



# 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*

# PropSIMA (Propulsion Supplier Integrated Modeling and Analysis)

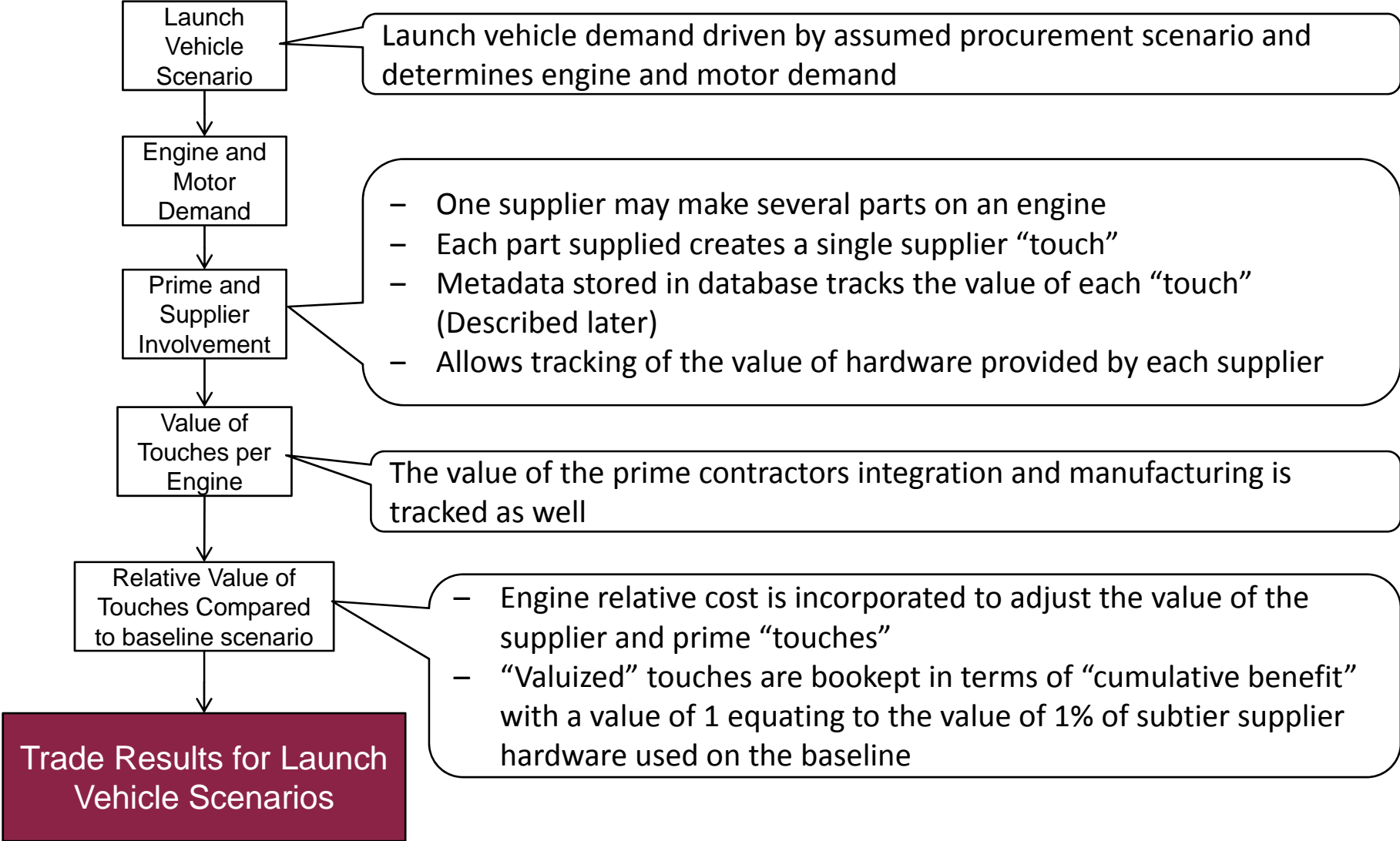
## What the Tool Does

- *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*

# PropSIMA (Propulsion Supplier Integrated Modeling and Analysis)



# 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)	Operations (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, <a href="http://free.salestue">http://free.salestue</a>
		Pump Inlet		Machining & Fabrications	Machining		3	3	Y	\$10M-\$49.9M; 100-249 emp	<a href="http://free.salestue">http://free.salestue</a>
		Pump Inducer		Raw Materials, Castings, Forgings	Casting		3	1	Y	\$10M-\$49.9M; 100-249 emp	<a href="http://free.salestue">http://free.salestue</a>
		1st Stage Impeller		Machining & Fabrications	Machining		3	3	Y	\$10M-\$49.9M; 100-249 emp	<a href="http://free.salestue">http://free.salestue</a>
		2nd Stage Impeller		Machining & Fabrications	Machining		3	2	Y	\$40M; <200 emp	therm.com & <a href="http://">http://</a>
		Turbine Exhaust Housing		Machining & Fabrications	Turbopump Machining		3	2	Y	\$35M; 110 emp	InsideView
		Turbine Manifold		Machining & Fabrications	Turbopump Machining		3	2	Y	\$35M; 110 emp	InsideView
				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	<a href="http://free.salestue">http://free.salestue</a>
				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	<a href="http://free.salestue">http://free.salestue</a>
		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			

# Supply Chain Details

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

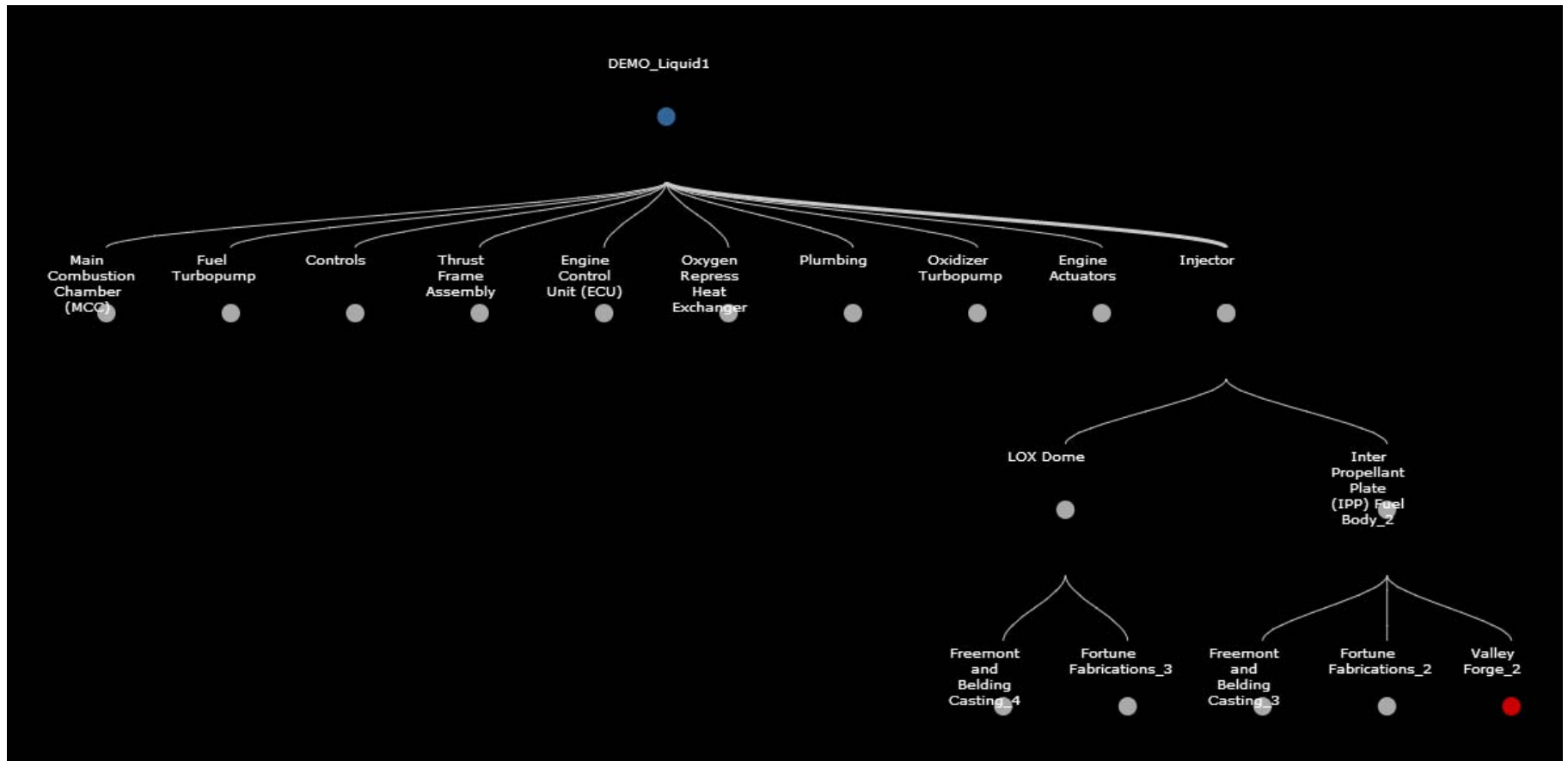
	Development	Production
Prime	60%	67%
Suppliers	30%	25%

- 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

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

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

# Demo Liquid Engine Model Database



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

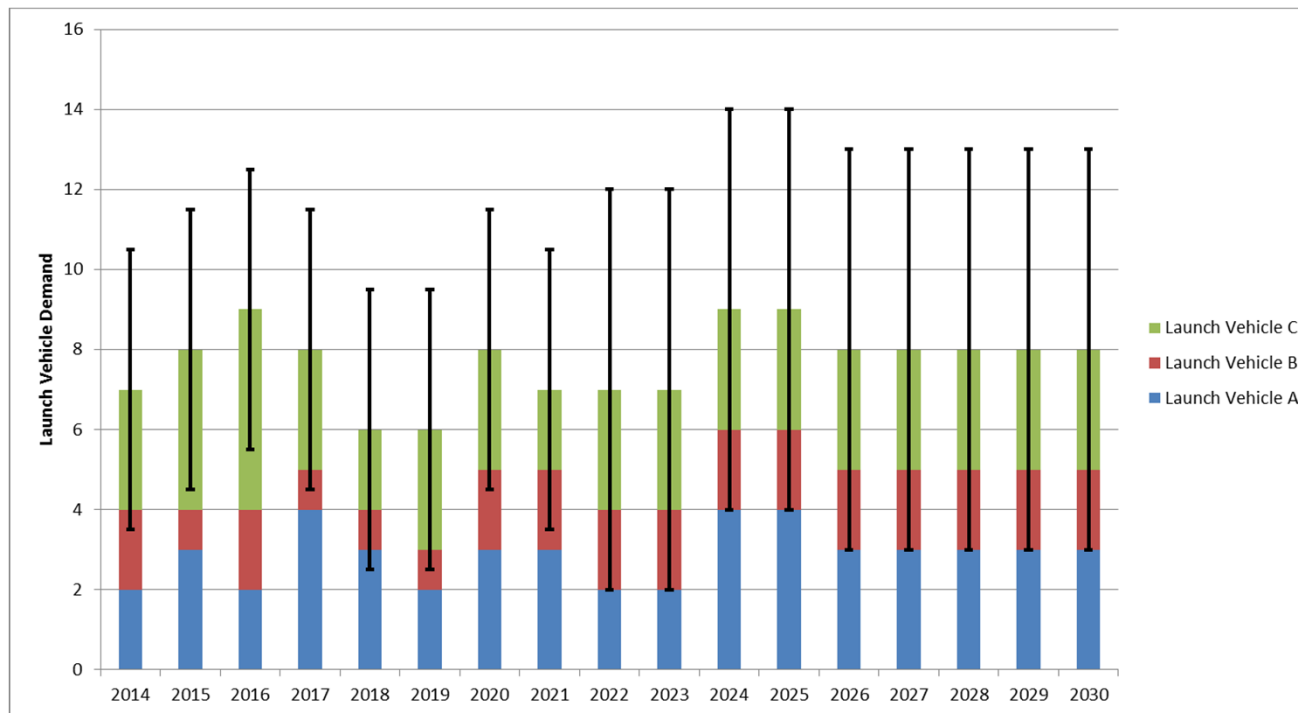


# Launch Vehicle Scenarios: Engine Demand

- 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*



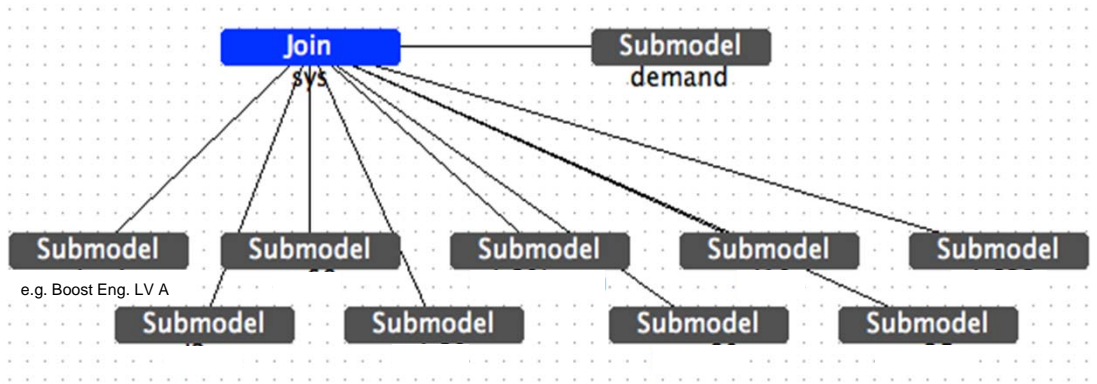


## Möbius Overview

- 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



- 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)

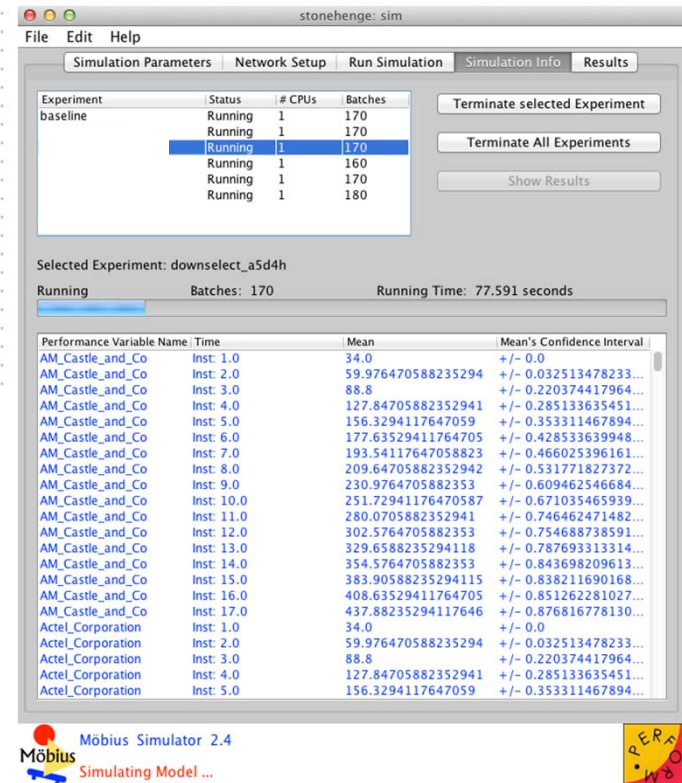
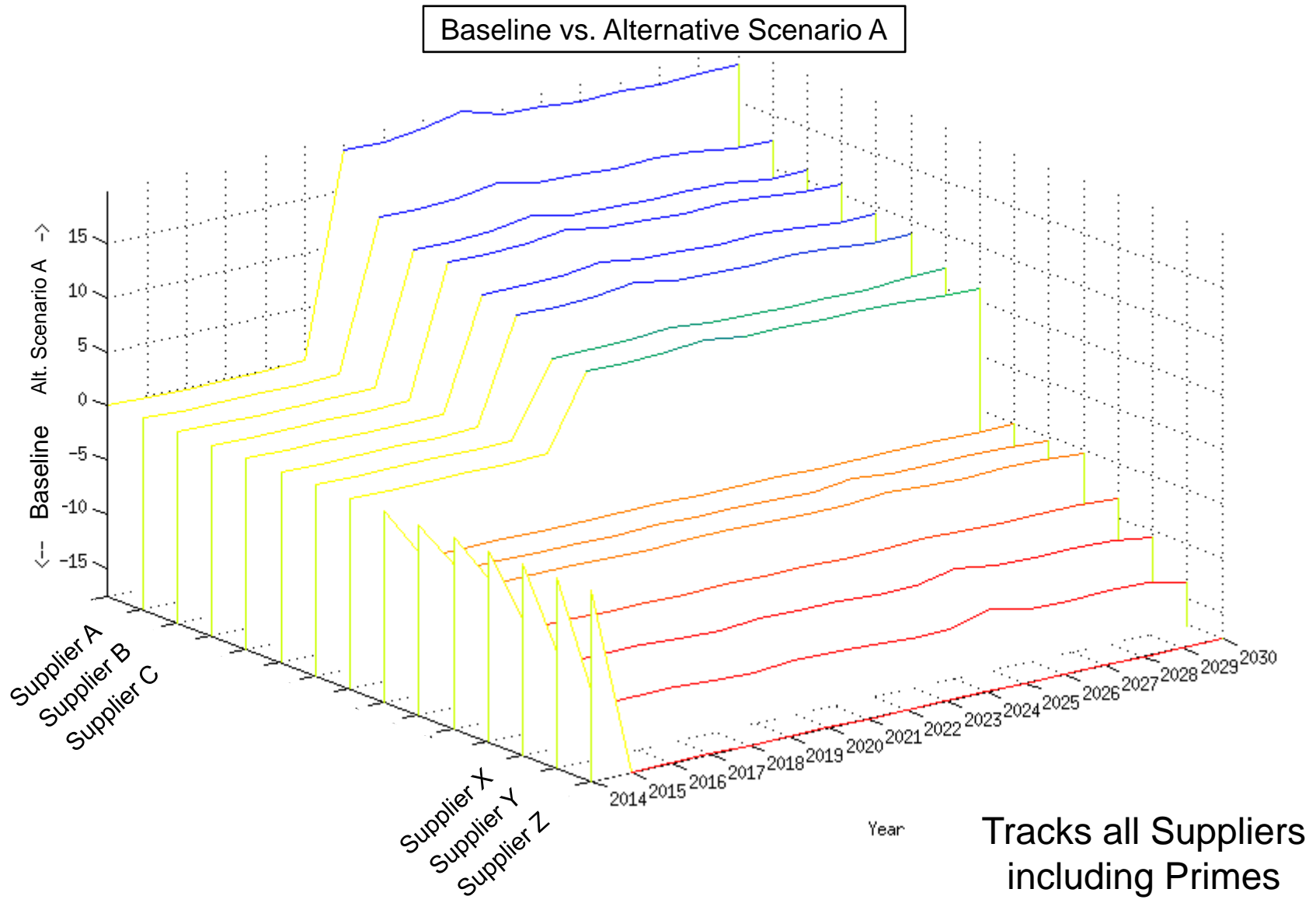
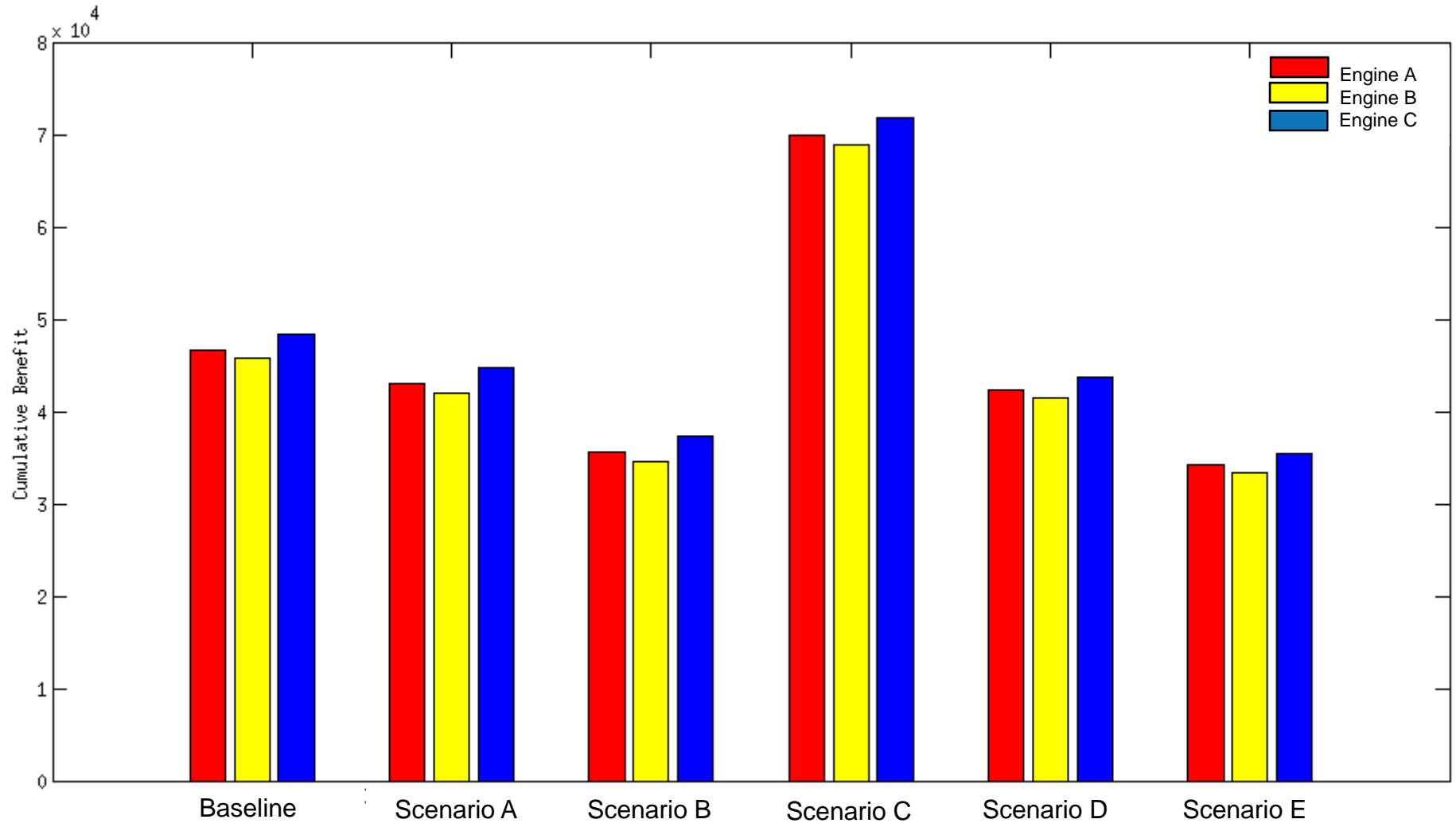


Figure courtesy of <https://www.mobius.illinois.edu/>

# Supplier Disruption Alternative Scenario Analysis



# 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