Jet Propulsion Laboratory
California Institute of Technology

MBSE on NASA's Proposed Europa Mission

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Flight System Requirements Team

Model System Engineering Team

Agenda

- Introduction
- Europa?
- MBSE on the Europa Project?
- How’s that going?
- Recommendations

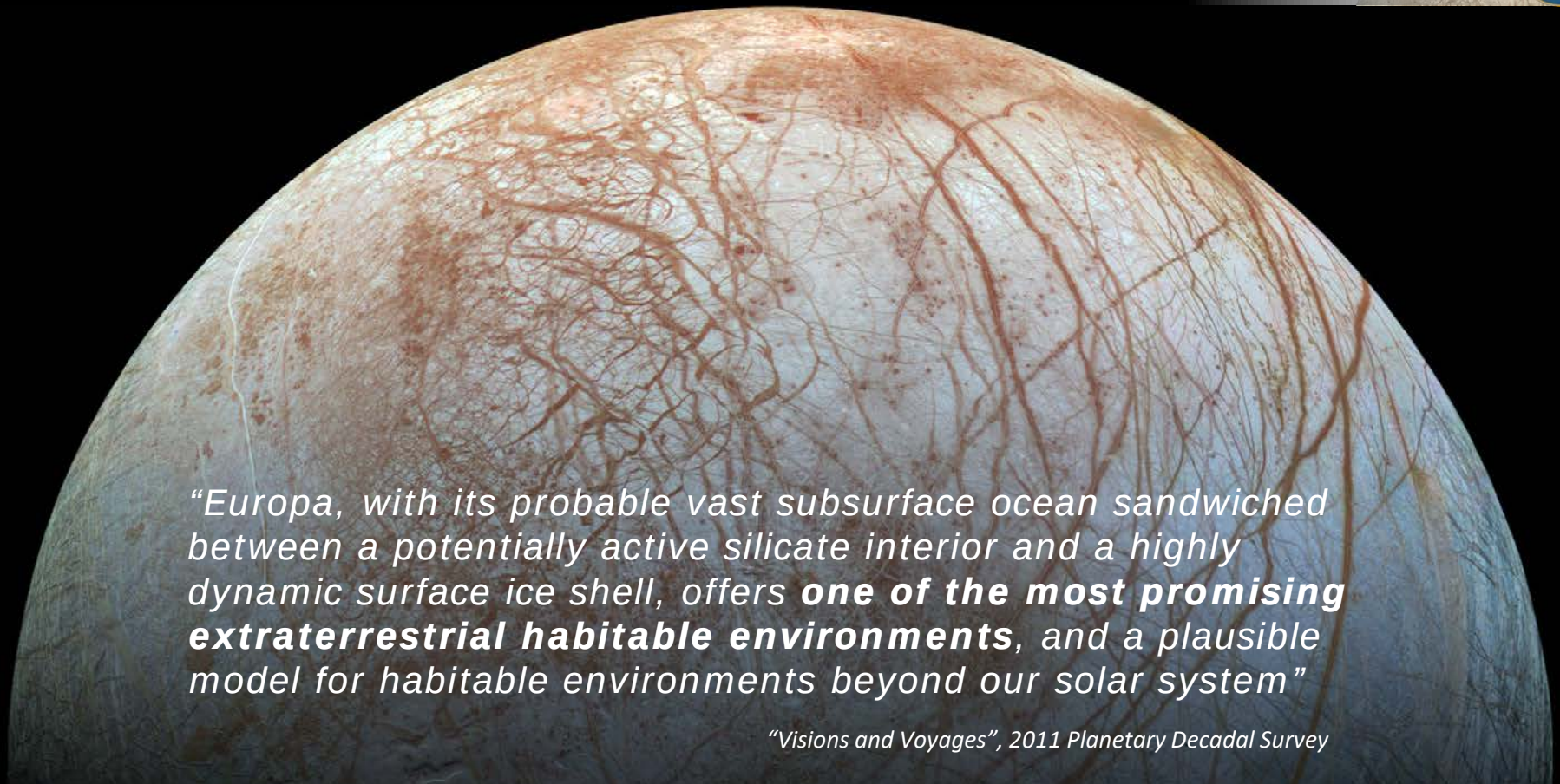
INTRODUCTION

Introduction

- Me: Europa Project for ~2 years
- MBSE for 7
- Roles:
  - Practitioner
  - Systems Engineer on FS requirements team
    - Do requirements engineering, *happen* to use MBSE as tool of choice
    - SW developer for query, automation, tool, visualization, and any other as-need infrastructure
  - Model System Engineer for PSE
    - *One* interface between SEs with more traditional skill sets and system model
    - My particular role is software management

EUROPA?

Europa



"Europa, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers ***one of the most promising extraterrestrial habitable environments****, and a plausible model for habitable environments beyond our solar system"*

"Visions and Voyages", 2011 Planetary Decadal Survey

- How do we solve Europa's mysteries? By potentially sending a spacecraft and instruments to collect data for our investigation!
- Europa Project:
  - Early phase
  - Dual focus on system/design architecture and closing big trades *and* requirements derivation, analysis, and flow-down.

MBSE… ON EUROPA

(not literally)

MBSE on the Europa Project

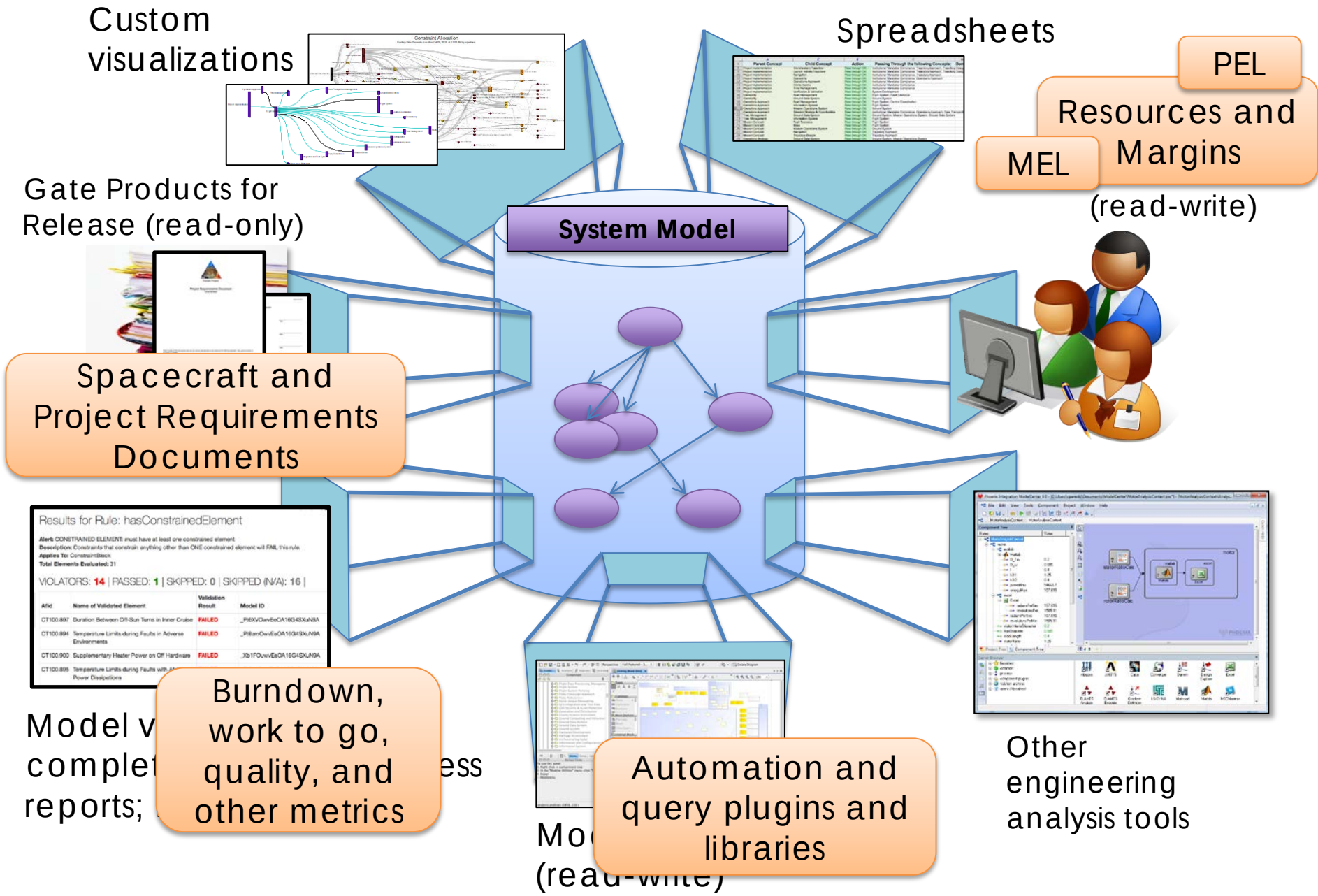
- Europa is fully MBSE mission concept
  - We *use* MBSE to do our SE
  - MBSE is not the product

- Specifically, for our phase:
  - MELs, PELs, resource allocation and analysis, system decomposition, etc
  - All systems engineering activities
    - Requirements (derivation, justification, traceability, analysis, maturity, history, verification, document generation, metrics, etc.)
    - This talk will focus on the SE aspects

What can you do with MBSE?

- Single Source of Truth
  - Multiple interfaces (tailored), no confusion
  - Living, interlinked, customized views of data
- Automated generation of traditional and non-traditional documents
  - Gate products
  - Release documents
  - Analysis products, spreadsheets, visualizations, etc.
- Semantically rich (and rigorous) patterns for expressing SE knowledge
  - Reduces interpretation confusion
  - Forces clarity, completeness, correctness
  - Machine analyzable and queryable

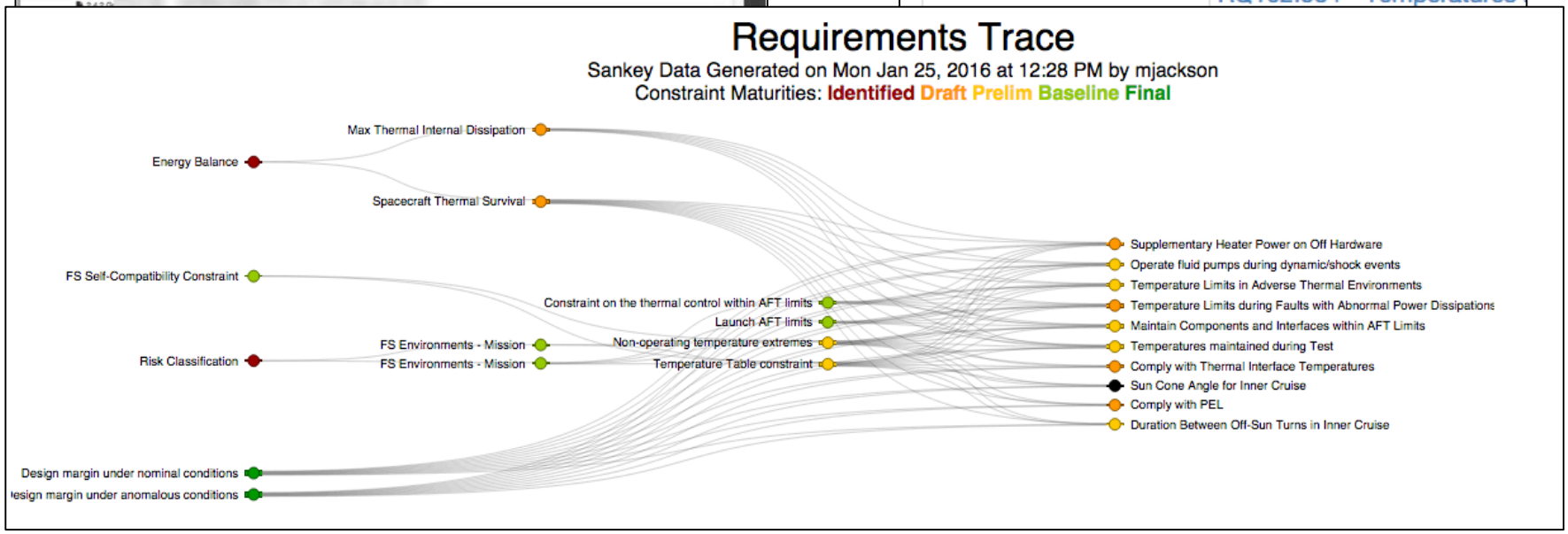
What does the Europa Project do with that?



What have we done with MBSE?

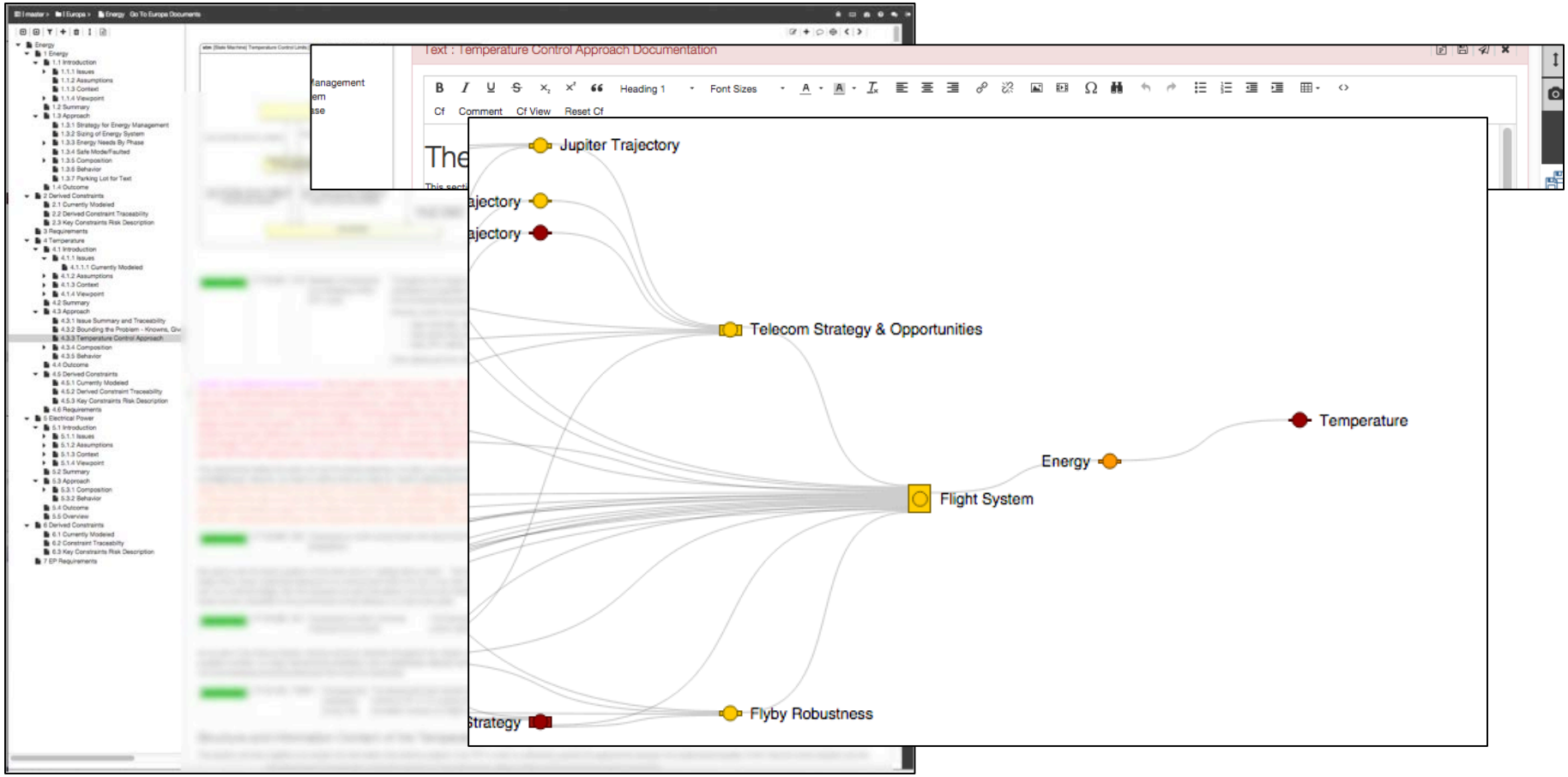
- Requirements → documents
- Requirements → traceability

Parent Requirement(s)	Child Requirement(s)
RQ103.735 - Energy Balance	RQ101.691 - Supplementary
	RQ104.302 - Instrument Hea
	RQ101.041 - Operate fluid p
	RQ102.584 - Temperatures



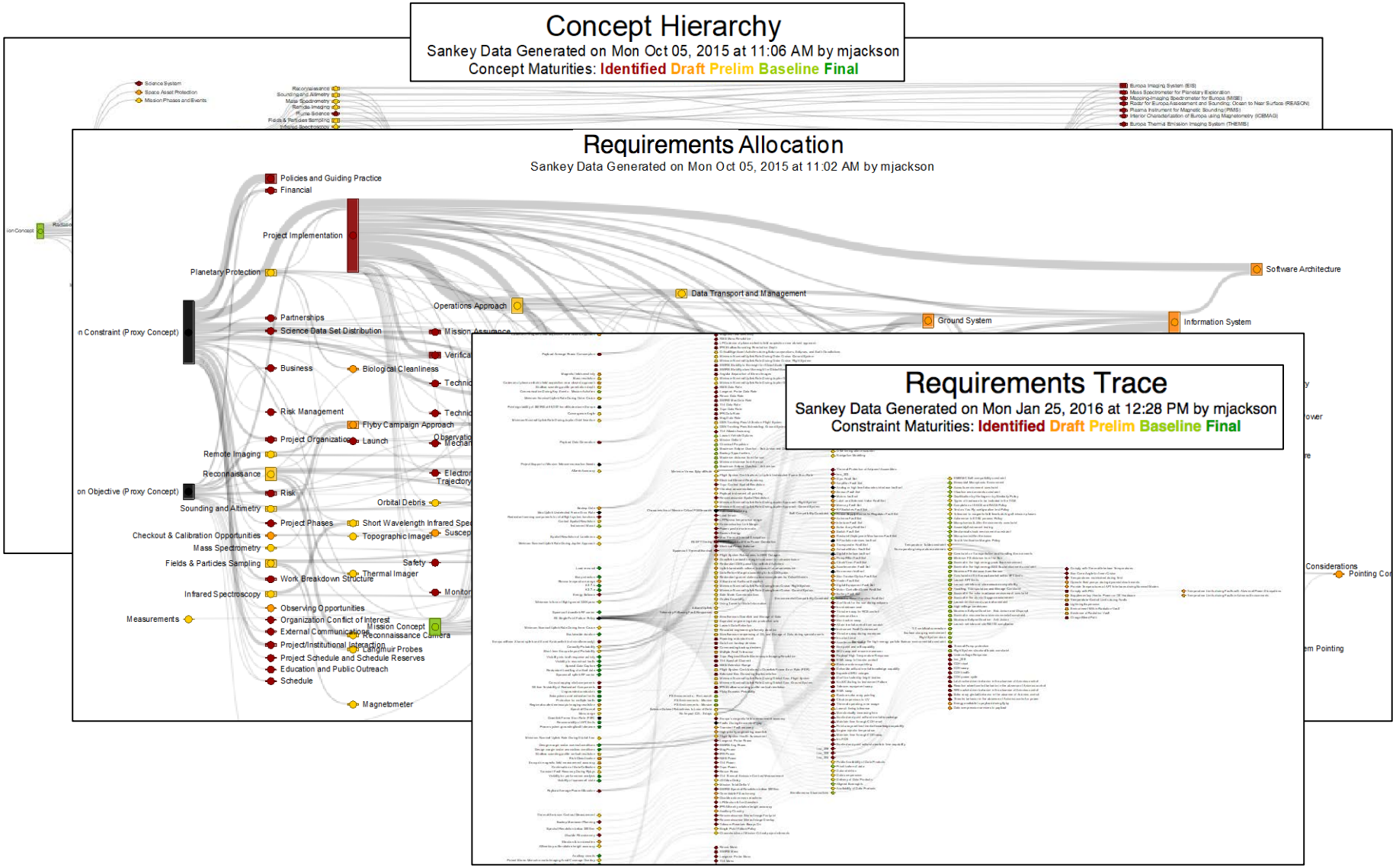
What have we done with MBSE?

- Requirements context, rationale, justification, narrative
- “Functional” decomposition



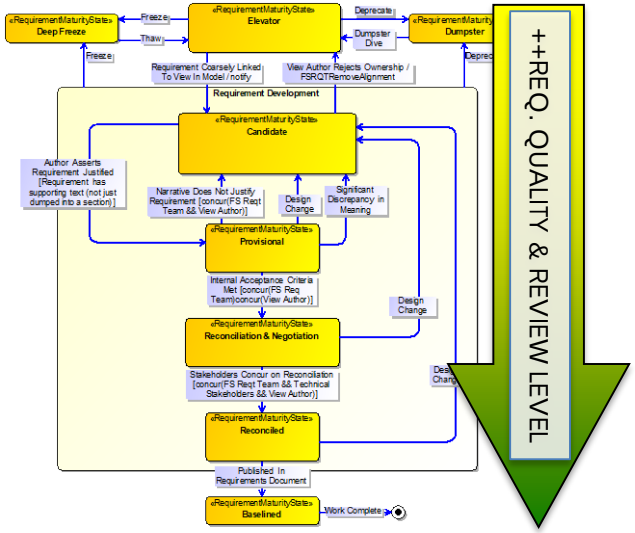
What have we done with MBSE?

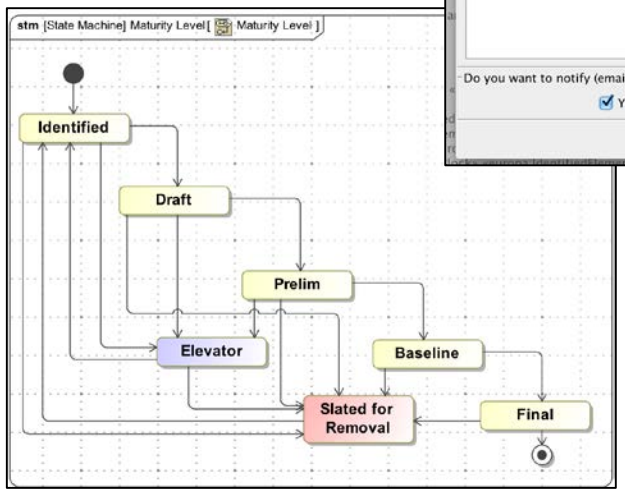
- Traceability

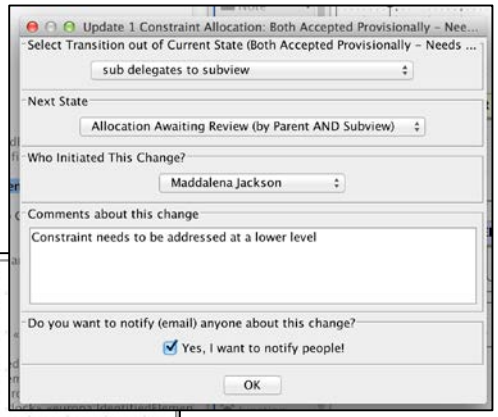


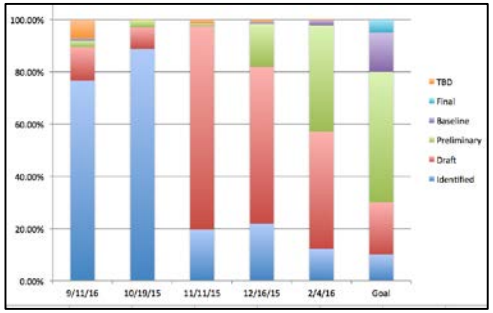
What have we done with MBSE?

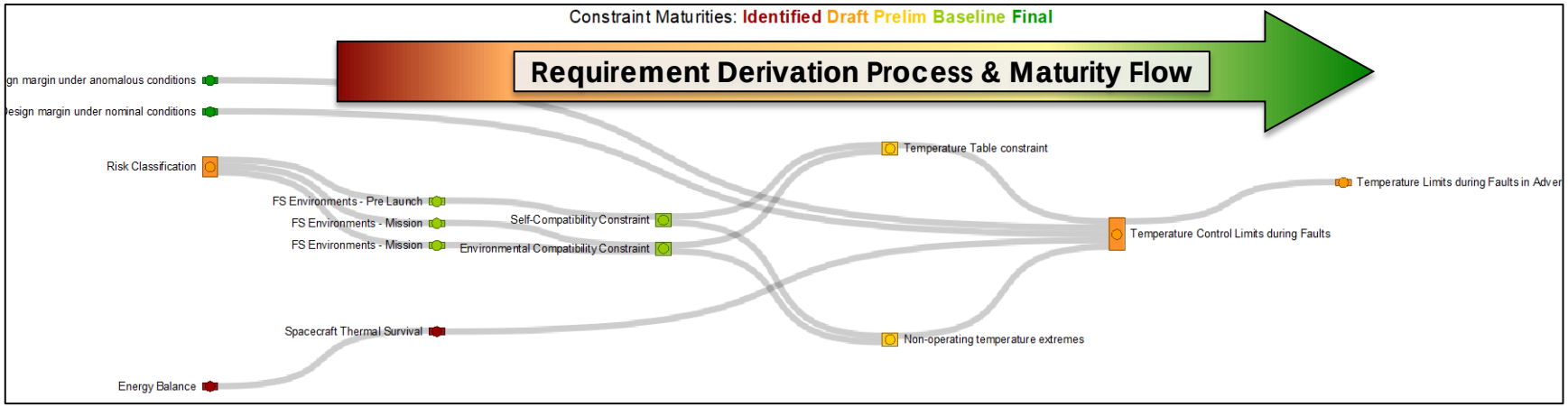
- Maturity Evolution







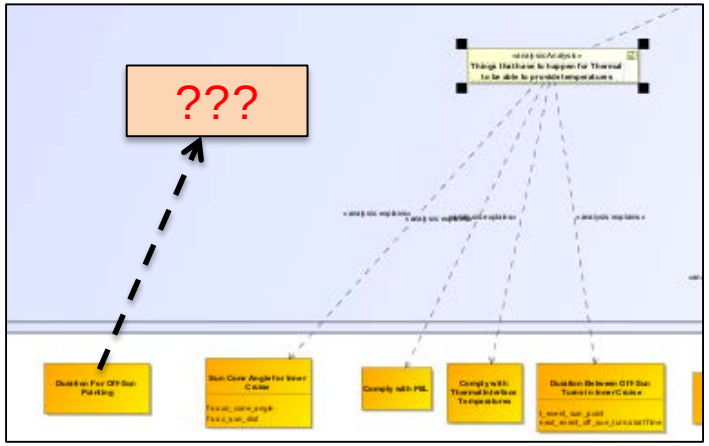


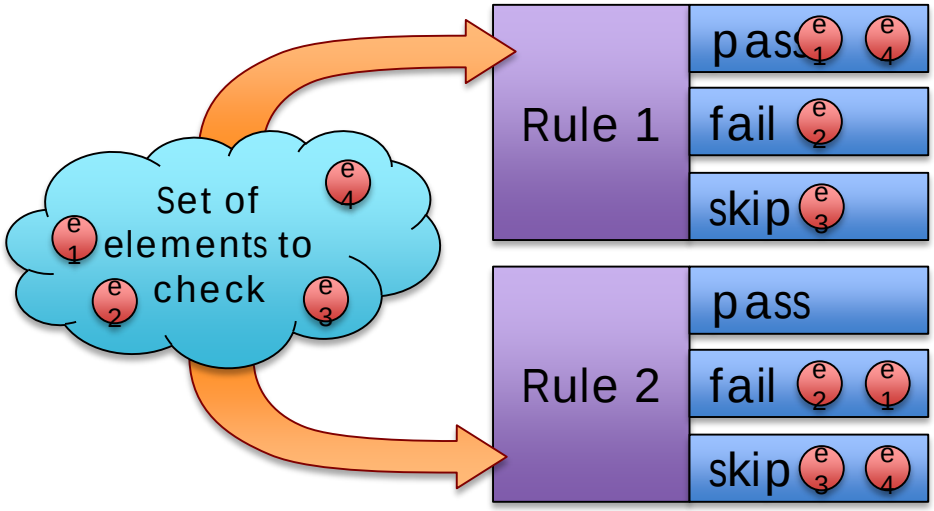


What have we done with MBSE?

- Metrics! Validation! History!

Was this supposed to have one of those?





Results for Rule: allConstraintsTraceToParent

Alert: TRACE: at least one trace to a parent
Description: all linked constraints must constrain a conceptual element with <<europa:constrains>>
Applies To: mission:Requirement
Total Elements Evaluated: 7

VIOLATORS: **5** | PASSED: **2** | SKIPPED: **0** | SKIPPED (N/A): **0** |

Afid	Name of Validated Element	Validation Result	Model ID
RQ101.916	Uplink Re-transmit Attempts	FAILED	_17_0_2_3_f36036c_1380586409090_1713_30703
RQ101.913	Processing at Maximum Uplink Rates	FAILED	_17_0_2_3_f36036c_1380586629373_871672_31028
RQ100.696	Instrument Sequences	FAILED	_17_0_2_3_f36036c_1380654798802_58135_30666
RQ100.673	Information Structure	FAILED	_17_0_2_3_f36036c_1380570837251_801942_28653
RQ101.910	Processing Uplink Data Stream	FAILED	_17_0_2_3_f36036c_1380586561865_227644_30963
RQ101.911	Uplink Frame Error Rate	PASS	_17_0_2_3_f36036c_1380586734624_886838_31074
RQ101.907	Uplink Accountability Report	PASS	_17_0_2_3_f36036c_1380586511996_571134_30900

Results for Rule: hasMaturityChar

Also: store records in model; generate metrics

What else (if only there was more time…)

- Requirements → documents
- Requirements → traceability
- Requirements context, rationale, justification, narrative
- "Functional" decomposition
- Maturity Evolution
- Metrics! Validation! History!
- MEL, PEL, resources, margin
- Point design
- Instrument fact sheets
- System block diagrams

Intangibles

- MBSE is not a product
- Intangible benefits:
  - Information consistency: reduced overhead, increased confidence
  - No “where’s the latest” confusion
  - Propagation of changes
  - Drives out assumptions (and forces clarity)
  - Changes tracked and versioned
  - Ease of communicating and maintaining current project baseline
  - Cross-training/experience for earlier-career engineers

Reality check

- MBSE is not trivial
  - Efforts require systems engineering, management, planning, discipline
- "Modeling" is not a data entry job
  - MBSE is simply a way of doing systems engineering.
  - People who become skilled at modeling are still primarily systems engineers (with a different tool of choice)
- There are growing pains and upfront engineering costs
- Do we think it's worth it? **Yes!**

LET'S TALK LOGISTICS

Unique Europa challenges:

- **Scope**: trying to capture information from across the project, content from >40 people who need to interact with the environment in some way. 10-15 people working in the modeling tool.

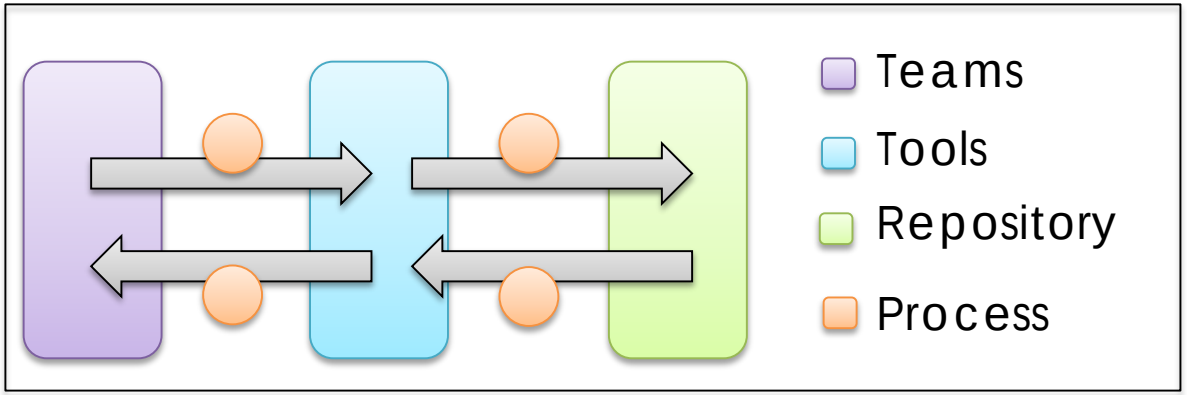
- **Tooling**: Needed to build infrastructure (automation, web interfaces, query and analysis, etc.)
  - Challenge: it is being developed as MBSE approach is applied.

- **Architecture Framework**: project chose to use an approach to architecting and requirements development that is new to many on project.

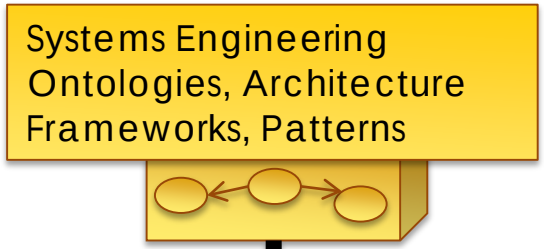
Focus areas

- Staffing for operation, training, and development of new tools
- Knowledge representation
  - Need precise semantics in order to model
- Information organization and storage
- Process

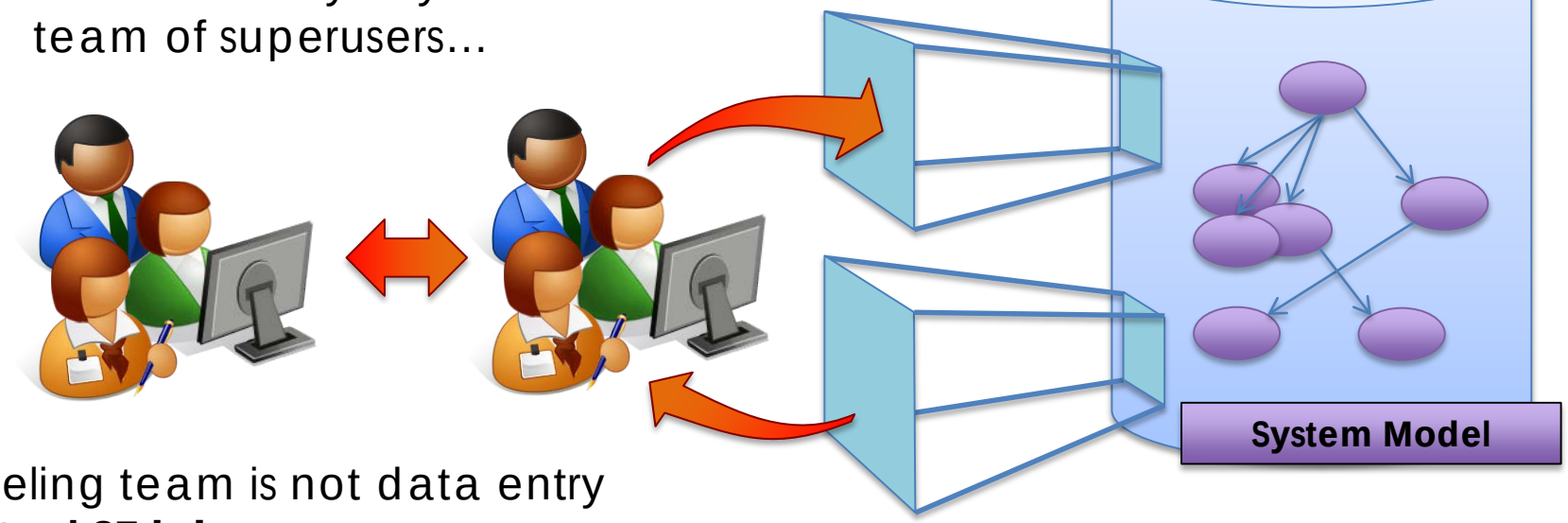
People



Large one-time investment in modeling patterns, ontologies, frameworks

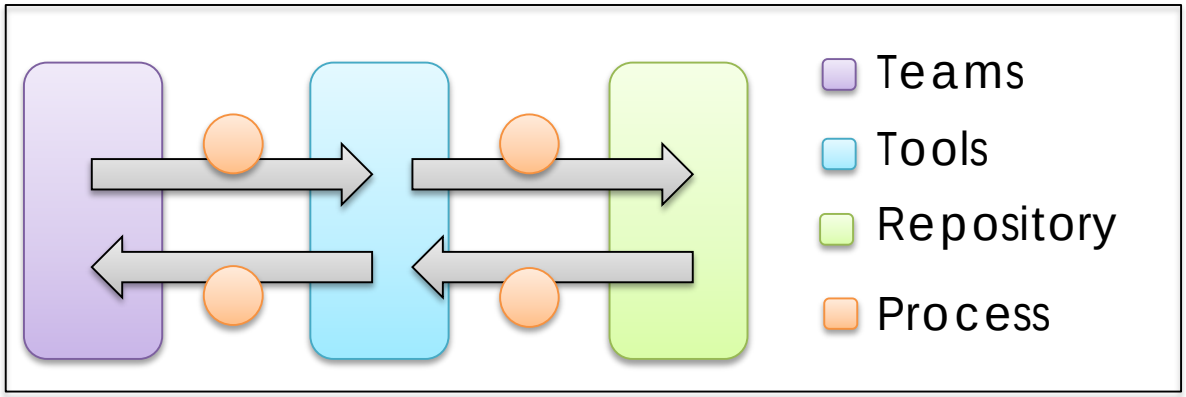


Whether your SEs work in model directly or you have a team of superusers…



Modeling team is not data entry
Is **actual SE job**

Teams, Tools, Process



- Staffing of teams
  - Mix of career levels
  - Mix of skills (traditional SE vs software)
- Selection/development of tools
  - Leverage OTS when possible
  - …but we have significant and ongoing development of supporting infrastructure
    - Good: all projects can re-use
    - Bad: can be frustrating, incur all of one-time expense
- Process
  - Have had to do a lot of process engineering
    - Good: clarity, formality, automation
    - Bad: “well this will be easy!” => unpleasant surprises

RECOMMENDATIONS

Recommendations

- Apply SE and actively manage MBSE
  - You should have modeling **requirements**
  - Success criteria for modeling effort
  - Specific products (documents, analyses, etc.)
  - **Do not model for the sake of modeling**
- Before you model...
  - Agree on information model (knowledge representation)
  - Use cases, scenarios (drive out unknown unknowns in knowledge representation)
  - What can you do with “vanilla” tools? What additional features do you want/need?

Recommendations

- Choosing your team
  - Do you want your SEs to be modelers?
    - Do you want to train them?
    - Do they want to learn?
    - SE 🡐🡒 modeler:
      - Good: cross-training, exposure, target skills
      - Bad: bottlenecks, lag
  - SE/Software combination is very effective
    - Do you need something beyond your MBSE tool? **Then you will need developers**
    - Personal bias: SEs who code ☺
      - I’ve seen what people do with excel…
    - Get everyone talking algorithms

Final Recommendations

- MBSE is not a product
- MBSE efforts need to be scoped and managed as real projects
  - Because they are
- Decide what success looks like before you start
- Enjoy!

Acknowledgements

- Alek Kerzhner, Todd Bayer, Brian Cooke, Marcus Wilkerson – slide ~~cannibalism~~ inspiration
- MSET and FSRQT for hard work and support in making MBSE viable
- PSE and FSE
- JPL Integrated Model Centric Engineering (IMCE)
- JPL Computer-Aided Engineering (CAE)

BACKUP

What is MBSE?

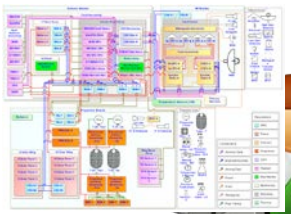
"Structural" Validation

Results for Rule: hasConstrainedElement

Alert: CONSTRAINED ELEMENT: must have at least one constrained element
Description: Constraints that constrain anything other than ONE constrained element will FAIL this rule.
Applies To: ConstraintBlock
Total Elements Evaluated: 31

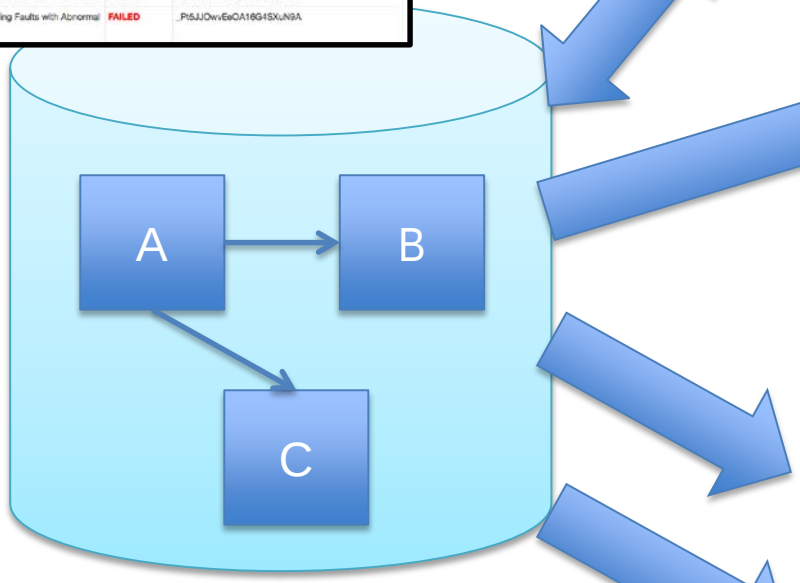
VIOLATORS: **14** | PASSED: **1** | SKIPPED: **0** | SKIPPED (N/A): **16** |

AfId	Name of Validated Element	Validation Result	Model ID
CT100.897	Duration Between Off-Sun Turns in Inner Cruise	FAILED	_Pt6XVOwvEeOA16G4SXuN9A
CT100.894	Temperature Limits during Faults in Adverse Environments	FAILED	_Pt8zmOwvEeOA16G4SXuN9A
CT100.900	Supplementary Heater Power on Off Hardware	FAILED	_Xb1FOuwvEeOA16G4SXuN9A
CT100.895	Temperature Limits during Faults with Abnormal Power Dissipations	FAILED	_Pt5JJOwvEeOA16G4SXuN9A

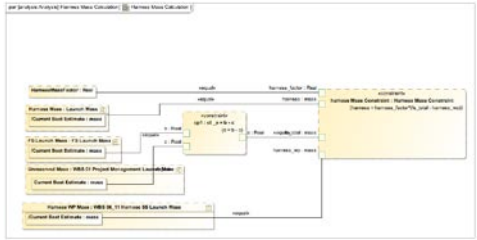


(Interactiv
e) Views

Gate
Products



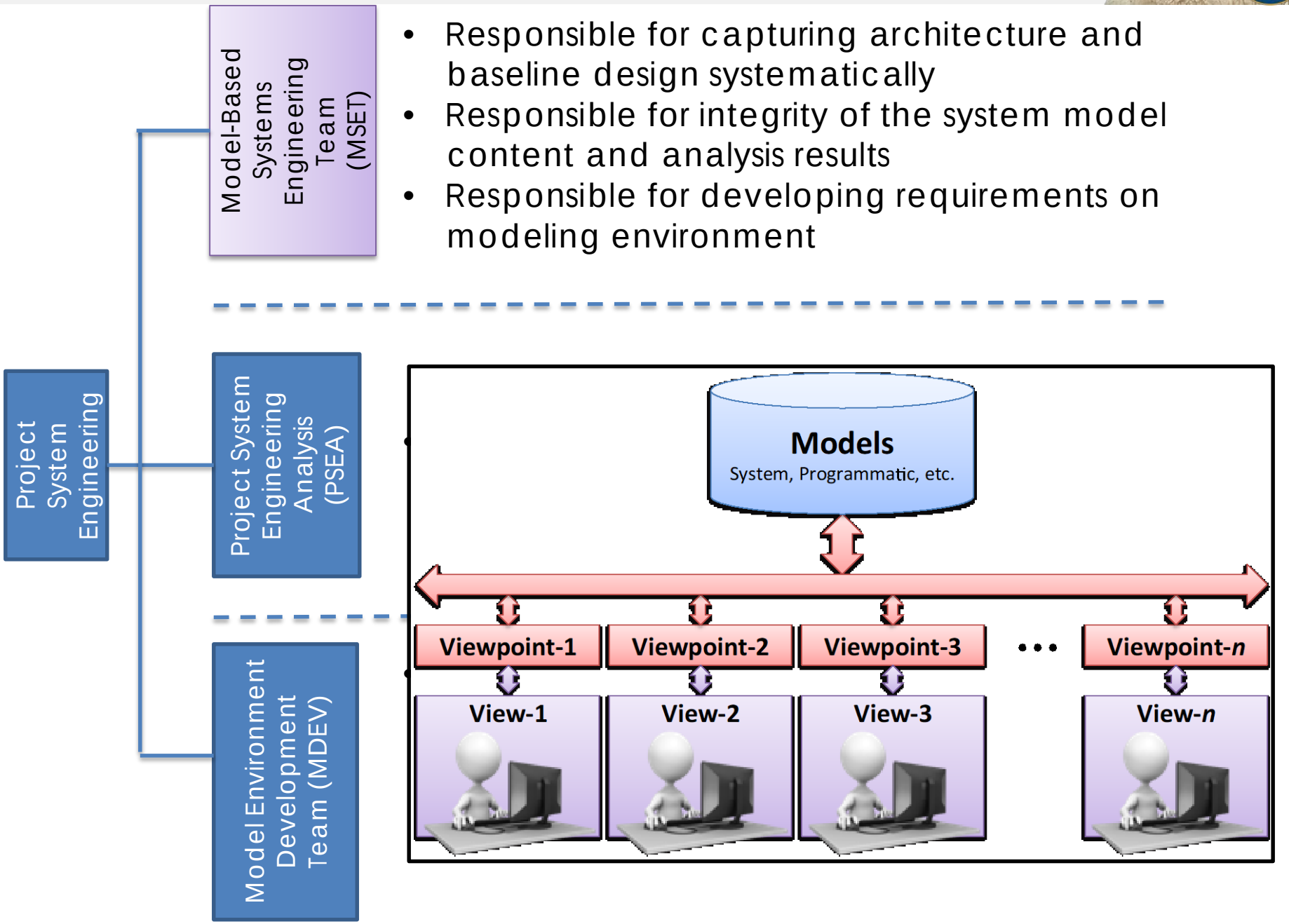
Repository



Analyses

Performance
Validation

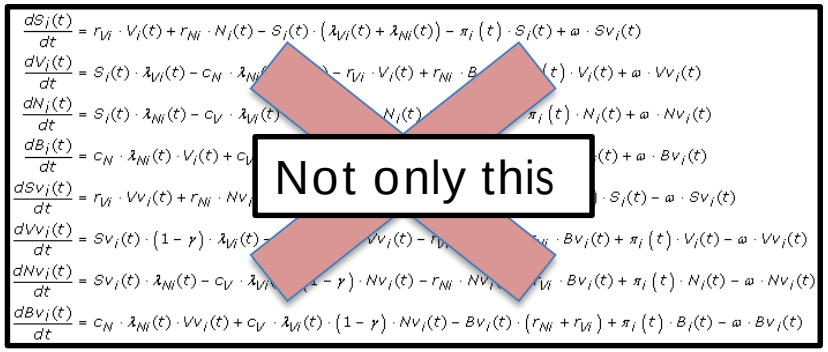
What is MSET?



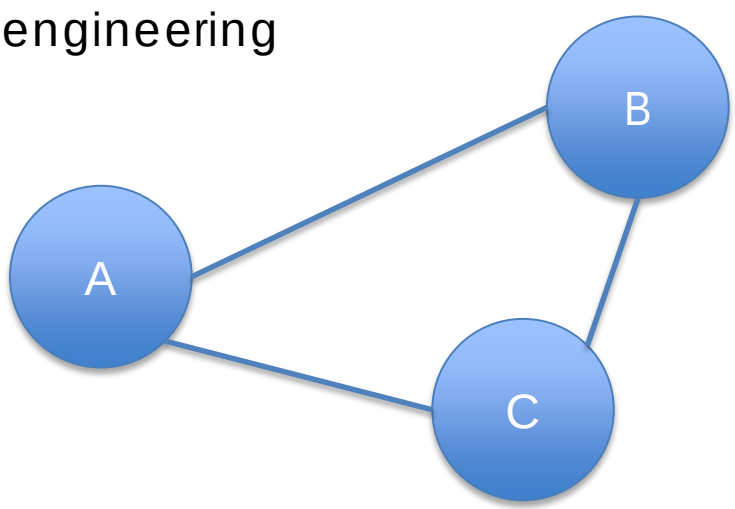
- Responsible for capturing architecture and baseline design systematically
- Responsible for integrity of the system model content and analysis results
- Responsible for developing requirements on modeling environment

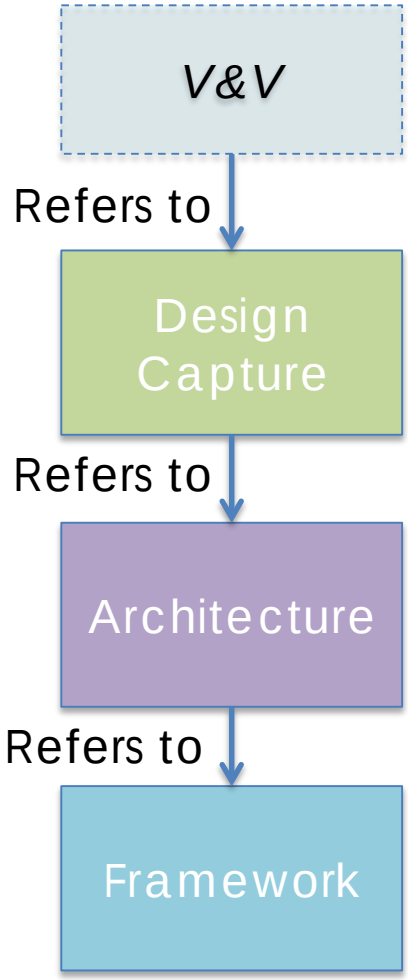
What is the System Model?

"Model" is a very broad term



System Model: Model of the system to support systems engineering





Currently under construction

Block Diagrams, MEL, PEL, Mission Data

Concepts, Requirements, Elements, Functions

Basic information about the model and project

What problems does MBSE try to address?

- Gaps and issues in project design because of implicit assumptions
- Inconsistency between information sources (project documents, etc.):
  - Disconnected tools with their own data store: inconsistent or incorrect analysis results
- Communicating and maintaining current project baseline
- Common changes need to be made separately to all information sources
  - Bigger issue when you have multiple variants
  - Bigger issue when you have a large # of information sources
- Tracking changes to the project baseline over time
- What to do with our early career hires & interns?

Value Proposition

- Better Products delivered More Efficiently:
  - Model repository can act as a single source of truth
  - By providing a structured and interconnected representation, consistency can be maintained
  - Capturing information in a structured way can reduce implicit assumptions
  - Validation of model structure can identify gaps and inconsistencies
  - Common changes can be made in one place and propagated to various products via automated transformations
  - The impact of changes can be identified by tracing relationships
  - System level analyses can utilize the model to produce consistent results

Conclusion – From Brian Cooke (PSE)

- The Europa Clipper mission concept has embraced MBSE as core to our formulation effort
- Product development and release efficiency improvement realized (and getting better)
- Some SE process improvement realized with much more to come
- Sh el-
  b g

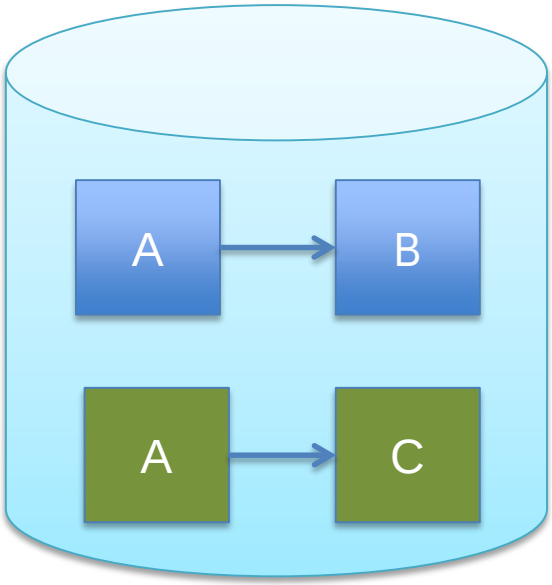
MBSE is ready to support flagship class mission formulation

What MBSE is NOT!

- SysML & MagicDraw – These are just tools that allow us to implement MBSE
- A particular toolset or methodology
- The solution to all our problems

Value Proposition vs. Implementation

- The value achieved depends on a particular MBSE implementation.
- "Small" issues or disconnects can quickly erode value.



Repository

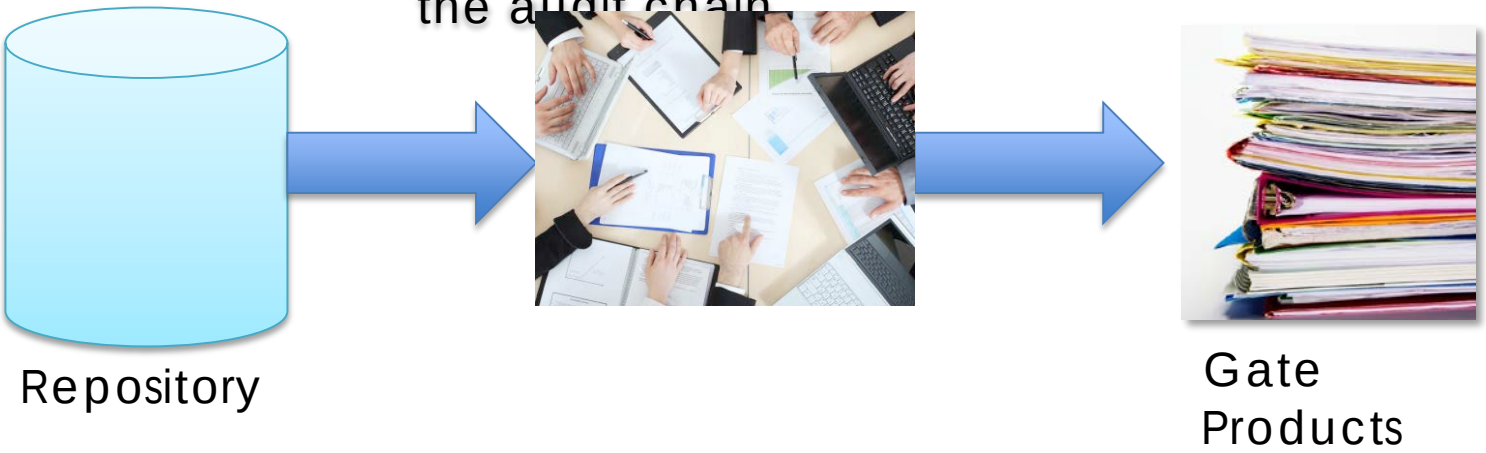
If the same information is stored in different forms in the repository, maintaining consistency becomes a challenge

Value Proposition vs. Implementation

- The value achieved depends on a particular MBSE implementation.
- "Small" issues or disconnects can quickly erode value.

If manual work is needed during the transformation process:

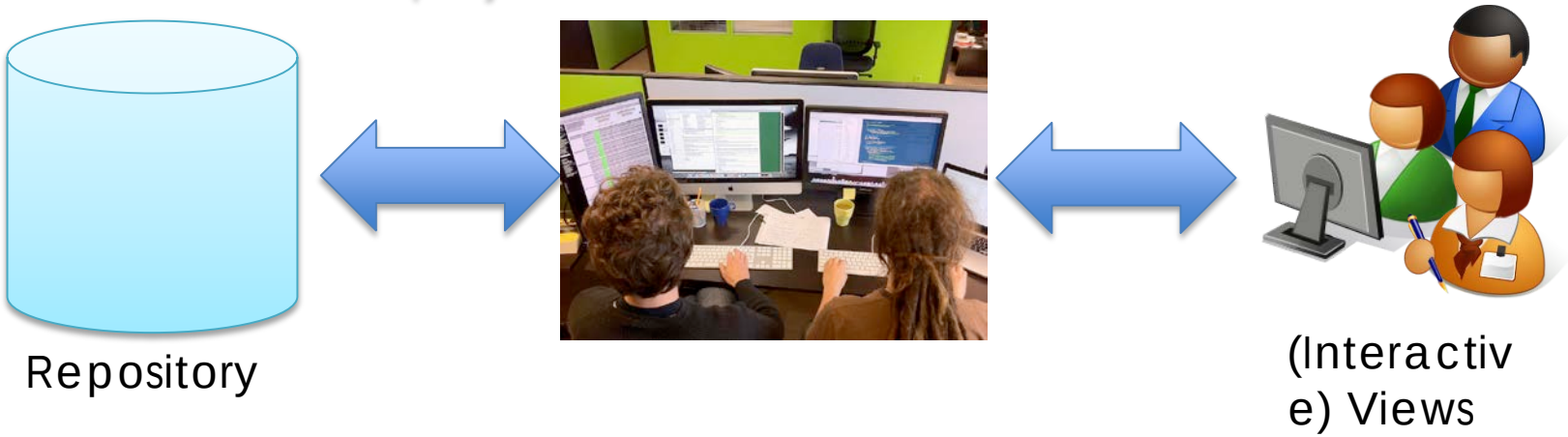
- common changes may need to be remade
- new inconsistencies or gaps may be introduced outside of the audit chain.



Value Proposition vs. Implementation

- The value achieved depends on a particular MBSE implementation.
- "Small" issues or disconnects can quickly erode value.

Interaction with the repository can add friction, resulting in the repository no longer reflecting the project baseline



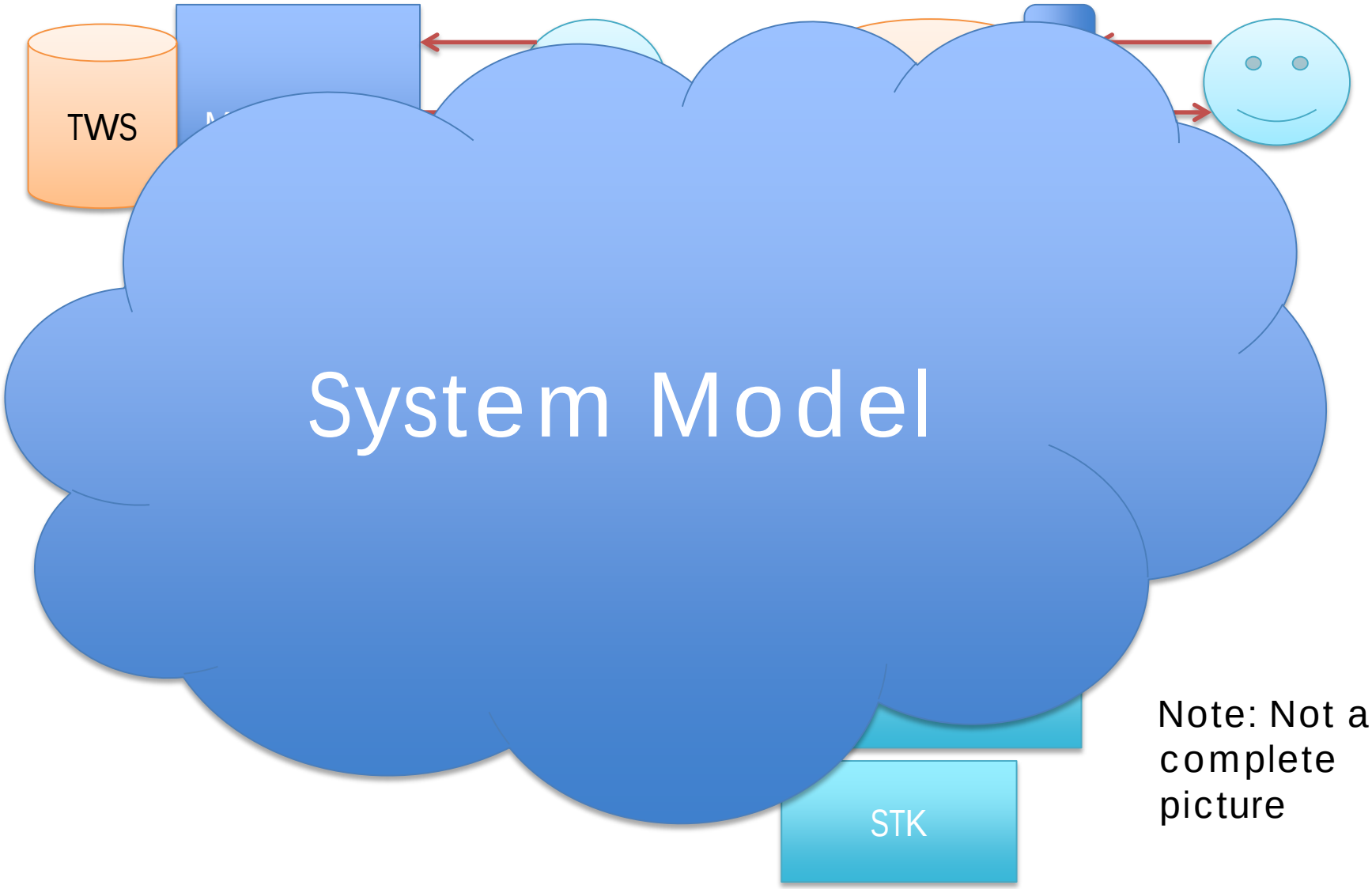
Unique Europa Project challenges:

- **Scope**: trying to capture information from across the project, content from >40 people who need to interact with the environment in some way. 10-15 people working in MagicDraw.

- **Tooling**: being developed as approach is applied. Tools such as EMS, View Editor, etc.

- **Architecture Framework**: endeavoring on a different approach to architecting and requirements development.

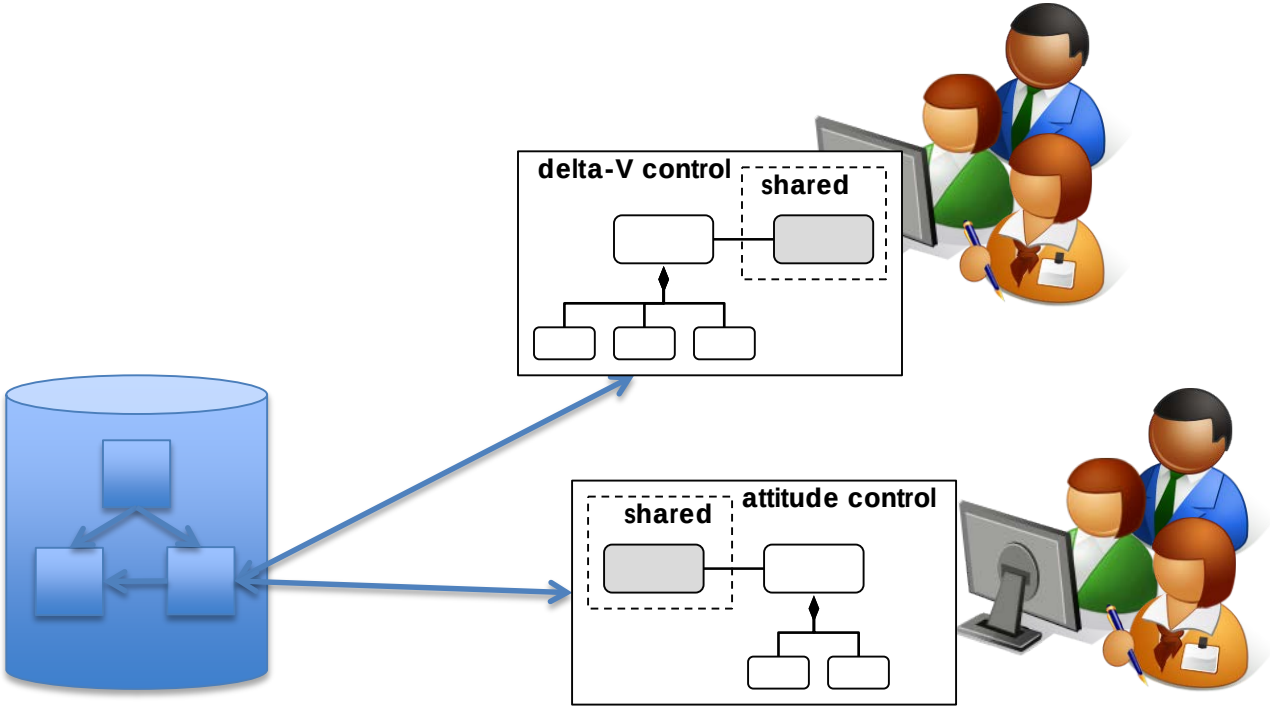
What does the environment really look like?



Note: Not a complete picture

IMPLICATIONS & CHALLENGES

Single source of truth

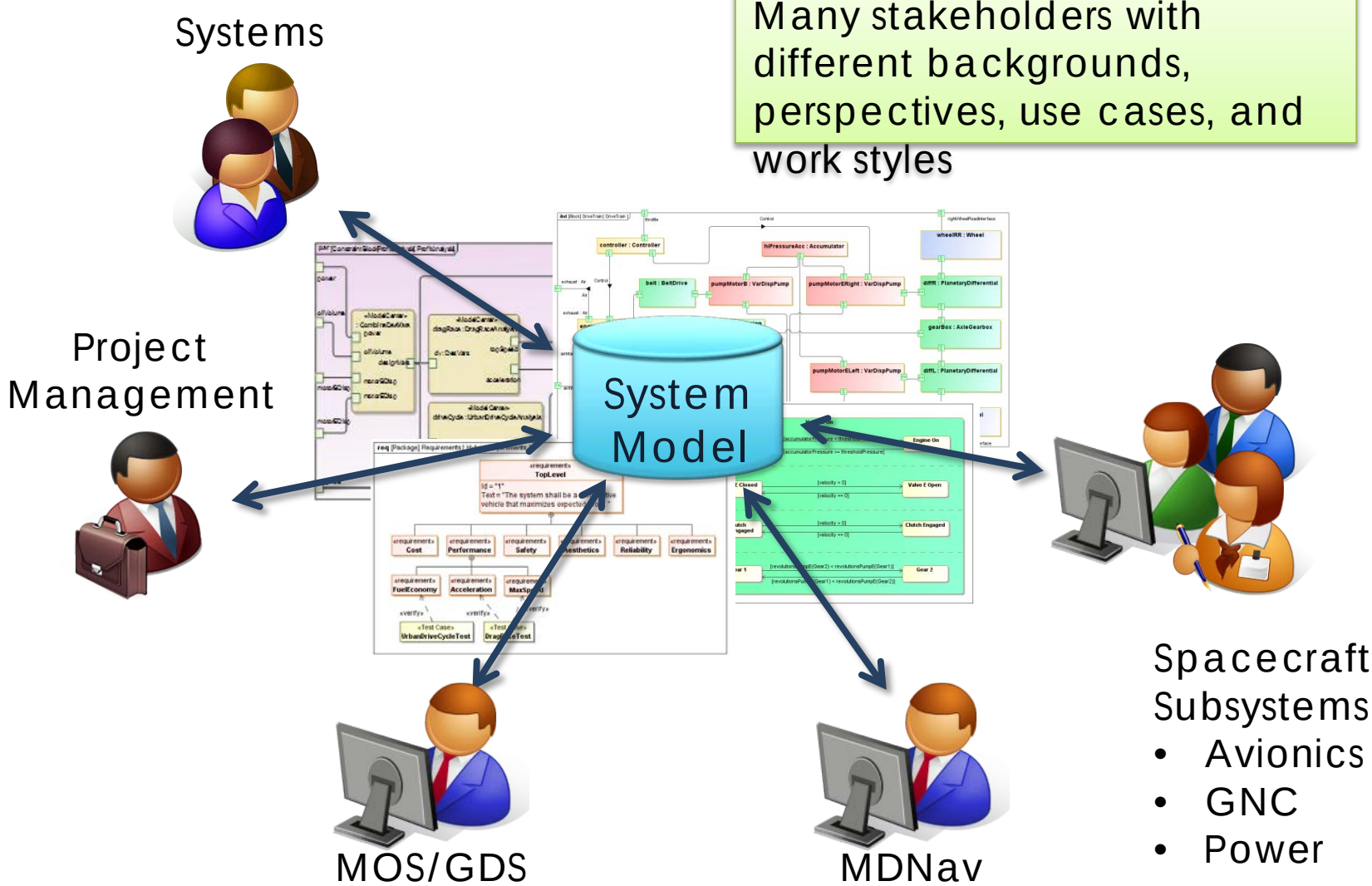


The same piece of underlying information will show up in multiple views.

- Which is the one to edit?
- Which one is the source of truth?
- Who can edit what?
- What happens if someone else edits it?

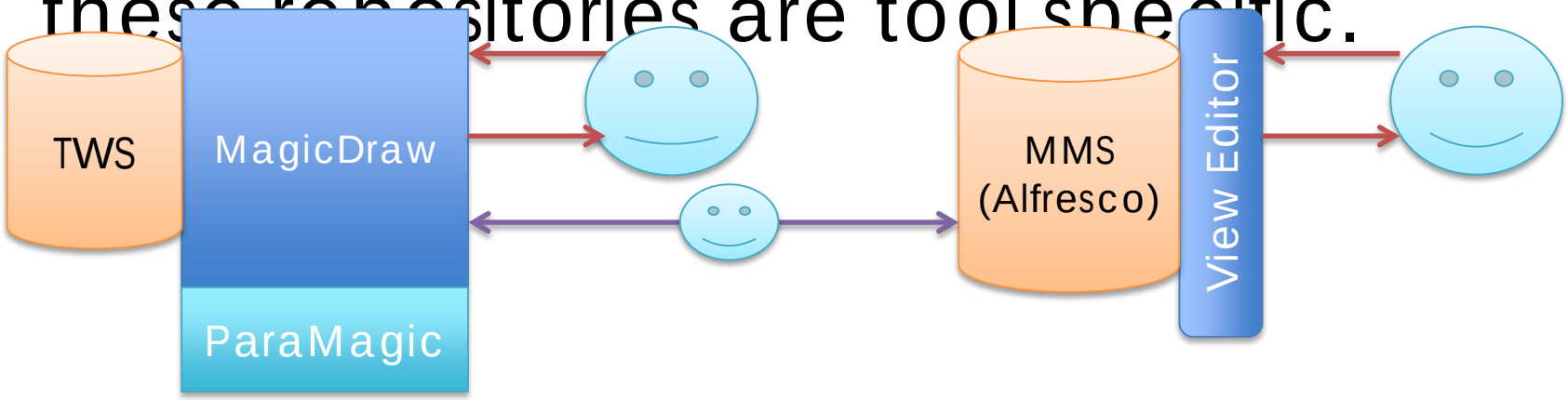
Heterogeneity of Stakeholders

Many stakeholders with different backgrounds, perspectives, use cases, and work styles

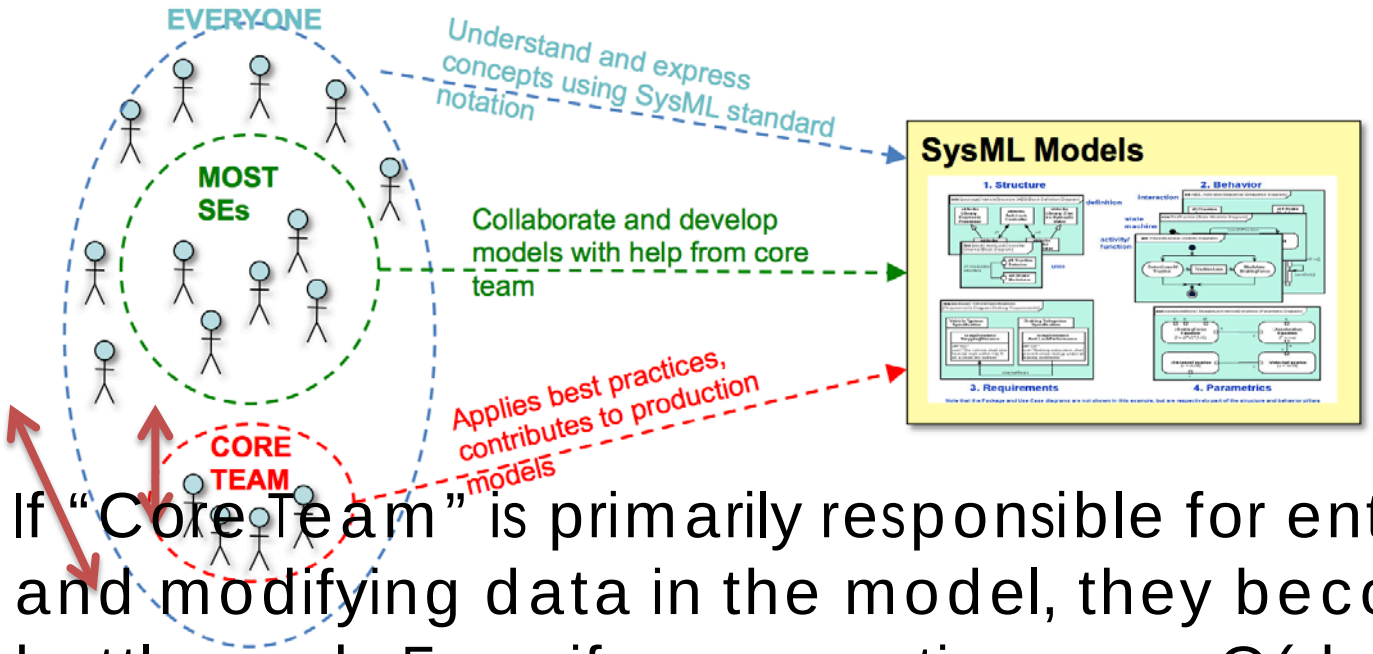


Federated but consistent repositories

- Current database technologies have strengths and weaknesses
  - No one size fits all solution for all data types
- Also, many tools use existing repositories to store information. Often, these repositories are tool specific.



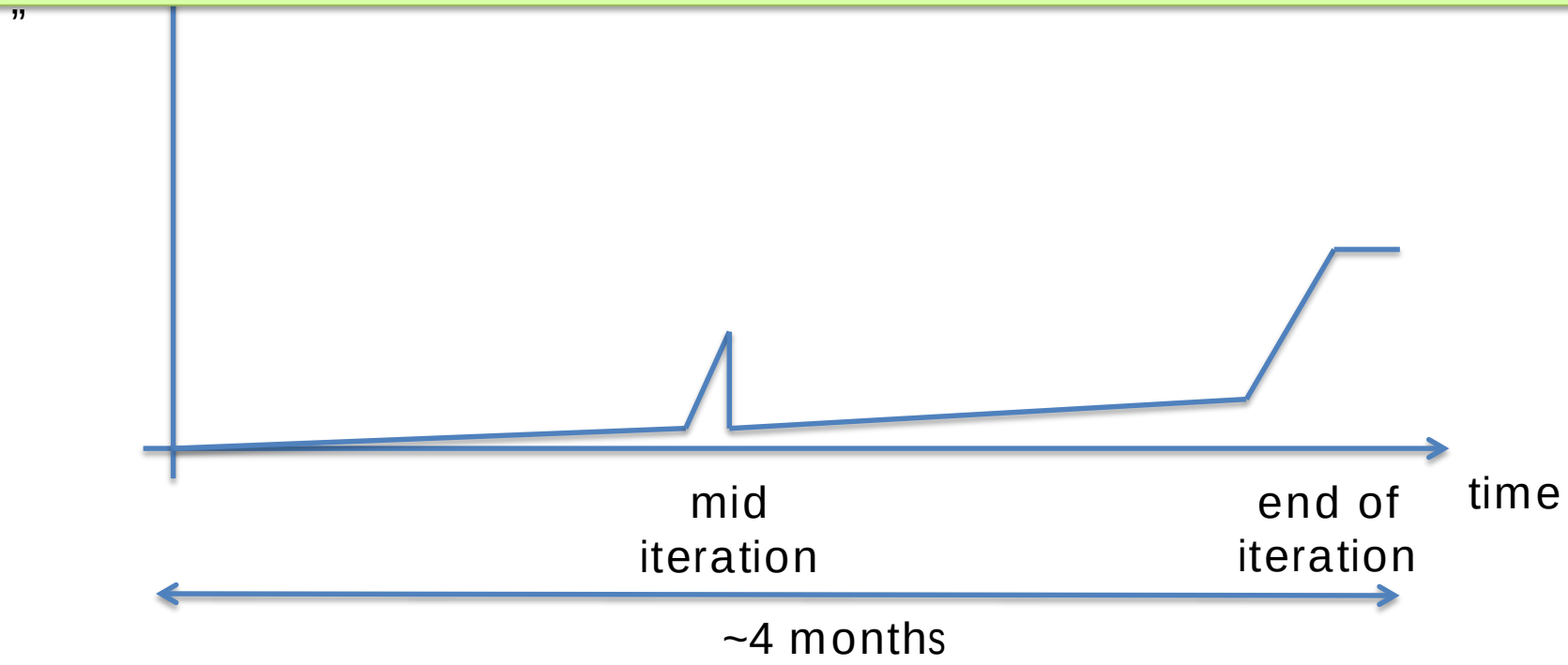
Bottlenecks



- If "Core Team" is primarily responsible for entering and modifying data in the model, they become a bottle neck. Even if response times are O(days), this can breakup SE work making it less efficient.
- This makes the ability for the entire team to enter and modify data extremely important -> this mechanism needs to be sufficiently simple.

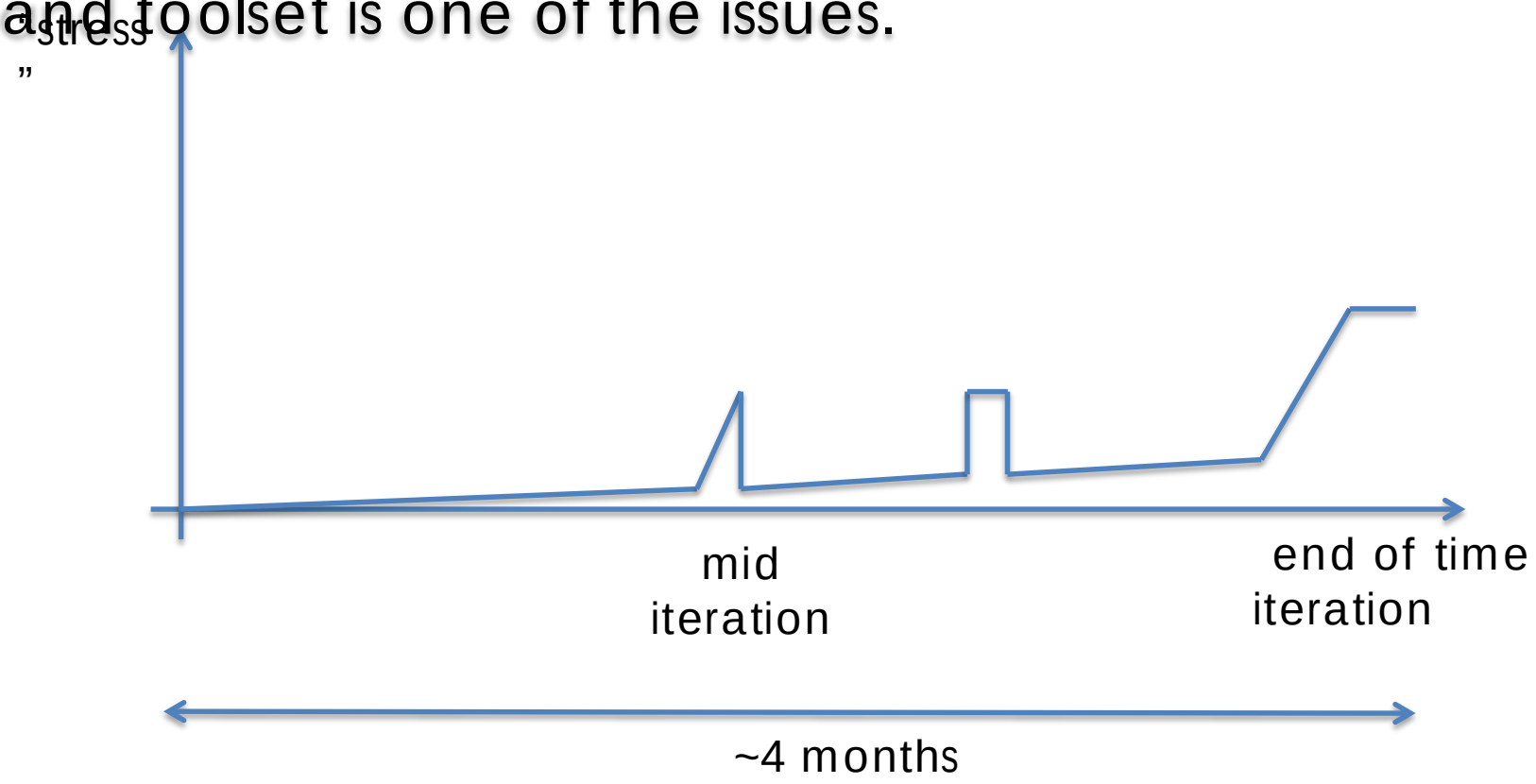
Heartbeat of the Project

Background: On the Europa Project currently, work is divided up by iterations. An iteration is ~4 months. During an iteration, many tasks will run in parallel with the intent that these tasks will be complete and consistent at the end of the iteration. Internal reviews are usually held in the middle and at the end of an iteration.



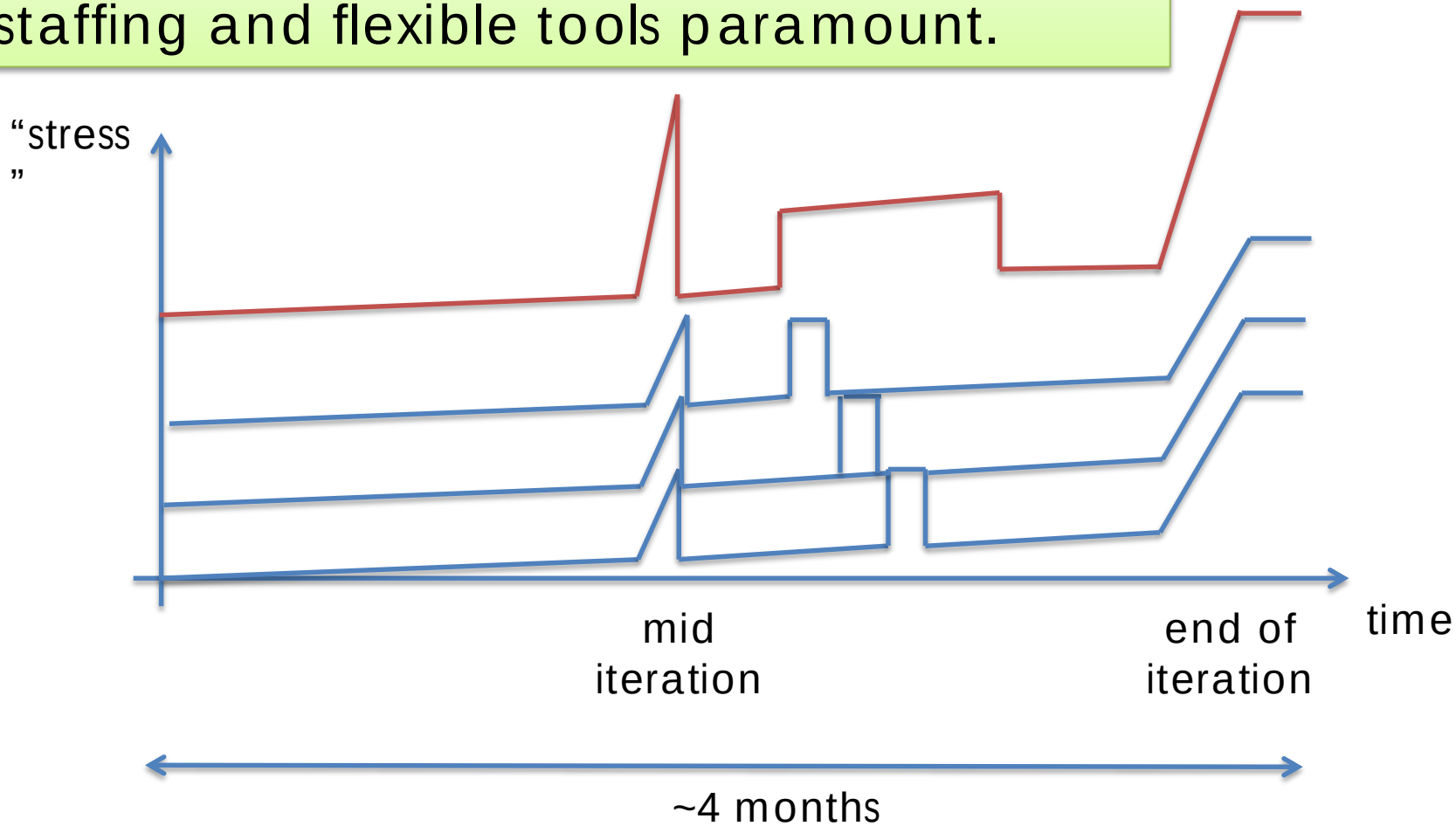
Heartbeat of the Project

Stress also rises during “the model ate my homework” moments, i.e. the information being presented in a view, gate product, or analysis is unexpected. There are many factors, but lack of visibility into the underlying repository and toolset is one of the issues.



Heartbeat of the Project

The modeling effort absorbs the sum of project stress. This makes adequate staffing and flexible tools paramount.



Software & Process Maturity

- Currently, MBSE software and processes are at varying maturities

- What does this really mean?
  - Some have been utilized repeatedly
  - Some have been utilized repeatedly on smaller projects
  - Some have never been utilized but there is a “ready for production version” that has been tested
  - Some have prototypes
  - Some are under development
  - Some are still an idea

Software & Process Maturity

- Currently, there's not a consistent approach to report maturity -> clouds deployment and development decisions

- MRL9: Utilized repeatedly, proven capability
- MRL8: Utilized but on a reduced set of use cases
- MRL7: Utilized on smaller projects
- MRL6: Utilized on smaller projects on a reduced set of use cases
- MRL5: Production delivery ready for user testing and deployment
- MRL4: Internal "Production" version
- MRL3: Prototype developed
- MRL2: Initial demonstration of feasibility
- MRL1: Idea on a napkin

Software & Process Maturity

- Currently, there's not a consistent approach to report maturity -> clouds deployment and development decisions

- MRL9: Utilized repeatedly, proven capability
- MRL8: Utilize[illegible]n a reduced set of use cases
- MRL7: Utilize[illegible]aller projects
- MRL6: Utilized on smaller proj[illegible] set of use cases
- MRL5: Production delivery re[illegible] and deployment
- MRL4: Intern[illegible]duction" [illegible]
- MRL3: Proto[illegible]veloped [illegible]
- MRL2: Initial demonstration of feasibility
- MRL1: Idea on a napkin

60 %

40 %

Many developments get stuck in this "gap":

- Positive visibility comes from a demo
- large amount of effort left but less visibility to make sure deployment goes smoothly

Case Study: "Automatic Document Generation"

- Often, gate products need to be delivered in a particular format and signed by the appropriate parties
- For MBSE to be successful, the information in the repository needs to be easily translated into this

Europa Project

Project Requirements Document
Initial Release

Paper copies of this document may not be current and should not be relied on for official purposes. The current version is available in PDMS,
https://pdms.jpl.nasa.gov

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August 11th 2015
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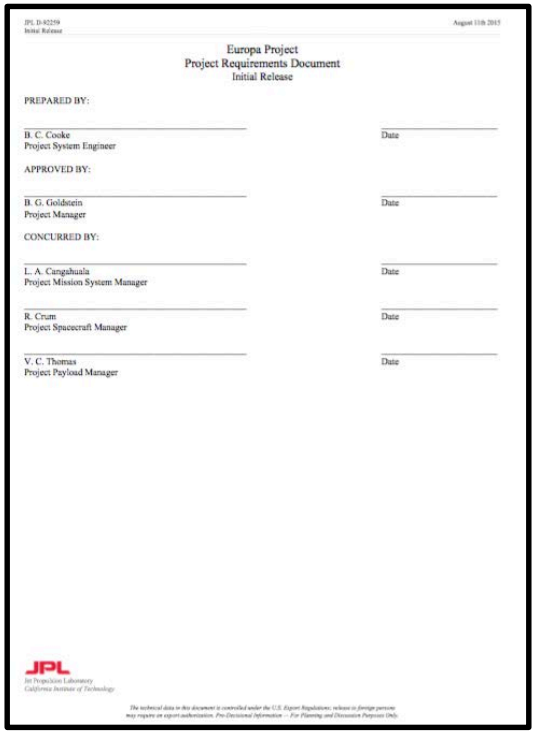
California Institute of Technology



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Europa Project
Project Requirements Document
Initial Release

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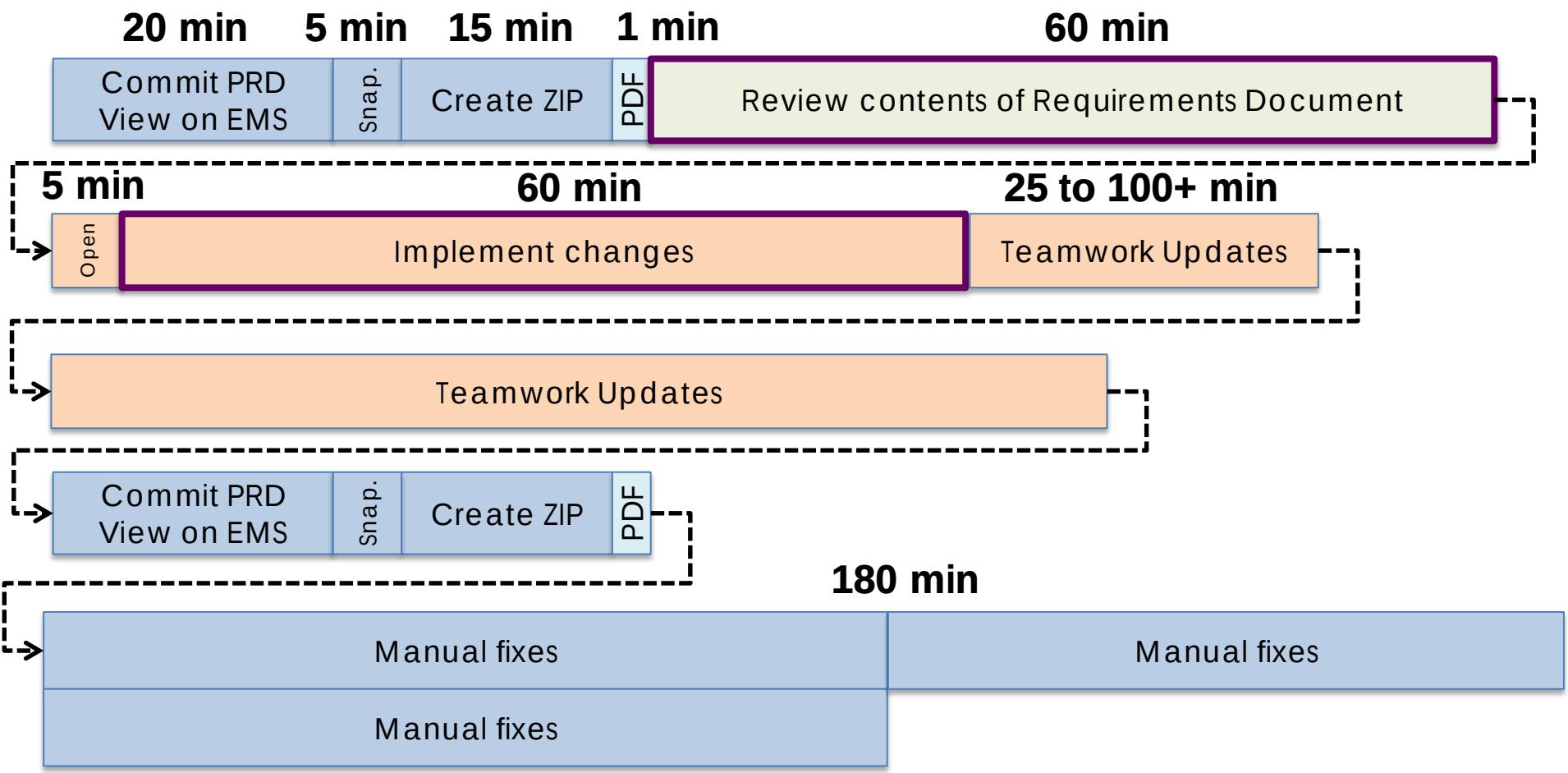
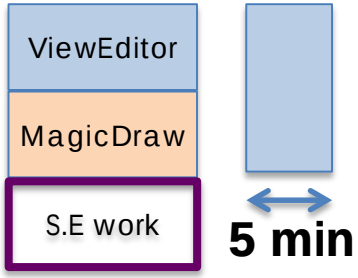
This is often thought of as "push button"

PRD Example (Dec 2015)

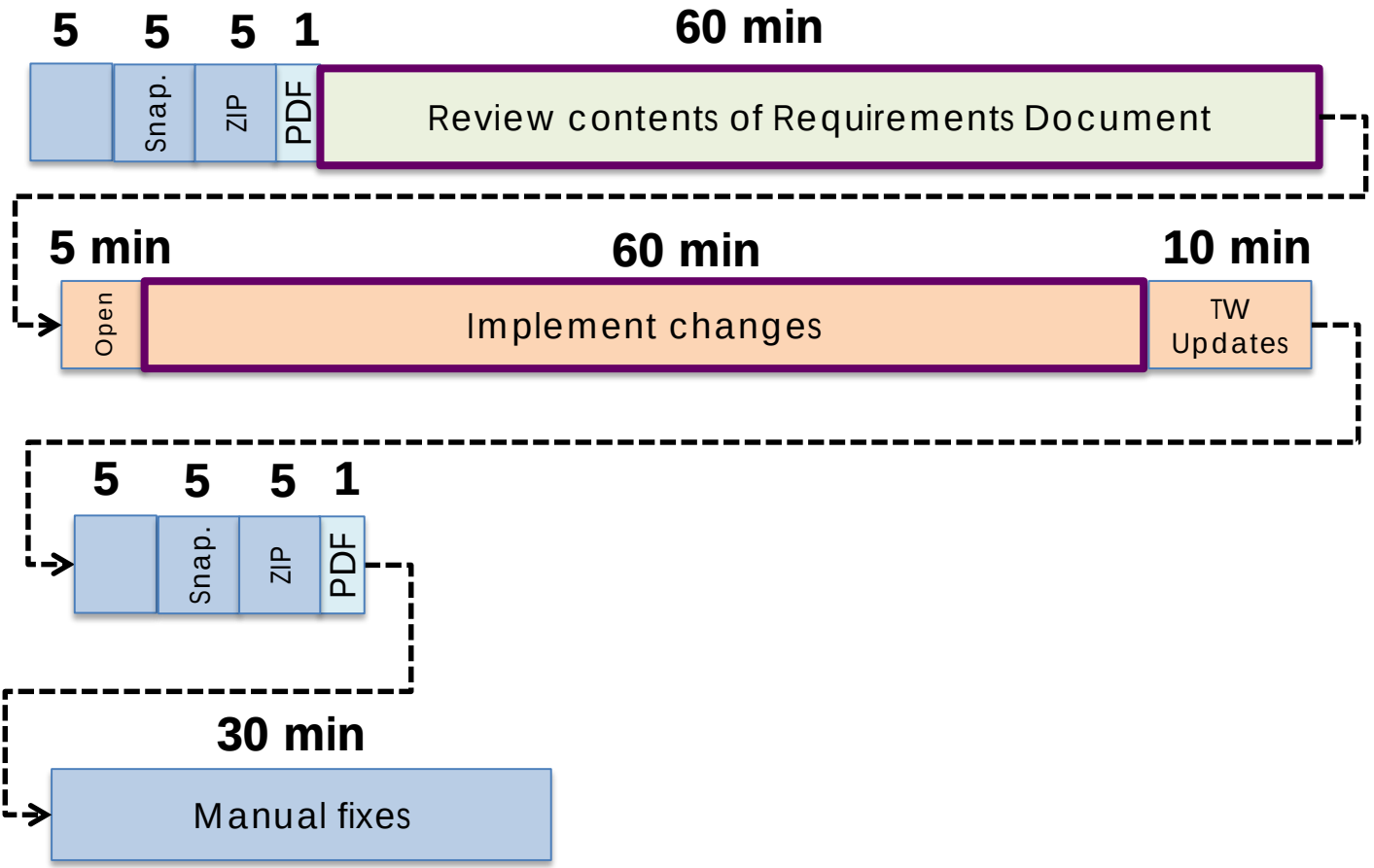


Total = 412 to 487 min (7 – 8 hours)

Systems Engineering work actually accounts for **less than 30%** of total timeline. Rest of it is spent **waiting for tools to process data** and **fixing format errors…**

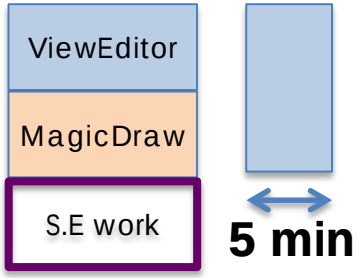


How to shorten the timeline?



Total = 197 min (~ 3 hours)

Fixing software bugs ***once*** and improving overall **software response time** could **reduce total timeline by more than 50%**



LESSONS LEARNED

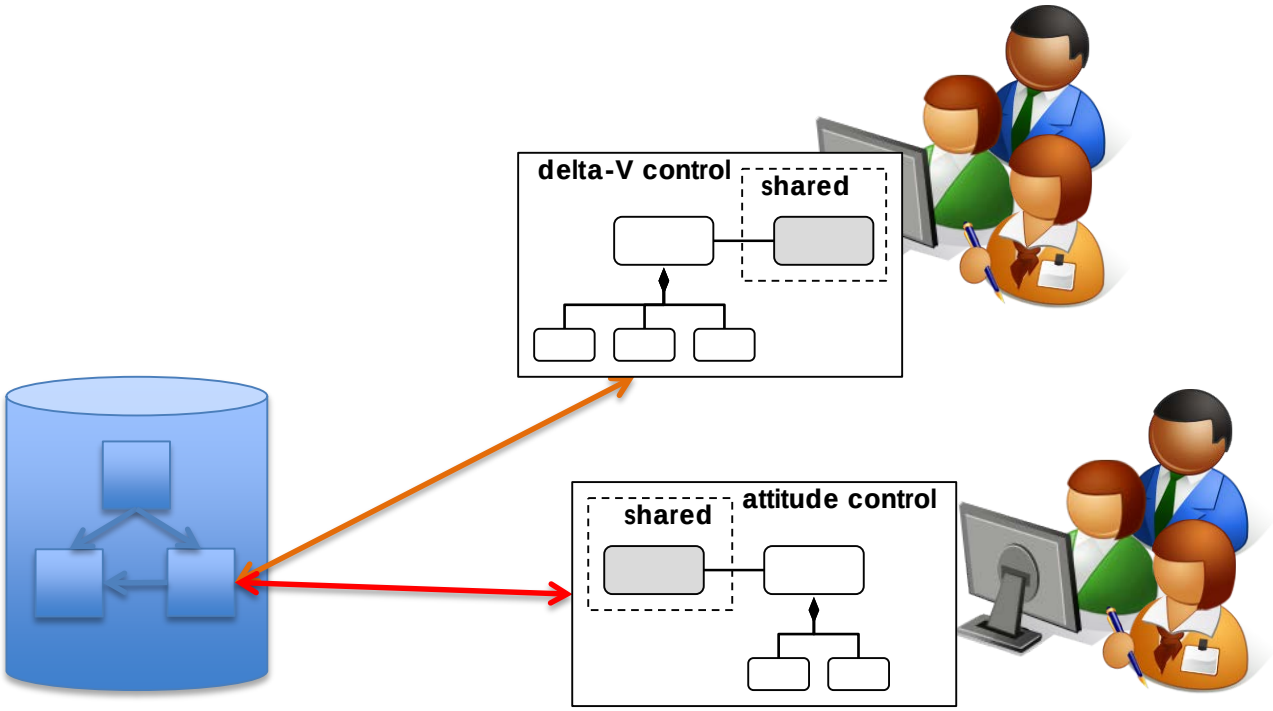
Keep it Super Simple

- Patterns (aka Data Structures):
  - Identify an approach for what needs to be captured, and try to maintain that scope.
  - Keep it flexible but remember diminishing returns. Refactoring can always be done later.
  - Flight the urge to make “rapid” changes when unexpected corner cases arise -> need to keep whole team on the same page.

- Communicating with the Project:
  - Keep terminology consistent, avoid jargon.
  - Make sure value is clearly communicated, be upfront about gaps.

Data Ownership & Change Process

- Clear change processes required. Since IM/CM processes are not already “baked” into most tools, need to manage with process.
- For information under ECR control related to the baseline design of the Flight System, a specific group is responsible for making the changes and the changes are verified. Changes are tracked through JIRA.
- For information under less strict control, anyone can make changes, although should be discussed with data owner.
- Where possible, try to put owner information with any displayed data.



Value Proposition – A Look Back

- On the Europa Project (Out of 3 ✓s) :
  - Model repository can act as a single source of truth (✓)
  - By providing a structured and interconnected representation, consistency can be maintained (½)
  - Capturing information in a structured way can reduce implicit assumptions (✓)
  - Validation of model structure can identify gaps and inconsistencies (✓)
  - Common changes can be made in one place and propagated to various products via automated transformations (½)
  - The impact of changes can be identified by tracing relationships (½)
  - System level analyses produce consistent re

Significant progress made but a lot of value is not yet realized.

Conclusions

- The MBSE effort combining people, processes, & software tools is it's own system.
- The value of employing an MBSE effort depends strongly on the particular implementation.
- Consistency matters but need to be flexible.
- MBSE is not a magical solution: the effort needs to be considered in staffing, resources, and schedule.