Agile Systems Engineering

Bruce Powel Douglass, Ph.D. Unleash the Labs
Chief Evangelist
IBM Rational
Bruce.Douglass@us.ibm.com

Graham Bleakley Ph.D, Unleash the Labs
IBM Rational
graham.bleakley@uk.ibm.com

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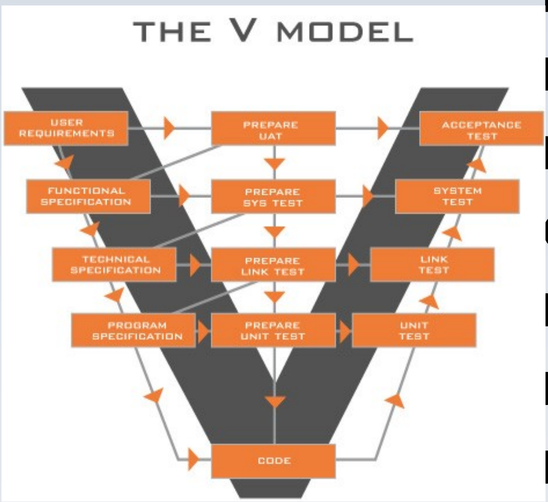
State of the Practice for Systems Development

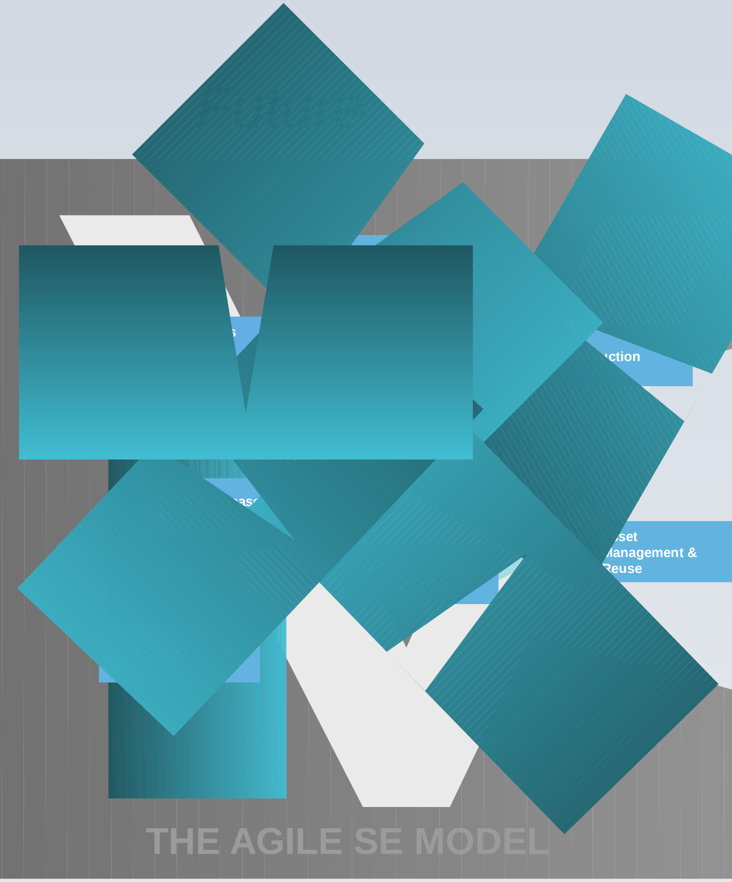
- Systems and Software Engineering Environments, in general,
  - Are document-centric
  - Require huge investment in planning that doesn't reflect actual project execution
  - Have difficulty adapting to change.
  - Require expensive and error-prone manual review and update processes.
  - Require long integration and validation cycles to beat out many defects
  - Are difficult to maintain over the long haul
- Additional standards constraints (eg DO-178C, ARP4761, ISO26262, IEC 62304, AUTOSAR, DoDAF) add to the challenge
  - Tooling Selection
  - Dependability engineering
    - Safety
    - Reliability
    - Security
  - System certification

Modern Processes and Practices are Evolving

Past



Model-Based Engineering
Defect Avoidance
Defensive Design
Continuous Integration
Risk Management
Project Governance
Dynamic Planning



Moving from waterfall “ballistic” planning to incremental, adaptive approach

Key Concepts for Agility

- Improve quality through *continuous feedback*
  - Verification (*do it right*)
    - Analysis
    - Review
    - Testing via execution or simulation
  - Customer feedback (*meet the need*)
    - Correctness
    - Appropriateness
    - Usability
  - Defensive Design
- Efficiency through
  - Concentrate on high-value tasks
  - Avoid rework
  - Paying attention to how you're doing against goals
    - Project retrospective
    - Risk management
- Planning
  - Don't plan beyond the fidelity of the information you have
  - Plan enough but not more than that
  - Adjust plans based on "truth on the ground" (metrics)

Primarily build *executable things*
Verify them continuously
Validate them with the customer early & often

Active and continuous risk mitigation

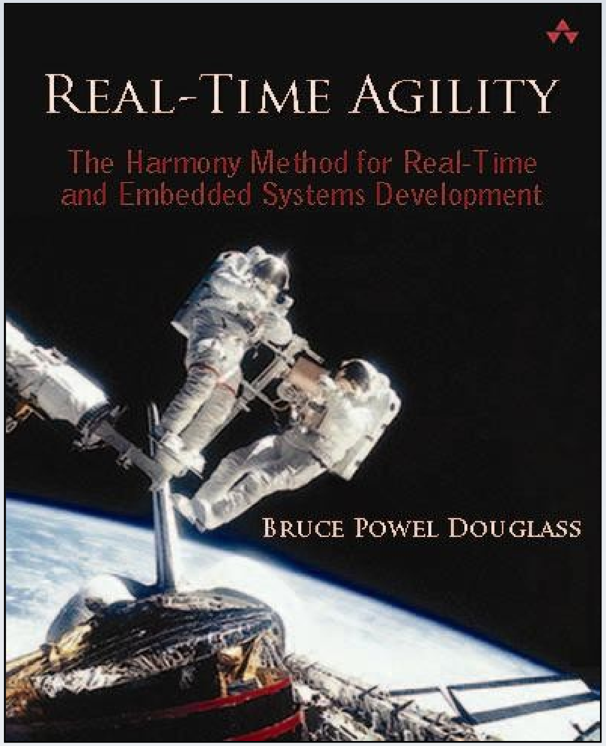
Dynamic planning

What does “agile” mean for Systems Engineering?

- Do what you need to do, no more and no less
  - This depends heavily on industry, regulation, and business environment
  - Often requires detailed traceability links among work products (e.g. requirements traceability)
  - Use tooling to automate manually-intensive, error-prone work
- Work iteratively and incrementally
  - Group requirements with user stories or use cases
- Verify continuously
  - With Q/A activities
  - With testing
  - With customer
- Outcome contains textual specifications but linked to executable & *verifiable* specifications
- Use dynamic planning to adjust project plans based on “truth on the ground”
  - Use goal-based metrics (KPIs) to track project progress
  - Continuously track progress against plan. Adjust planning frequently
- Safety, Reliability, Security
  - Not “done once” but continuously assessed
- Model-based hand off to downstream engineering

Best Practices for Agile Systems Engineering

- High-fidelity model-based engineering (Hi-MBE)
- Incremental functional analysis with use cases
- Executable requirements modeling with SysML / UML
- Test-driven development of system specifications
- Integrated safety and reliability analysis
- Model-based handoff to downstream engineering
- Automated document generation from model artifacts

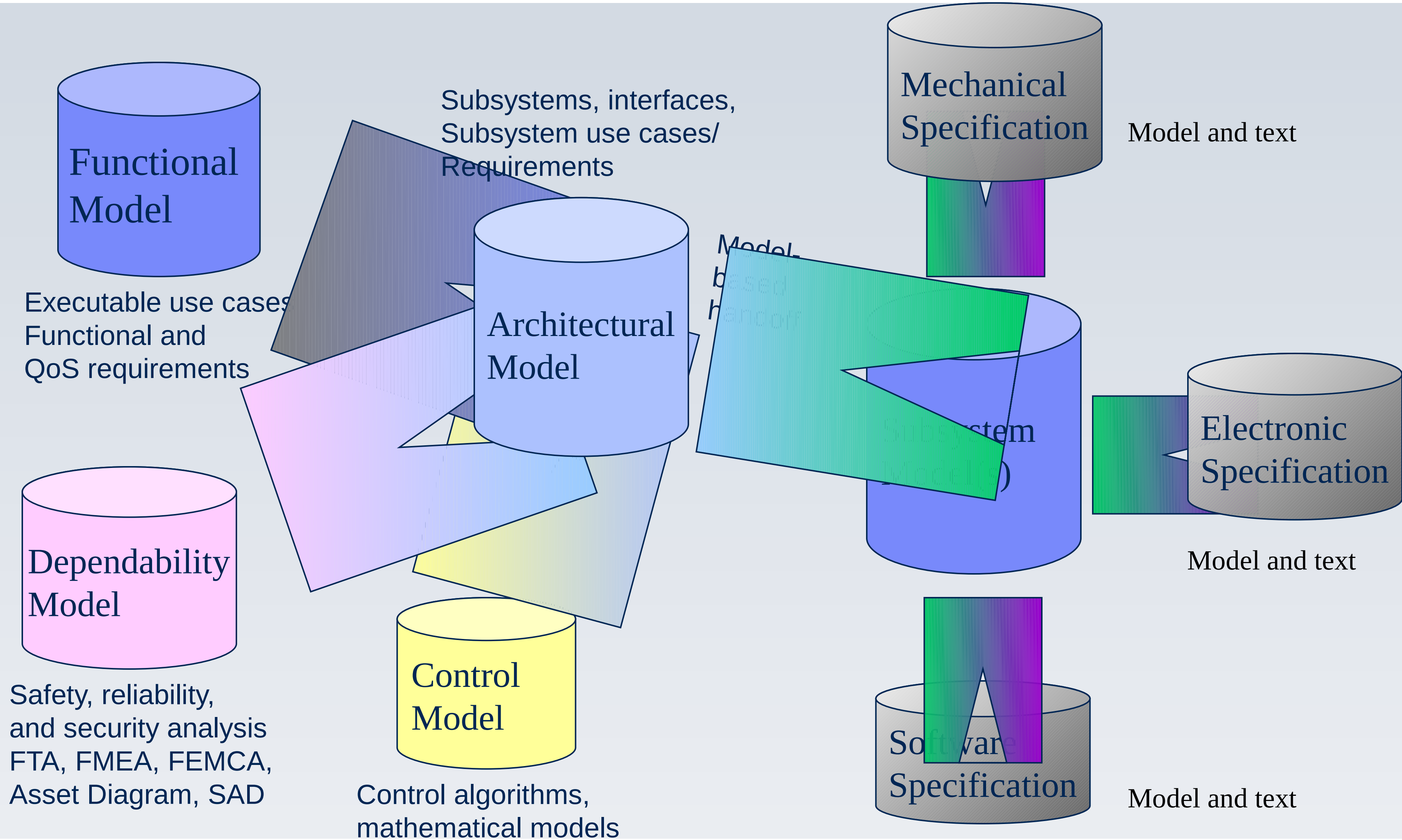


Note: a key difference between agile SW and agile SE is that the *outcome* of SE is *specifications* and the *outcome* of SW is *implementation*

But Why High-Fidelity Modeling???

- Hi-MBE brings to engineering
  - Precision
  - Verification via executability or formal methods
  - Stakeholder/Analysis-relevant viewpoints at any desired level of abstraction e.g.
    - Functionality
    - State-based behavior
    - Algorithmic/control behavior
    - Structure and Architecture
  - Integration of engineering work, e.g.
    - Functional requirements
    - Dependability analysis
      - Safety
      - Reliability
      - Cyberphysical security and Information Assurance
    - Architectural structure, behavior, and allocation
    - Control modeling and analysis

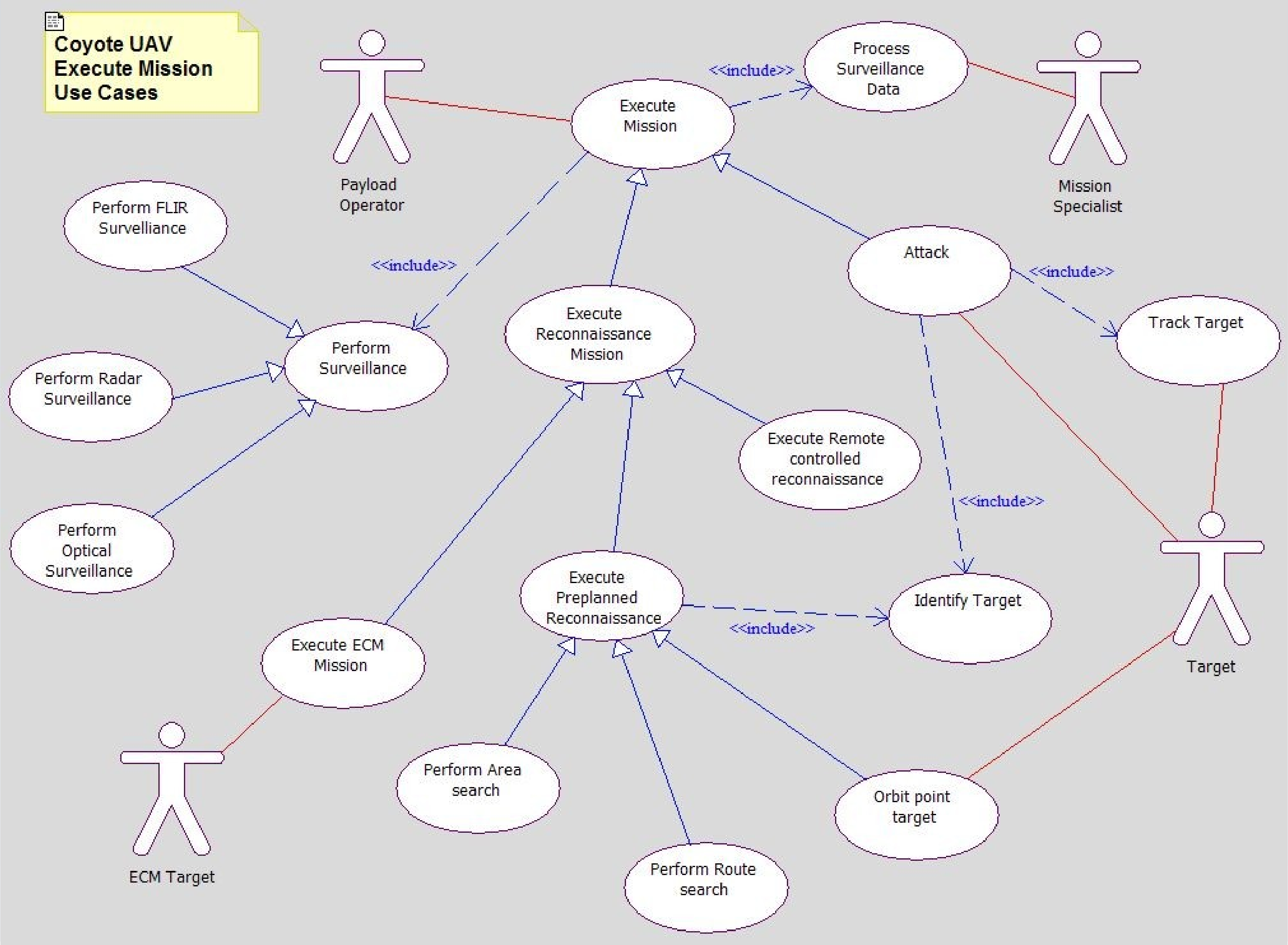
Models and Viewpoints in Model-Based Systems Engineering



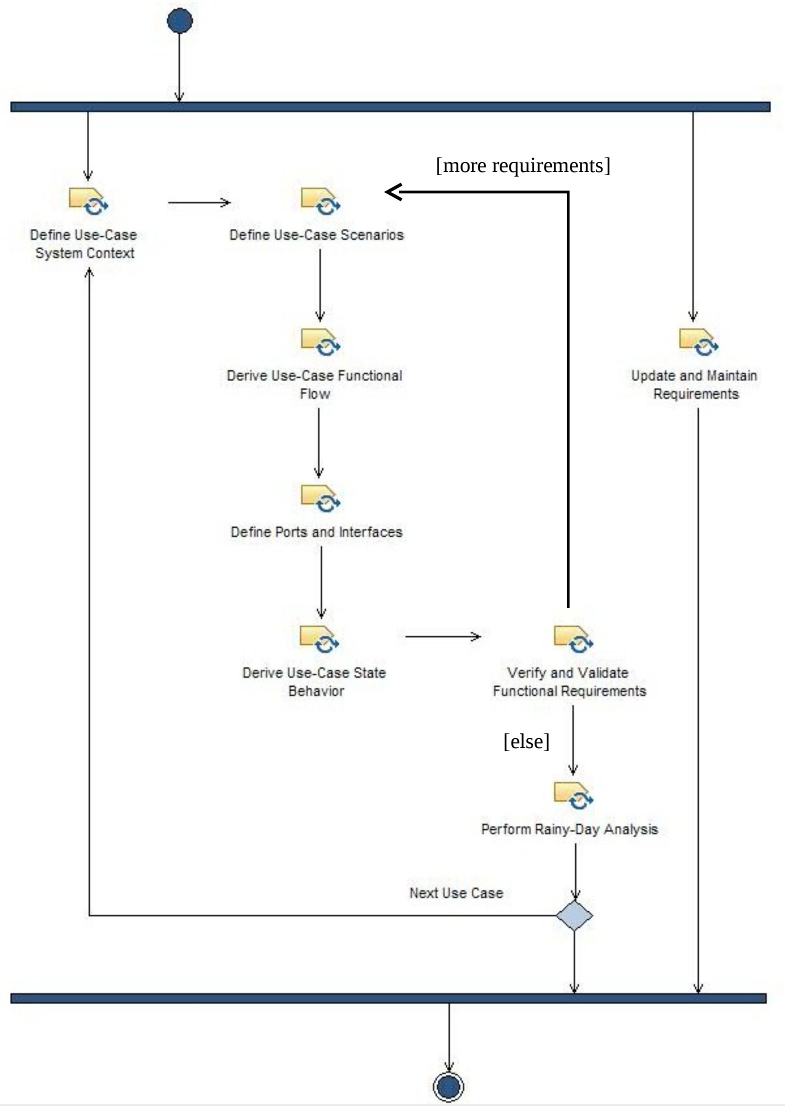
Use Cases for Systems Engineering

- A system-level use case
  - Can be thought of as a comprehensive user story
  - Is cross-discipline and usually results in mechanical, electronic and software implementation
  - Is a coherent set of requirements clustered around a systems capability or usage
  - Has bi-directional traceable links to system requirements
  - While focusing on functionality, *must* also include quality of service requirements and constraints, such as
    - Safety
    - Reliability
    - Security
    - Performance (worst-case, throughput, average case, etc)
    - Maintainability
    - Parametric requirements (heat, weight, recurring cost, etc)
- Three primary work flows for "detailing the use case"
  - Scenario-driven
  - Activity-driven
  - State-driven
    - It should be noted that the use case state machine is really the normative specification of the system with respect to that system capability

Detailing Use Cases with Statecharts and Scenarios



Scenario Driven Use Case Construction / Validation



Making it agile

1. Incrementally specify
   1. Use cases/User stories
   2. Specification nanocycles
2. Continuously verify
   1. Build executable models
3. Frequently validate
   1. Demonstrate to customer
4. Identify missing requirements
   1. Unspecified state transitions
   2. Unspecified scenarios
5. Incrementally add traceability
6. Annotate with qualities of service
7. Integrate with other specifications
   1. Other use cases
   2. Non-functional requirements
      1. Safety
      2. Security
      3. Reliability

Executable Requirements?

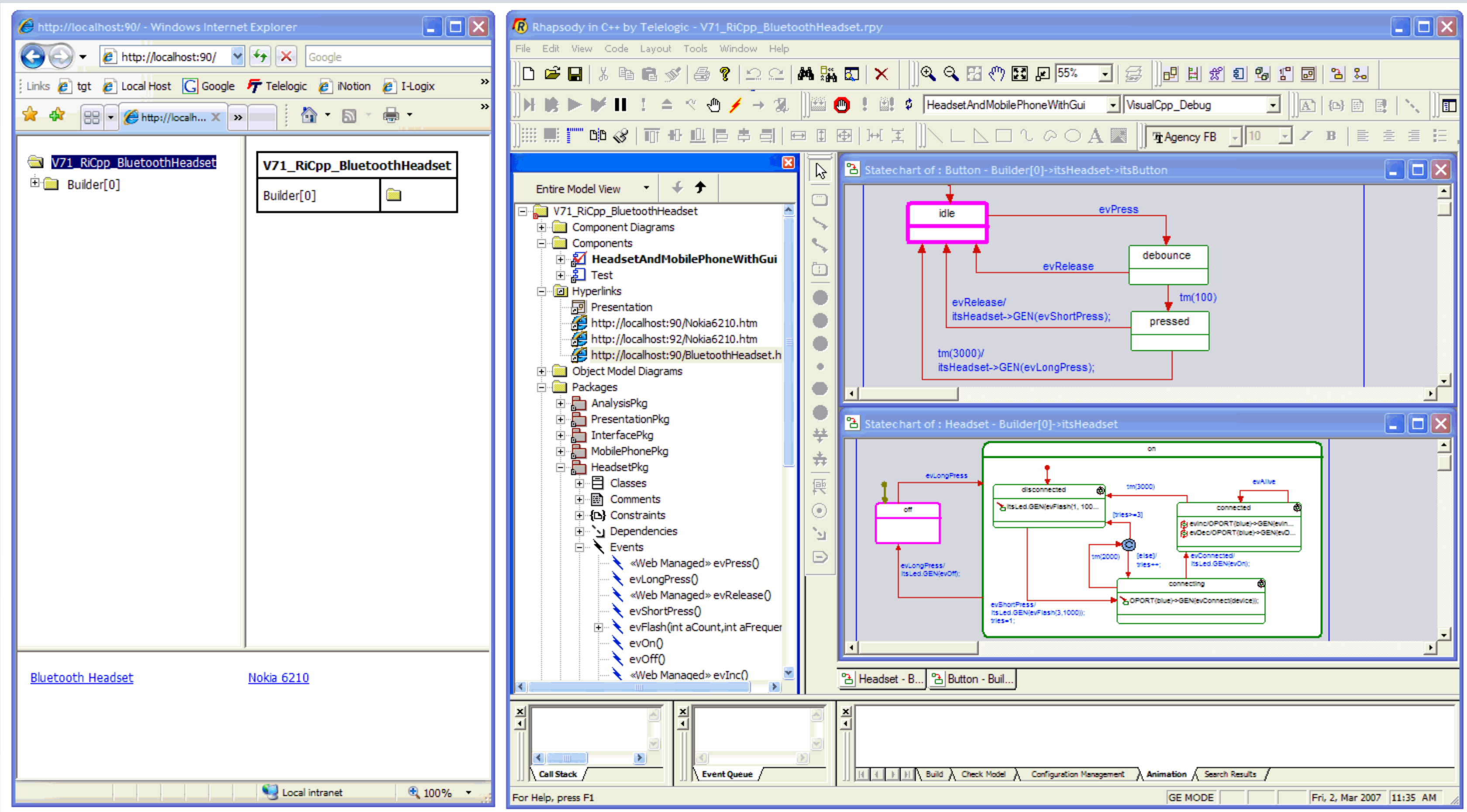
- A key problem is ensuring the quality of requirements for complex systems
- This is *not just* a matter of making good stand alone “shall” statements
  - Truly, most requirements specifications have poorly-specified “shall” statements that
    - Are ambiguous
    - Lack precision
    - Inappropriately include design detail
  - But the *hard part* is the subtle interactions of requirements
    - Don’t cover all cases, situations, or operational environments
    - Don’t discuss system error and fault responses
    - Missing data specification
    - Missing performance properties
    - Inconsistent requirements
- The “state of the practice” for requirements is protracted manual review of textual documents
  - The problem is this is error-prone and hugely expensive
- The “state of the art” is to create executable requirements models that *demonstrate* the system black-box behavior
  - The point is to *clearly and unambiguously specify the* ***control and data transformations*** *(and their constraints) to be performed by the system in all relevant situations, conditions, environments, and operational scenarios*

Executable Requirements

- Most common workflow
  - Start with textual specifications
  - Incrementally construct use case behavioral model
    - Test Driven Development
    - Nanocycle Iteration
    - Constrain with quality of service requirements
    - Continuous trace linking to textual requirements
    - Continuous safety, reliability, security assessment
- Outcome
  - Better requirements as workflow mitigates against
    - Incorrect requirements
    - Missing functionality
    - Missing QoS & performance requirements
    - Inconsistent requirements
    - Ambiguous requirements
  - Validation with the customer via execution of the use case
  - Model-based handoff to downstream engineering
  - Traceability supports impact analysis, change management, and safety certification

Validation of requirements through “what if” executions

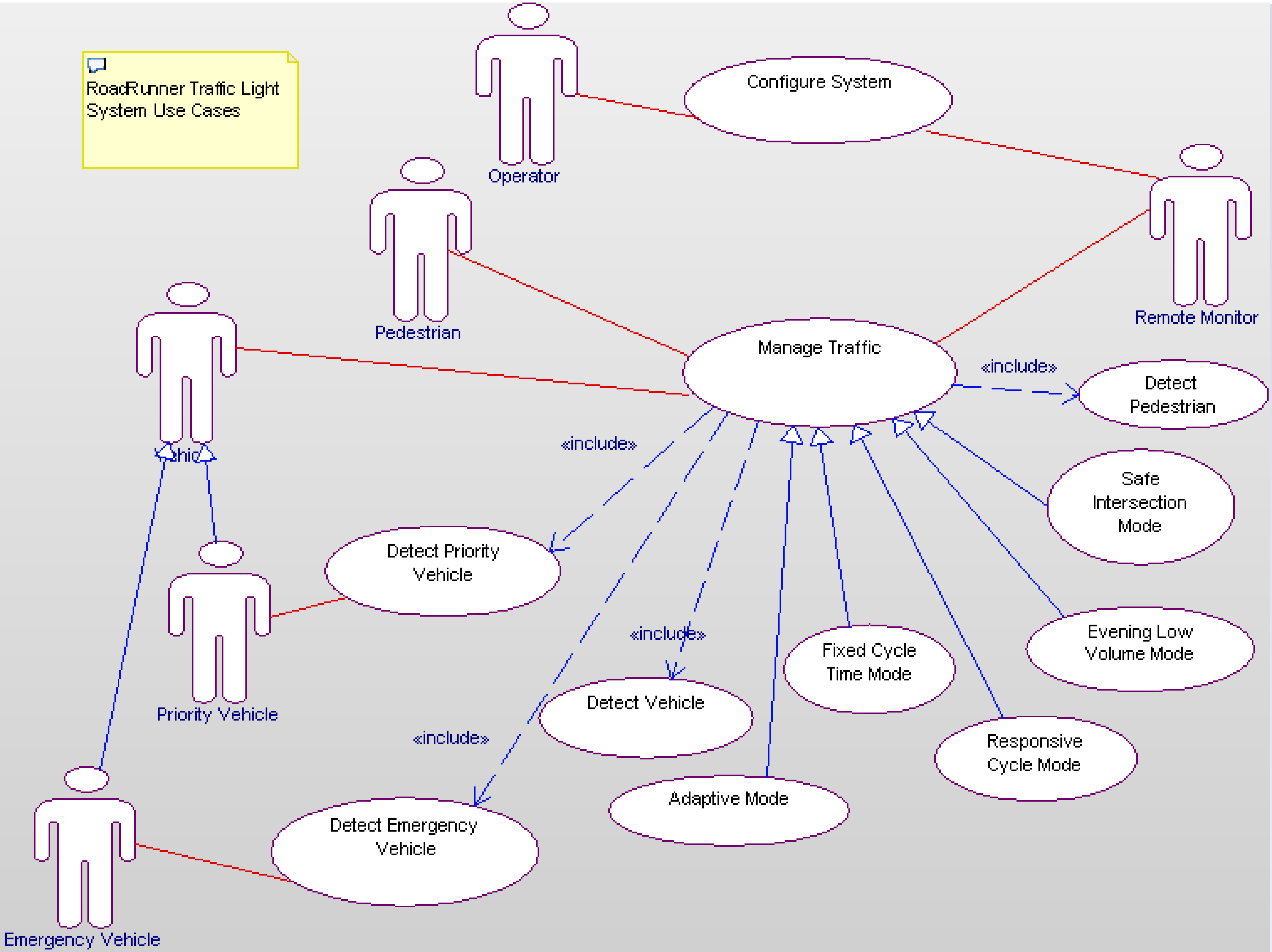
- Virtual prototype / Panel graphics support
  - Ideal communications aid for validation of customer requirements
  - Clearly shows data and control transformations specified by requirements



Test-Driven Development isn't just for software anymore

- The principle behind TDD is to develop and apply test cases *as you develop* a system to demonstrate that it is correct
  - This is done in parallel with the system development and *not* ex post facto
  - This is about *defect avoidance* and less about *defect identification and repair*
- TDD applies to the development of complex system use case models
  - During the nanocycle of a use case's development
    - Make small incremental changes (e.g. add a state, or a couple of actions, or a transition or two)
    - Identify what is the desired behavior of the system that you've specified *so far*
    - Execute that incomplete use case model to ensure that it is correct
    - Repeat until all requirements for the use case and all scenarios defined for the use case have been met in the normative specification
- TDD may be realized
  - By "instrumenting the actors" – specifying behavior of the actors to perform tests
  - Tooling implementing the UML Profile for Test (e.g. Test Conductor™ and Automatic Test Generator™)
  - Manually writing test scripts

Example: Traffic Light Control Fixed Cycle Mode Spec



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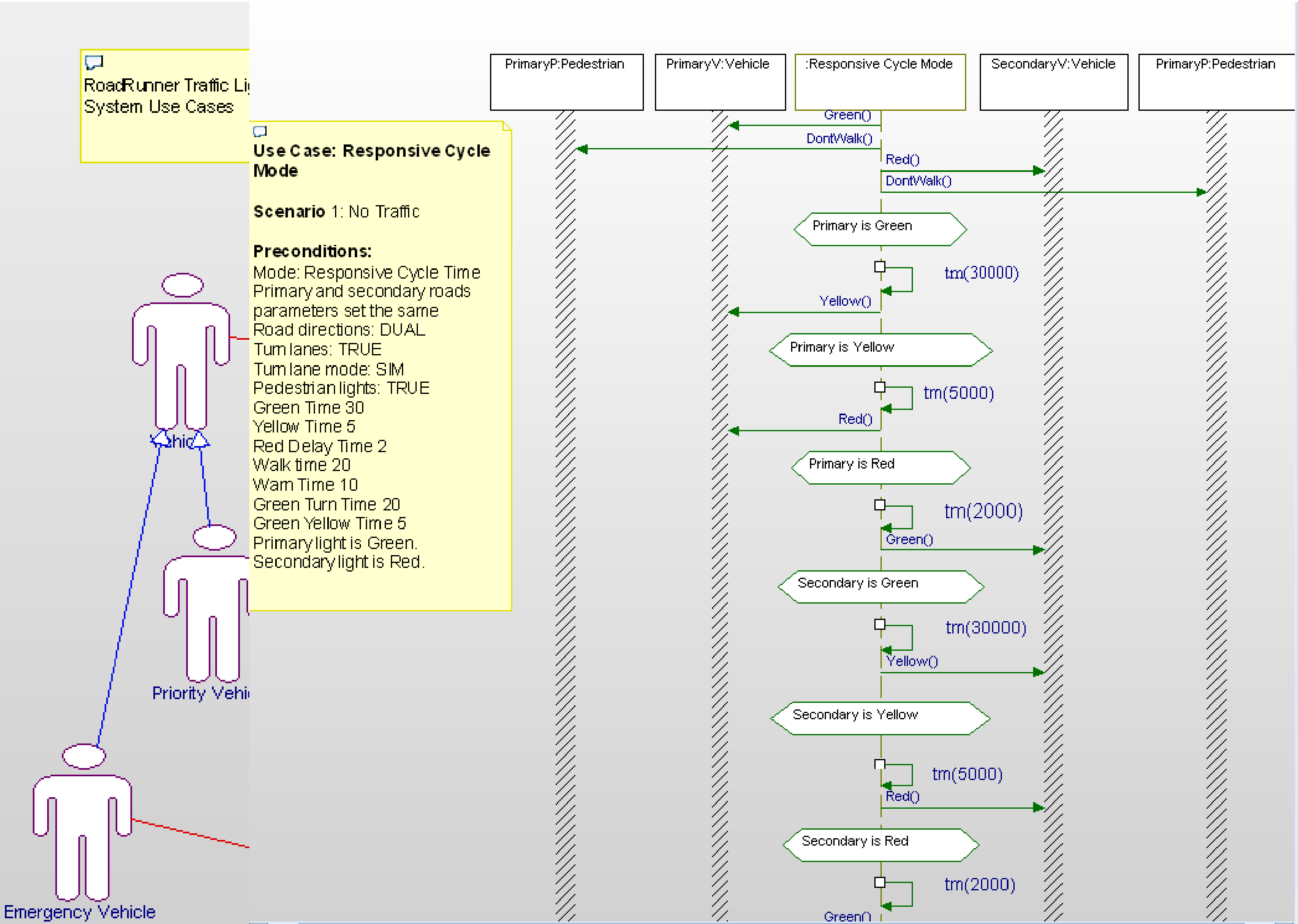

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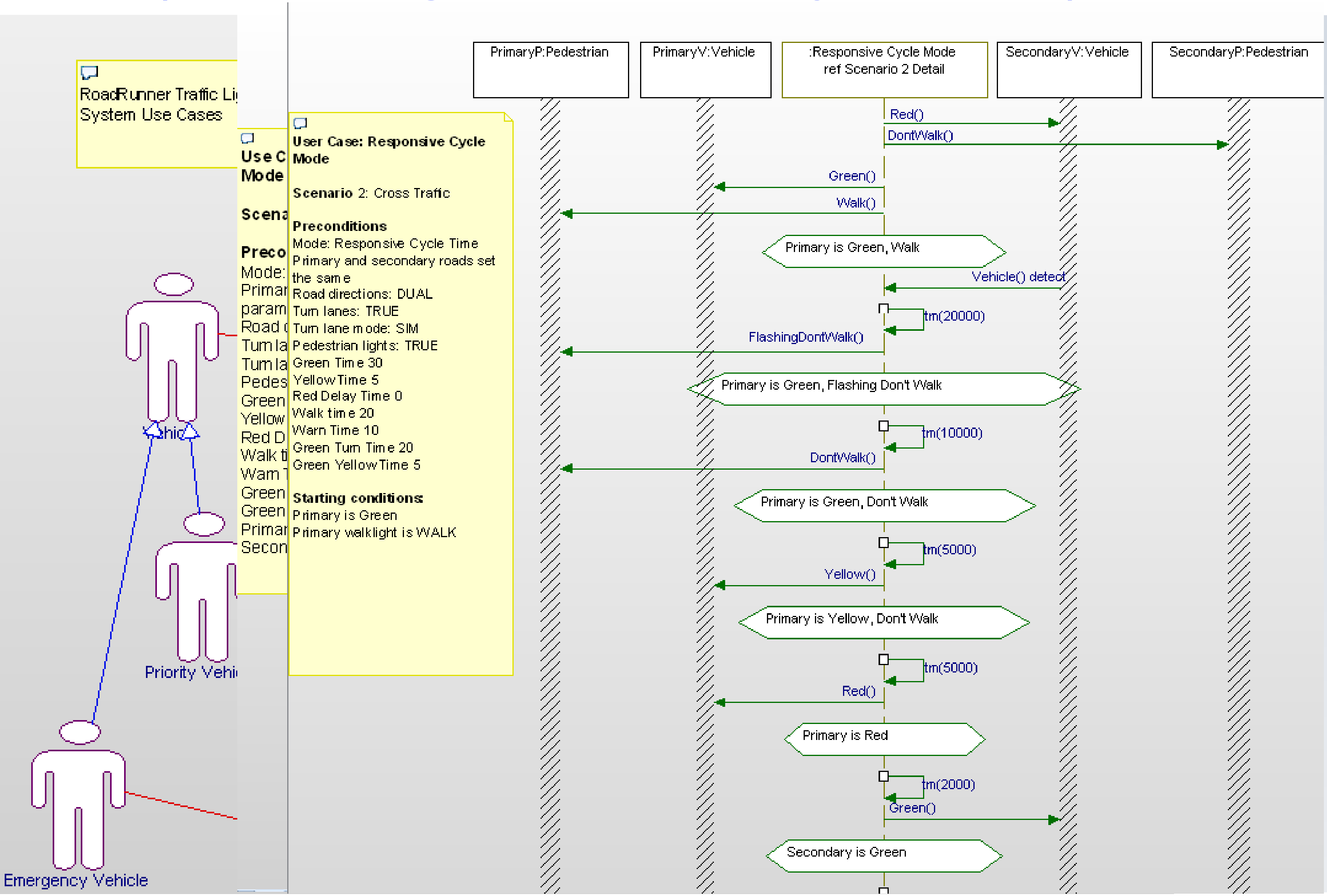

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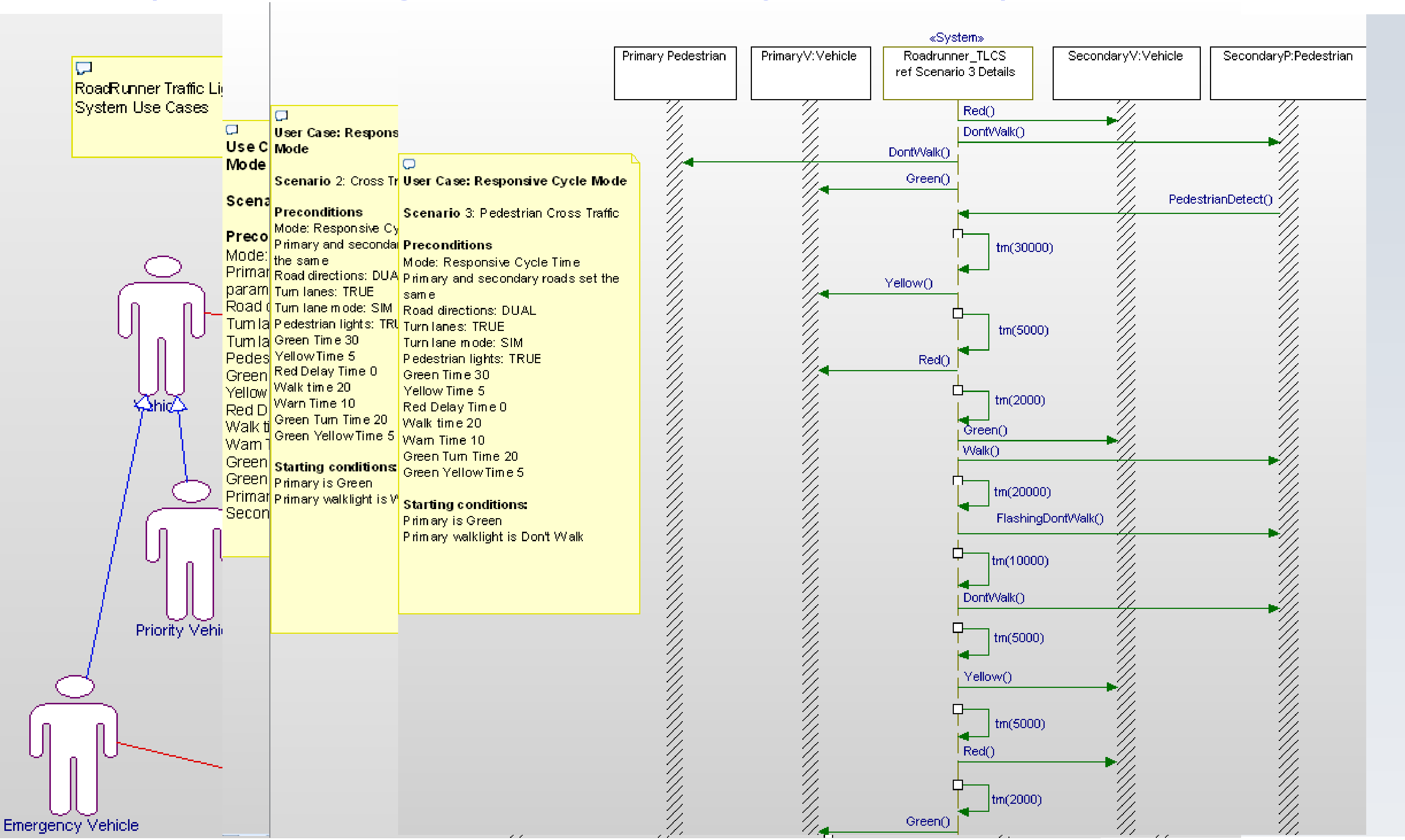

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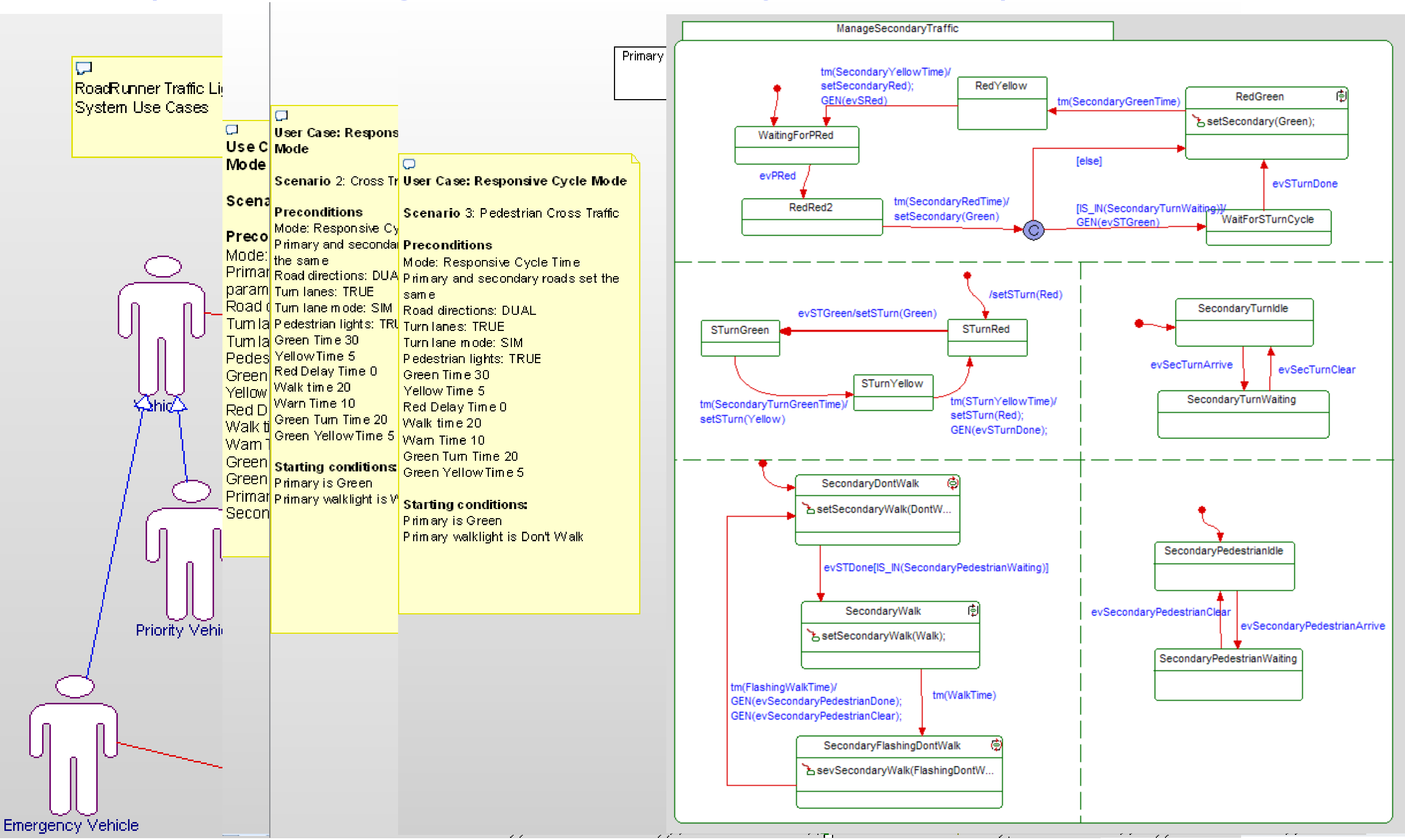
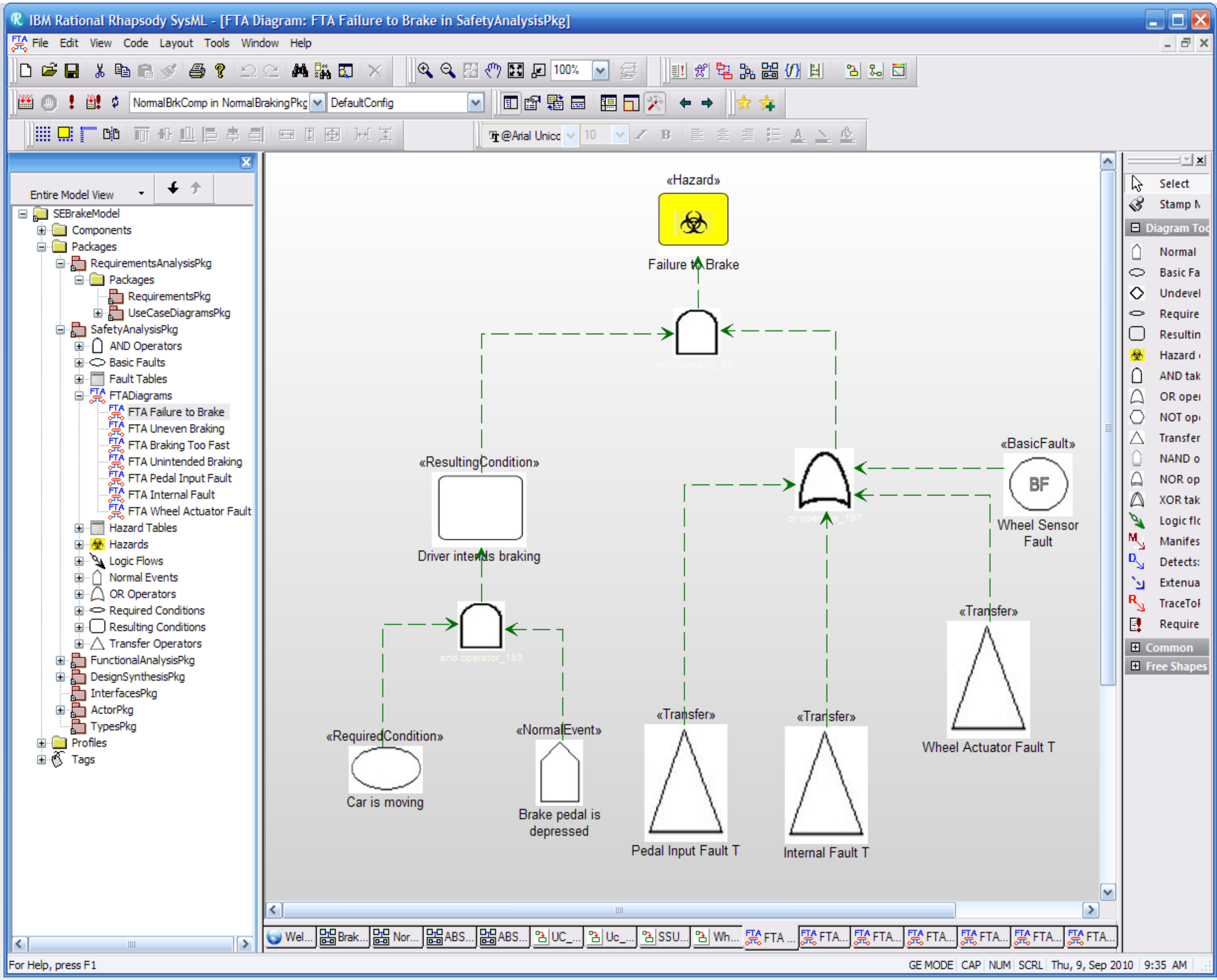
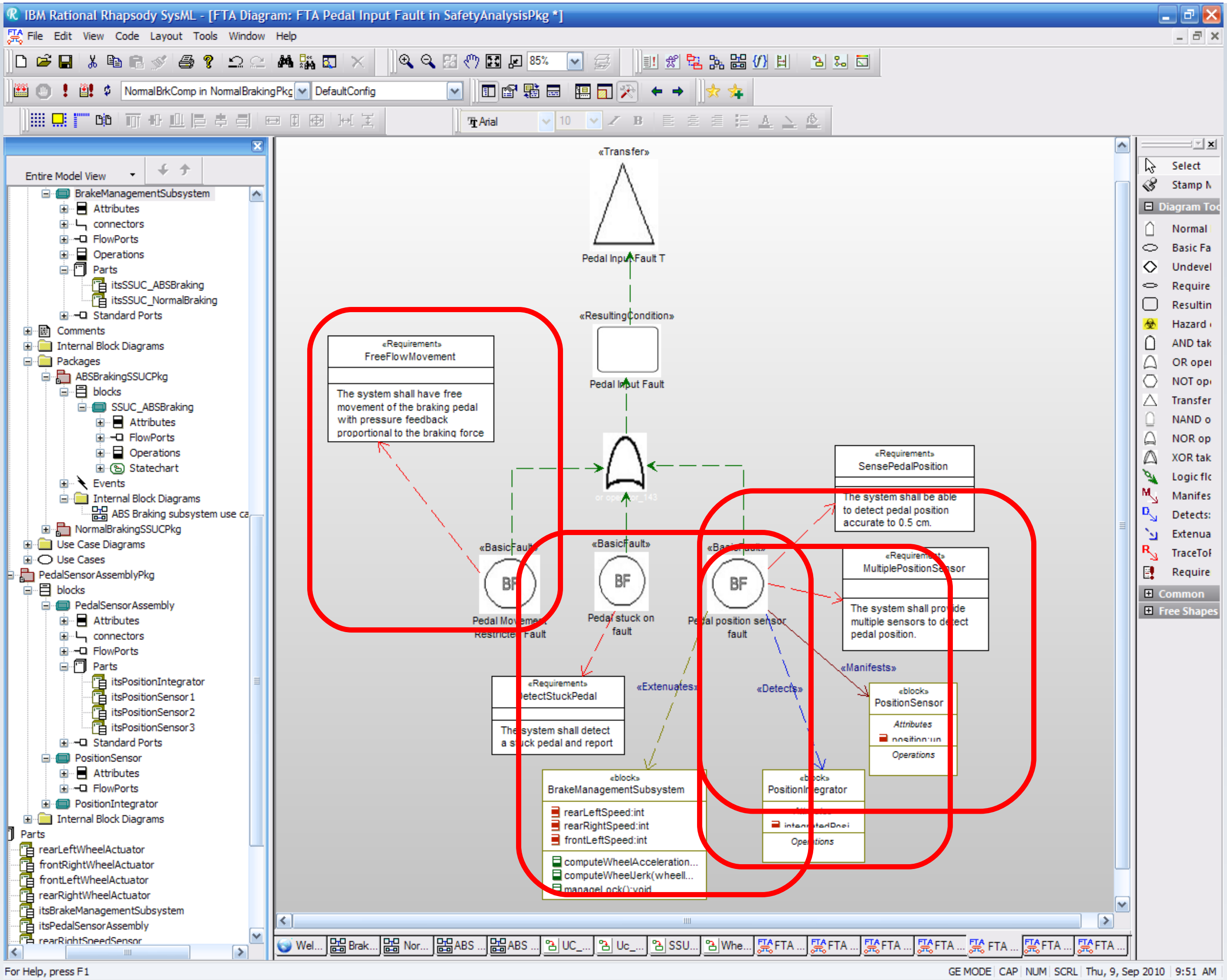


Integrated Safety and Reliability Analysis

- Fault Tree Analysis (FTA) connects *hazards* with logical combinations of events, conditions, errors, and faults
- Allows you to identify
  - Effects of combinations of conditions and events on safety
  - Safety measures
  - Safety requirements
    - DO 178B/C
    - IEC 61508
    - ISO 26262
  - Impacts of architectural, technological, and design choices on safety

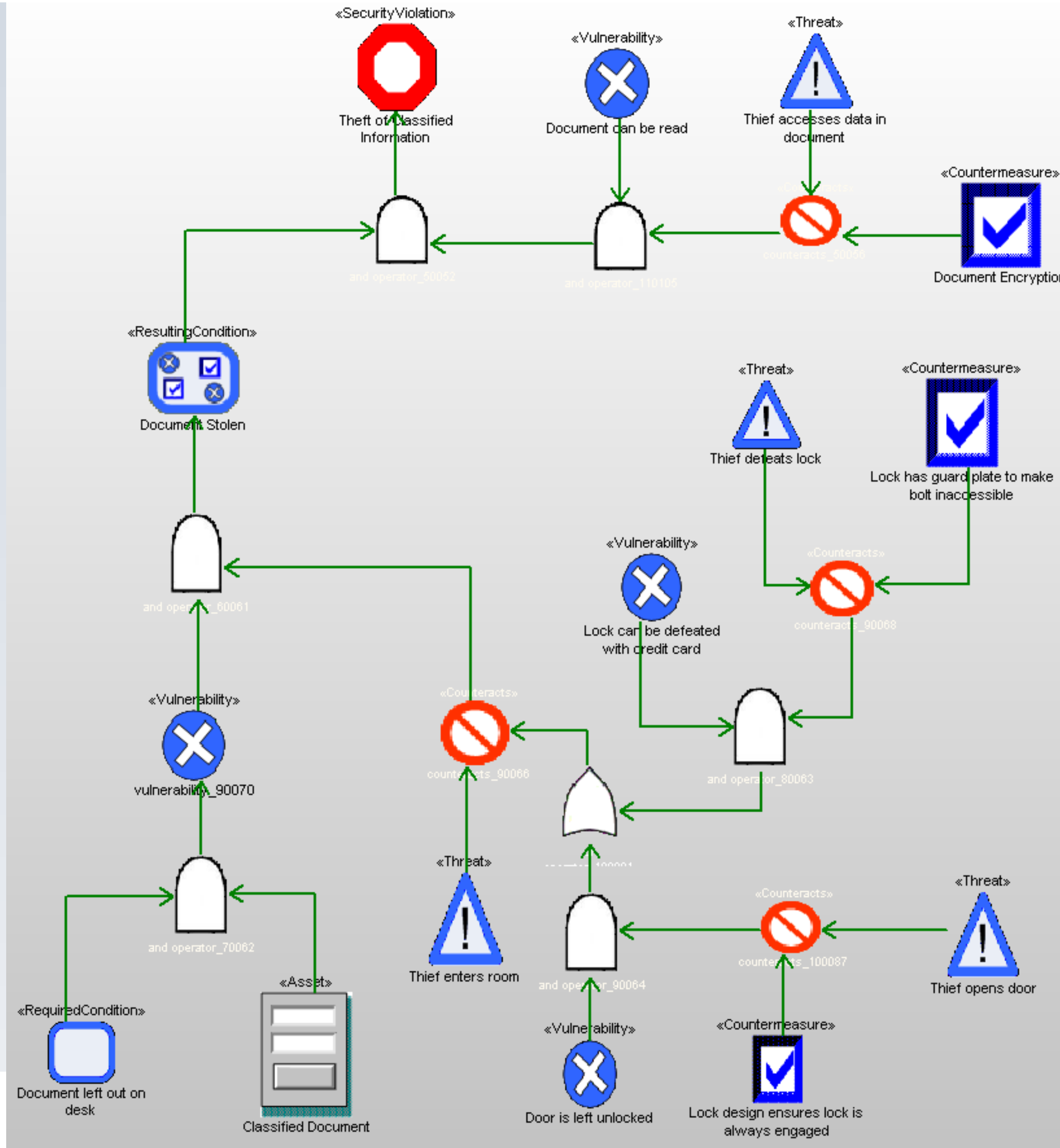


Integrated Safety and Reliability Analysis



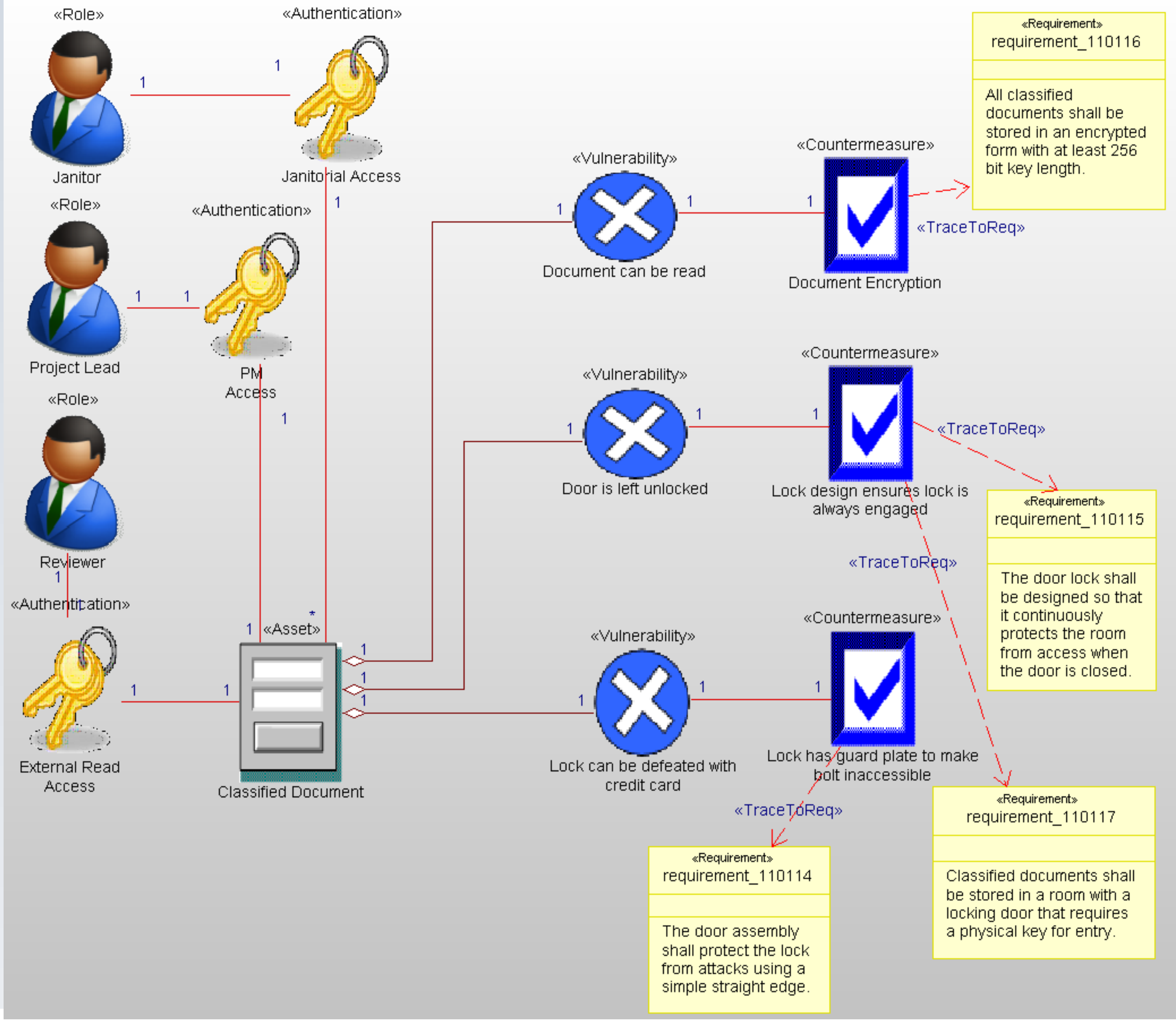
Model-Based Threat Analysis

- **Security Analysis Diagram** (SAD) is like a Fault Tree Analysis (FTA) but for security, rather than safety
  - It looks for the logical relation between assets, vulnerabilities, attacks, and security violations
  - Permits reasoning about security
    - What kind?
    - How much?
    - Risk assessments



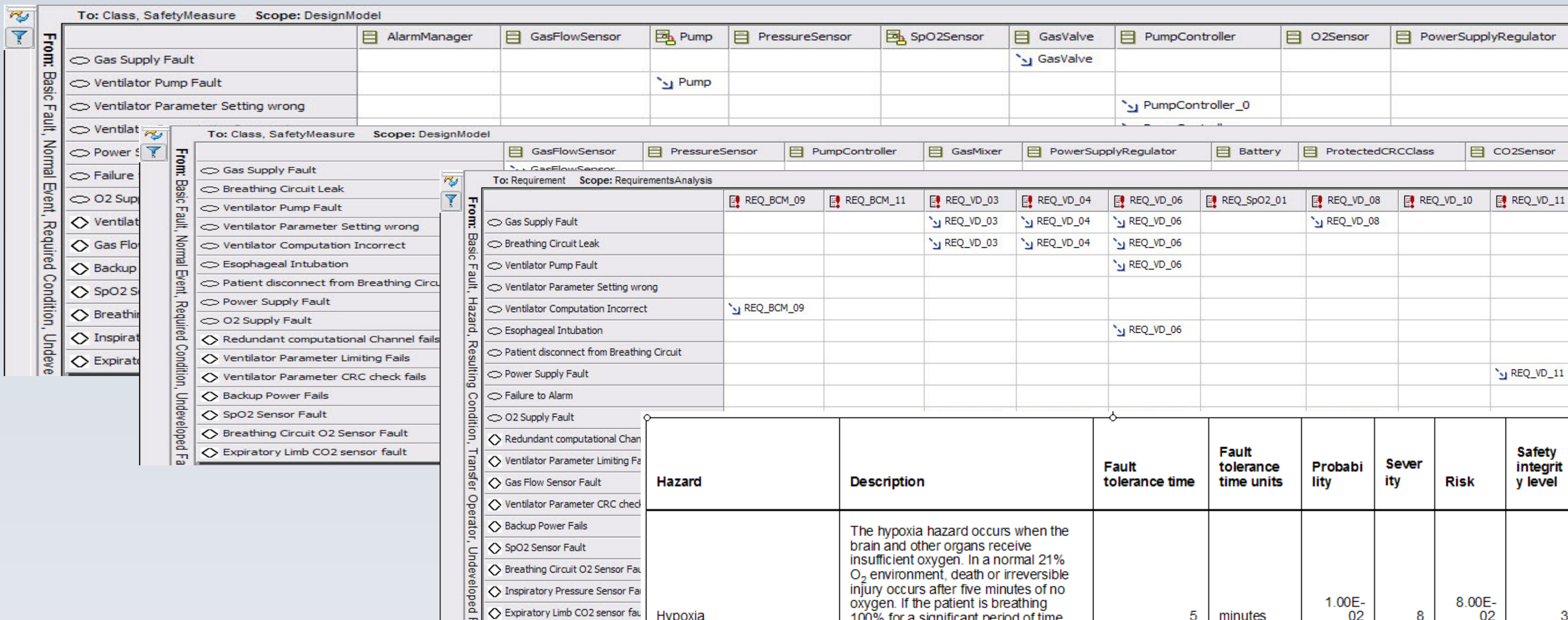
Model-Based Threat Analysis

- An **Asset Diagram** looks at the semantic relations between roles, authentication, vulnerabilities, and countermeasures. It is a way of representing the security-relevant design elements.
  - Here it is shown with traceability links to requirements
- Assets are things you want to protect, e.g.
  - Physical
  - Informational
  - Currency
  - Resource
  - Security



Auto-generation of dependability-relevant summary data

Fault Source Matrix, Fault Detection Matrix, Fault-Requirement Matrix, FMEA, Hazard Analysis…



Hazard	Description	Fault tolerance time	Fault tolerance time units	Probability	Severity	Risk	Safety integrity level
Hypoxia	The hypoxia hazard occurs when the brain and other organs receive insufficient oxygen. In a normal 21% O_2 environment, death or irreversible injury occurs after five minutes of no oxygen. If the patient is breathing 100% for a significant period of time, this time is about 10 minutes.	5	minutes	1.00E-02	8	8.00E-02	3
Overpressure	Overpressure can damage the lungs. This is an especially severe trauma, possibly fatal, to neonates.	200	milliseconds	1.00E+04	4	3.00E+04	3
Hyperoxia	Hyperoxia problems are usually limited to neonates, where it can cause blindness.	10	minutes	1.00E+05	4	4.00E+05	4
Inadequate anesthesia	Inadequate anesthesia leads to patient discomfort and memory retention of the surgical procedures. This is normally not life threatening but can be severely discomforting.	5	minutes	1.00E+04	2	2.00E+04	2
Over anesthesia	Over anesthesia can lead to death.	3	minutes	1.00E+03	4	4.00E+03	4
Anesthesia leak into ER	Anesthesia leak can lead to short or, in smaller doses, to long-term poisoning of medical staff.	10	minutes	1.00E+05	5	4.00E+05	5

- **Traceability improves your ability to make your safety/security case**

Dependability metadata guides
- **System requirements**
- **Downstream engineering work**
- **Regulatory approval submissions**

IBM Rational Harmony for Systems Engineering

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Harmony/SE

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Introduction to IBM® Rational® Harmony™ for Systems Engineering

Introduction to IBM® Rational® Harmony™ for Systems Engineering

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Relationships

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Main Description

Getting Started	Core Principles	Roles	Work Products	Disciplines	Delivery Process

Welcome to IBM® Rational® Harmony™ for Systems Engineering

Harmony for Systems Engineering is a member of the The IBM® Rational® Harmony™ Library of Best Practices specifically for Systems Engineering development The Harmony for Systems Engineering process focusses around integrated systems and software development. The process provides systems engineers with a step-by-step guide on using SysML in a way that allows a seamless transition to subsequent system development.

Harmony for Systems Engineering is model-based systems engineering process that leverages industry standard SysML language to develop executable requirements and architecture models in order to create verified and validated inputs to the system development and V&V activities.

Harmony for Systems Engineering may be used "out-of-the-box" or as the starting point for process tailoring and continuous improvement.

Getting Started	Core Principles	Roles	Work Products	Disciplines	Delivery Process

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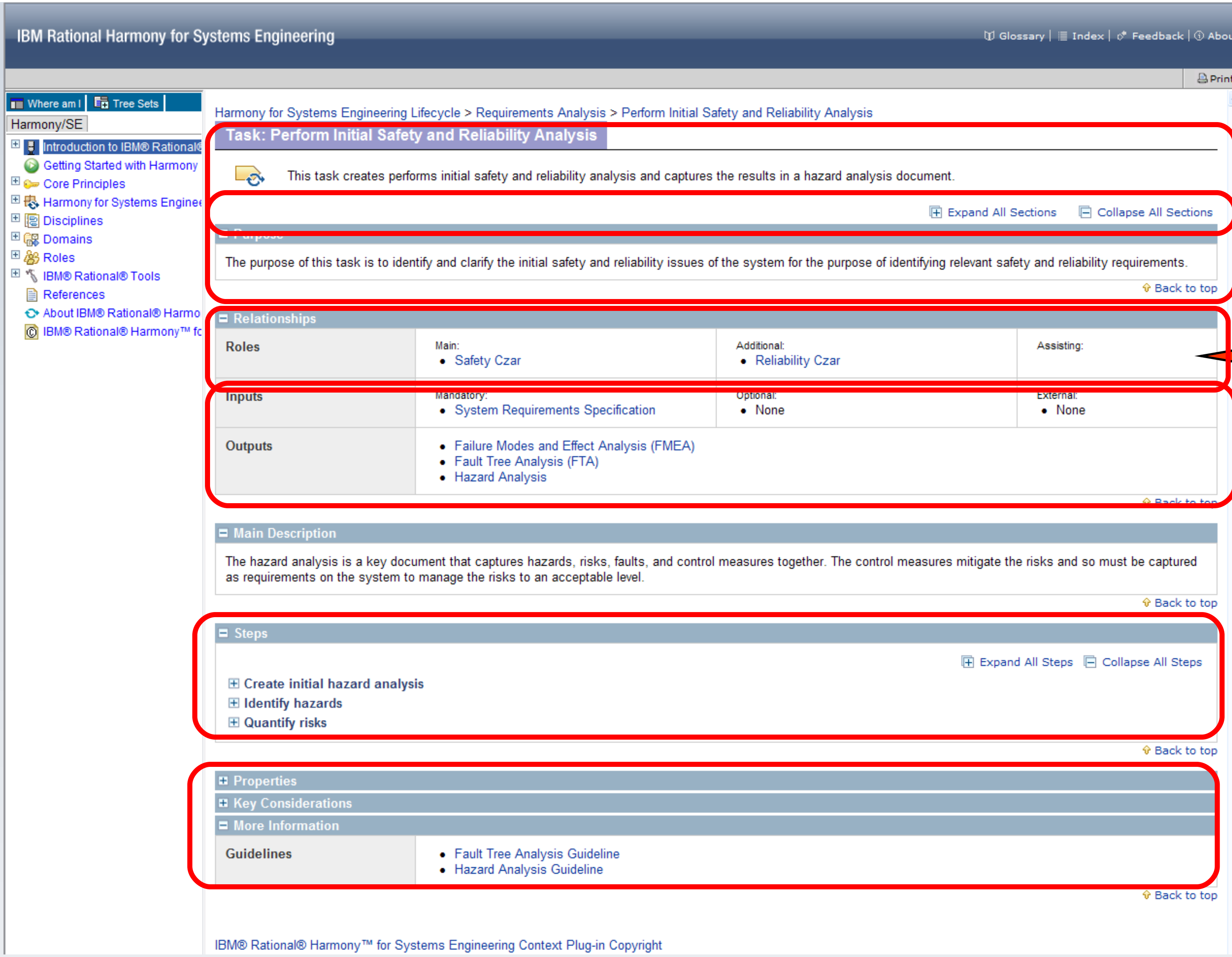
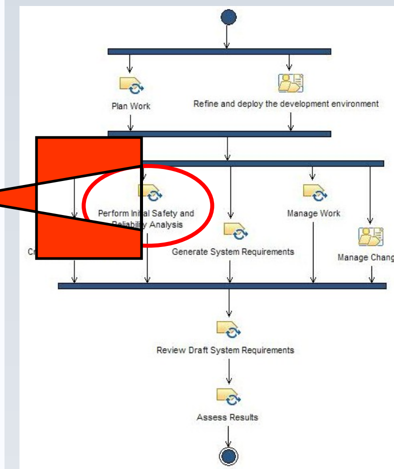
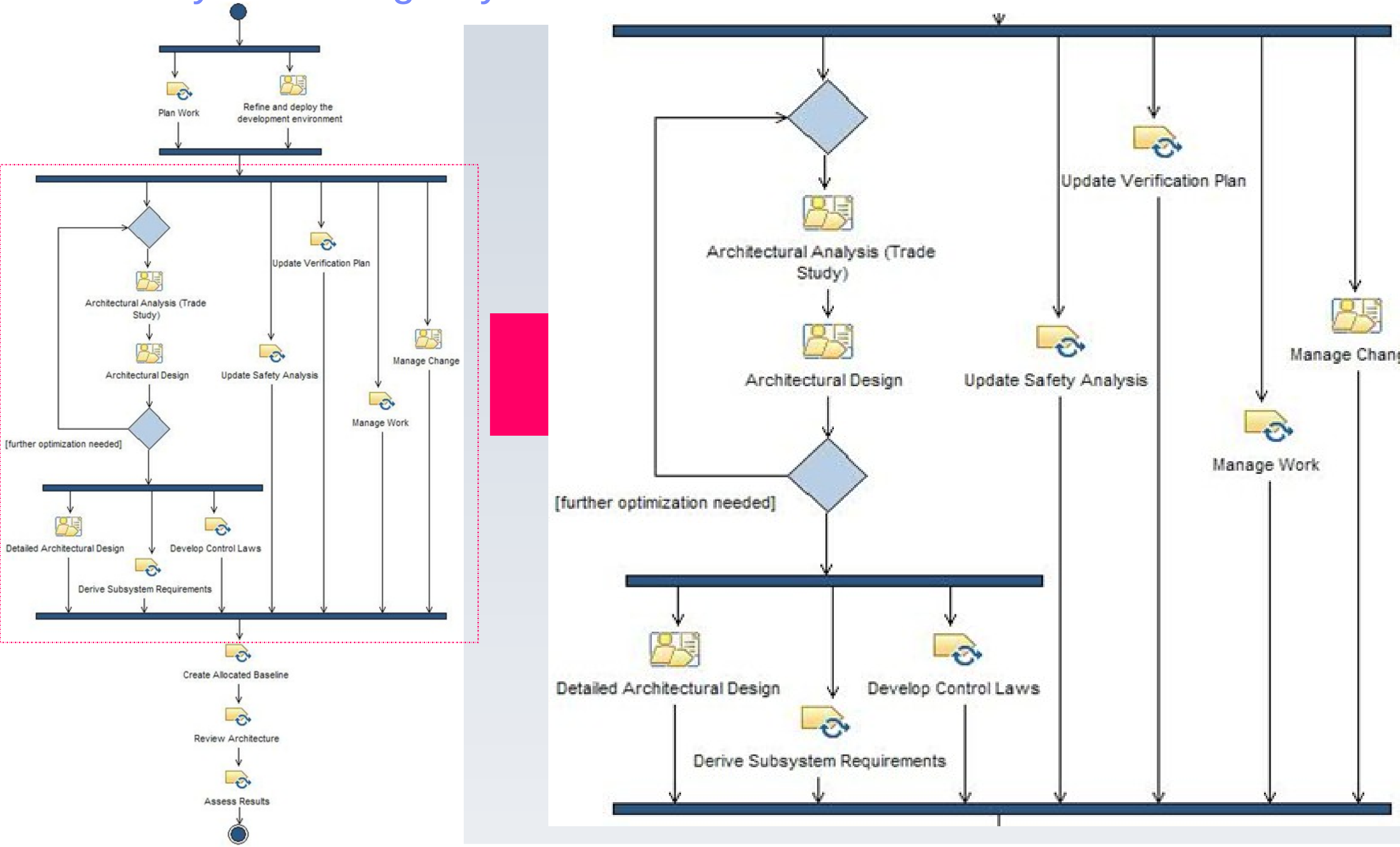
Harmony Systems Engineering Workflows



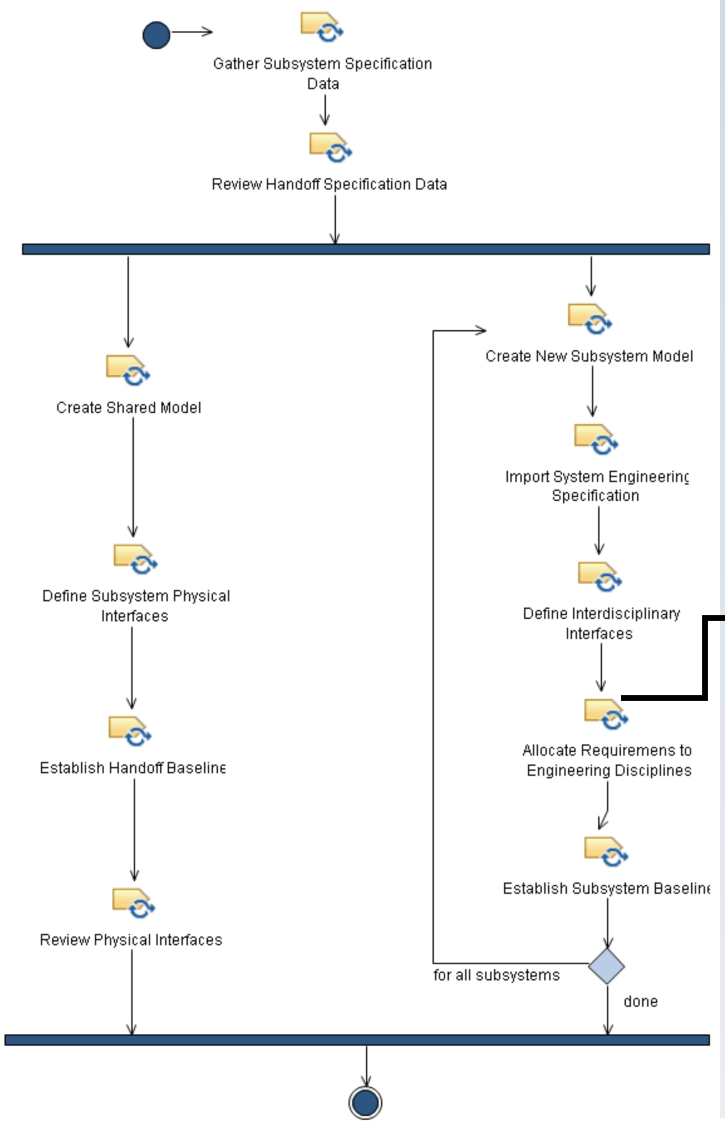
Systems Engineering: Requirements Analysis



Harmony/SE: Design Synthesis



Model-Based Hand-off to Downstream Engineering



Task: Allocate Requiremens to Engineering Disciplines

This task takes the requirements allocated to a subsystem as a whole and allocates them to the different engineering disciplines inolved (e.g. software, electronics, mechanical, optical, hydraulic).

Expand All Sections | Collapse All Sections

Purpose

The purpose is to clearly delinate the required contributions of different engineering disciplines to the engineering development of a subsystem by allocating the requirements allocated to the subsystem by the system engineering team.

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Relationships

Roles	Primary Performer: • Control Engineer • Developer • Electrical Engineer • Mechanical Engineer • Miscellaneous Engineer	Additional Performers: • Architect • Reliability Czar • Safety Czar
Inputs	Mandatory: • Requirements Traceability • Subsystem Model • Systems Requirements Specification	Optional: • Failure Modes and Effect Analysis • Fault-Tree Analysis • Hazard Analysis
Outputs	• Requirements Traceability • Subsystem Requirements Specification	
Process Usage	• handoff_cp > Allocate Requirements to Engineering Disciplines	

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Main Description

A subsystem team is usually comprised of engineers within different disciplines, such as software, digital electronics, analog electronics, hydraulic, pneumatic, control, and mechanical. Once the subsystem specification is handed off, certain of the requirements will belong to one discipline or the other. Other requirements will require decomposition into derived requirements, allocating portions of a subsystem-level requirement to different discipline. This is particularly true of quality-of service requirements.

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Steps

Collapse All Steps

- Review subsystem requirements
- Allocate single-discipline requirement
- Decompose multi-discipline requireme
- Allocate derived requirements
- Update traceability record
- Review allocations

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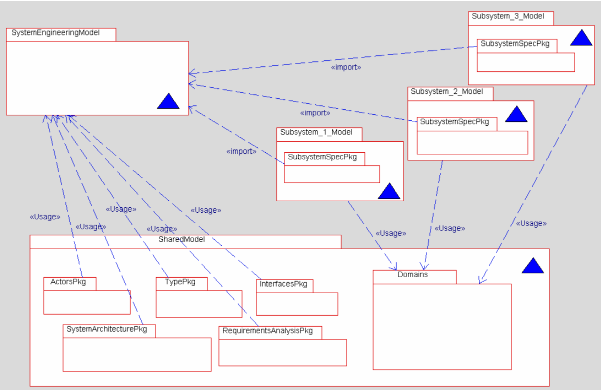

Summary

- Systems Engineering capability can be greatly enhanced with two key technologies
  - Use of SysML/UML Modeling to capture system
    - Behavior (executable use cases)
    - Structure (architecture)
    - Data and performance modeling
    - Model-based hand off to downstream engineering
    - Automatic generation of documentation from model-based work products
  - Agile methods employing
    - Incremental construction of use cases
    - Test Driven Development nanocycle-level iteration
    - Incorporating dependability analysis with the use case development
- Harmony best practice workflows embody agile for embedded systems engineering
  - Rational provides the services
    - R&D Capability Assessment
    - “Agile Systems Engineering” and “Agile Embedded Software Development” courses
    - Rapid Deployment Package (training, mentoring, frequent design reviews by modeling experts)
  - Rational has the tools
    - **Rational DOORS** provides requirements management with great traceability
    - **Rational Rhapsody** provides tooling for best practice realization
    - **Rational Method Composer** manages process and practice definitions
    - **Rational Team Concert** provides a project enactment & governance environment
    - **Rational Quality Manager** manages test cases and procedures

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