Evolved Expendable Launch Vehicle (EELV) Discrete Event Simulation

Ensuring the Buck Results in a Bang

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Technomics
The Science of Informed Decision Making

Outline

Evolved Expendable Launch Vehicle (EELV)

- Program Overview
- Project Motivation

Project Overview

- Problem Statement
- Supply Chain Process

Methodology

- Discrete Event Simulation (DES)
  - Methodology Overview
  - Cost Analysis and DES
- EELV DES
  - Simulation Model
  - Preliminary Findings

Planned Future Effort

EELV Program Overview

EELV is a USAF program intended to replace legacy launch vehicles (e.g. Delta II, Atlas II/Centaur, and Titan IV) and improve the **affordability** and **reliability** of US satellite launches through modular vehicle design based on common components and a central management body.

Launch Facilities

- Cape Canaveral Air Force Station (CCAFS), Florida
- Vandenberg Air Force Base (VAFB), California

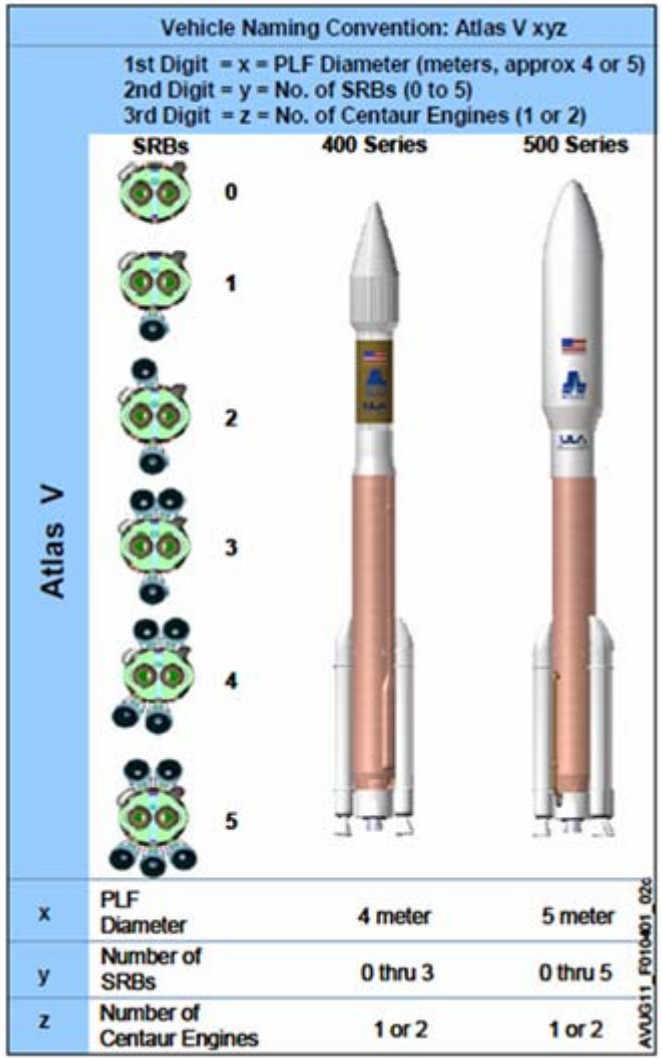
Atlas V

History

- Developed by Lockheed Martin
- Evolved from Atlas II & III
- Common Core Booster (CCB) Design

Characteristics

- Propulsion
  - CCB, powered by RD-180 engine
  - 0-5 Solid Rocket Boosters (SRBs)
  - Centaur, powered by RL10A-4-2 engine(s)
- Primary Variants
  - 400 Series (4m PLF)
  - 500 Series (5m PLF)
- Production Facility Locations
  - Denver, CO
  - Harlingen, TX
  - San Diego, CA
  - Decatur AL



Source: Atlas V User's Guide (ULA)

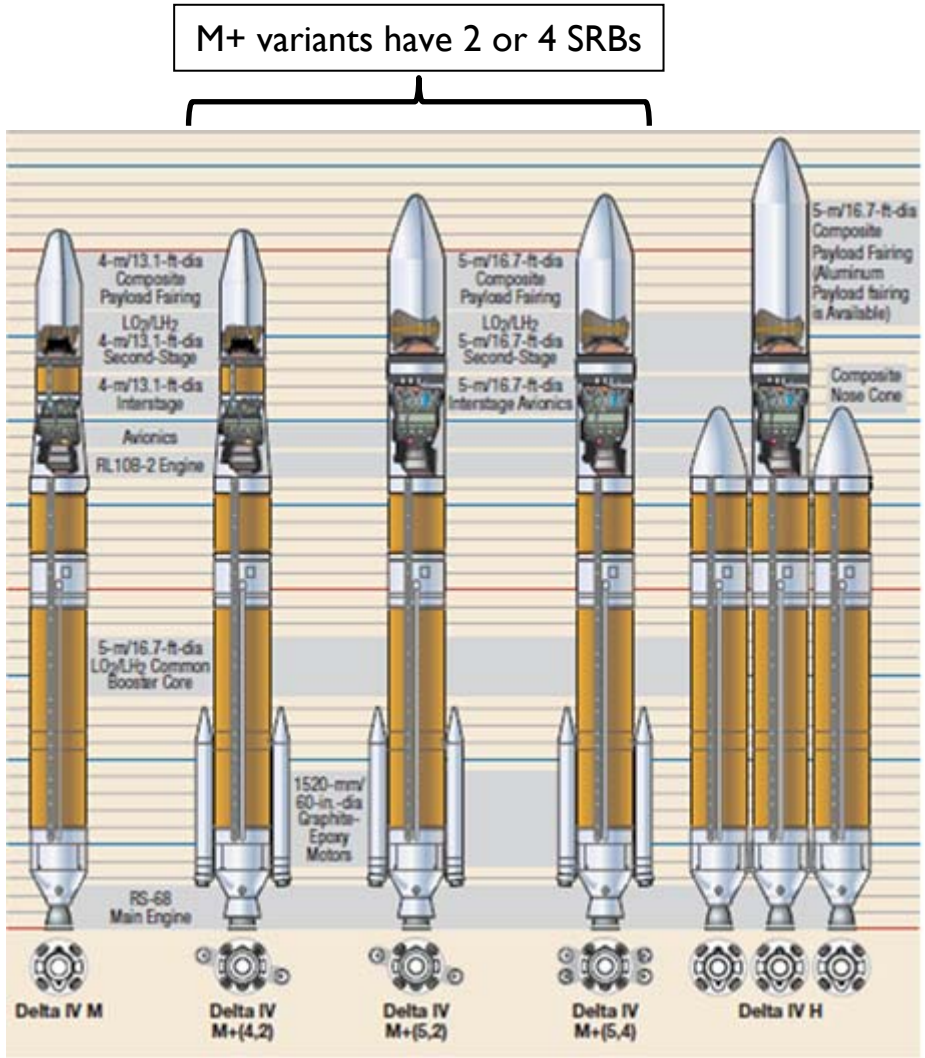
Delta IV

History

- Developed by Boeing
- Evolved from Delta II
- Common Booster Core (CBC) Design

Characteristics

- Propulsion
  - CBC, powered by Rocketdyne RS-68 engine(s)
  - 2 or 4 SRBs
  - Upper Stage, powered by RL10B-2 engine
- Primary Variants
  - Medium (1 CBC)
  - Heavy (3 CBCs)
- Production Facility Location
  - Decatur AL



Source: Delta IV User's Guide (ULA)

Delta IV

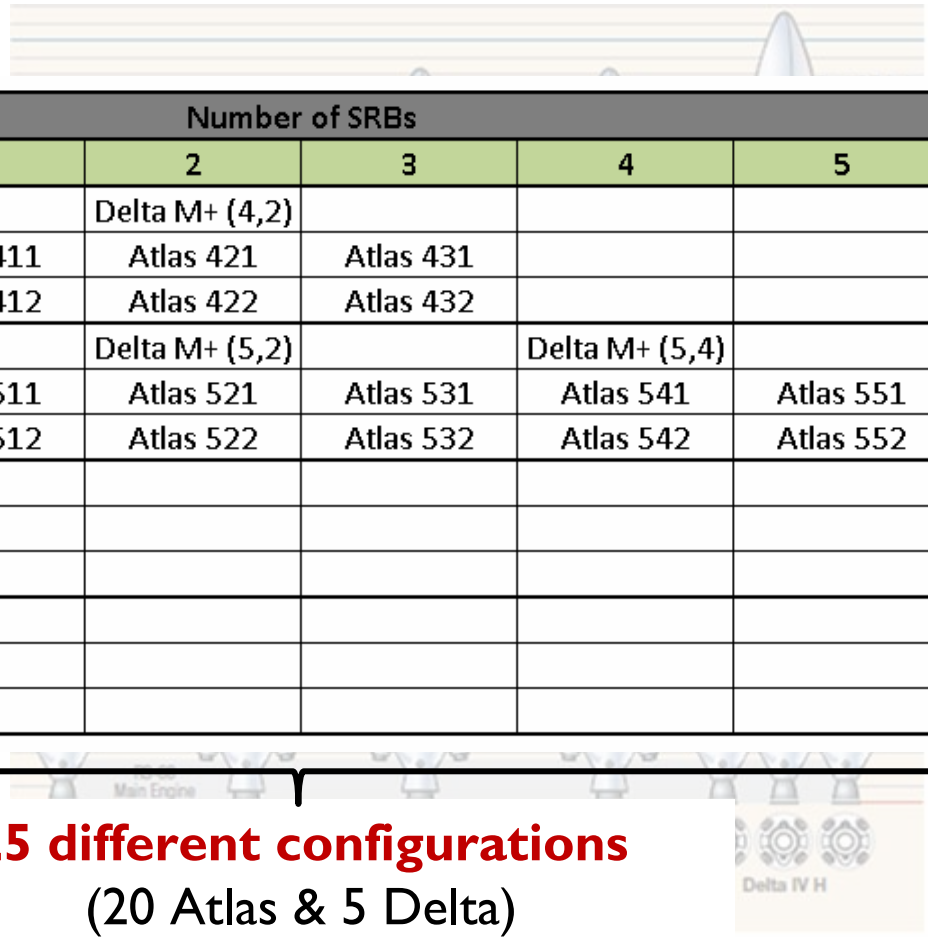
History

- Developed by Boeing
- Evolved from Delta II
  - Medium (1 CBC)
  - Heavy (3 CBCs)
- Production Facility Locatic
  - Decatur AL

M+ variants have 2 or 4 SRBs

			Number of SRBs					
CBCs	PLF Diameter	Centaur Engines	0	1	2	3	4	5
1	4	0	Delta M		Delta M+ (4,2)			
		1	Atlas 401	Atlas 411	Atlas 421	Atlas 431		
		2	Atlas 402	Atlas 412	Atlas 422	Atlas 432		
	5	0			Delta M+ (5,2)		Delta M+ (5,4)	
		1	Atlas 501	Atlas 511	Atlas 521	Atlas 531	Atlas 541	Atlas 551
		2	Atlas 502	Atlas 512	Atlas 522	Atlas 532	Atlas 542	Atlas 552
3	4	0						
		1						
		2						
	5	0	Delta H					
		1						
		2						

25 different configurations
(20 Atlas & 5 Delta)

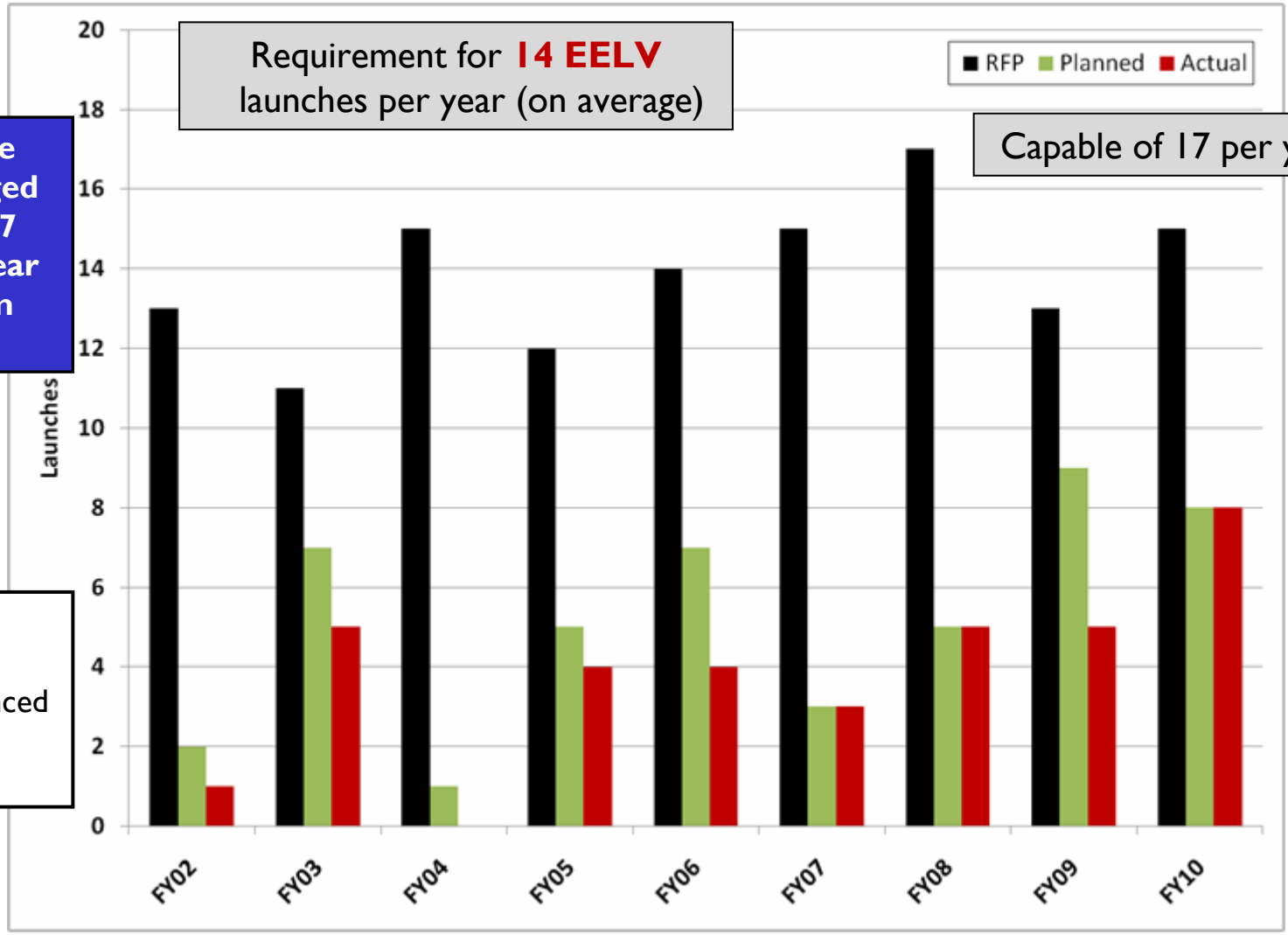


Source: Delta IV User's Guide (ULA)

Motivation

EELV heritage vehicles averaged an additional 7 launches per year (in total) from 2002-2010

Significant **launch delay** has been experienced for several EELV missions



These requirements have yet to be tested

Motivation

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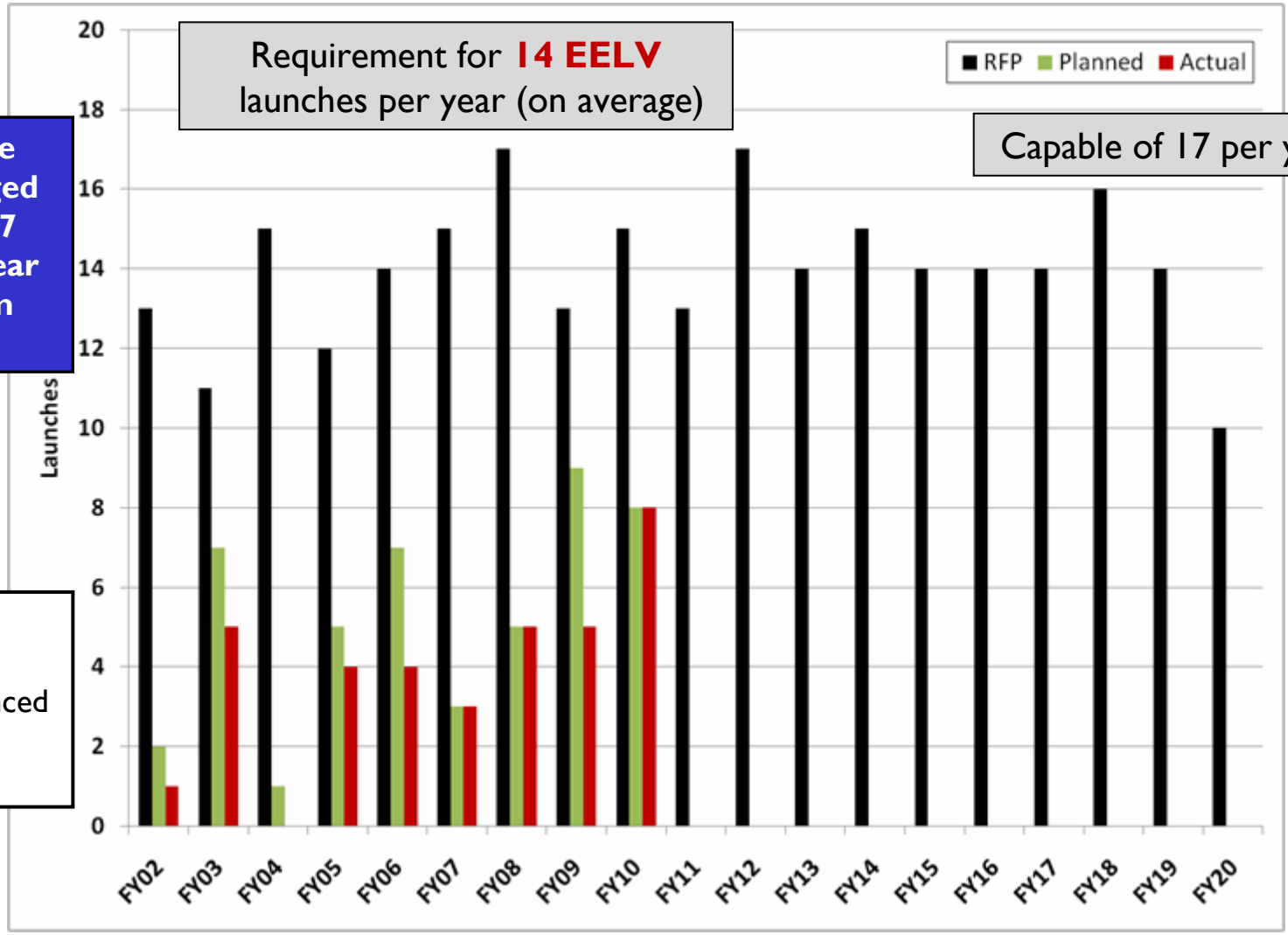
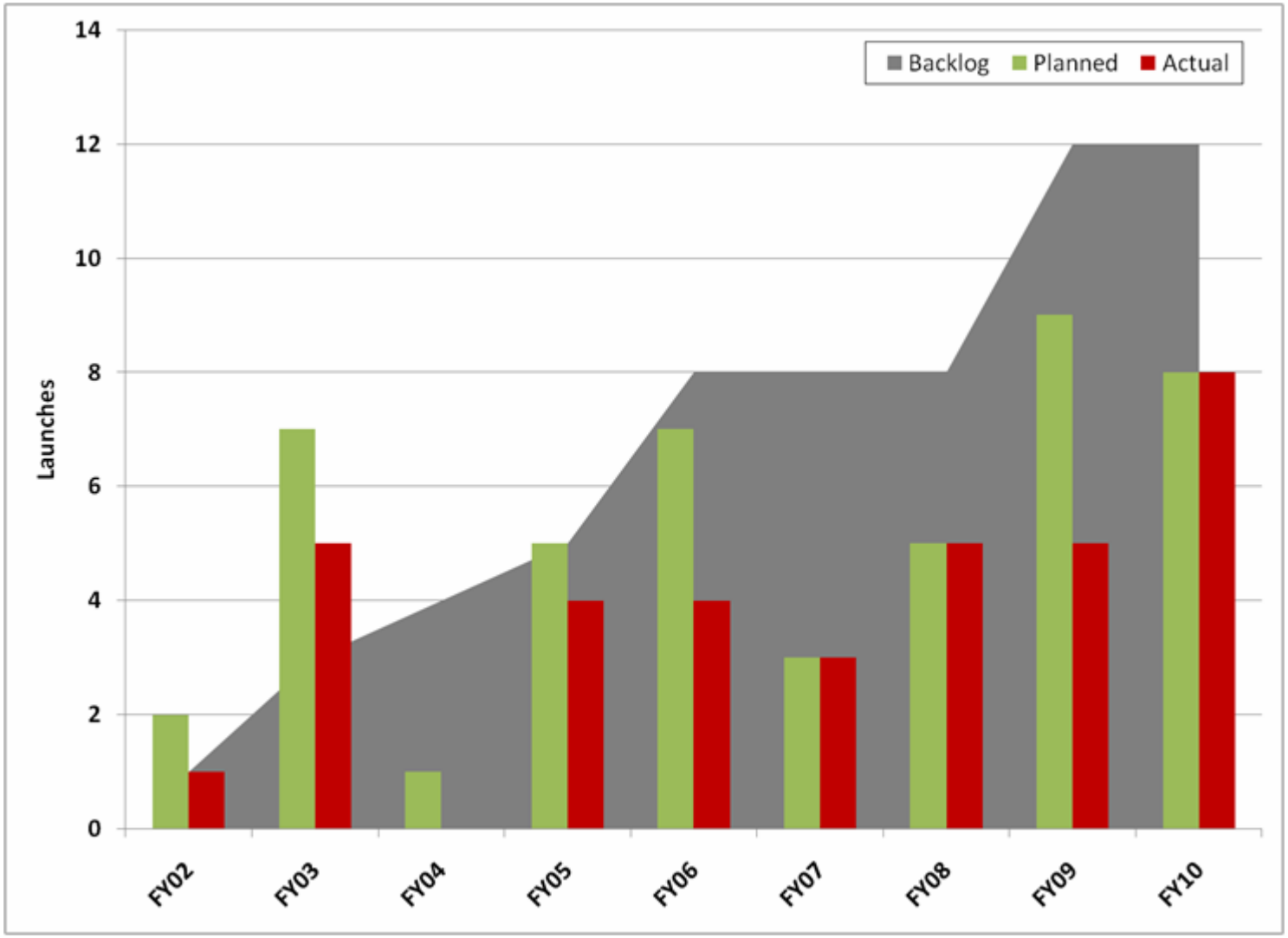
Significant **launch delay** has been experienced for several EELV missions



Can these requirements be handled by EELV alone?

Motivation



Some evidence exists to the contrary

Problem Statement

Near Term Objectives

- Determine the **effective capacity** of the system
- Diagnose reasons for system congestion
- Analyze effect of alternative resource configurations

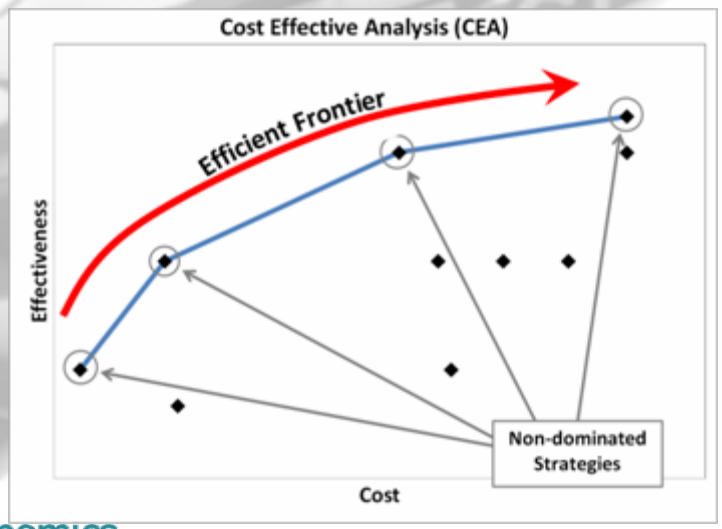
and unplanned (catastrophic) events on **throughput**

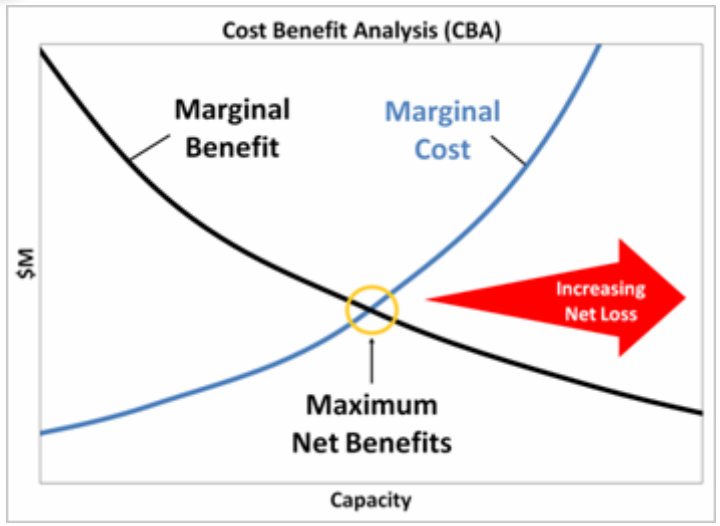
Effective Capacity[1]

- Accounts for internal capacity and availability of supplies (i.e., satellites) and other external effects
- At the end of the supply chain, effective capacity is final product throughput (per year)

Long Term Objectives

- Ensure investments (i.e. budget increase) yield desired results
- Determine Effectiveness for a **CEA** or Benefit for a **CBA**
- **Enable decision-makers to select the most effective strategy for improvement**





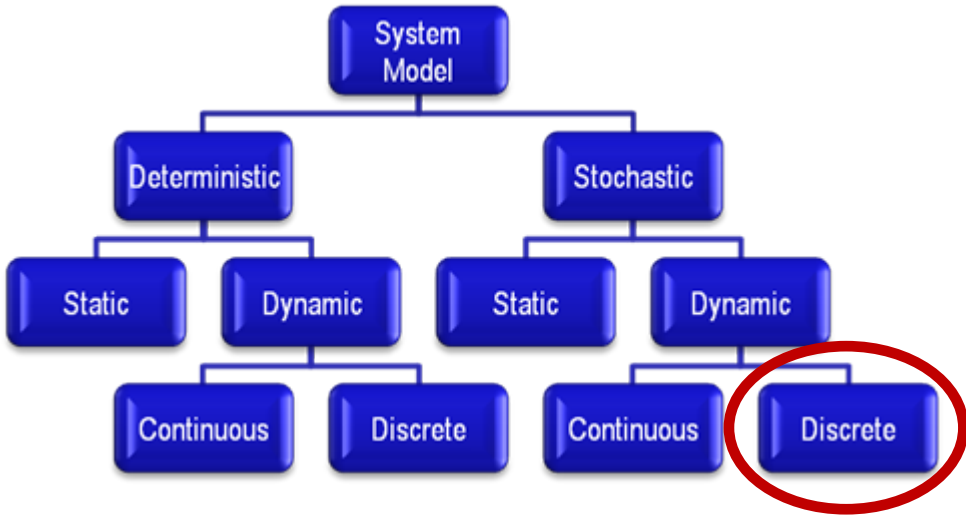
Methodology

Discrete Event Simulation (DES) is the modeling of a system as it evolves over time in which the state variables change instantaneously at separate points in time.[2]

DES System Characteristics

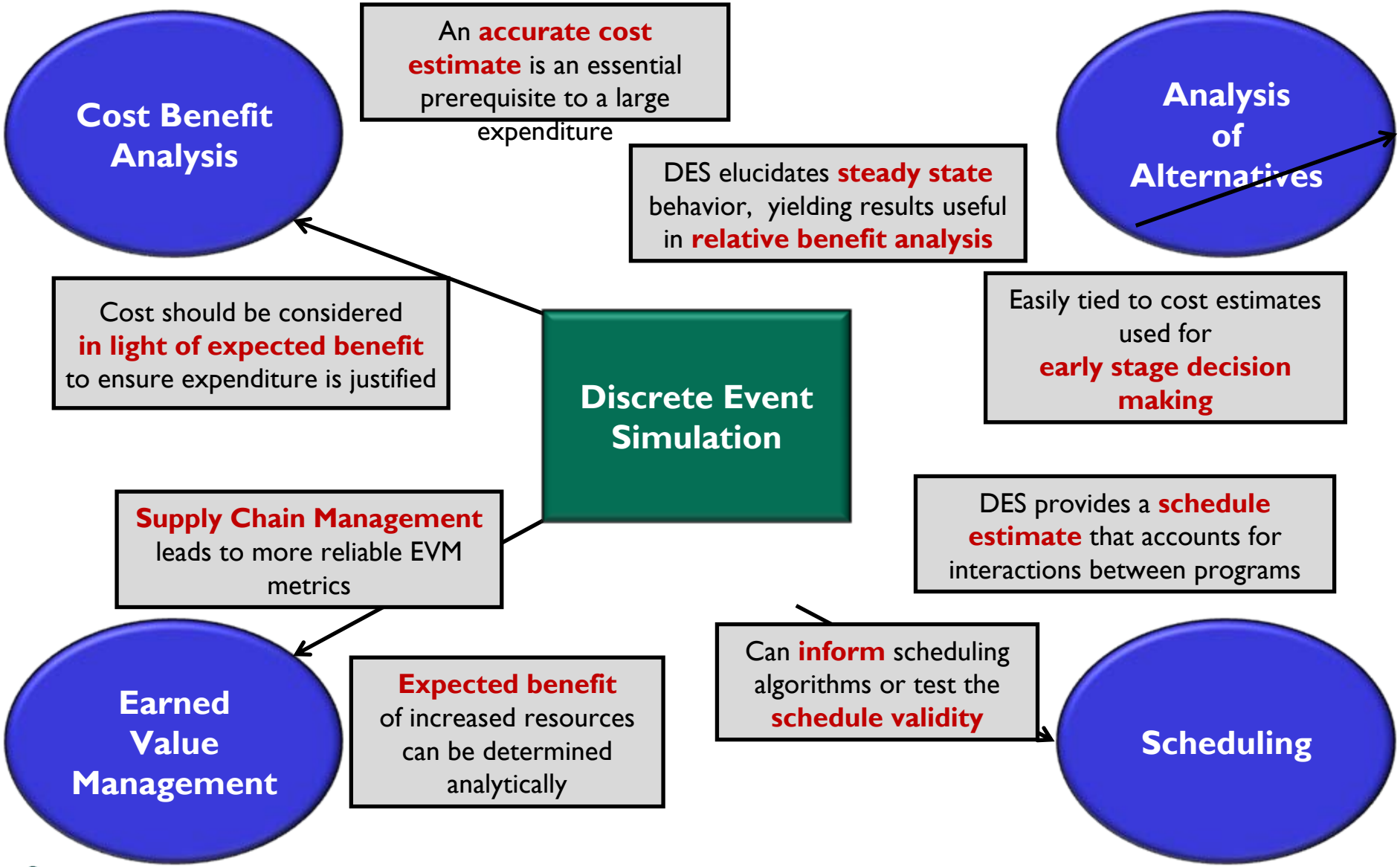
- **Stochastic**: some state variables are random
- **Dynamic**: time evolution is important
- **Discrete**: significant changes occur at discrete time instances

Nature of the state change and the time at which it occurs mandate precise description.[3]



Source: http://www.cs.wm.edu/~esmirni/Teaching/cs526/DESAFC-1.1.pdf

Cost Analysis and DES



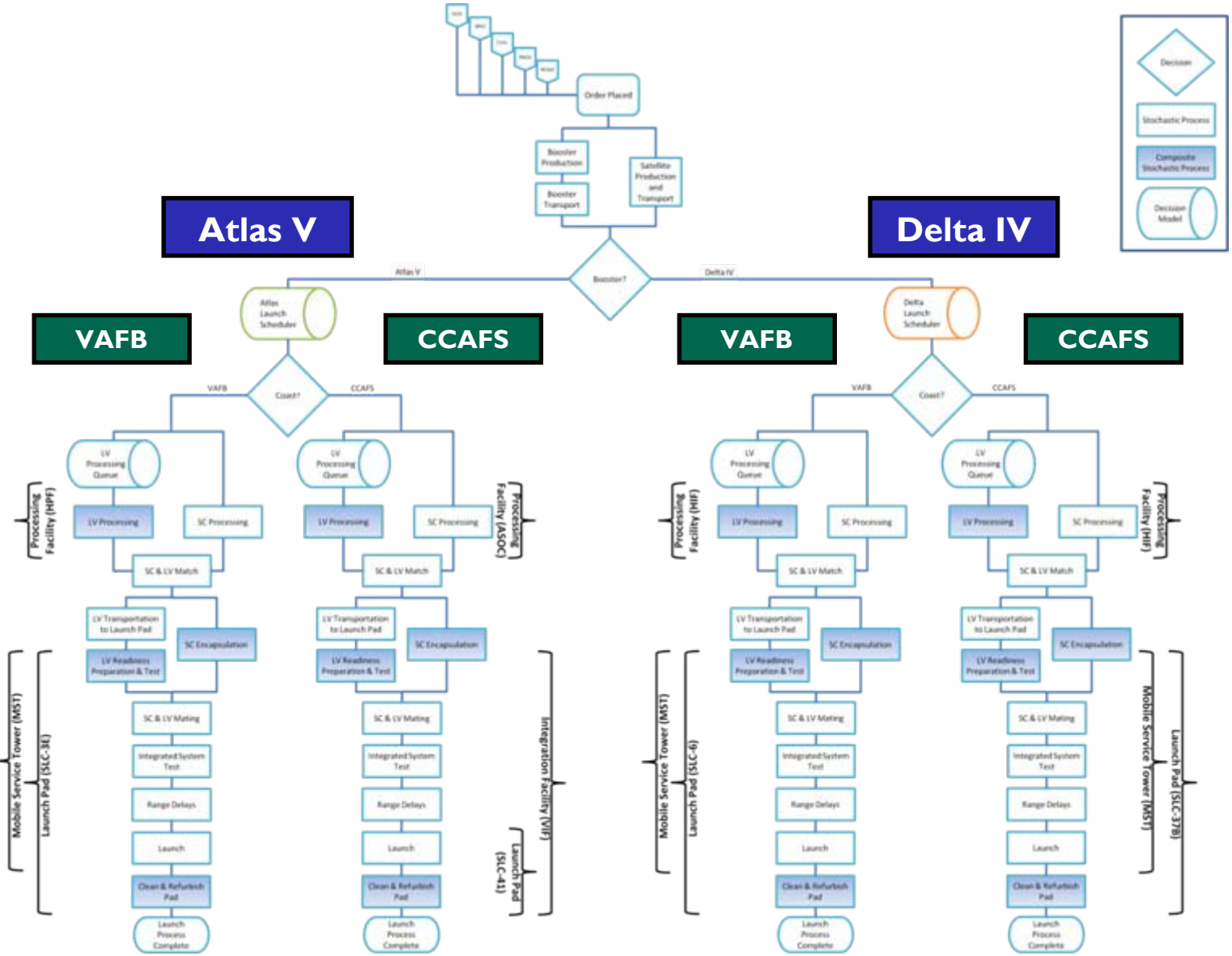
Logical Representation

Booster & Satellite Production

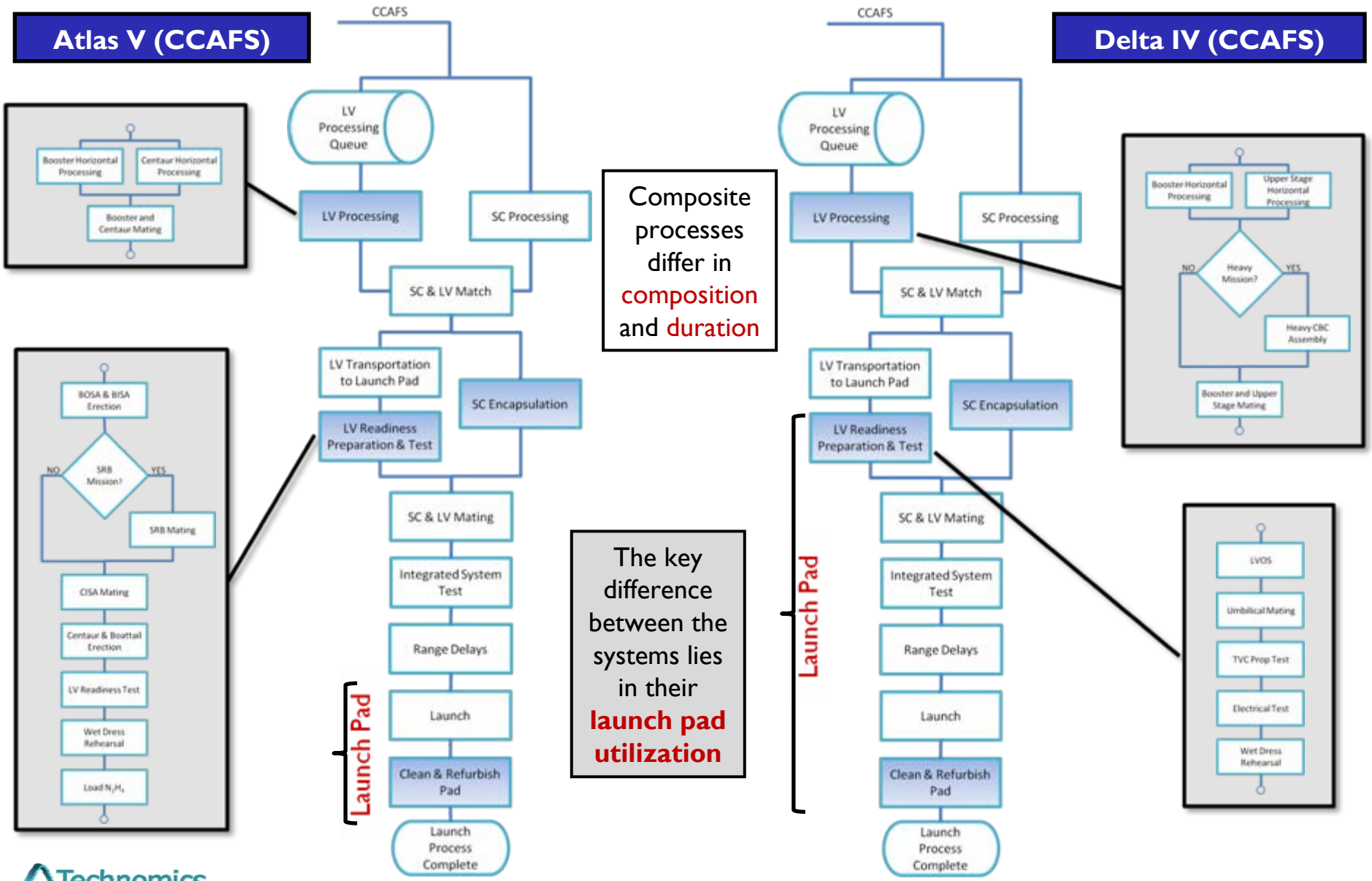
Launch Scheduling Decision

Satellite & Vehicle Integration

Launch Prep, Launch, & Cleanup

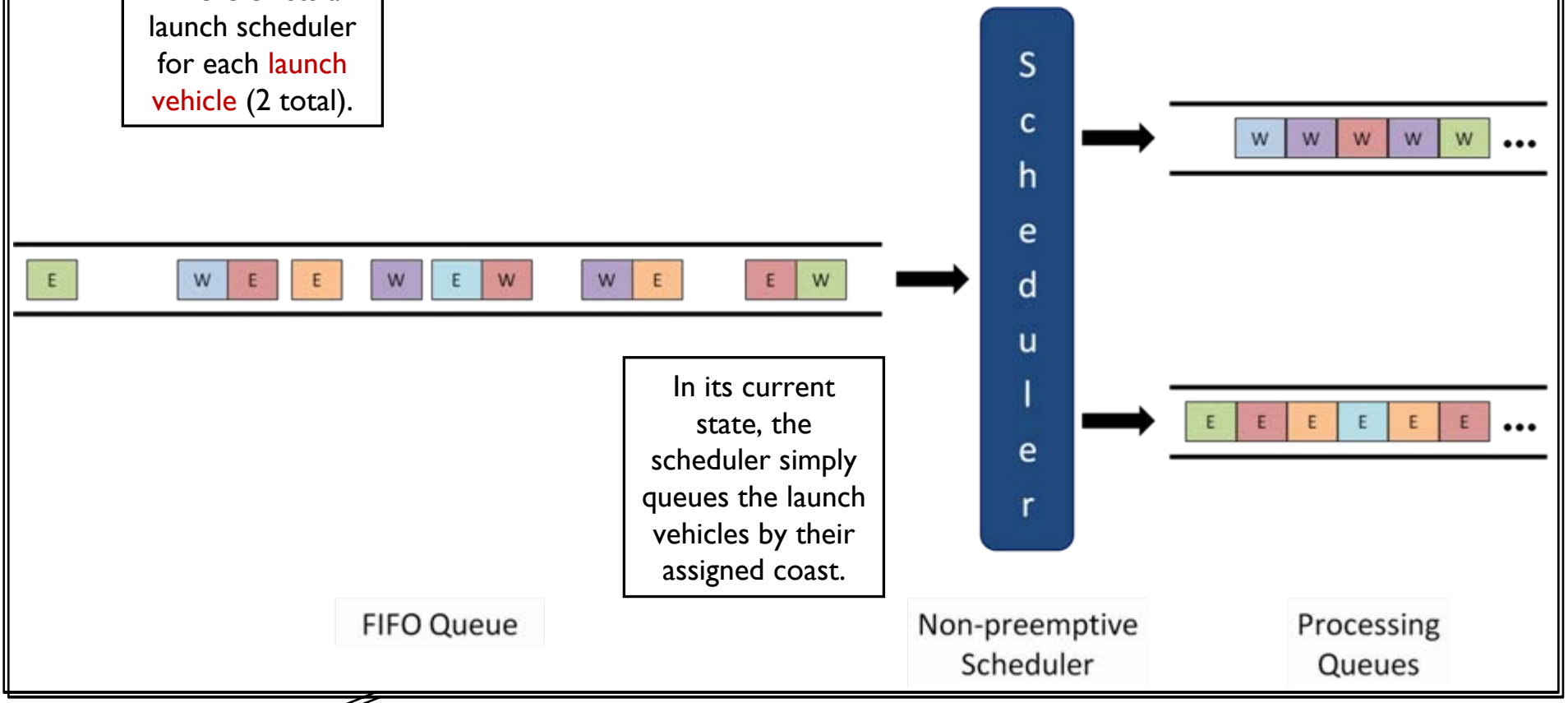


Launch Process Detail

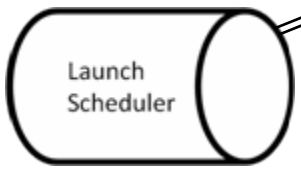


Launch Scheduler

There exists a launch scheduler for each launch vehicle (2 total).



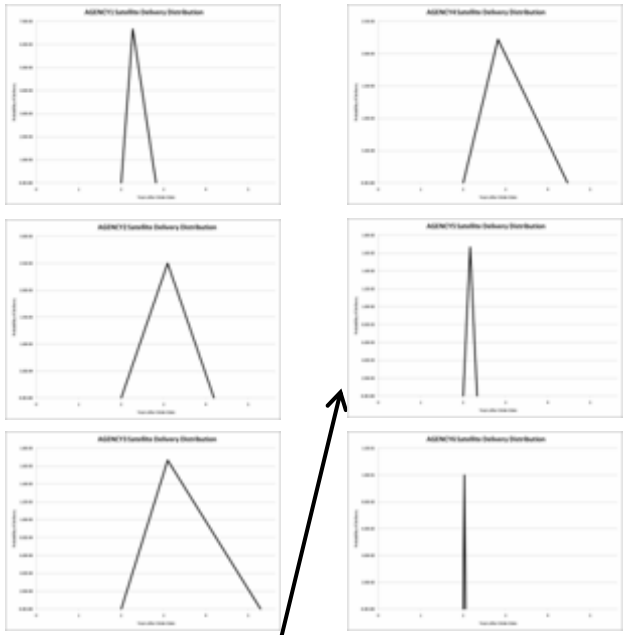
In its current state, the scheduler simply queues the launch vehicles by their assigned coast.



The launch scheduling process represents an area of **significant capability growth**.

Delivery Delay Distributions

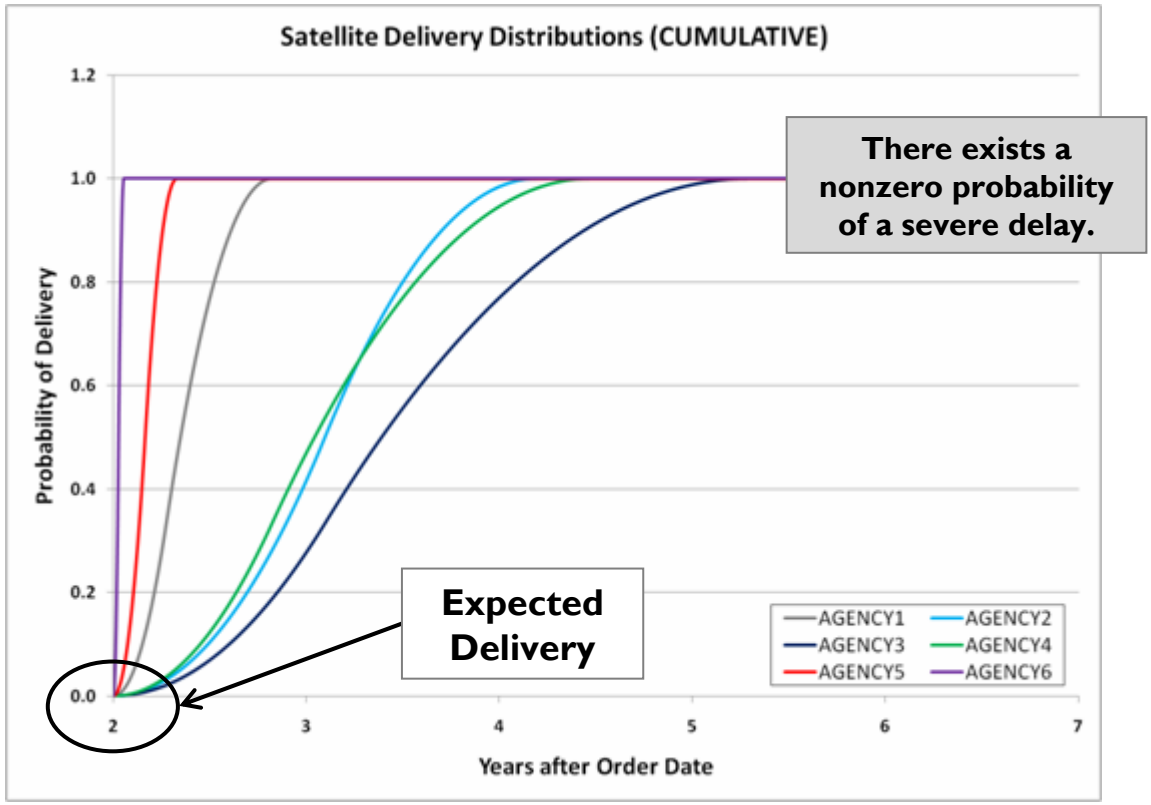
3-point engineering estimates were converted to triangular probability distributions for each agency.



Due to unforgiving launch timing requirements, delivery estimates from some agencies are very conservative, resulting in narrow delay distributions

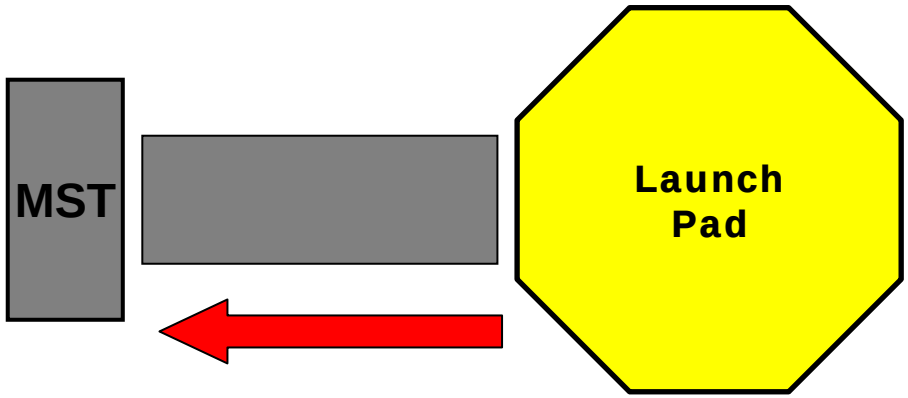
Accurate Delivery Delay Distributions are Critical

- Majority of time required results from production process
- Variability in this process **appears** to be greater
- Order in which payloads arrive tends to dictate schedule



Pad Design Comparison

Standard Design



Mobile Service Tower (MST) is free during launch

MST is moved off the pad before launch

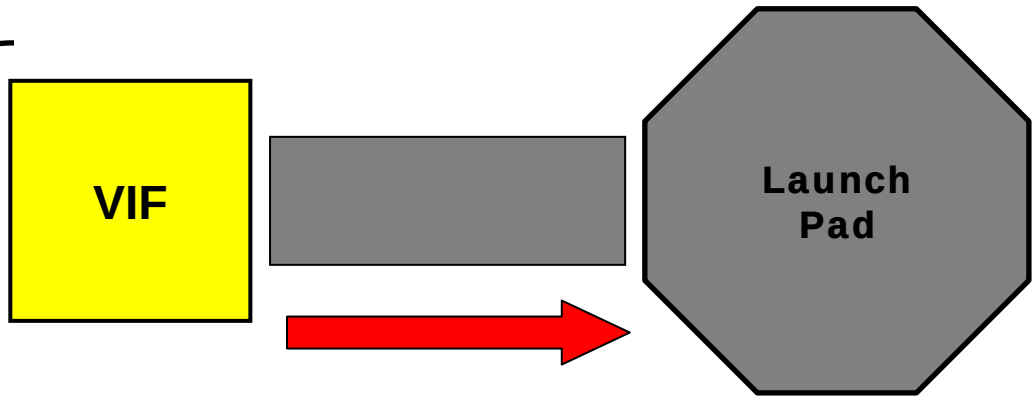
I & T is performed in MST on the pad

90-Day Pad Utilization

Pad is constrained during I & T (30-60 days), launch (1-2 days) and refurbishing (~20-30 days)

Adding capacity to the standard design requires a new launch pad, while the clean pad design requires only a new integration facility.

Clean Pad Design



I & T is performed in the Vertical Integration Facility (VIF)

Launch Vehicle is moved to the pad 1-2 days before launch

Launch activities take place on the pad.

14-Day Pad Utilization

Pad is only constrained during launch (1-2 days) and refurbishing (~12 days)

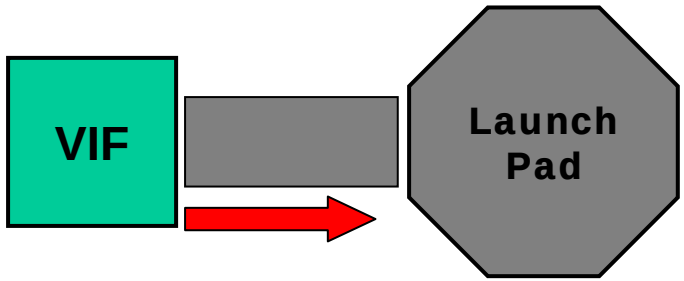
Clean Pad Design

Current Capability

- Atlas V launches at CCAFS
- CCAFS limited by **single VIF**

"If you want to get rid of the choke point, and if you don't want the pad to be the end of the factory, the clean pad is your answer."[4]

Pete Portanova
Principal Engineer/Scientist, Launch
The Aerospace Corporation
1st Principal Director for EELV



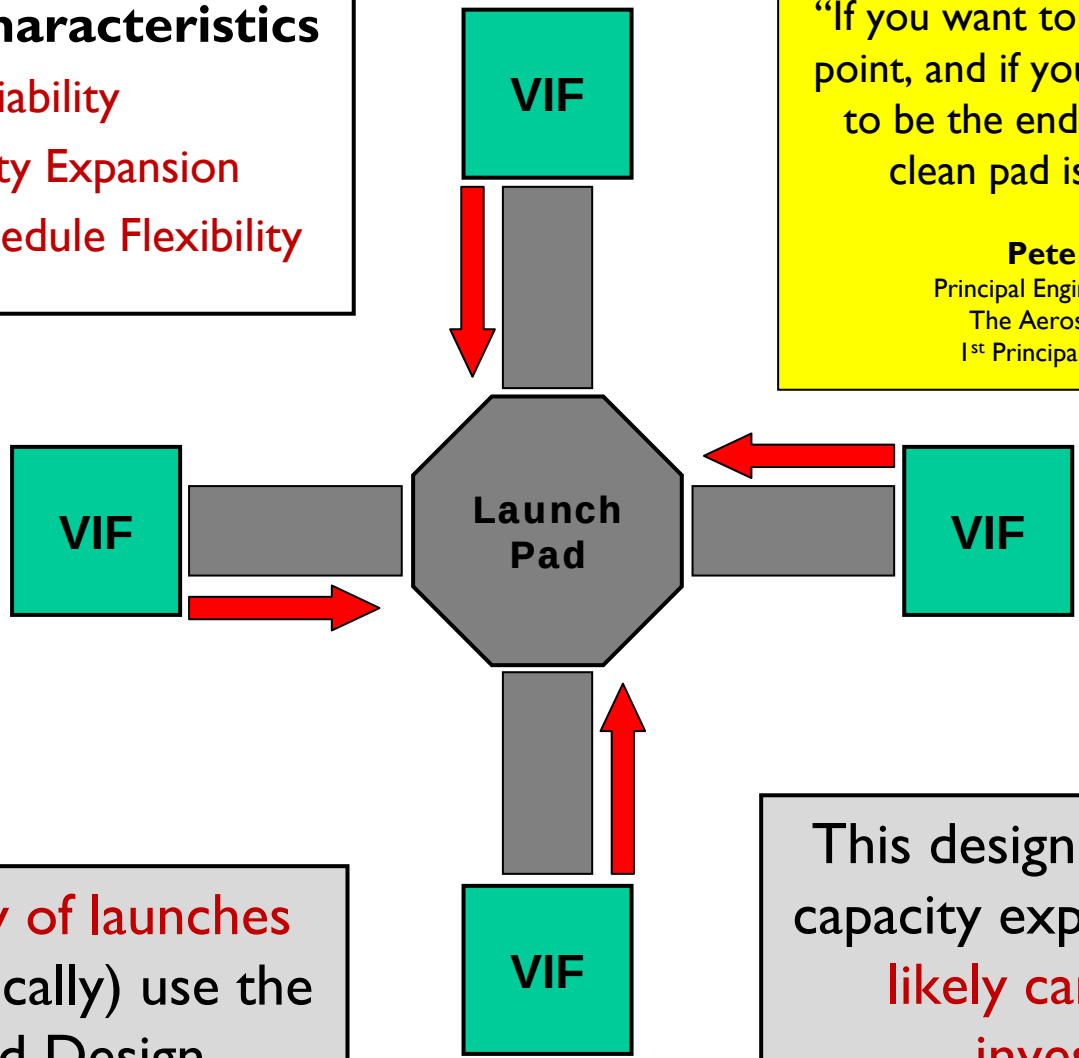
The majority of launches (~65% historically) use the Clean Pad Design

This design lends itself to capacity expansion and is a likely candidate for investment.

Clean Pad Design

Clean Pad Characteristics

- Increased Reliability
- Easier Capacity Expansion
- Increased Schedule Flexibility



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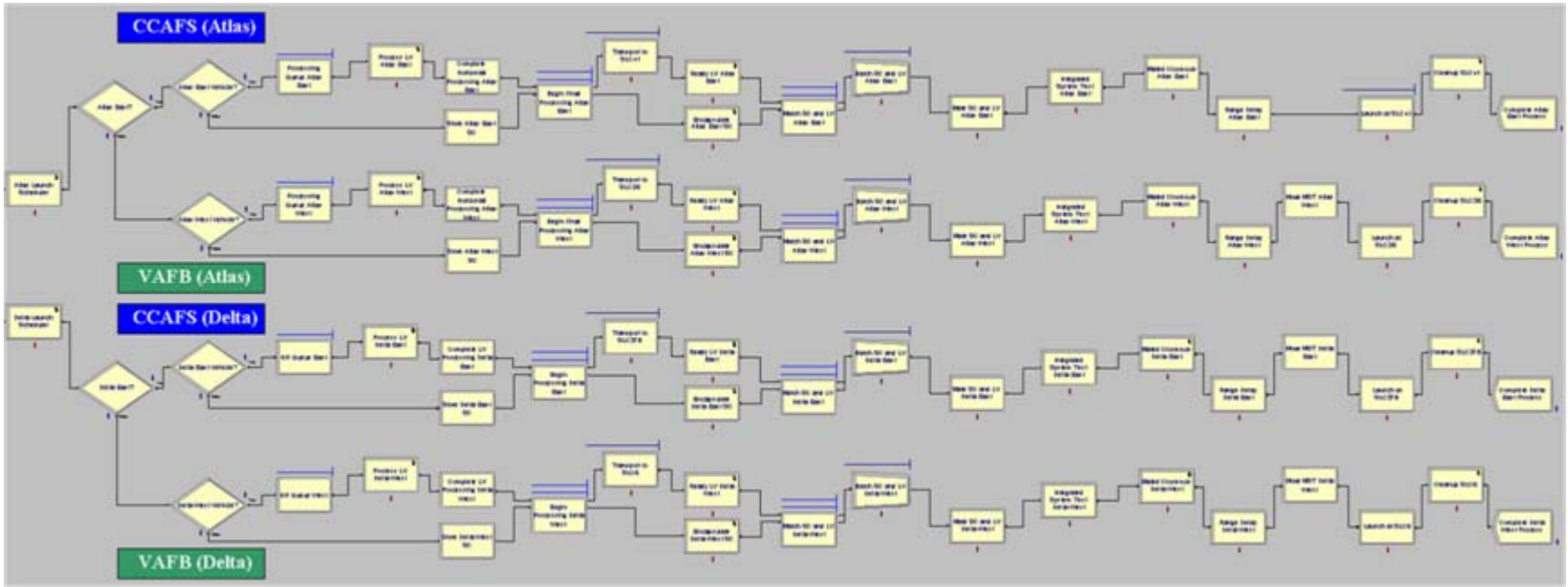
Arena Simulation Model

EELV supply chain structure and process durations supplied by United Launch Alliance (ULA) and OSD-CAPE

Rockwell Arena v13.0 Professional Simulation Software



Launch Scheduling Decision

Satellite and Launch Vehicle Integration

Launch Prep, Launch, and Cleanup

Satellite and **Booster** Production

Model is designed to accept both random data and actual launch manifests as input.

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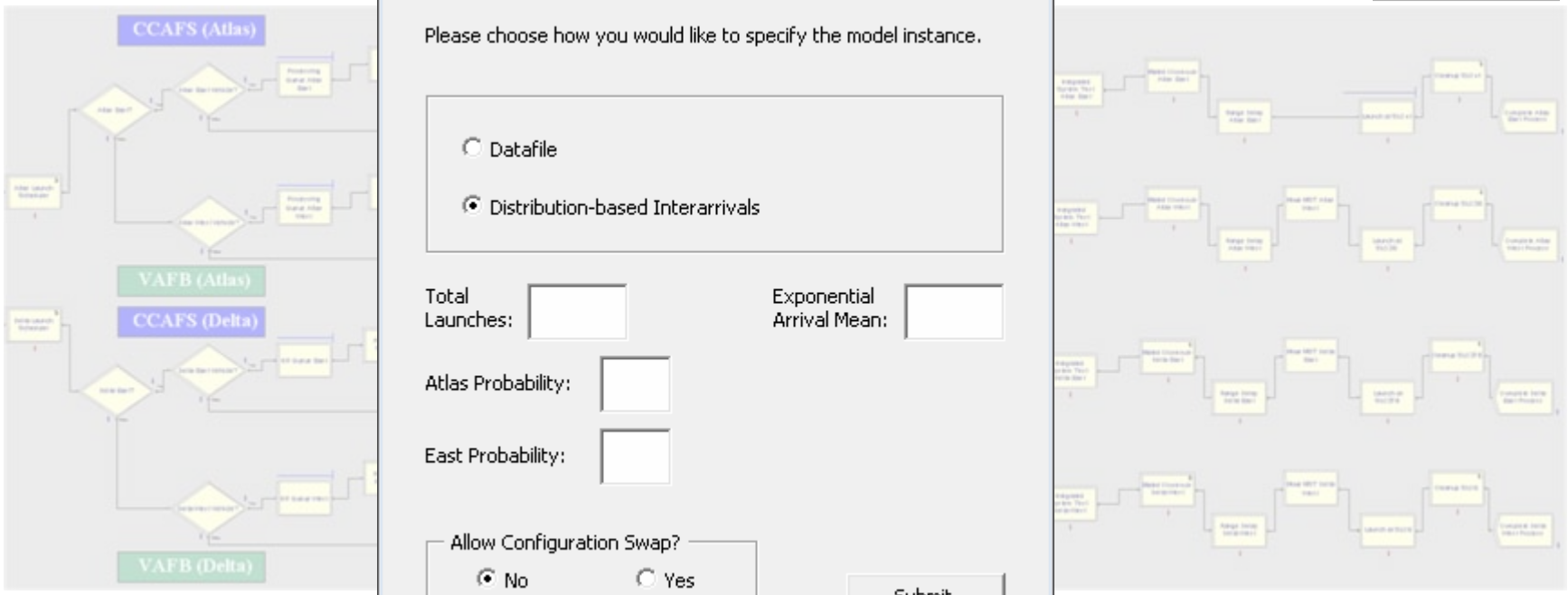


Launch Scheduling Decision

Launch Prep, Launch, and Cleanup

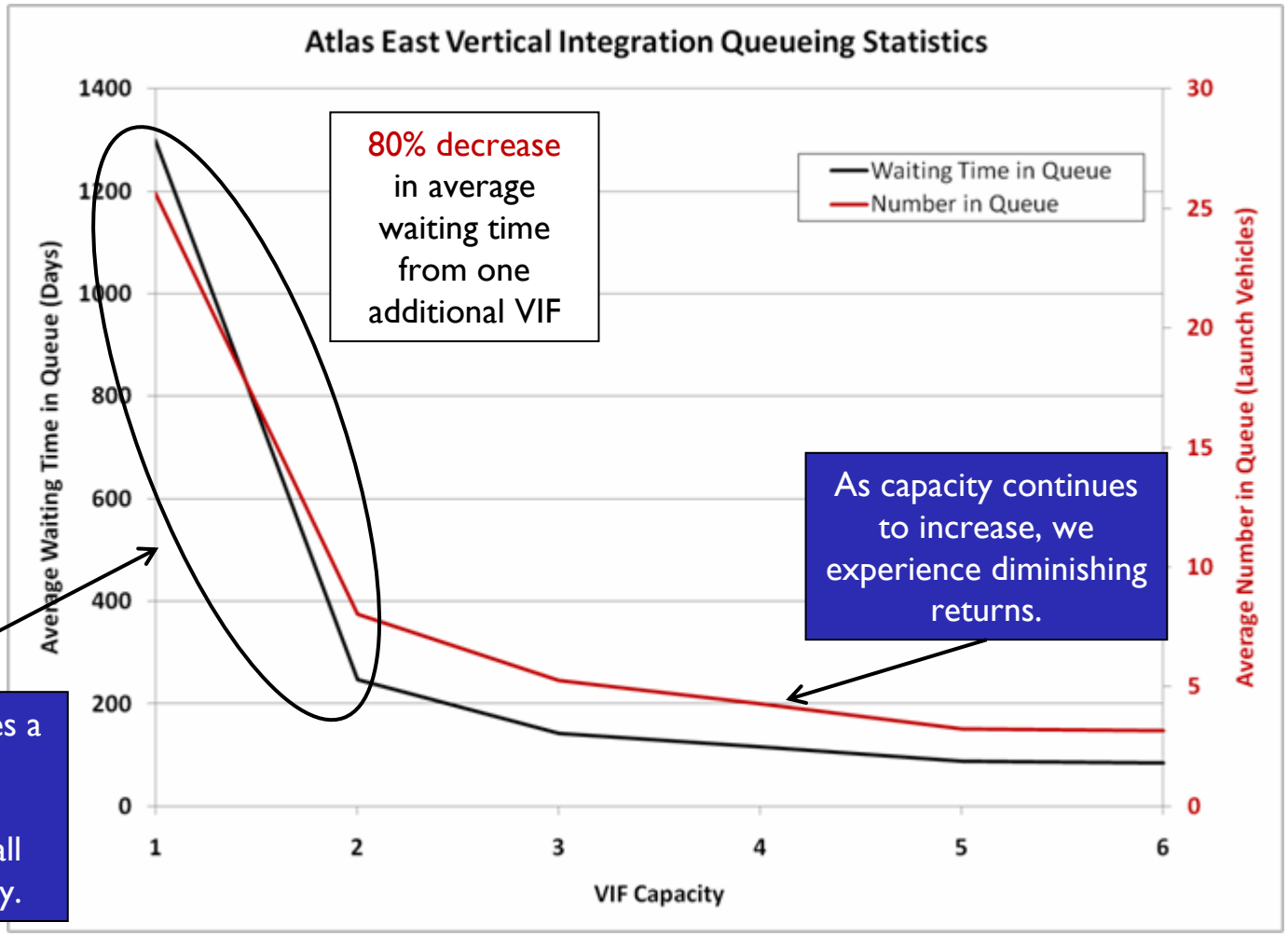
Satellite and **Booster** Production

Model is designed to accept both random data and actual launch manifests as input.

Preliminary Results

Initial experimentation on the VIF capacity shows potential for improvement

Experimental Setup
- Monte Carlo DES
- Exponential Interarrivals (every 15 days on avg.)
- 100 replications
- 100 launches/replication
- Atlas East launches only
- Random Atlas Vehicle Configuration
- **Deterministic integration durations**



Sample Model Outputs

Satellite and Booster Specific Outputs

Duration (Days)	Satellite & Booster Production		Satellite & Vehicle Integration		Launch Prep, Launch, & Cleanup			Total Time in System
Entity	Satellite Production	Booster Production	Integration & Test	Booster Wait Time	Launch Delay	Launch	Cleanup & Travel	
1								
2								
3								
...	...	...	...	...	...	...	...	...
Average								

Days	Booster Wait Times				
Entity	Booster Processing	Booster Wait for Satellite Delivery	VIF/MST Availability	Satellite Encapsulation	Total Wait
1					
2					
3					
...	...		...	...	...
Avg					

Longest Wait Time

Process Specific Outputs

Longest Process Time

Duration (Days)		Average	Min	Max
Satellite & Booster Production	Satellite Production			
	Booster Production			
Satellite & Vehicle Integration	Integration & Test			
Launch Prep, Launch, & Cleanup	Launch Delay			
	Launch			
	Cleanup & Travel			
Wait Time				

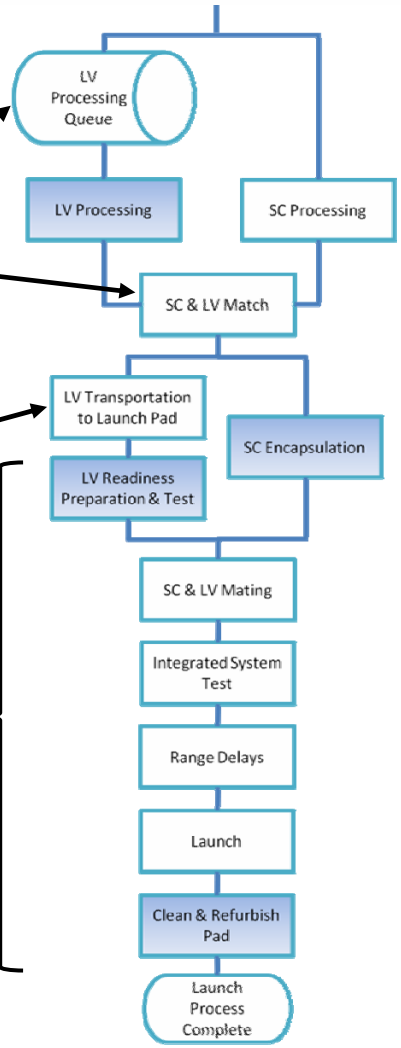
Bottleneck Diagnosis

Delays in satellite production lead to high wait times for launch vehicles.

	Average	Min	Max
Satellite Production			

	Process	Average	Min	Max
LV Wait Times	Processing Queue			
	LV & SV Match			

	Process	Average	Min	Max
LV Wait Times	VIF/MST Availability			

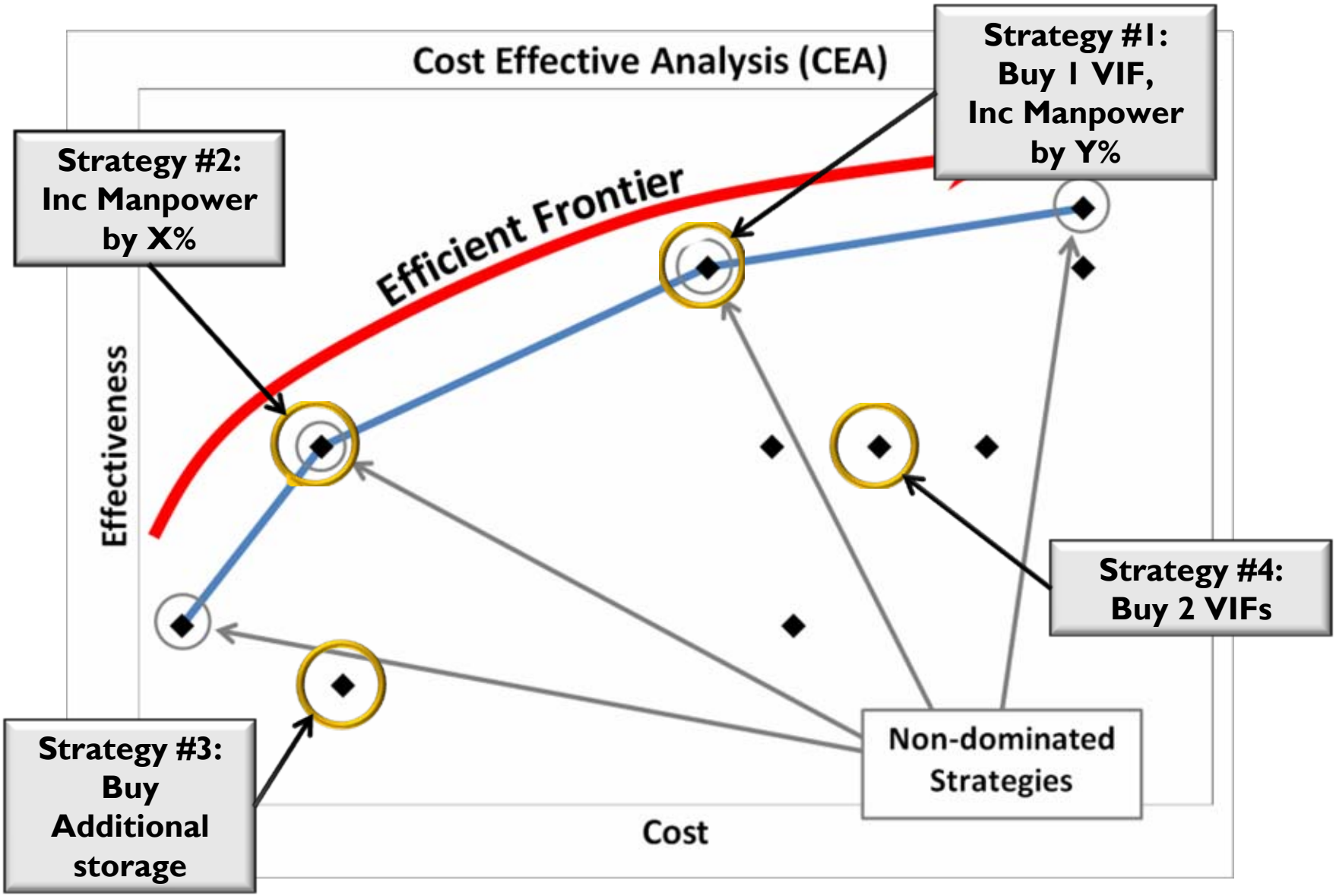


Model outputs identify system inefficiencies and bottlenecks.

Longest average wait time for launch vehicles appears to occur prior to seizing a critical resource (MST or VIF).

MST or VIF

Configuration Comparison



Planned Future Effort

Historical Data Analysis

- Satellite Delivery Delay Distributions
- Integration Process Distributions
- Test Failure Probabilities

Manpower Factor Development

Analysis and Conclusion Development

- Alternative Resource Configuration Definition
- Resource Configuration Benefit Analysis

References

[1] Basu, R., & Wright, J. (2008). Total supply chain management. Oxford: Elsevier.

[2] Law, A., & W. David. Kelton. (2000). *Simulation Modeling and Analysis*. Boston: McGraw-Hill.

[3] Nance, R. E. (1993). History of Discrete Event Simulation Programming Languages. Proceedings of the *Second ACM SIGPLAN History of Programming Languages Conference*, 20-23.

[4] Portanova, P. (2009). Excerpt from an oral history interview conducted with Portanova. El Segundo, California. (http://www.aero.org/publications/crosslink/spring2010/03_side2.html).