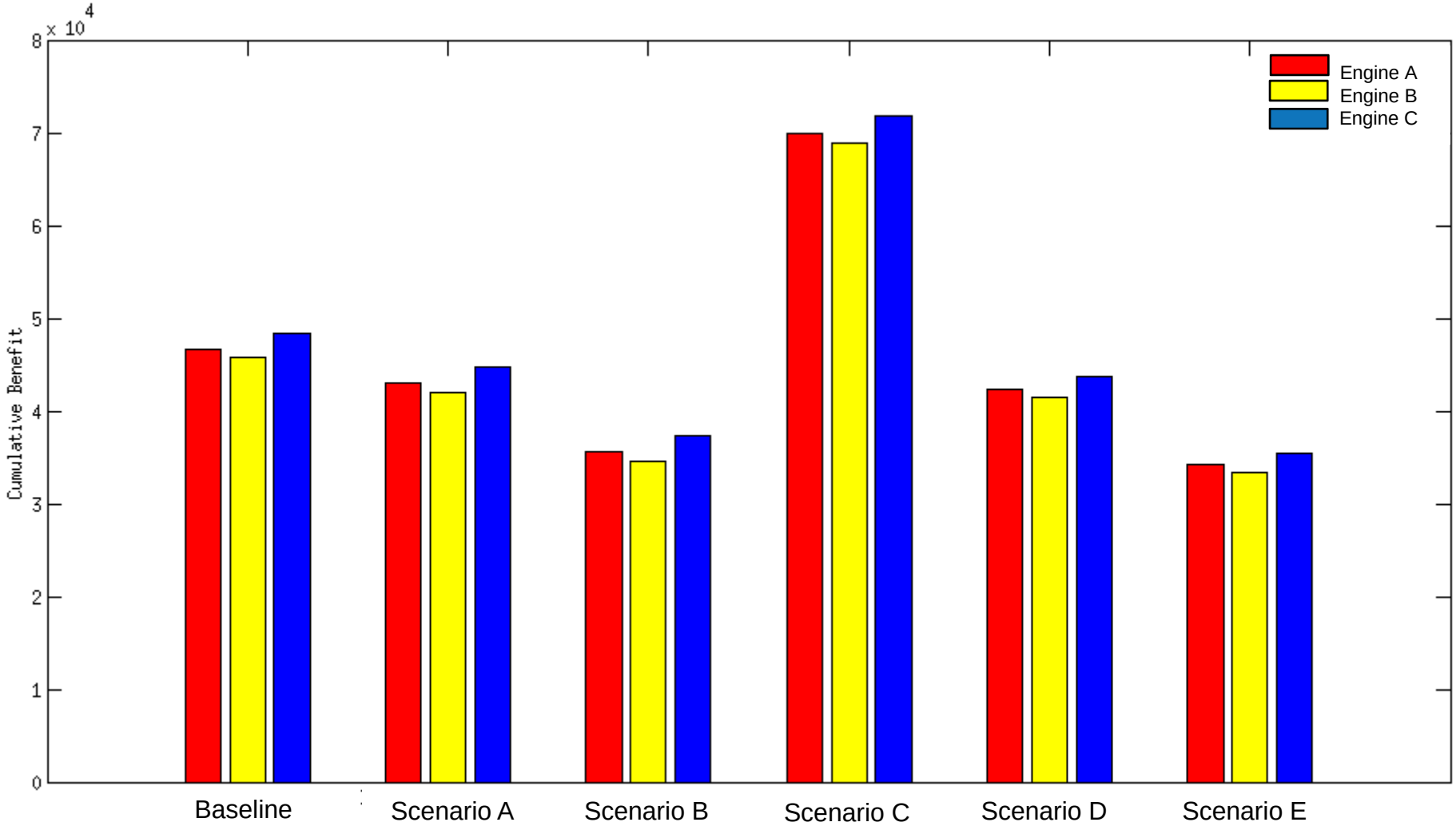
Cumulative Benefit of Scenarios Compared



Summary and Future Work

- Prototype tool developed (PropSIMA) to perform industrial base analysis including
  - *Baseline launch vehicle demand scenario including variability in launch manifest*
  - *Trade Studies featuring alternative scenarios for launch vehicle options based on potential future developments in the market*
- PropSIMA Tool Structure
  - *Launch Vehicle Demand Model*
  - *Flexible Engine/Motor supplier databases with user-specified metadata tagging*
  - *Engine Hardware & Supplier Network Visualization*
  - *Discrete Event Simulation Tool*
  - *Analysis Tools for Extracting Significant Findings of Industrial Base Impact*
- Future Work
  - *Expand capabilities and information in Engine/Motor Database*
  - *Develop additional visualization capabilities*
  - *Further develop trade study analysis/visualization methodology*
- Propose JANNAF PIB to develop industry panel to provide guidance on how to define PropSIMA inputs and metrics