# Model-Based Flight Software Development

## Flight Software Pathfinder

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# FSW Pathfinder – Introduction

**The Flight Software Pathfinder**

- A software modeling demonstration activity
- Performed to directly compare the productivity, quality, advantages, and disadvantages of:
  - A typical heritage, documentation centric flight software development process
  - Integrated, model based flight software development process using graphical modeling tools

# FSW Pathfinder - Introduction

## Demonstrated a model-based approach

- Software design that incorporates automated source code generation targeted to modern flight-qualified processors, while providing a migration path for future space vehicles

## Addressed each phase of the software lifecycle

- Architecture, Requirements, Design, Implementation, Integration, and Test

## Produced evidence

- Metrics taken to support competitive, credible, CMMI compliant proposals, and the associated Basis of Estimates (BOEs)

# FSW Pathfinder – Model Based Engineering (MBE) Rationale

## MBE reduces risk and cost

- Decreased development time
- Flexibility
- Readability

## Provides improved techniques for managing technical information

- Model artifacts persist throughout lifecycle, eliminating duplication and divergence
- Maintains traceability of architecture, requirements, design, implementation, and test information
- Provides improved support for practical reuse
  - Design is more reusable and extensible than source code
  - Not bound to a specific programming language

## MBE reduces defects

- Requirements analysis based on understanding concept of operations and required functionality, resulting in greater analytical rigor
- Eliminates re-work effort by detecting defects earlier in the life cycle
- Enables early test and verification before coding

# FSW Pathfinder – Objectives

1. **Leverage Model Based System Design (MBSD) to:**
   - Increase software productivity & quality
   - Reduce software risk & schedule
2. **Demonstrate the fundamental tenets of an efficient Model Based approach to flight software development, integration, and test**
   - Modeling Maturity
   - Model Driven Architecture
   - Graphical Models & Domain Specific Languages
   - Code & Test Automation
3. **Compare the efficiency and quality of the MBSD approach for software lifecycle activities against the heritage approach**
   - Collect, analyze and report both quantitative and qualitative measures for each approach.
   - Prove the value of MBSD for flight software development, integration, and test.
4. **Produce supporting products for use by programs applying MBSD software development.**
   - Standard Modeling Methods process guidebook for modeling tools and methods.
   - Basis of Estimate templates & supporting metrics for proposing MBSD software activities.
   - Identify deficiencies and the associated improvements required to optimize the processes and tools.

# FSW Pathfinder – Process (slide 1 of 2)

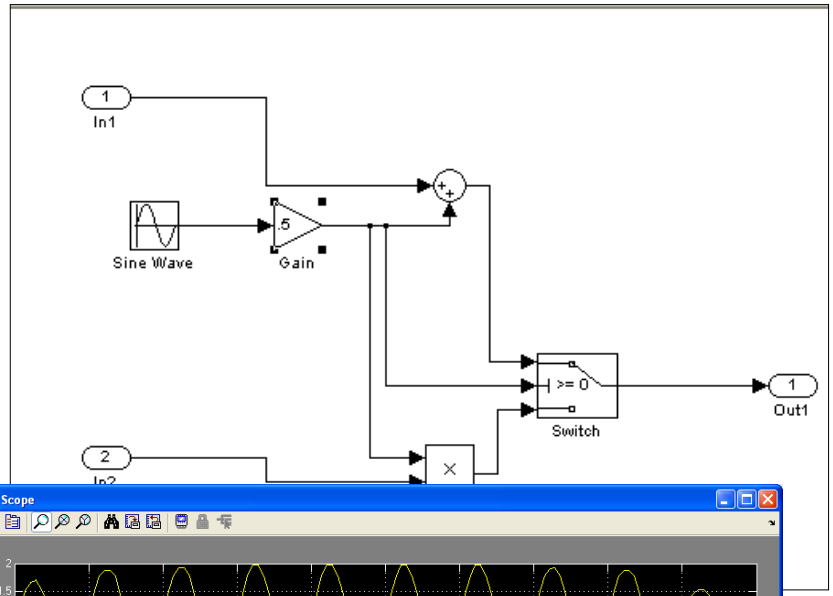
- Develop 3 Incremental Subsets of Flight Software Functionality
  - GNC and EPS subject matter domains.
  - 2 independent SW engineers per domain.
    - Each SW engineer applies both approaches incrementally

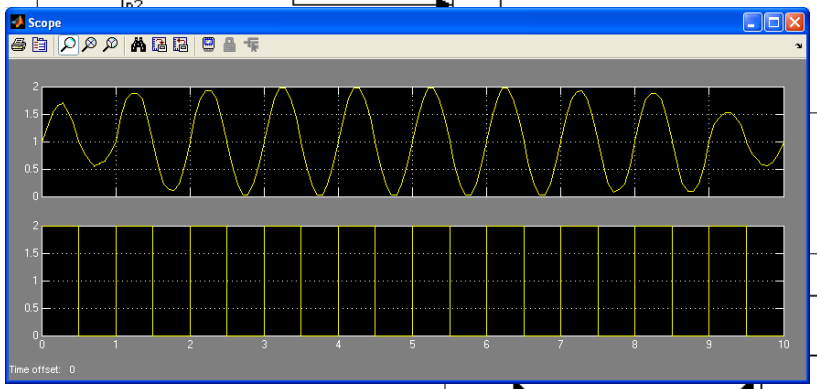
| Model-Based | Heritage |
| --- | --- |
| • Both GNC and EPS use UML for Architecture and Requirements analysis<br>• GNC using domain specific tools Matlab / Simulink<br>  • Fully auto-generated code<br>• EPS using general OOA/D UML with IBM Rational Rhapsody<br>  • Semi auto generated code, adding implementation detail by hand | • Documentation centric approach<br>• Documents and drawings using Microsoft Office<br>• Hand generated code |

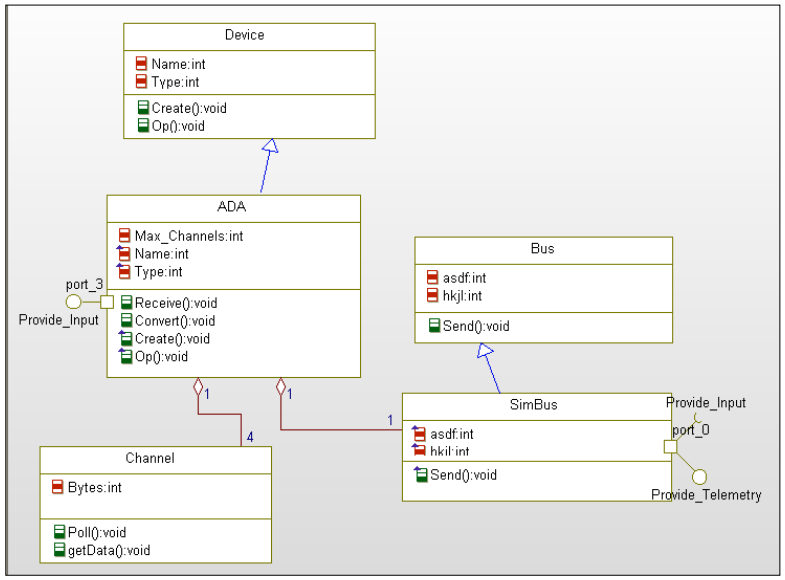
# FSW Pathfinder – Process (slide 2 of 2)

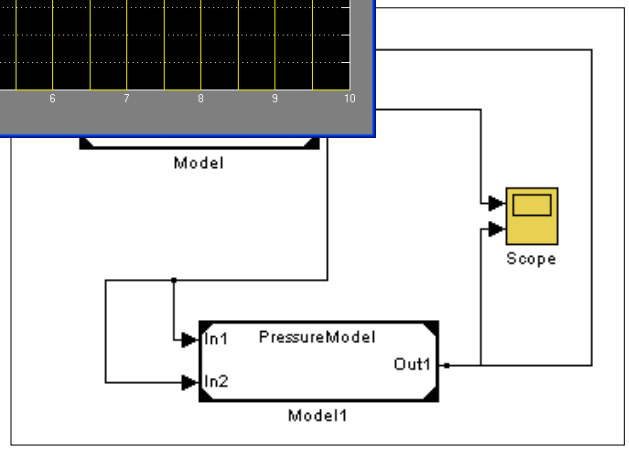
- Compare approaches through quantitative and qualitative measures
  - Cost metrics taken for each phase of development
  - Review artifacts produced for readability and reusability
  - Document issues encountered and lessons learned
  - Measure and characterize trends from one increment to the next.
- Integrate and test products in each domain for both approaches
  - Both to find defects and learn if efficiency and thoroughness is improved through MBSD
  - Unit testing
    - Leverage features of MBSD tools to automate
  - Functional verification
  - Final code efficiency benchmarks

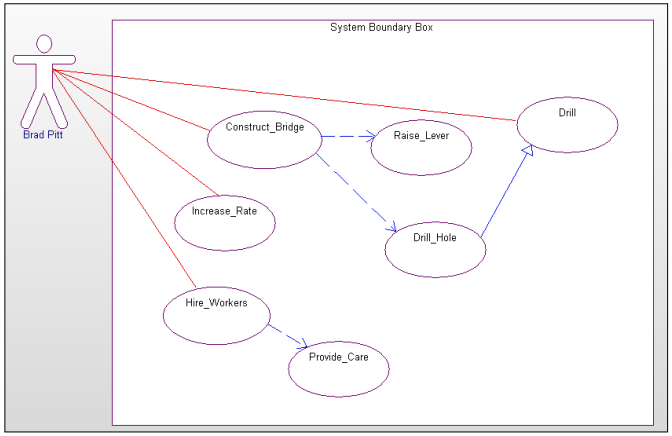
# FSW Pathfinder – Modeling Tools



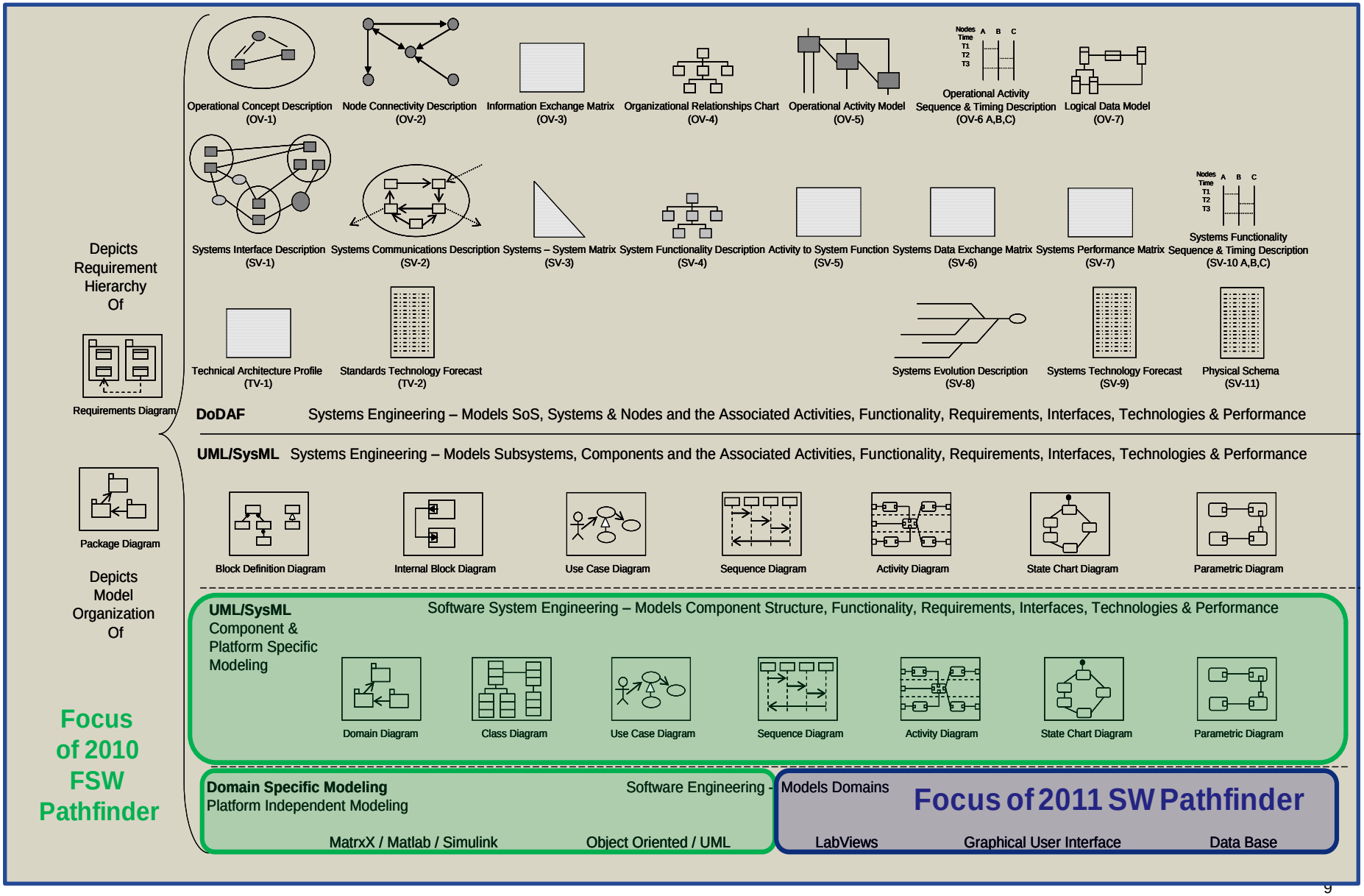



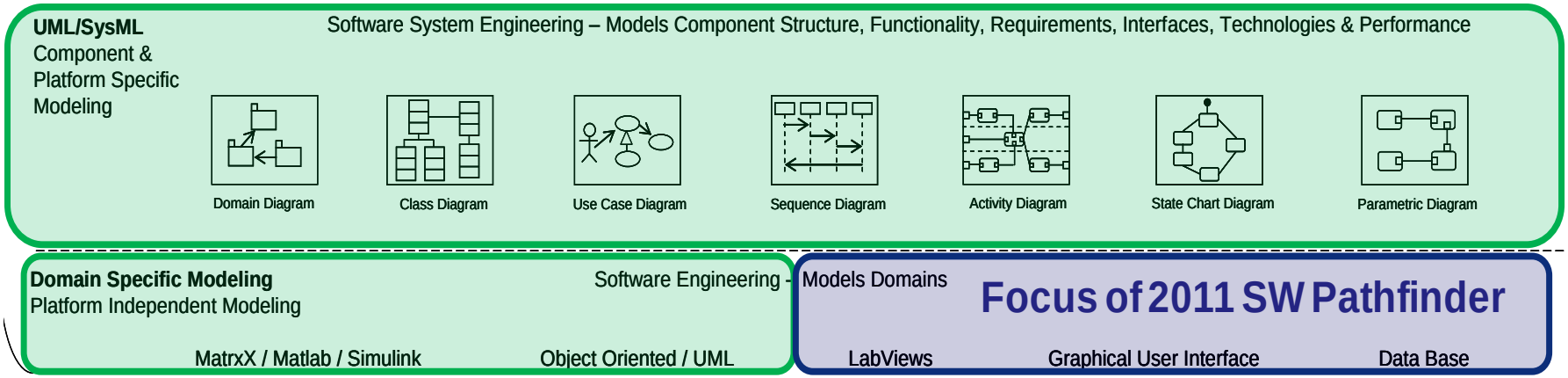



# FSW Pathfinder – MBSD Artifacts



# FSW Pathfinder – Engineering Focus

- Systems Engineering Inputs to Software
  - Heritage Approach
    - Used heritage documentation to ensure realism in development
  - Model Based Approach
    - Created modeling equivalents of heritage documentation

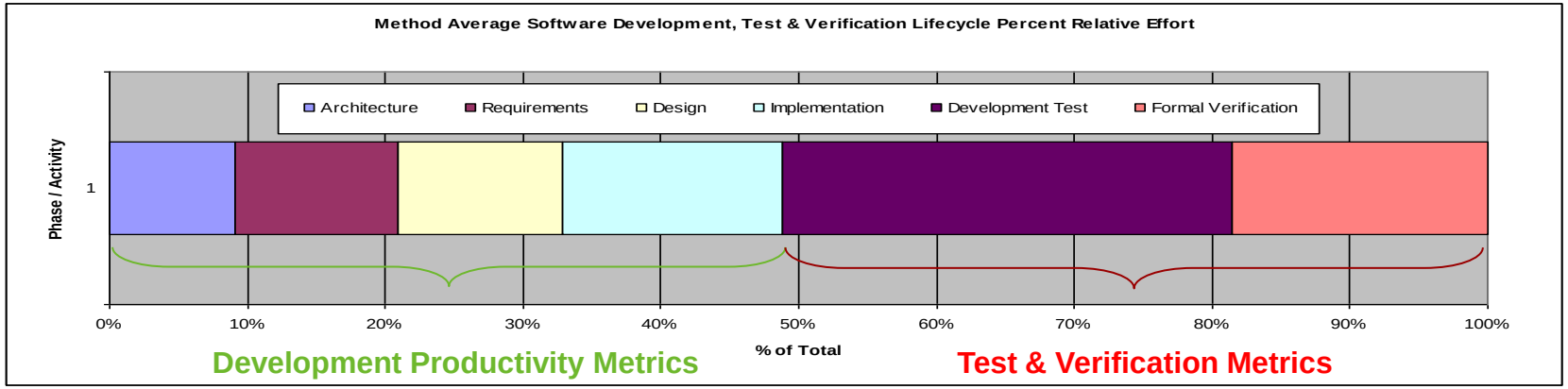



**Appropriate SE Paradigm Used to Provide SE Pre-Development Artifacts**

# FSW Pathfinder – Schedule

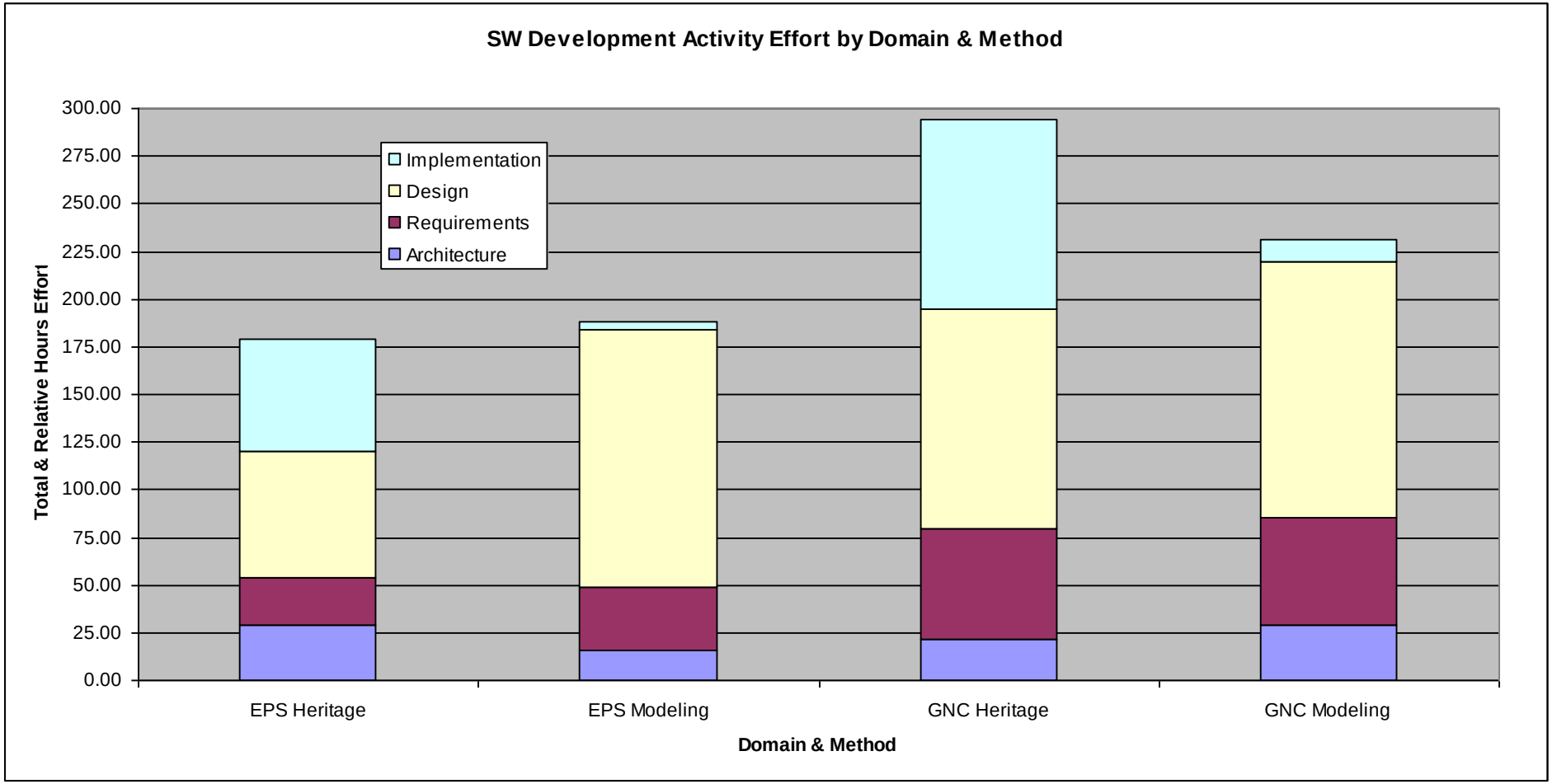
- 2009
  - Oct-Dec: Detailed planning
- 2010
  - Jan-Feb: Systems Engineering inputs produced
  - Mar: Software Pathfinder kicked off
  - Mar-Nov: Architecture, Requirements, Design, Implementation, Integration completed
    - Metrics collected at each phase
    - SDP and BOE plans developed
- 2011
  - Testing and completion of project

# FSW Pathfinder - Context




- Development
  - Defined as the Architecture, Requirements, Design and Implementation Activities
  - Development comprises approximately 48% of the total NRE software lifecycle cost
- Test & Verification
  - Defined as the Unit, Integration, and Formal Verification / Qualification Test Activities
  - Test & Verification comprises approximately 52% of the total NRE software lifecycle cost

# FSW Pathfinder - Metrics



# FSW Pathfinder – Results (slide 1 of 2)

| SW Development Phase | Model Based Phase Development Cost Change from Heritage Baseline | Model Based Percent Cost Change of Total Development |
|---|---|---|
| Software Architecture | 12% Reduction | 1% Reduction |
| Software Requirements Analysis | 10% Increase | 2% Increase |
| Software Design & Implementation | Simulink: 32% Reduction<br>UML: 11% Increase | Simulink: 23% Reduction<br>UML: 8% Increase |
| Development (Unit/Integration) Test | Simulink: 60% Reduction<br>UML: 0% No Difference | Simulink: 11% Reduction<br>UML: 0% No Difference |
| Formal Verification / Qualification | Simulink: 33% Reduction<br>UML: 5% Reduction | Simulink: 6% Reduction<br>UML: 1% Reduction |

# FSW Pathfinder – Results (slide 1 of 2)

## Total Results using MBSD

| | |
|---|---|
| Net Delta of Development Cost | Simulink: 22% Reduction<br>UML: 8% Increase |
| Net Delta of total Development, Testing, and Validation Cost | Simulink: **39% Reduction**<br>UML: **7% Increase** (without T&V improvements)<br>UML: **8% Reduction** (with T&V improvements) |
| Defects & Errors | Defect Reduction 44%<br>Error Reduction 50% |

# FSW Pathfinder – Observations (slide 1 of 2)

Cost Productivity improvements better for both methods with larger code increments

The development effort is reduced for Model-Based Architecture due to greater support for automated document generation

Model-based Requirements Analysis effort increases slightly due to greater process rigor

More significant Design effort in model-based, due to the increased implementation detail necessary for model execution.

- Resulting in significantly decreased Implementation effort

The Testing effort is drastically reduced for the domain specific (Simulink) modeling.

- Similar benefits are possible for other executable modeling languages

Modeling produced more modular, encapsulated code

- Higher complexity under static analysis, requires more throughput
- Easier to read, debug, and reuse

# FSW Pathfinder – Observations (slide 2 of 2)

Model based approach produced higher quality documentation of the software architecture, requirements, design and implementation

- Improved readability, traceability

Persistence of original architectural models through design and implementation ensures adherence to original requirements and early design

Verification test planning was made easier due to the improved understanding of functional requirements in the model-based approach

- Use Cases enable scenario based test

Longer design phase and shorter implementation phase fulfill stated goal of shifting work to the "left" under the process curve, reducing risk

Tool maturity issues that hampered development

- IBM Rational Rhapsody (UML)
  - Some unpredictable behavior, fragility in code generation options
  - Reported issues to IBM, tool maturity still progressing

# FSW Pathfinder - Caveats

- The effect of the learning curve was significant
  - As developers grew more comfortable with the tools, development time decreased dramatically (2-3x)
  - Once learning curve passed, experienced engineers became more productive with model-based vs heritage
- Code efficiency was worse for model-based/auto-generated code
  - This is consistent with earlier results provided by other programs
  - Possible to utilize optimizations and expert features in the tools to improve this
  - Code bloat factor of ~2.5 for auto-generated code

# FSW Pathfinder - Conclusions

## Model-Based Engineering reduces risk and cost of FSW

- In our results, a 39% reduction from heritage baseline using domain specific modeling for both development and testing
- Generic UML modeling resulted in a small cost increase for development alone, but overall cost decrease when modeling used in testing and verification as well
  - Fewer defects and errors reduce cost of rework
- In addition to quantitative cost/time benefits, qualitative benefits of modularity, readability, and reusability are significant

## Use the right tools

- For software design and implementation, use domain-specific tools that support executable models, such as Simulink
- Leverage available tools, especially for unit testing and automation

## Avoid pitfalls

- Schedule must account for learning curve for first-time developers
- Current capabilities of code generators results in a loss of execution efficiency
  - Code optimizations should be investigated and used where possible
  - Vendors must improve the quality of their code generators