INCOSE
International Council on Systems Engineering

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Orlando, Florida

OMG SYSTEMS MODELING LANGUAGE SYS ML ™

OMG Systems Modeling Language (OMG SysML™) Tutorial

11 July 2006

Sanford Friedenthal
Alan Moore
Rick Steiner

Caveat

- This material is based on version 1.0 of the SysML specification (ad-06-03-01)
  - Adopted by OMG in May ’06
  - *Going through finalization process*

- OMG SysML Website
  - http://www.omgsysml.org/

Objectives & Intended Audience

At the end of this tutorial, you should understand the:

- Benefits of model driven approaches to systems engineering
- Types of SysML diagrams and their basic constructs
- Cross-cutting principles for relating elements across diagrams
- Relationship between SysML and other Standards
- High-level process for transitioning to SysML

This course is not intended to make you a systems modeler!
You must use the language.

Intended Audience:

- Practicing Systems Engineers interested in system modeling
  - Already familiar with system modeling & tools, or
  - Want to learn about systems modeling
- Software Engineers who want to express systems concepts
- Familiarity with UML is not required, but it will help

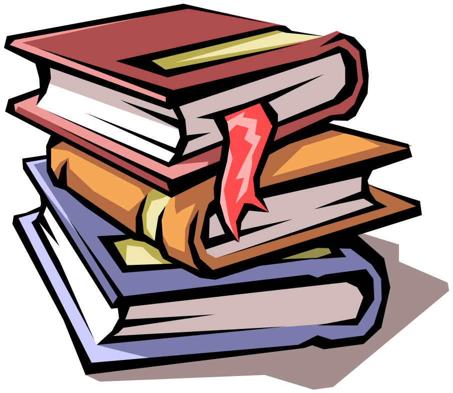
Topics

- Motivation & Background (30)
- Diagram Overview (135)
- SysML Modeling as Part of SE Process (120)
  - Structured Analysis – Distiller Example
  - OOSEM – Enhanced Security System Example
- SysML in a Standards Framework (20)
- Transitioning to SysML (10)
- Summary (15)

Motivation & Background

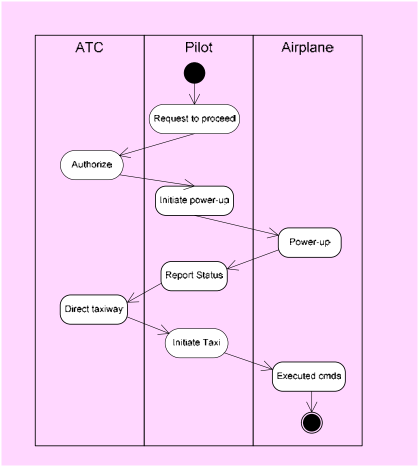
SE Practices for Describing Systems

Past



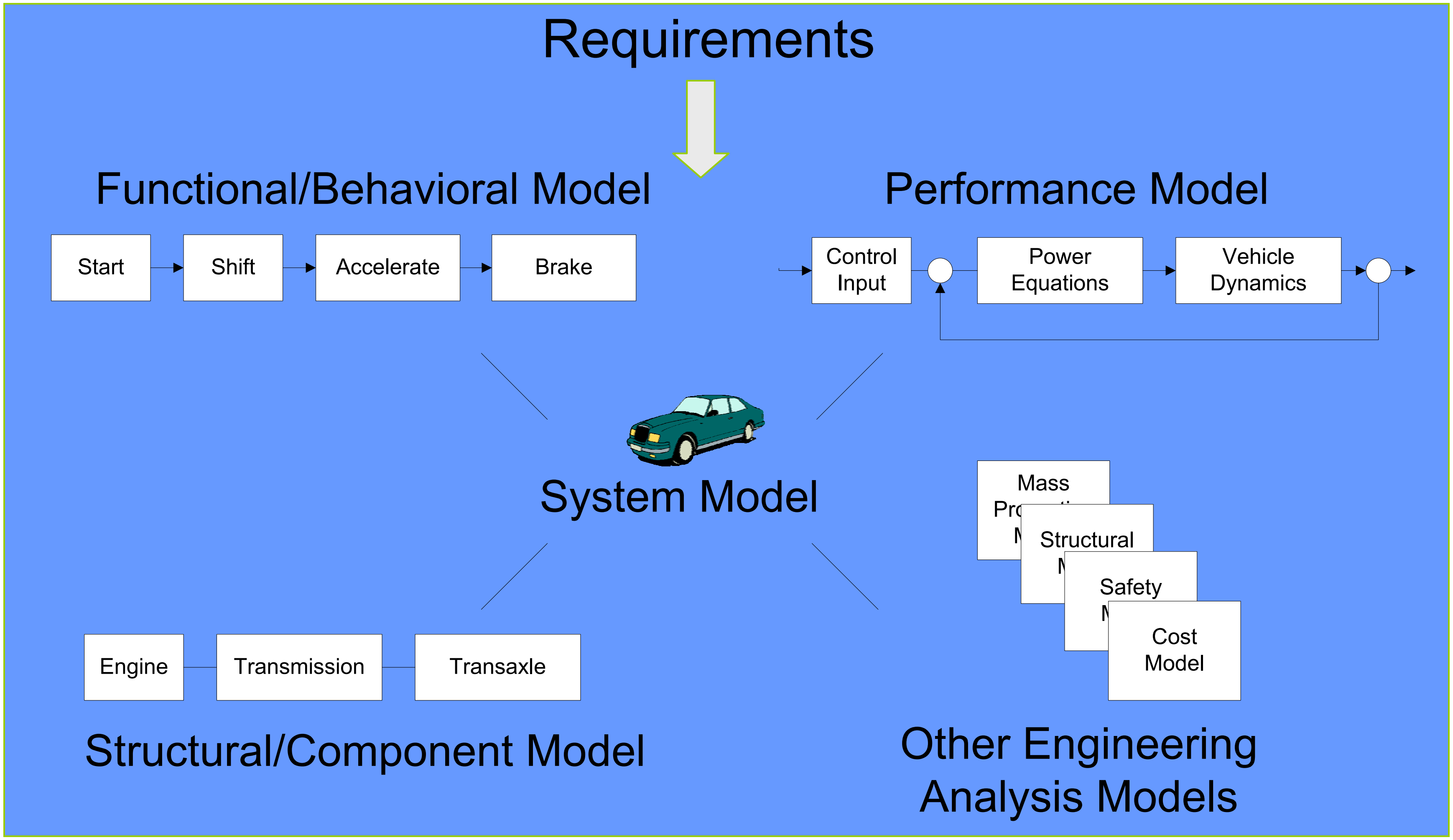
- **Specifications**
- **Interface requirements**
- **System design**
- **Analysis & Trade-off**
- **Test plans**

Future



Moving from Document centric to Model centric

System Modeling



Requirements

Functional/Behavioral Model

Start

Shift

Accelerate

Brake

Performance Model

Control Input

Power Equations

Vehicle Dynamics

System Model

Mass

Pro

M

Structural

M

Safety

M

Cost Model

Engine

Transmission

Transaxle

Structural/Component Model

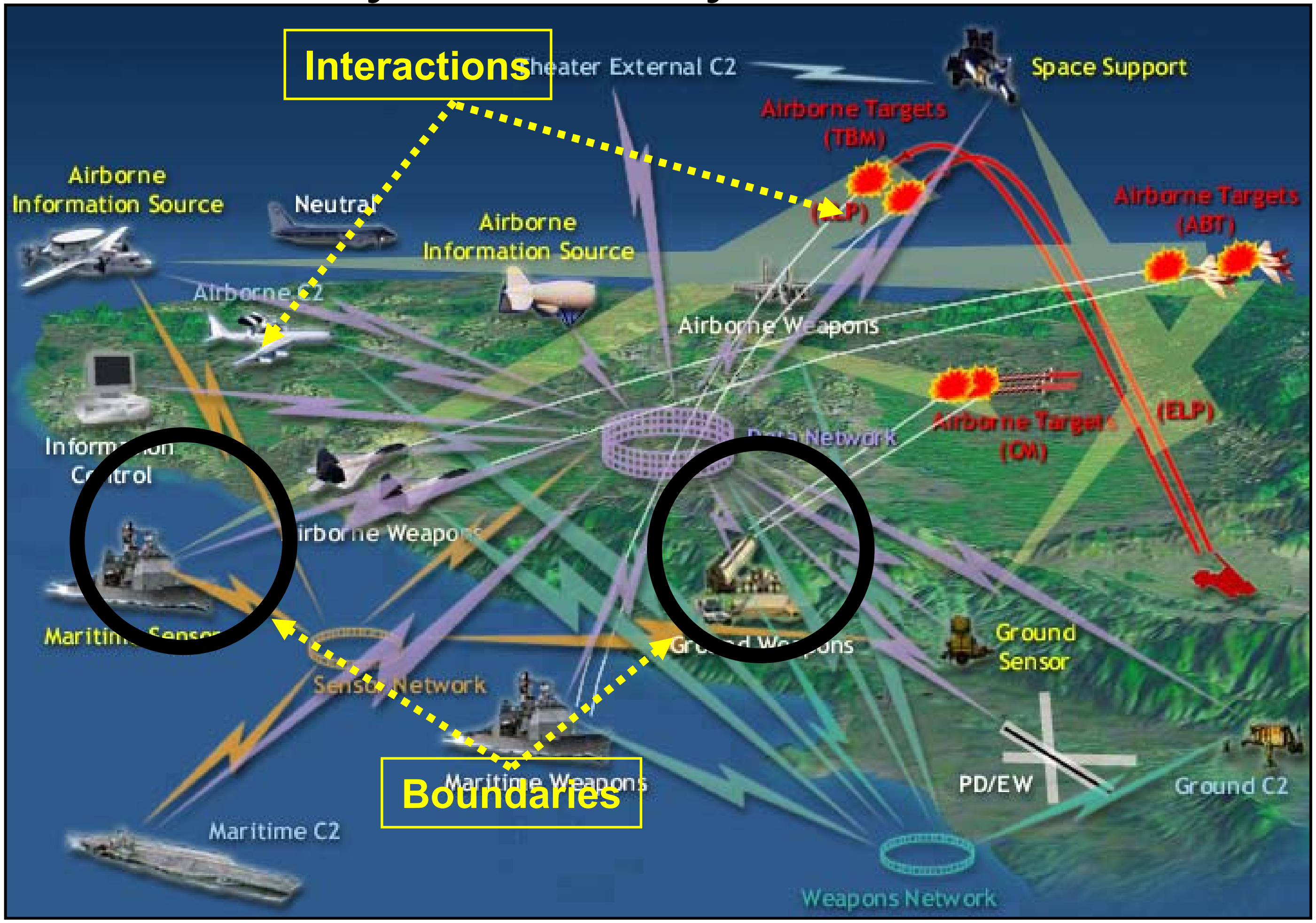
Other Engineering Analysis Models

Integrated System Model Must Address Multiple Aspects of a System

Model Based Systems Engineering Benefits

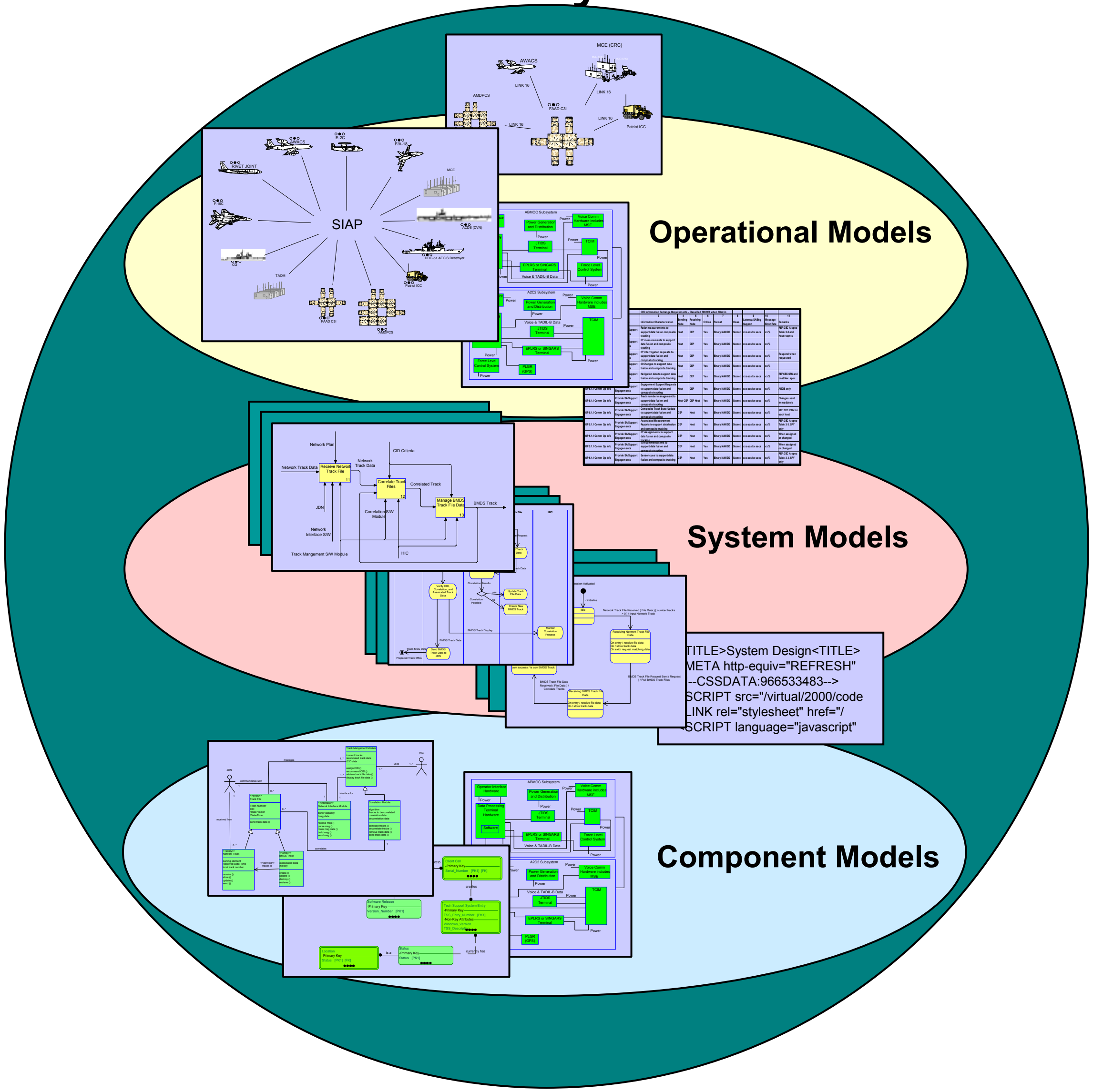
- Improved communications
- Assists in managing complex system development
  - Separation of concerns
  - Hierarchical modeling
  - Facilitates impact analysis of requirements and design changes
  - Supports incremental development & evolutionary acquisition
- Improved design quality
  - Reduced errors and ambiguity
  - More complete representation
- Early and on-going verification & validation to reduce risk
- Other life cycle support (e.g., training)
- Enhanced knowledge capture

System-of-Systems



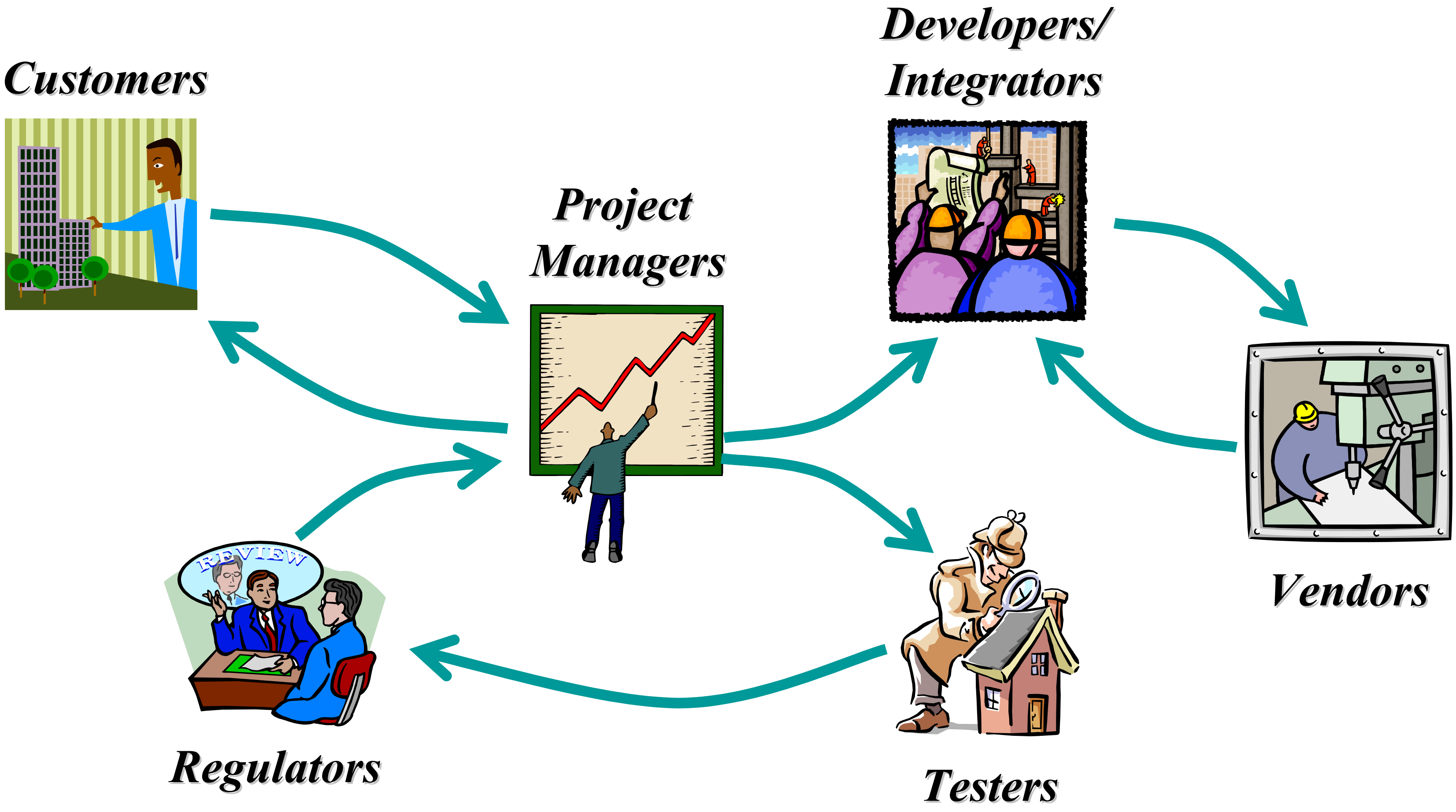
Modeling Needed to Manage System Complexity

Modeling at Multiple Levels of the System



```
TITLE>System Design<TITLE>
META http-equiv="REFRESH"
--CSSDATA:966533483-->
SCRIPT src="/virtual/2000/code
LINK rel="stylesheet" href="/
SCRIPT language="javascript"
```

Stakeholders Involved in System Acquisition



Customers

Project Managers

Developers/ Integrators

Vendors

Regulators

Testers

Modeling Needed to Improve Communications

What is SysML?

- A graphical modelling language in response to the UML for Systems Engineering RFP developed by the OMG, INCOSE, and AP233
  - a UML Profile that represents a subset of UML 2 with extensions

- Supports the specification, analysis, design, verification, and validation of systems that include hardware, software, data, personnel, procedures, and facilities

- Supports model and data interchange via XMI and the evolving AP233 standard (in-process)

SysML is Critical Enabler for Model Driven SE

What is SysML (cont.)

- ***Is*** a visual modeling language that provides
  - Semantics = meaning
  - Notation = representation of meaning
- ***Is not*** a methodology or a tool
  - SysML is methodology and tool independent

UML/SysML Status

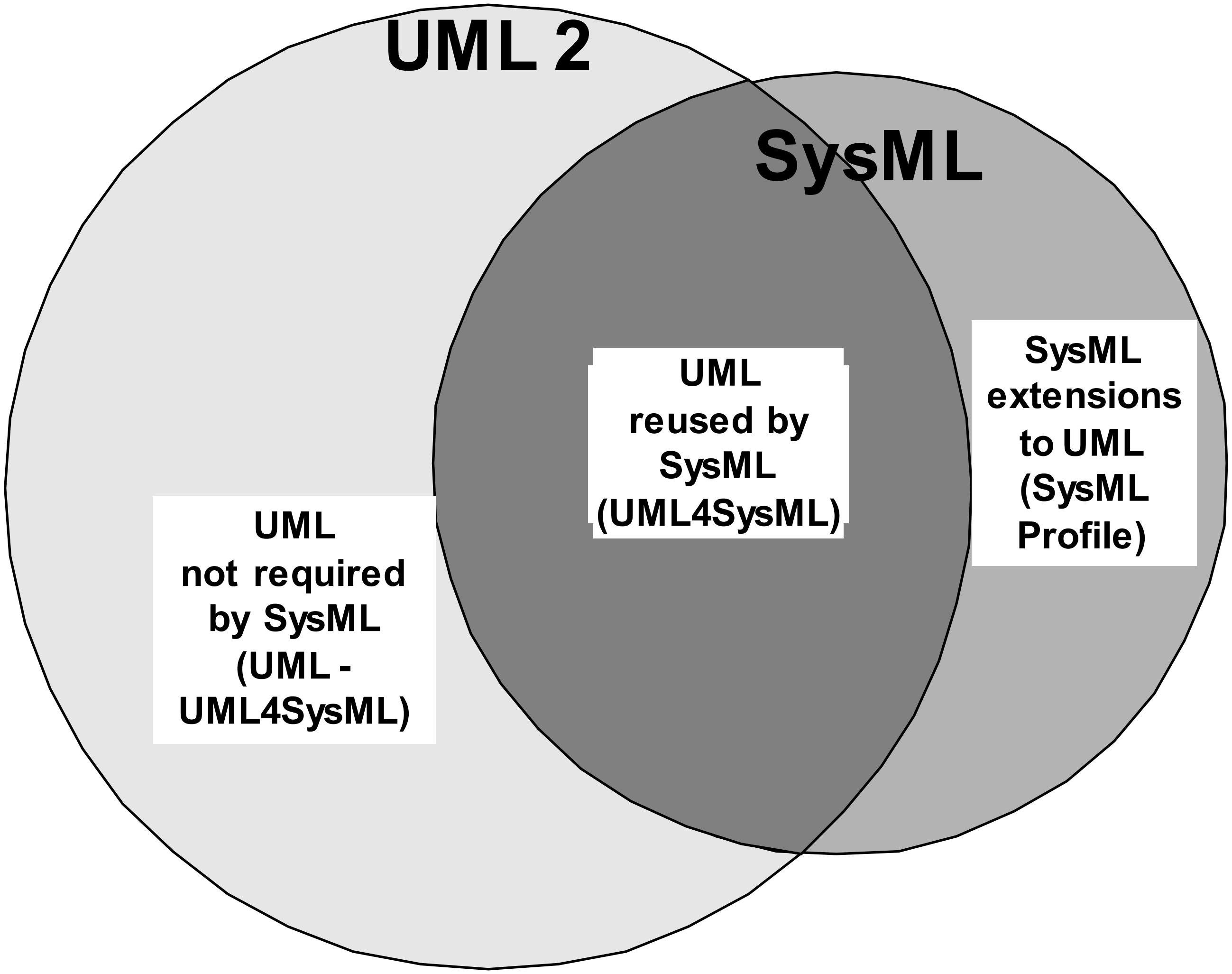
- UML V2.0
  - Updated version of UML that offers significant capability for systems engineering over previous versions
  - Finalized in 2005 (formal/05-07-04)
- UML for Systems Engineering (SE) RFP
  - Established the requirements for a system modeling language
  - Issued by the OMG in March 2003
- SysML
  - Industry Response to the UML for SE RFP
  - Addresses most of the requirements in the RFP
  - Version 1.0 adopted by OMG in May ’06 / In finalization
  - Being implemented by multiple tool vendors

SysML Team Members

- Industry & Government
  - American Systems, BAE SYSTEMS, Boeing, Deere & Company, EADS-Astrium, Eurostep, Lockheed Martin, Motorola, NIST, Northrop Grumman, oose.de, Raytheon, THALES
- Vendors
  - Artisan, EmbeddedPlus, Gentleware, IBM, I-Logix, Mentor Graphics, PivotPoint Technology, Sparx Systems, Telelogic, Vitech Corp
- Academia
  - Georgia Institute of Technology
- Liaison Organizations
  - INCOSE, ISO AP233 Working Group

Diagram Overview

Relationship Between SysML and UML



UML 2

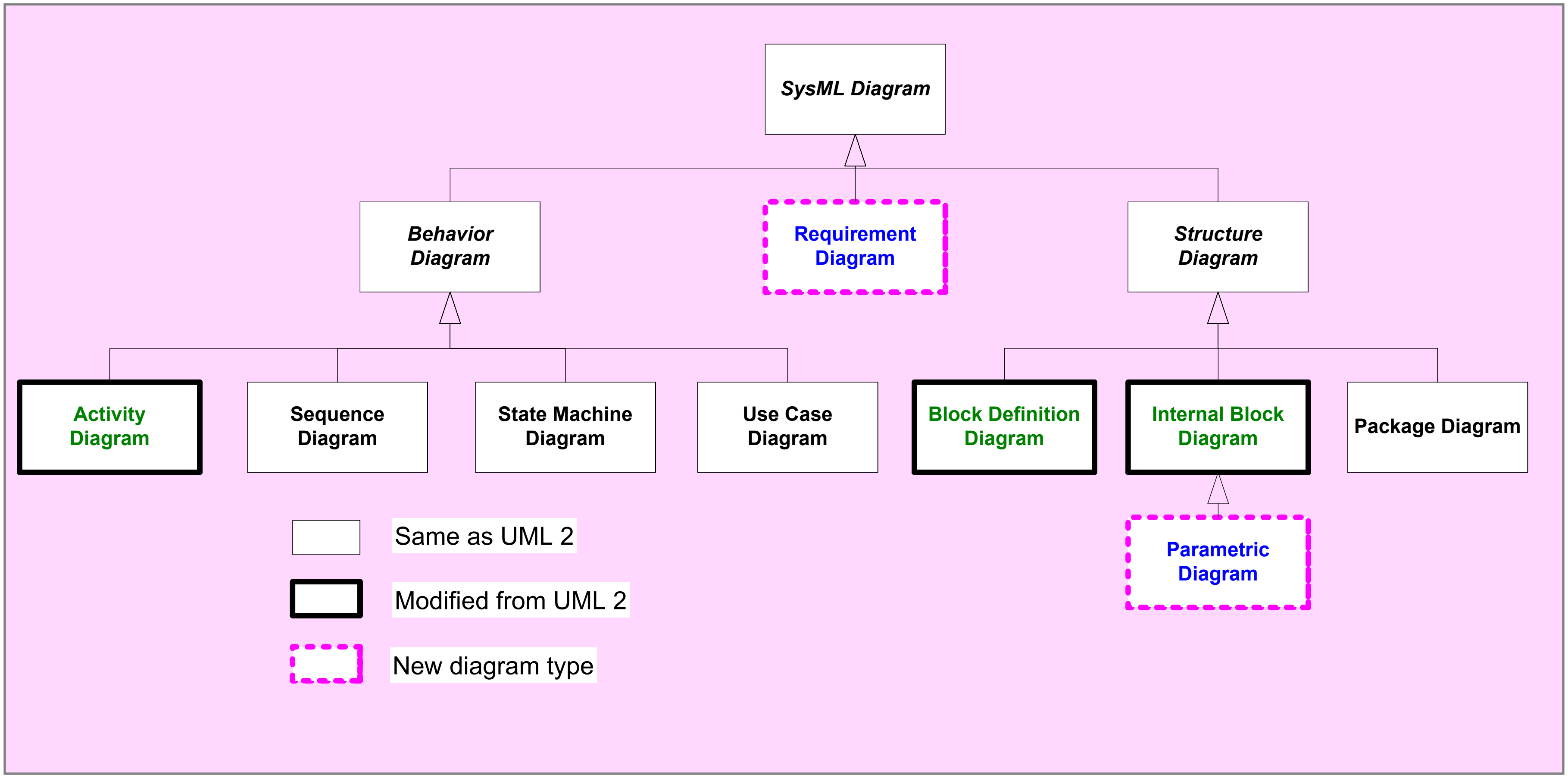
SysML

UML not required by SysML (UML - UML4SysML)

UML reused by SysML (UML4SysML)

SysML extensions to UML (SysML Profile)

SysML Diagram Taxonomy



SysML Diagram

Behavior Diagram

Requirement Diagram

Structure Diagram

Activity Diagram

Sequence Diagram

State Machine Diagram

Use Case Diagram

Block Definition Diagram

Internal Block Diagram

Package Diagram

Parametric Diagram

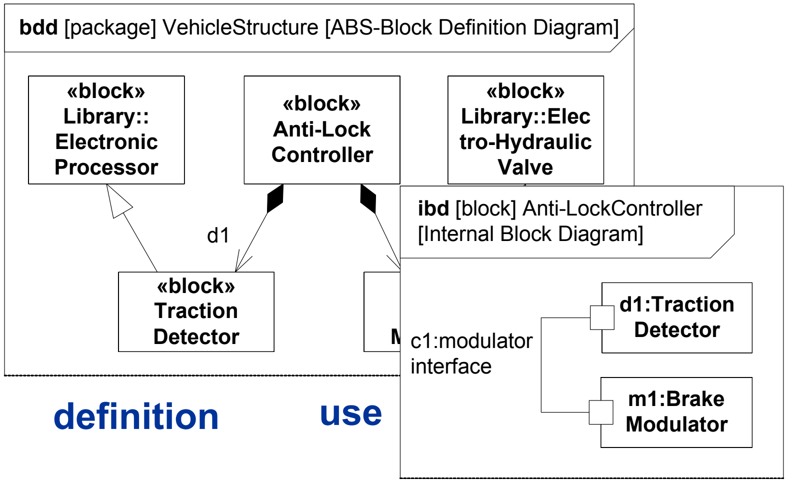
□ Same as UML 2

■ Modified from UML 2

▨ New diagram type

4 Pillars of SysML – ABS Example

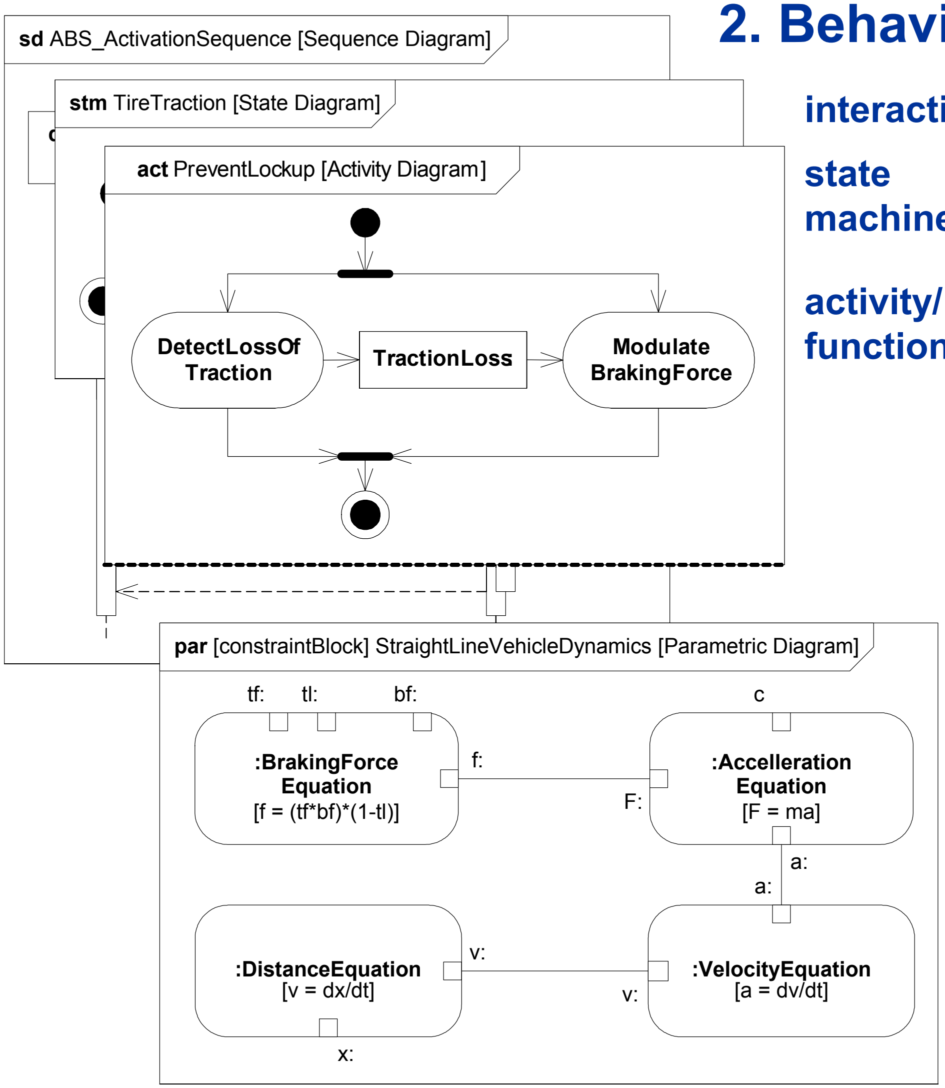
1. Structure


bdd [package] VehicleStructure [ABS-Block Definition Diagram]
«block» Library:: Electronic Processor
«block» Anti-Lock Controller
«block» Library::Electro-Hydraulic Valve
d1
«block» Traction Detector
M
ibd [block] Anti-LockController [Internal Block Diagram]
c1:modulator interface
d1:Traction Detector
m1:Brake Modulator

definition

use

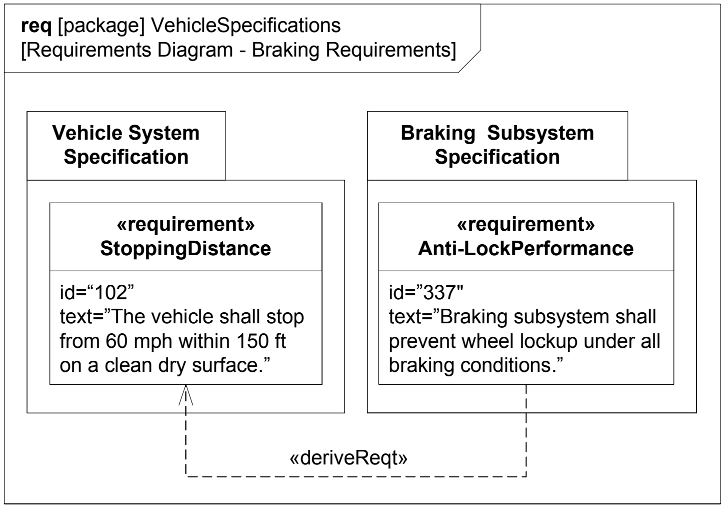
2. Behavior



interaction

state machine

activity/ function


req [package] VehicleSpecifications
[Requirements Diagram - Braking Requirements]
Vehicle System Specification
Braking Subsystem Specification
«requirement» StoppingDistance
id="102"
text="The vehicle shall stop from 60 mph within 150 ft on a clean dry surface."
«requirement» Anti-LockPerformance
id="337"
text="Braking subsystem shall prevent wheel lockup under all braking conditions."
«deriveReqt»

3. Requirements

4. Parametrics

SysML Diagram Frames

- Each SysML diagram represents a model element
- Each SysML Diagram must have a Diagram Frame
- Diagram context is indicated in the header:
  - Diagram kind (act, bdd, ibd, seq, etc.)
  - Model element type (activity, block, interaction, etc.)
  - Model element name
  - Descriptive diagram name or view name
- A separate diagram description block is used to indicate if the diagram is complete, or has elements elided

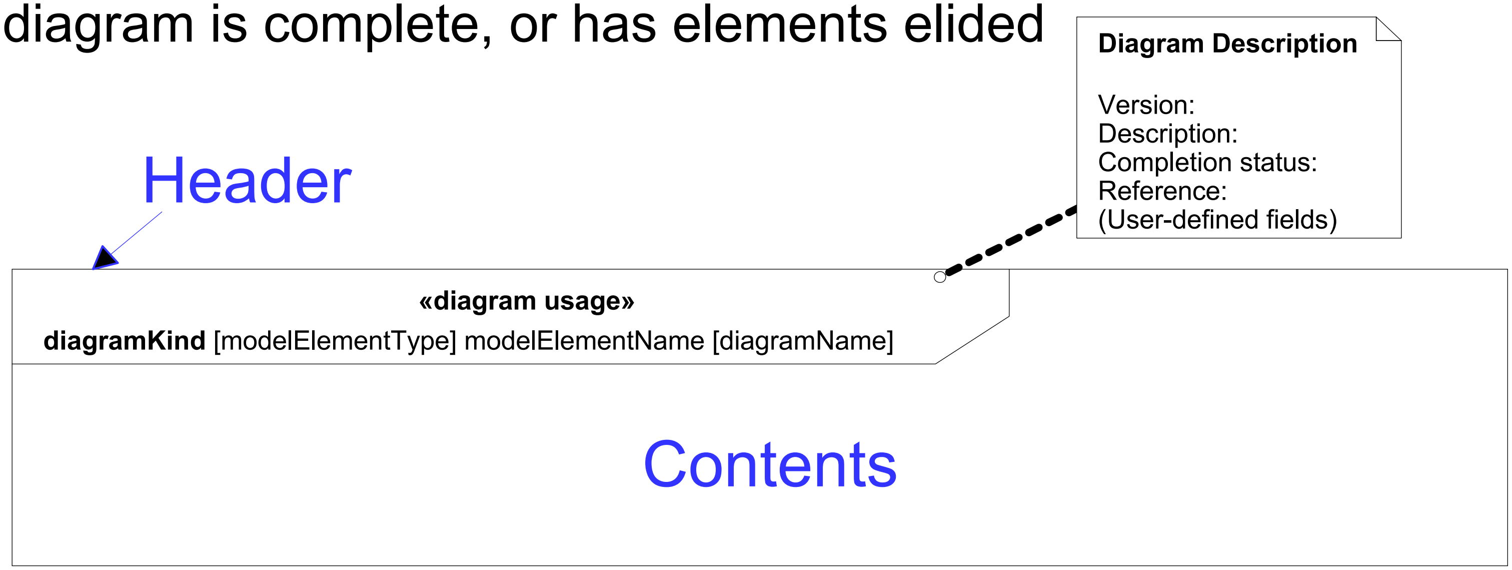


Diagram Description

Version:
Description:
Completion status:
Reference:
(User-defined fields)

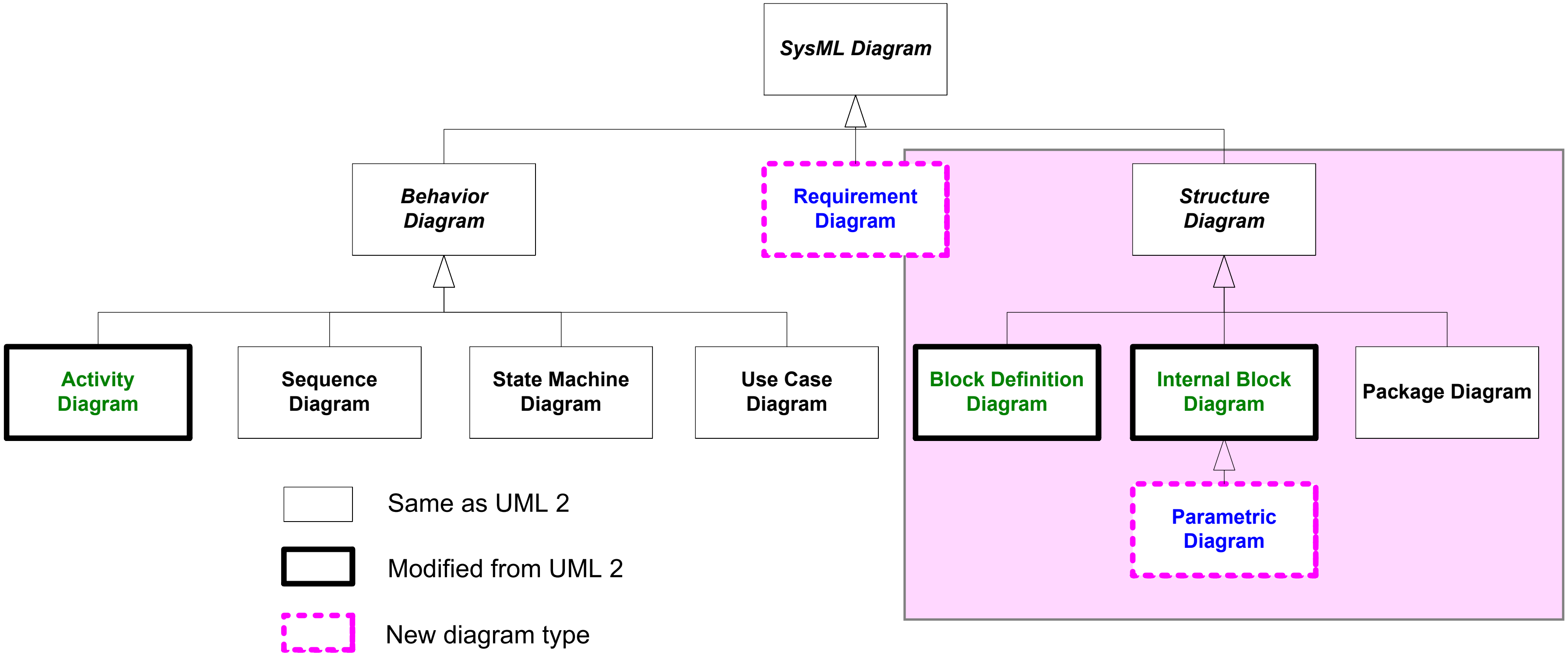
Header

«diagram usage»

diagramKind [modelElementType] modelElementName [diagramName]

Contents

Structural Diagrams



SysML Diagram

Behavior Diagram

Requirement Diagram

Structure Diagram

Activity Diagram

Sequence Diagram

State Machine Diagram

Use Case Diagram

Block Definition Diagram

Internal Block Diagram

Package Diagram

Parametric Diagram

□ Same as UML 2

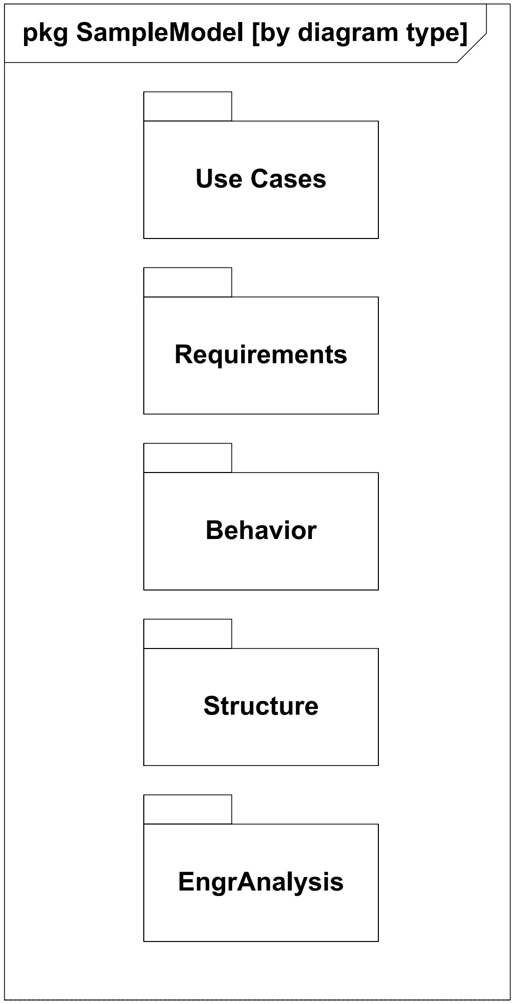
▣ Modified from UML 2

⬚ New diagram type

Package Diagram

- Package diagram is used to organize the model
  - Groups model elements into a name space
  - Often represented in tool browser
- Model can be organized in multiple ways
  - By System hierarchy (e.g., enterprise, system, component)
  - By domain (e.g., requirements, use cases, behavior)
  - Use viewpoints to augment model organization
- Import relationship reduces need for fully qualified name (package1::class1)

Package Diagram
Organizing the Model



pkg SampleModel [by diagram type]

Use Cases

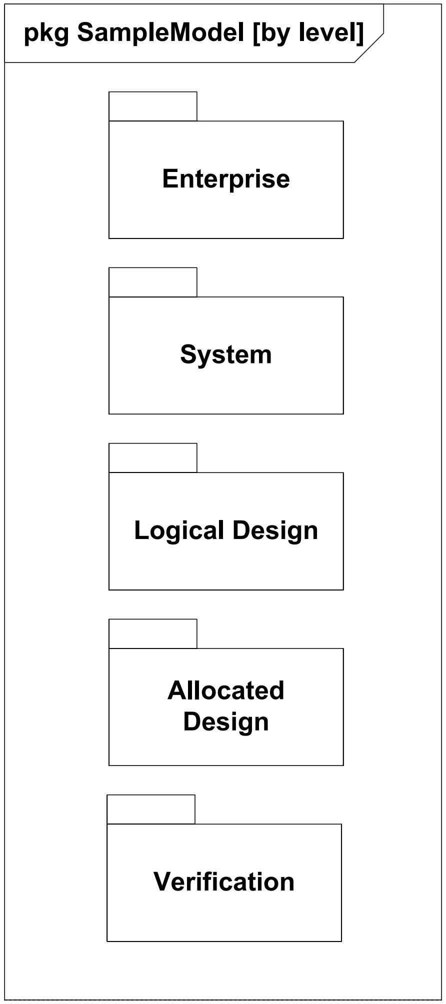
Requirements

Behavior

Structure

EngrAnalysis

By Diagram Type



pkg SampleModel [by level]

Enterprise

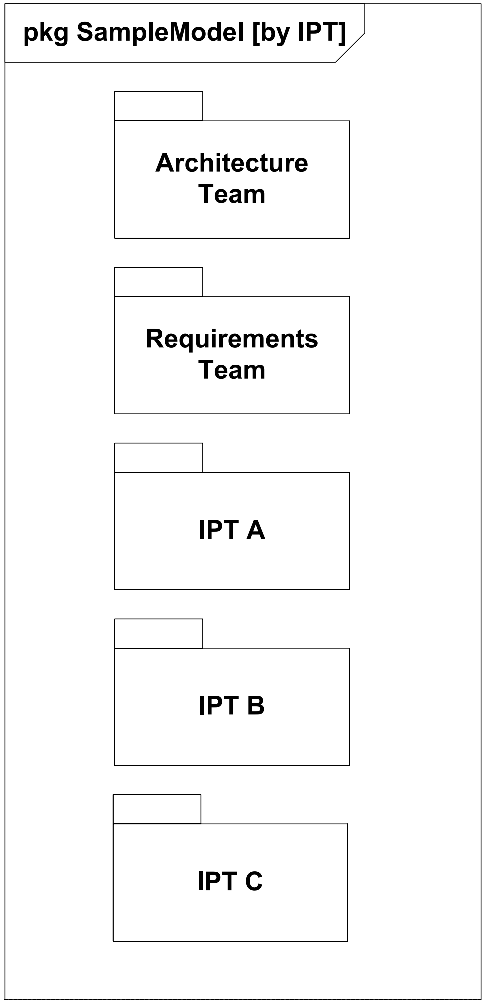
System

Logical Design

Allocated Design

Verification

By Hierarchy



pkg SampleModel [by IPT]

Architecture Team

Requirements Team

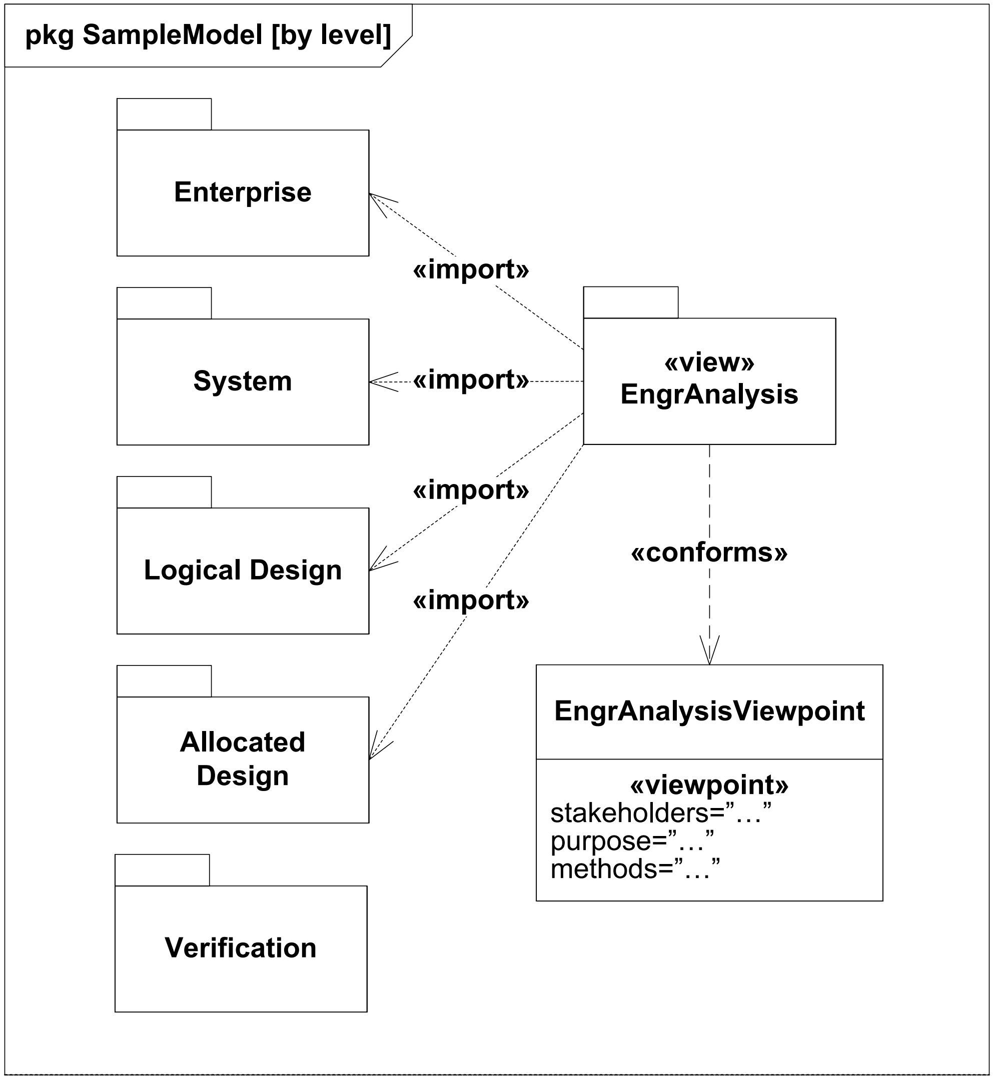
IPT A

IPT B

IPT C

By IPT

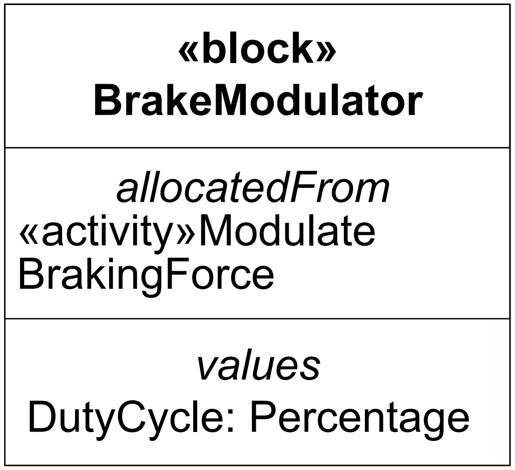
Package Diagram - Views



- Model is organized in one hierarchy
- Viewpoints can provide insight into the model using another principle
  - E.g., analysis view that spans multiple levels of hierarchy
  - Can specify diagram usages, constraints, and filtering rules
  - Consistent with IEEE 1471 definitions

Blocks are Basic Structural Elements

- Provides a unifying concept to describe the structure of an element or system
  - Hardware
  - Software
  - Data
  - Procedure
  - Facility
  - Person



«block»
BrakeModulator

allocatedFrom
«activity»Modulate
BrakingForce

values
DutyCycle: Percentage

- Multiple compartments can describe the block characteristics
  - Properties (parts, references, values)
  - Operations
  - Constraints
  - Allocations to the block (e.g. activities)
  - Requirements the block satisfies

Block Property Types

- Property is a structural feature of a block
  - **Part property** aka. part (typed by a block)
    - Usage of a block in the context of the enclosing block
    - Example - right-front:wheel
  - **Reference property** (typed by a block)
    - A part that is not owned by the enclosing block (not composition)
    - Example - logical interface between 2 parts
  - **Value property** (typed by value type)
    - Defines a value with units, dimensions, and probability distribution
    - Example
      - Non-distributed value: tirePressure:psi=30
      - Distributed value: «uniform» {min=28,max=32} tirePressure:psi

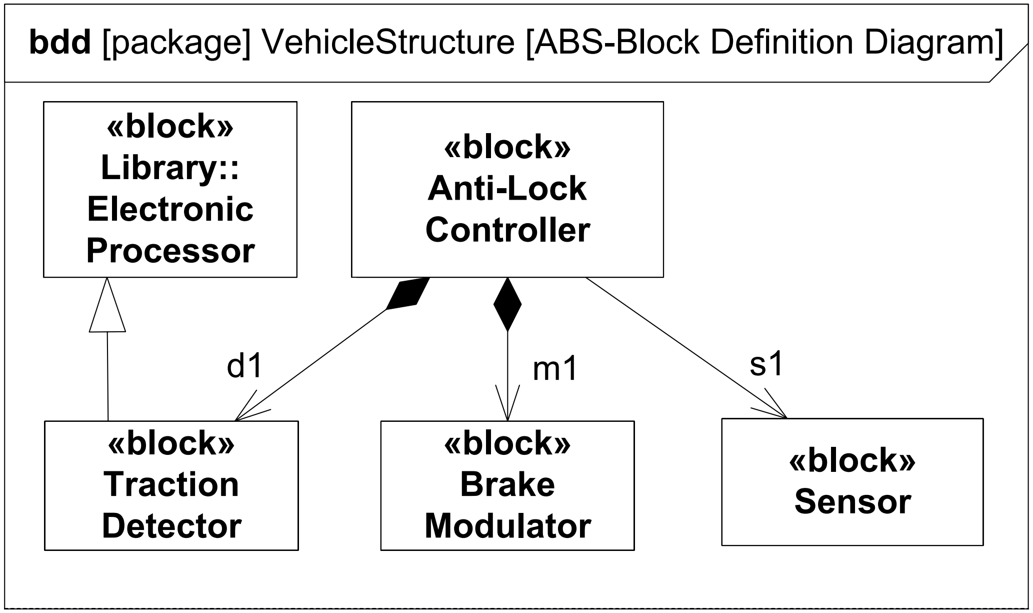
Using Blocks

- Based on UML Class from UML Composite Structure
  - Eliminates association classes, etc.
  - Differentiates value properties from part properties, add nested connector ends, etc.
- Block definition diagram describes the relationship among blocks (e.g., composition, association, classification)
- Internal block diagram describes the internal structure of a block in terms of its properties and connectors
- Behavior can be allocated to blocks

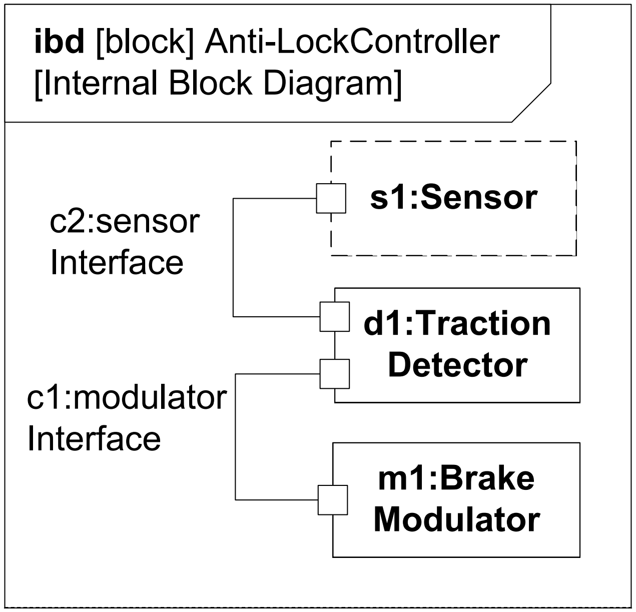
Blocks Used to Specify Hierarchies and Interconnection

Block Definition vs. Usage

Block Definition Diagram


bdd [package] VehicleStructure [ABS-Block Definition Diagram]
«block» Library:: Electronic Processor
«block» Anti-Lock Controller
d1
m1
s1
«block» Traction Detector
«block» Brake Modulator
«block» Sensor

Internal Block Diagram



Definition

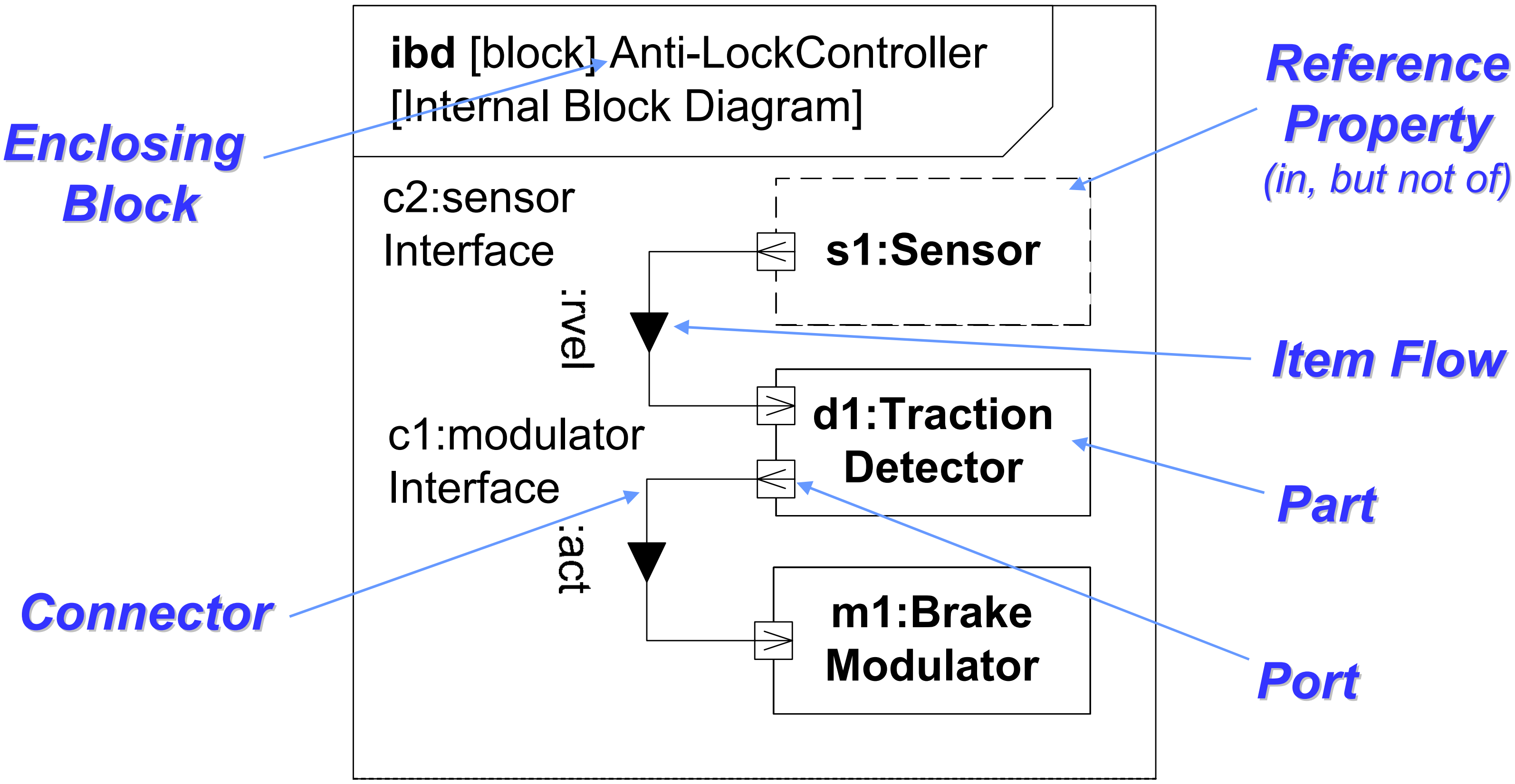
- Block is a definition/type
- Captures properties, etc.
- Reused in multiple contexts

Usage

- Part is the usage in a particular context
- Typed by a block
- Also known as a role

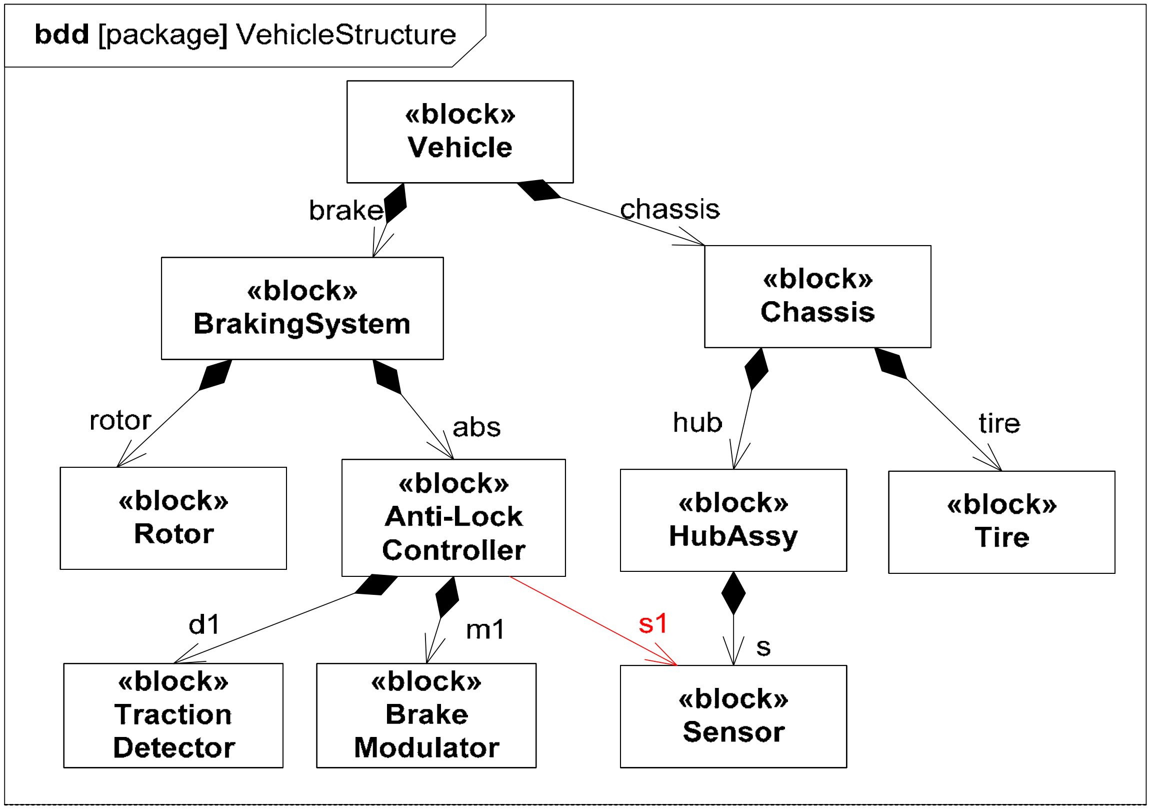
Internal Block Diagram (ibd)

Blocks, Parts, Ports, Connectors & Flows

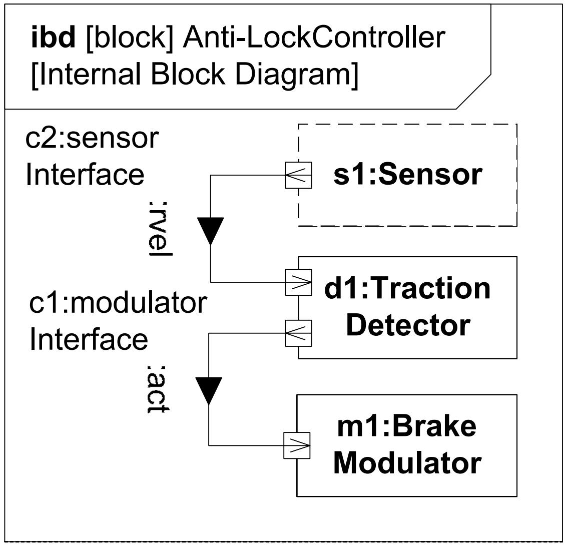


Internal Block Diagram Specifies Interconnection of Parts

Reference Property Explained



S1 is a reference part in ibd shown in dashed outline box

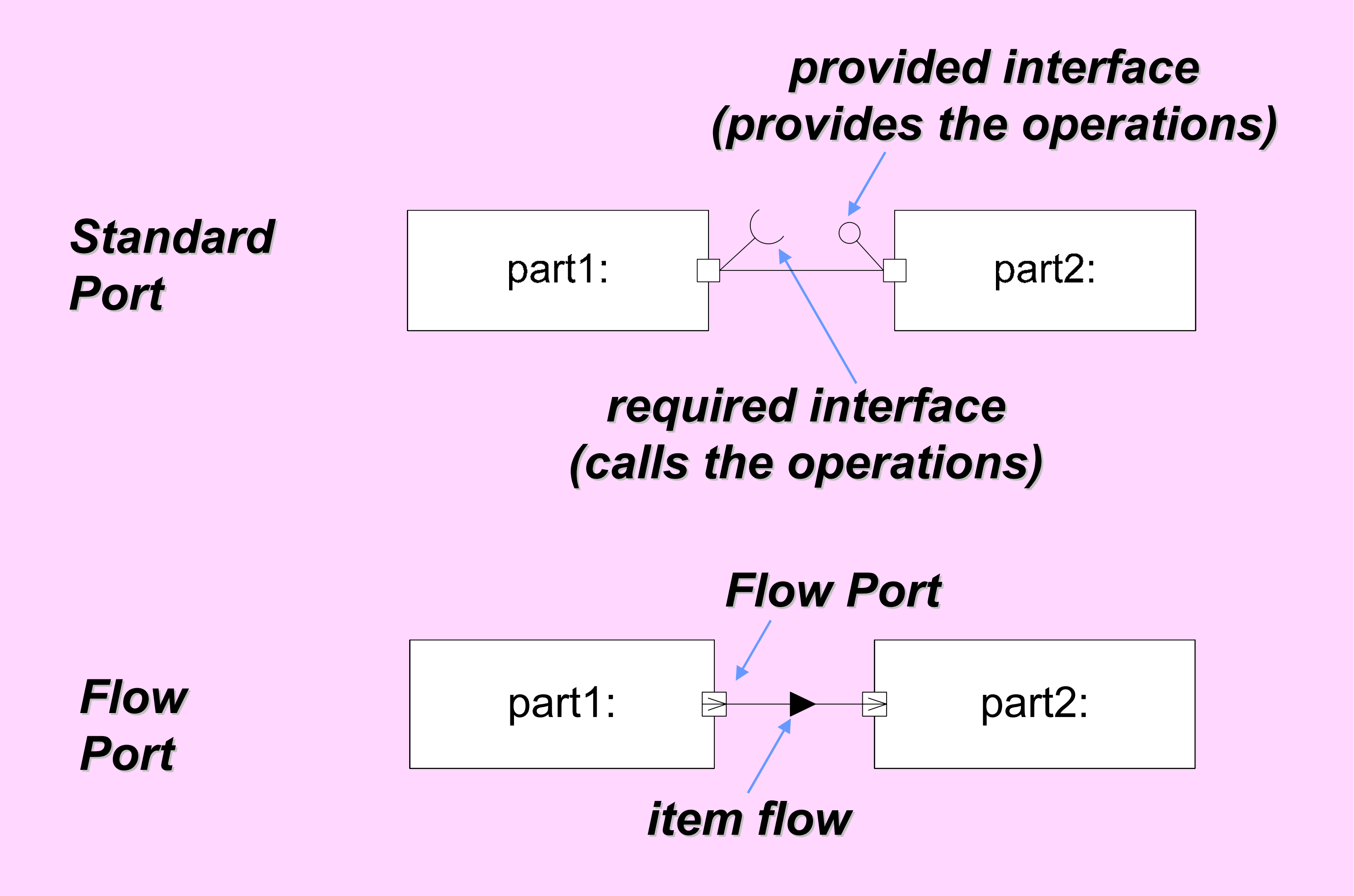


SysML Port

- Specifies interaction points on blocks and parts
  - Supports integration of behavior and structure
- Port types
  - Standard (UML) Port
    - Specifies a set of operations and/or signals
    - Typed by a UML interface
  - Flow Port
    - Specifies what can flow in or out of block/part
    - Typed by a flow specification

2 Port Types Support Different Interface Concepts

Port Notation



Standard Port

provided interface (provides the operations)

required interface (calls the operations)

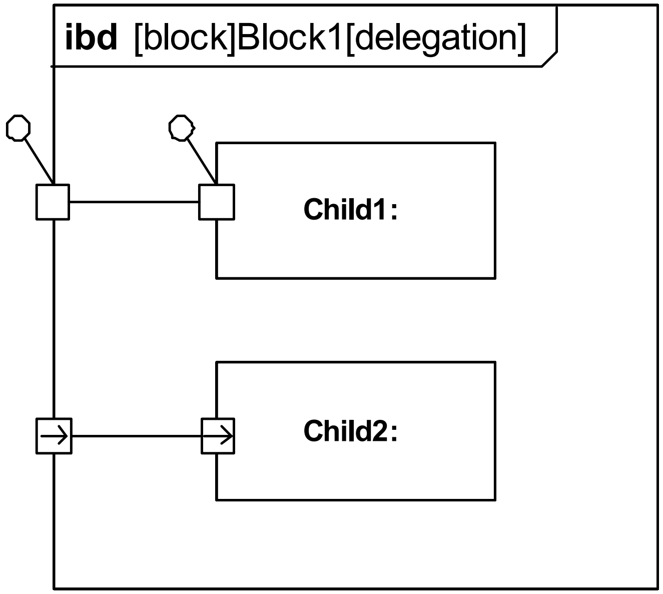
Flow Port

Flow Port

item flow

Delegation Through Ports

- Delegation can be used to preserve encapsulation of block
- Interactions at outer ports of Block1 are delegated to ports of child parts
- Ports must match (same kind, types, direction etc.)
- (Deep-nested) Connectors can break encapsulation if required (e.g. in physical system modeling)

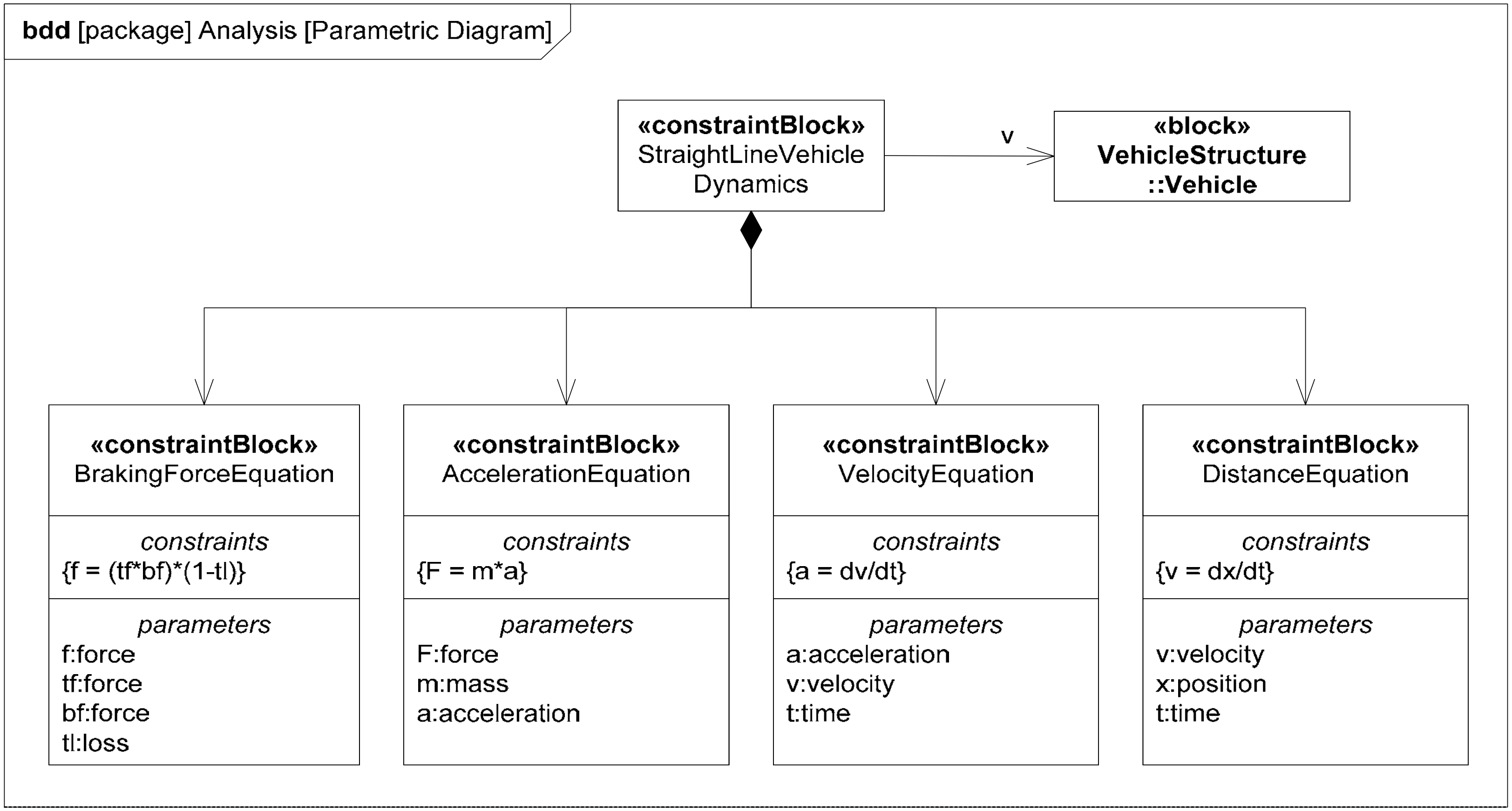


Parametrics

- Used to express constraints (equations) between value properties
  - Provides support for engineering analysis (e.g., performance, reliability)
- Constraint block captures equations
  - Expression language can be formal (e.g., MathML, OCL) or informal
  - Computational engine is defined by applicable analysis tool and not by SysML
- Parametric diagram represents the usage of the constraints in an analysis context
  - Binding of constraint usage to value properties of blocks (e.g., vehicle mass bound to F= m × a)

Parametrics Enable Integration of Engineering Analysis with Design Models

Defining Vehicle Dynamics



bdd [package] Analysis [Parametric Diagram]

«constraintBlock»
StraightLineVehicle Dynamics

«block»
VehicleStructure ::Vehicle

«constraintBlock»
BrakingForceEquation

constraints
{f = (tf*bf)*(1-tl)}

parameters
f:force
tf:force
bf:force
tl:loss

«constraintBlock»
AccelerationEquation

constraints
{F = m*a}

parameters
F:force
m:mass
a:acceleration

«constraintBlock»
VelocityEquation

constraints
{a = dv/dt}

parameters
a:acceleration
v:velocity
t:time

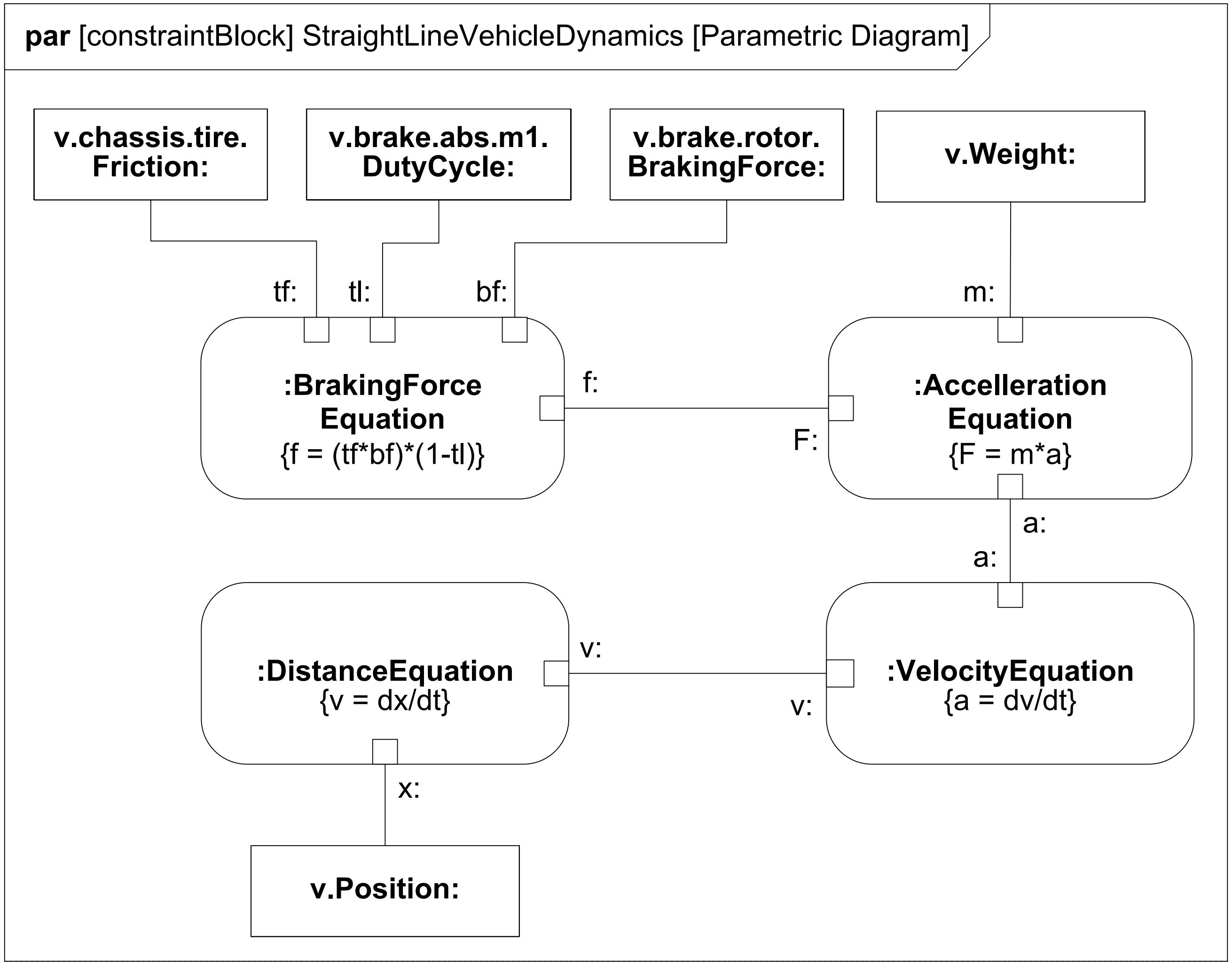
«constraintBlock»
DistanceEquation

constraints
{v = dx/dt}

parameters
v:velocity
x:position
t:time

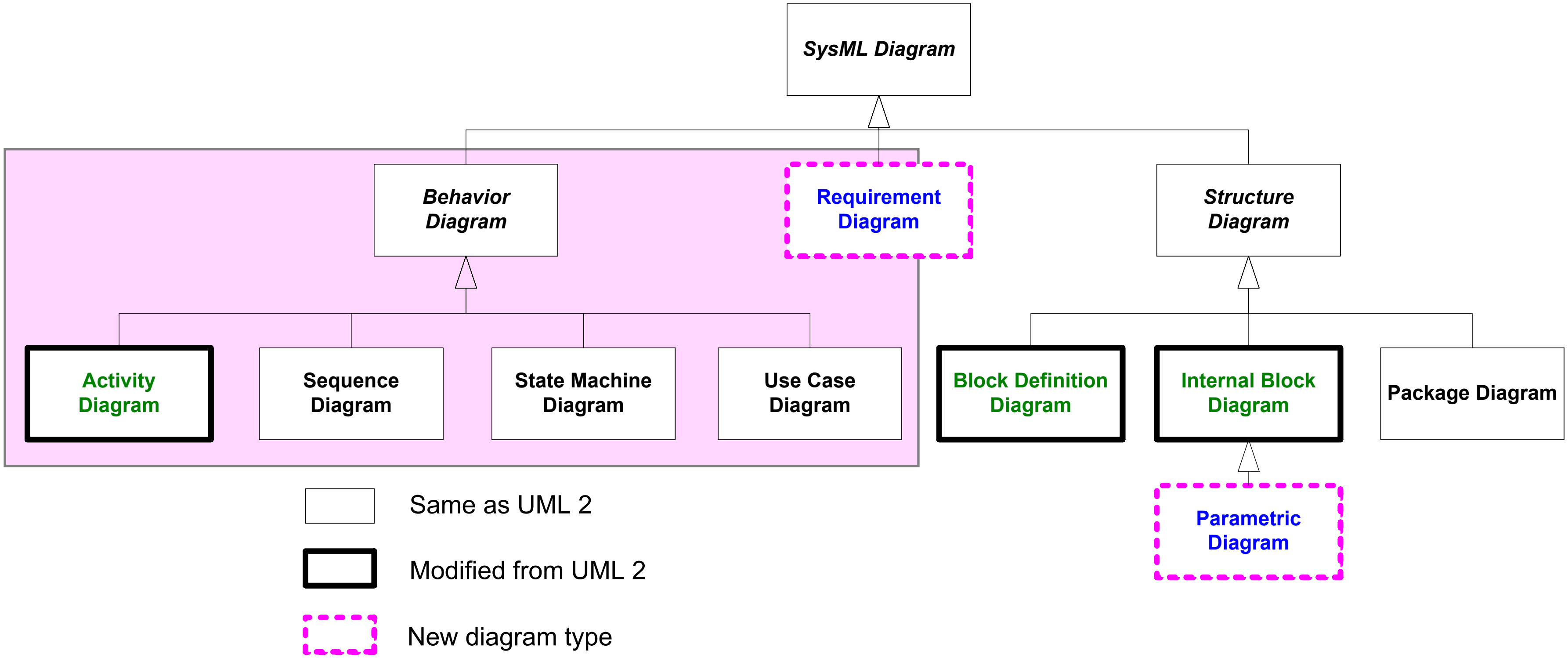
Defining Reusable Equations for Parametrics

Vehicle Dynamics Analysis



Using the Equations in a Parametric Diagram to Constrain Value Properties

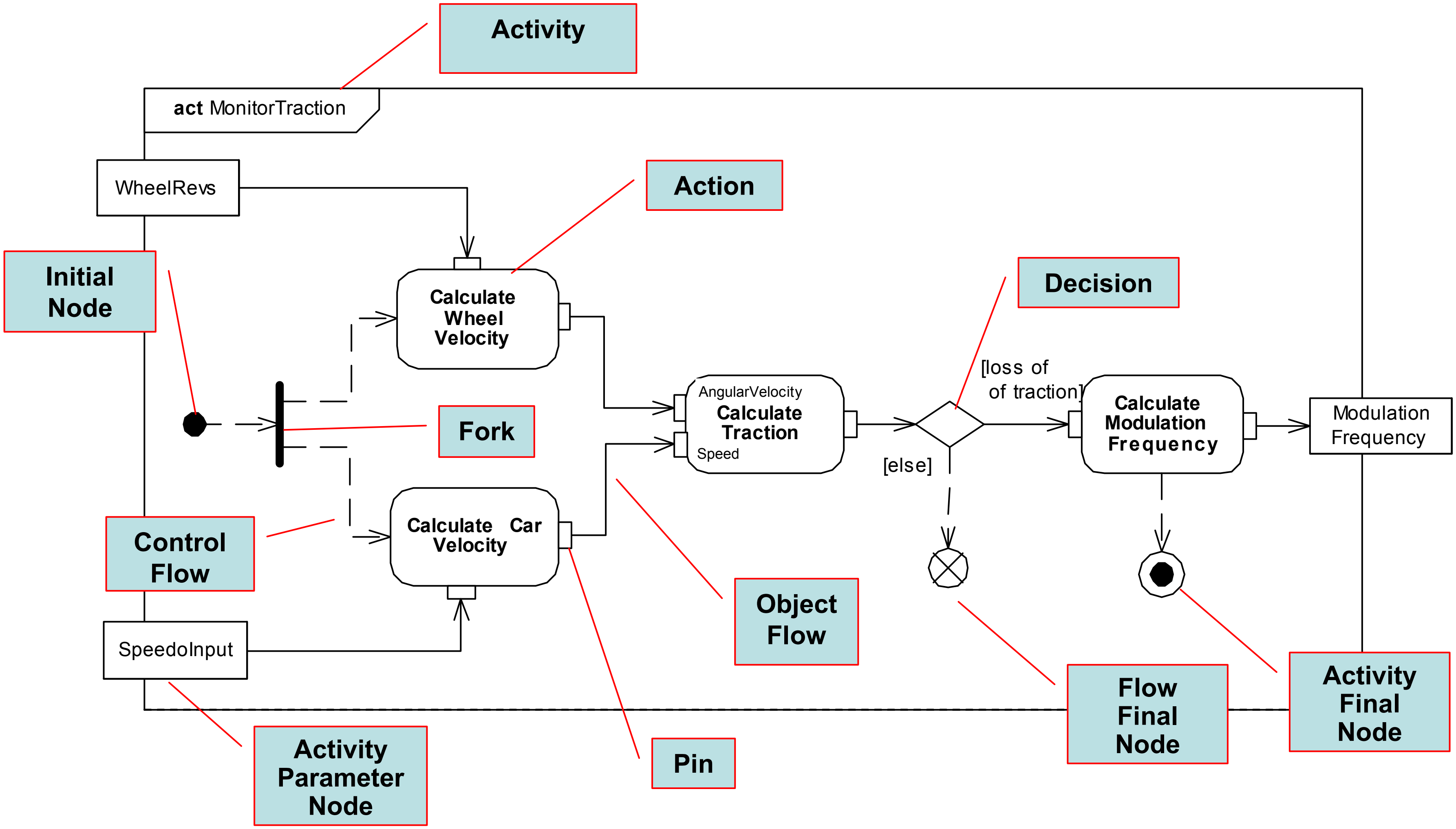
Behavioral Diagrams



Activities

- Activity used to specify the flow of inputs/outputs and control, including sequence and conditions for coordinating activities
- Secondary constructs show responsibilities for the activities using swim lanes
- SysML extensions to Activities
  - Support for continuous flow modeling
  - Alignment of activities with Enhanced Functional Flow Block Diagram (EFFBD)

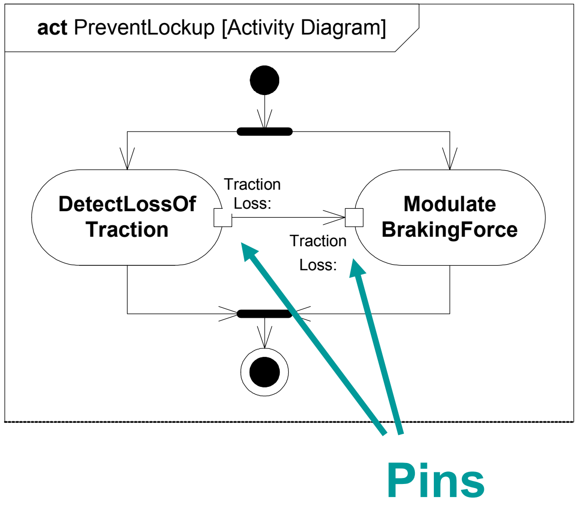
Activity Diagram Notation

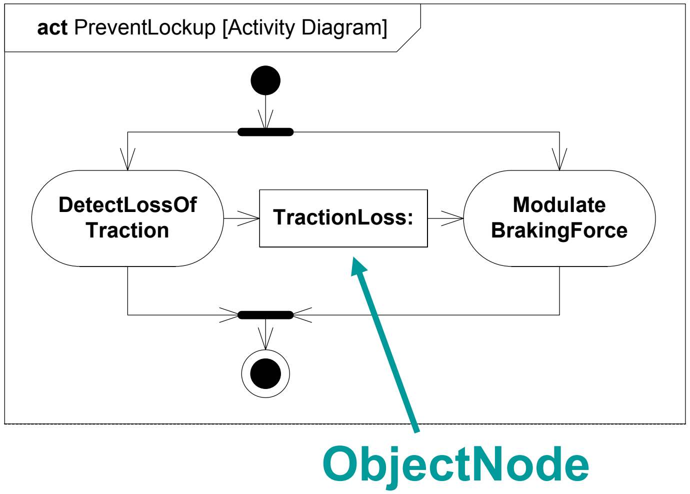


- Join and Merge symbols not included
- Activity Parameter Nodes on frame boundary correspond to activity parameters

Activity Diagrams
Pin vs. Object Node Notation

- Pins are kinds of Object Nodes
  - Used to specify inputs and outputs of actions
  - Typed by a block or value type
  - Object flows connect object nodes
- Object flows between pins have two diagrammatic forms
  - Pins shown with object flow between them
  - Pins elided and object node shown with flow arrows in and out

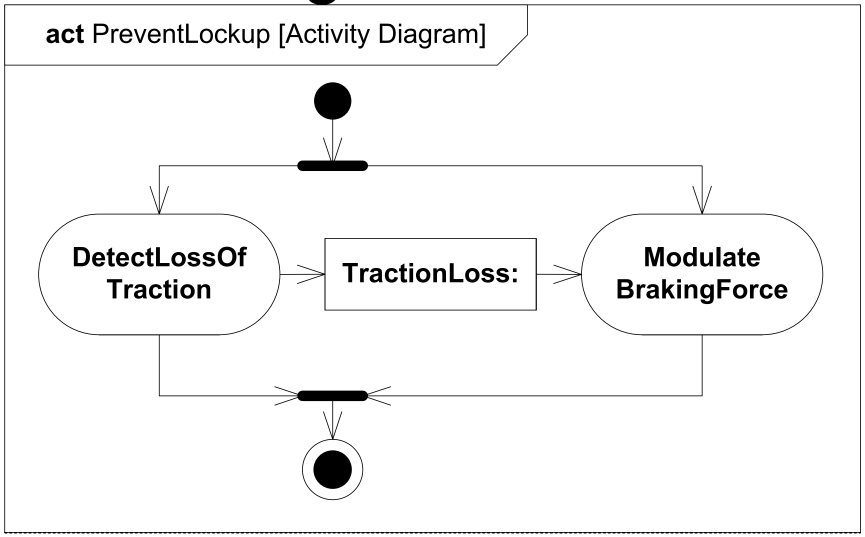




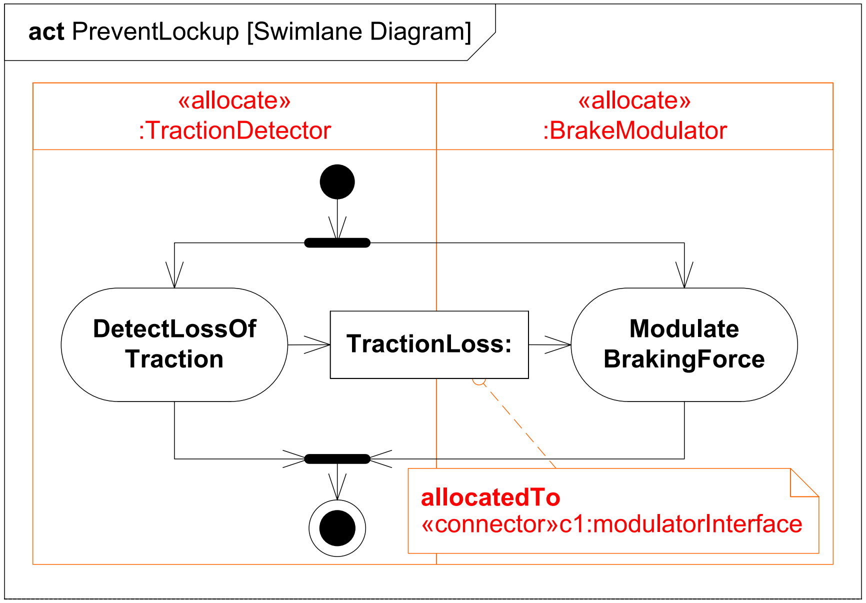
Pins must have same characteristics (name, type etc.)

Explicit Allocation of Behavior to Structure Using Swimlanes

Activity Diagram (without Swimlanes)

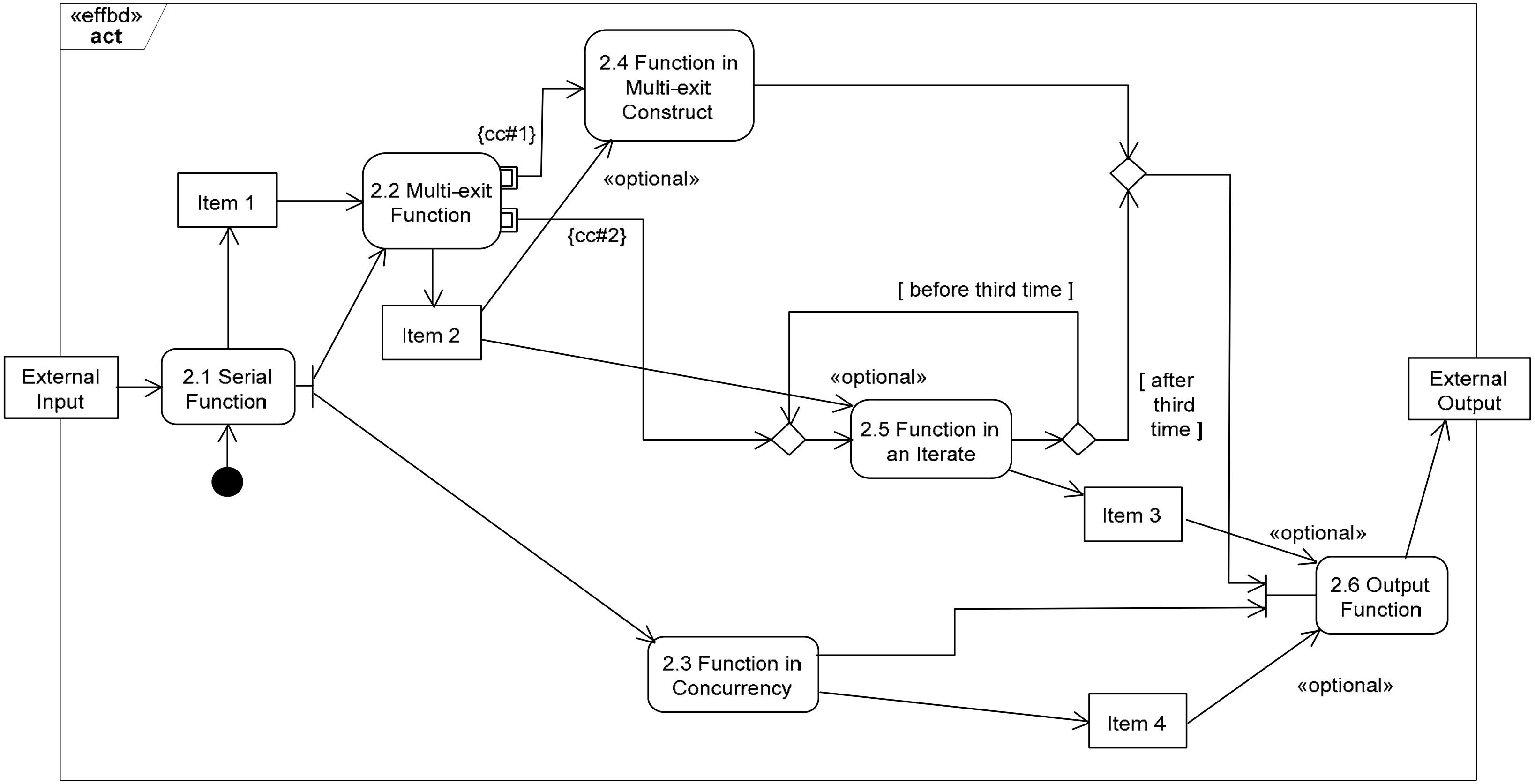


Activity Diagram (with Swimlanes)


act PreventLockup [Swimlane Diagram]
«allocate» :TractionDetector
«allocate» :BrakeModulator
DetectLossOf Traction
TractionLoss:
Modulate BrakingForce
allocatedTo
«connector»c1:modulatorInterface

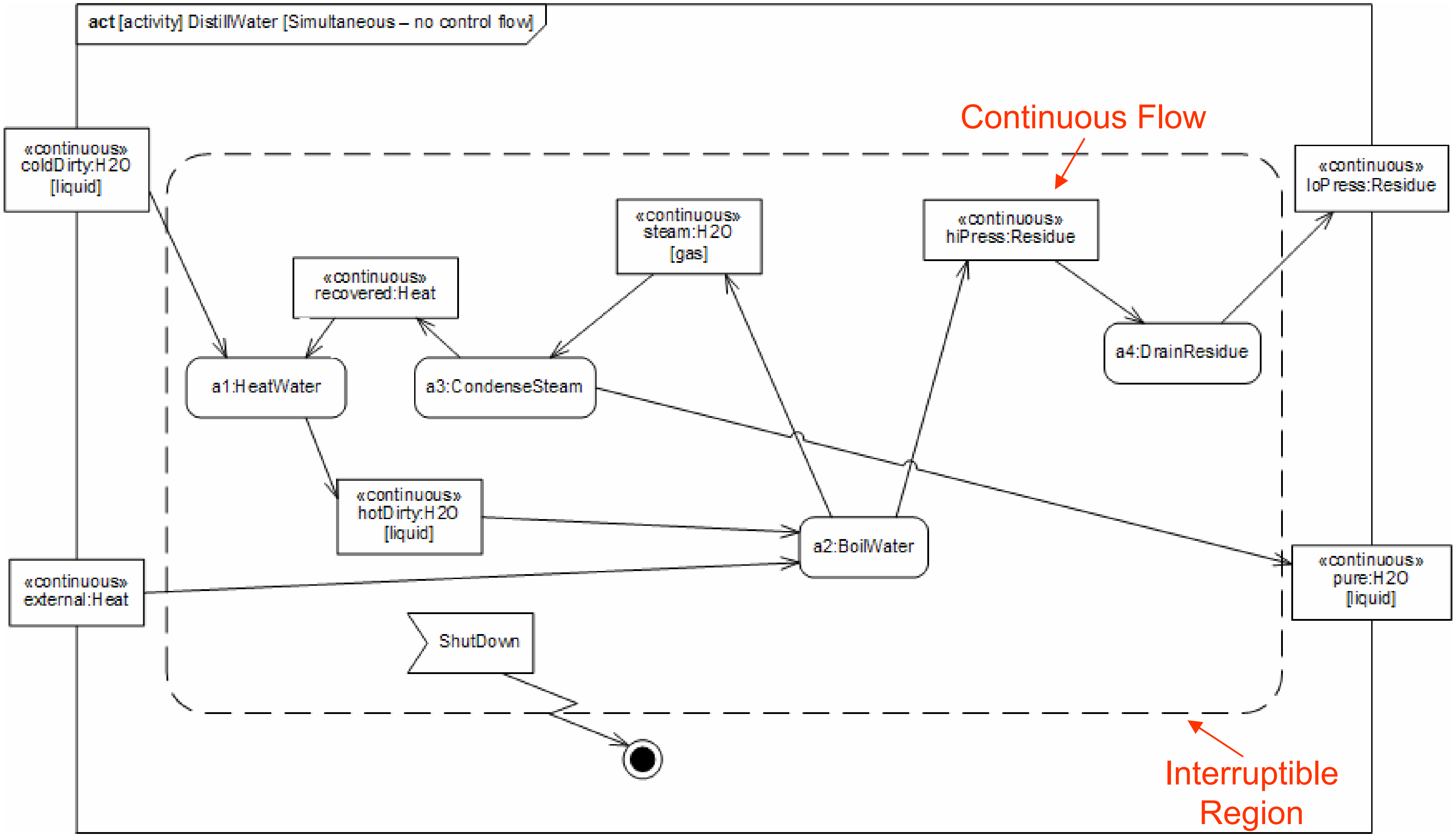
SysML EFFBD Profile

EFFBD - Enhanced Functional Flow Block Diagram



Aligning SysML with Classical Systems Engineering Techniques

Distill Water Activity Diagram (Continuous Flow Modeling)

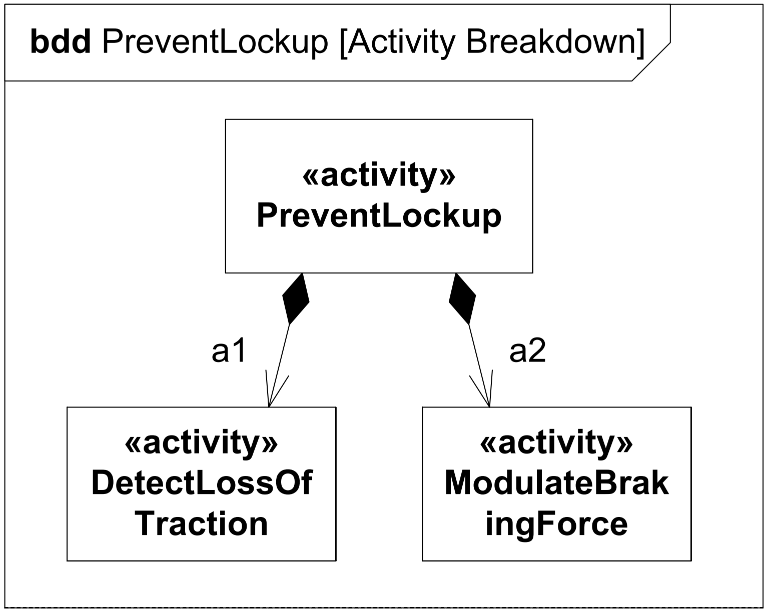

act [activity] DistillWater [Simultaneous – no control flow]
«continuous» coldDirty:H2O [liquid]
«continuous» recovered:Heat
«continuous» steam:H2O [gas]
«continuous» hiPress:Residue
«continuous» loPress:Residue
a1:HeatWater
a3:CondenseSteam
a4:DrainResidue
«continuous» hotDirty:H2O [liquid]
a2:BoilWater
«continuous» external:Heat
«continuous» pure:H2O [liquid]
ShutDown

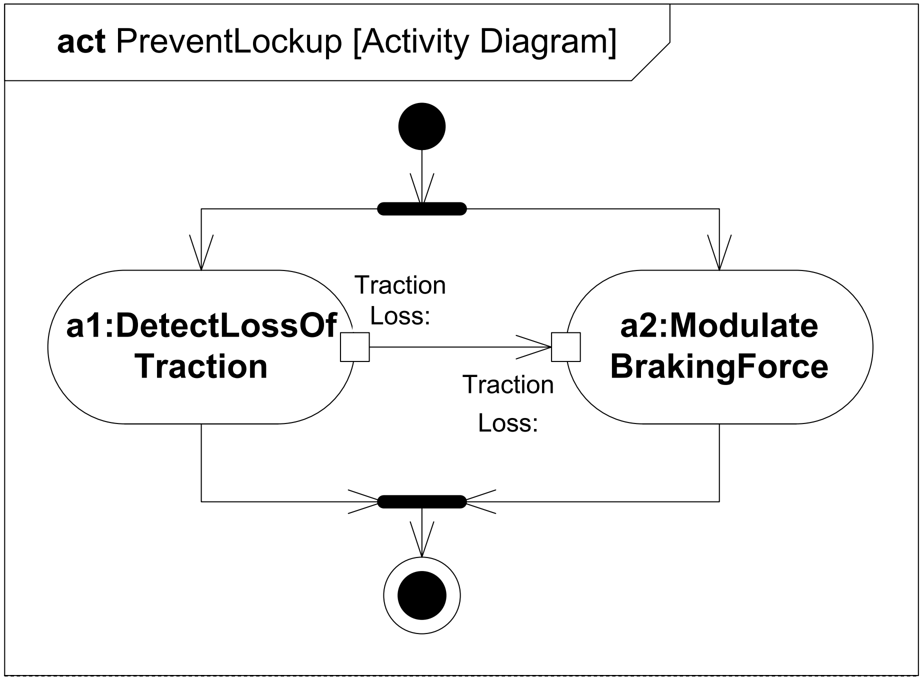
Continuous Flow

Interruptible Region

Representing Distiller Example in SysML Using Continuous Flow Modeling

Activity Decomposition





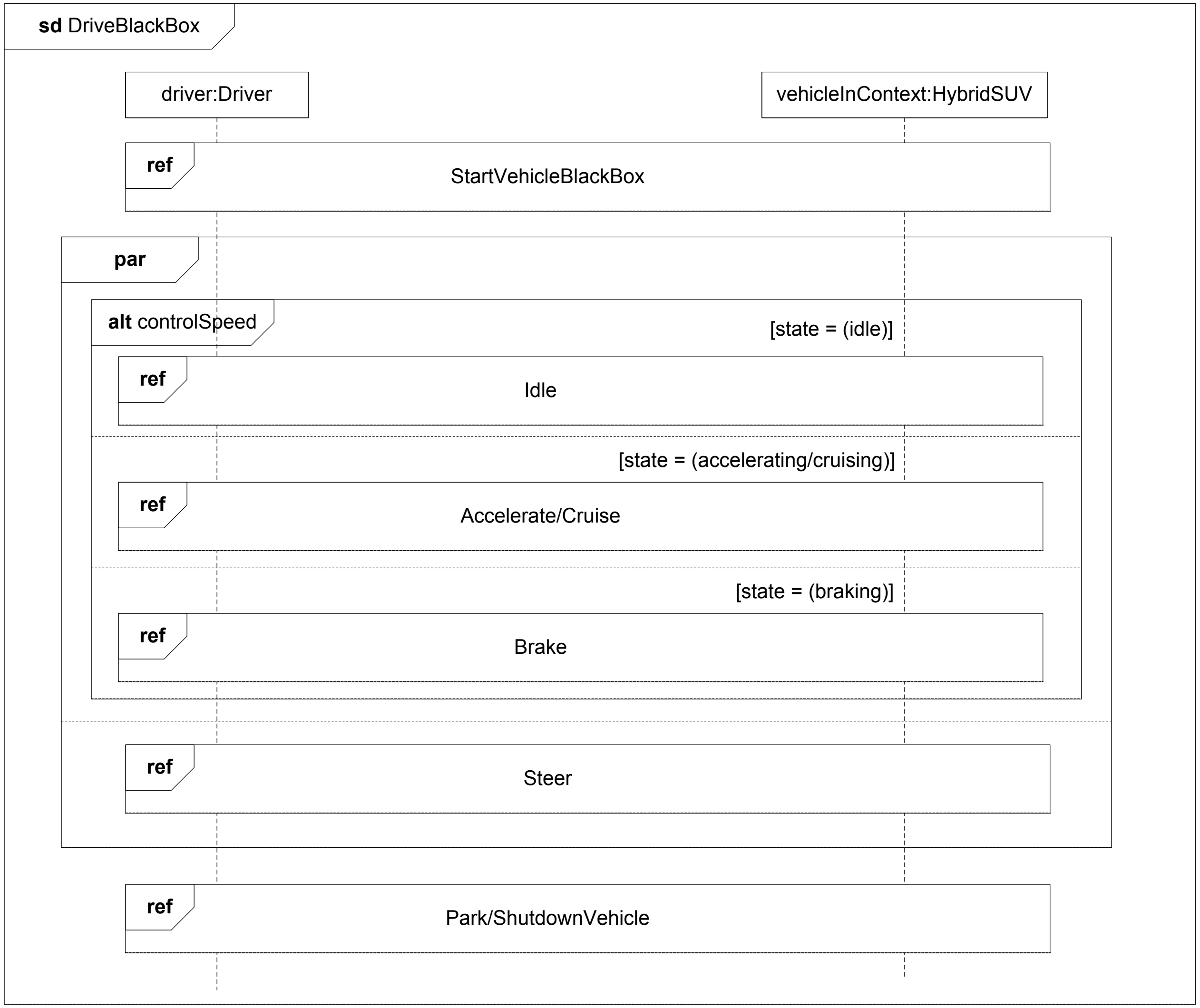
Definition

Use

Interactions

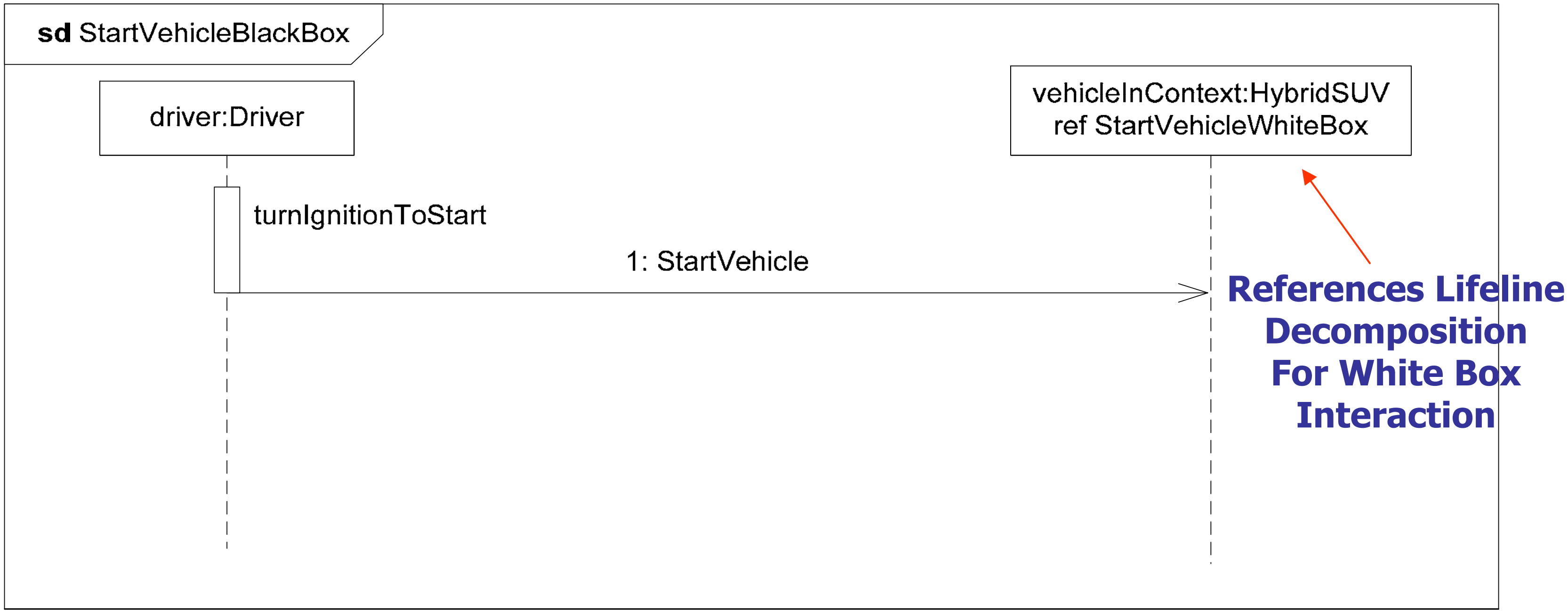
- Sequence diagrams provide representations of message based behavior
  - represent flow of control
  - describe interactions
- Sequence diagrams provide mechanisms for representing complex scenarios
  - reference sequences
  - control logic
  - lifeline decomposition
- SysML does not include timing, interaction overview, and communications diagram

Black Box Interaction (Drive)



UML 2 Sequence Diagram Scales by Supporting Control Logic and Reference Sequences

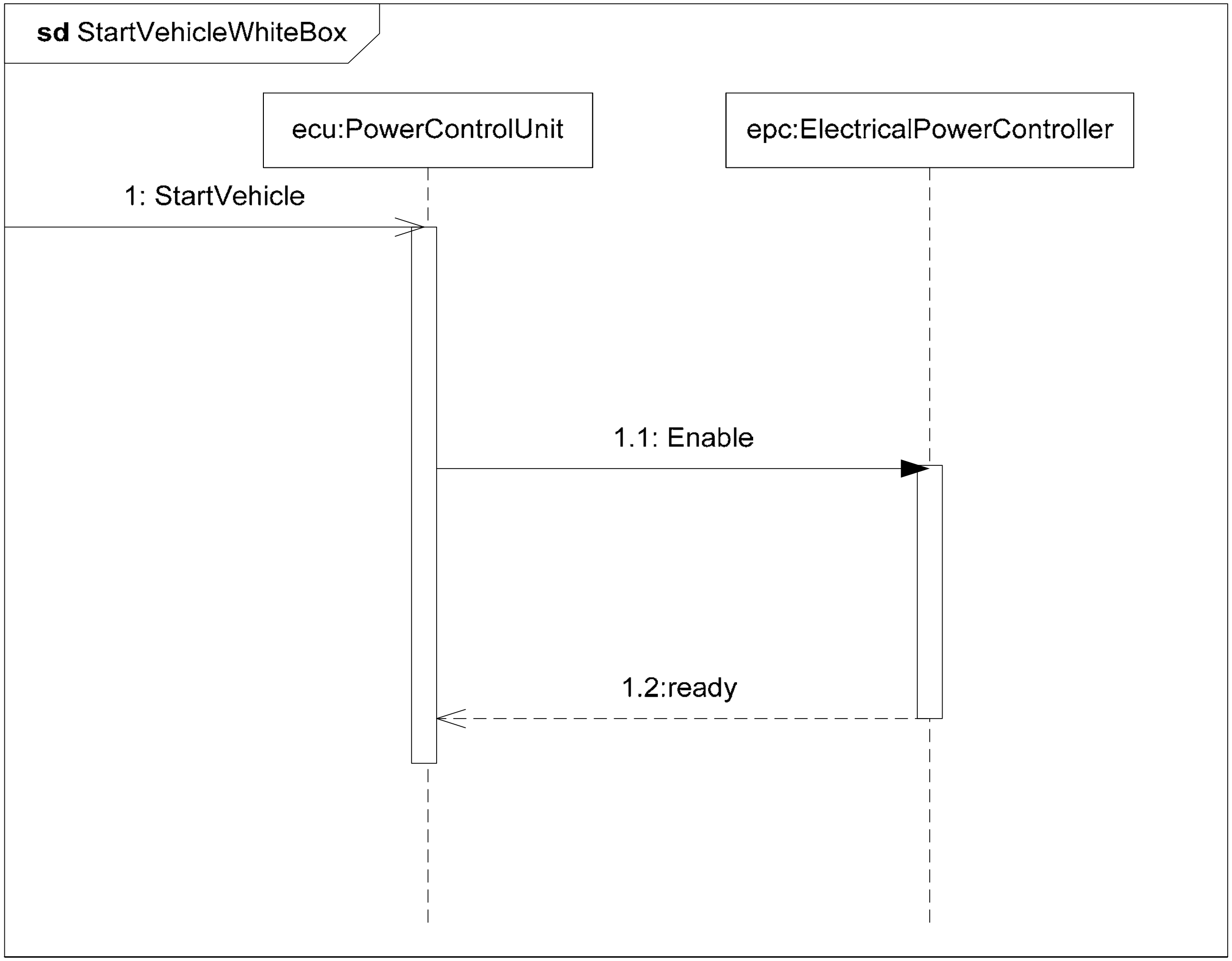
Black Box Sequence (StartVehicle)



References Lifeline Decomposition For White Box Interaction

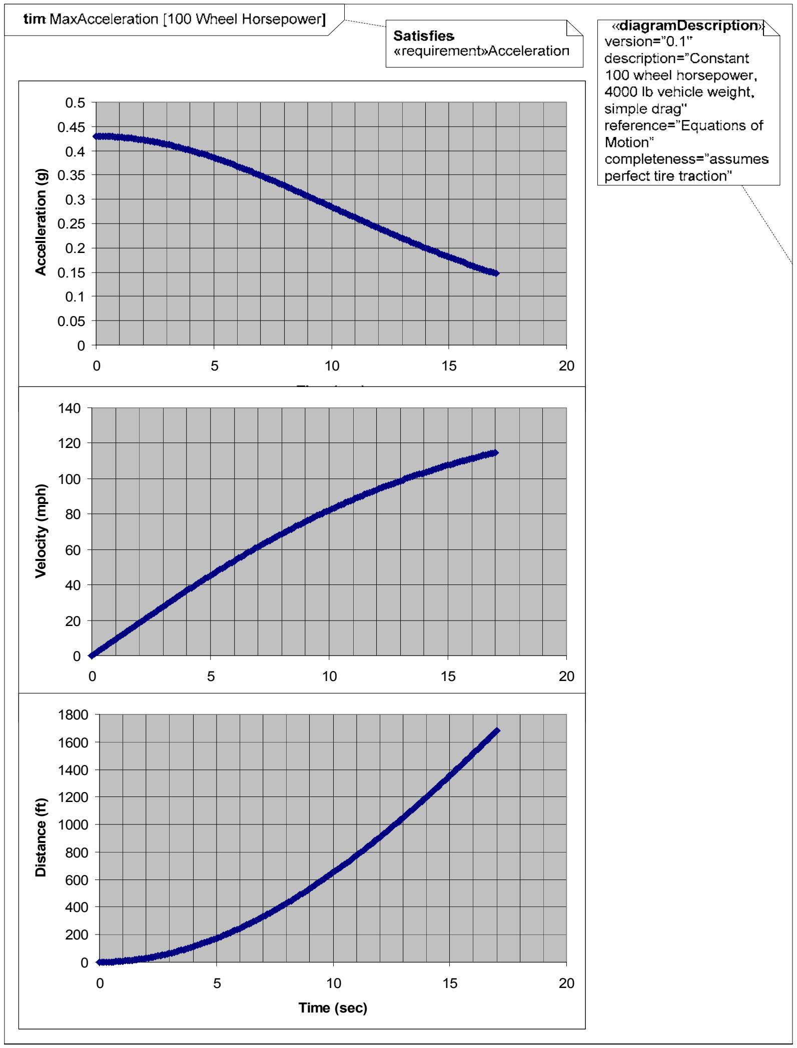
Simple Black Box Interaction

White Box Sequence (StartVehicle)



Decomposition of Black Box Into White Box Interaction

Trial Result of Vehicle Dynamics



tim MaxAcceleration [100 Wheel Horsepower]

Satisfies
«requirement»Acceleration

«diagramDescription»
version="0.1"
description="Constant 100 wheel horsepower, 4000 lb vehicle weight, simple drag"
reference="Equations of Motion"
completeness="assumes perfect tire traction"

Lifeline are value properties

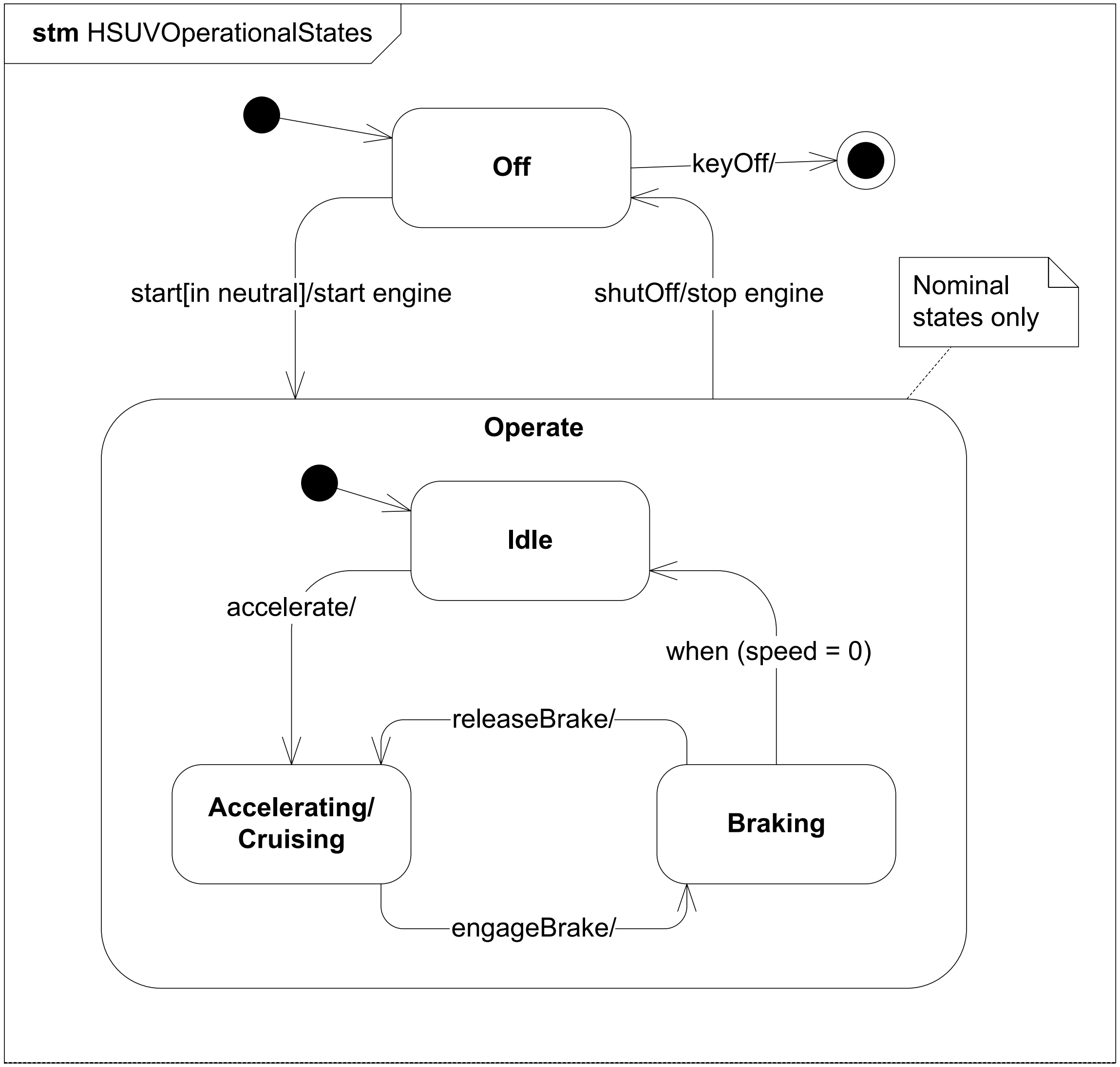
Timing Diagram Not Part of SysML

Typical Example of a Timing Diagram

State Machines

- Typically used to represent the life cycle of a block
- Support event-based behavior (generally asynchronous)
  - Transition with trigger, guard, action
  - State with entry, exit, and do-activity
  - Can include nested sequential or concurrent states
  - Can send/receive signals to communicate between blocks during state transitions, etc.

Operational States (Drive)

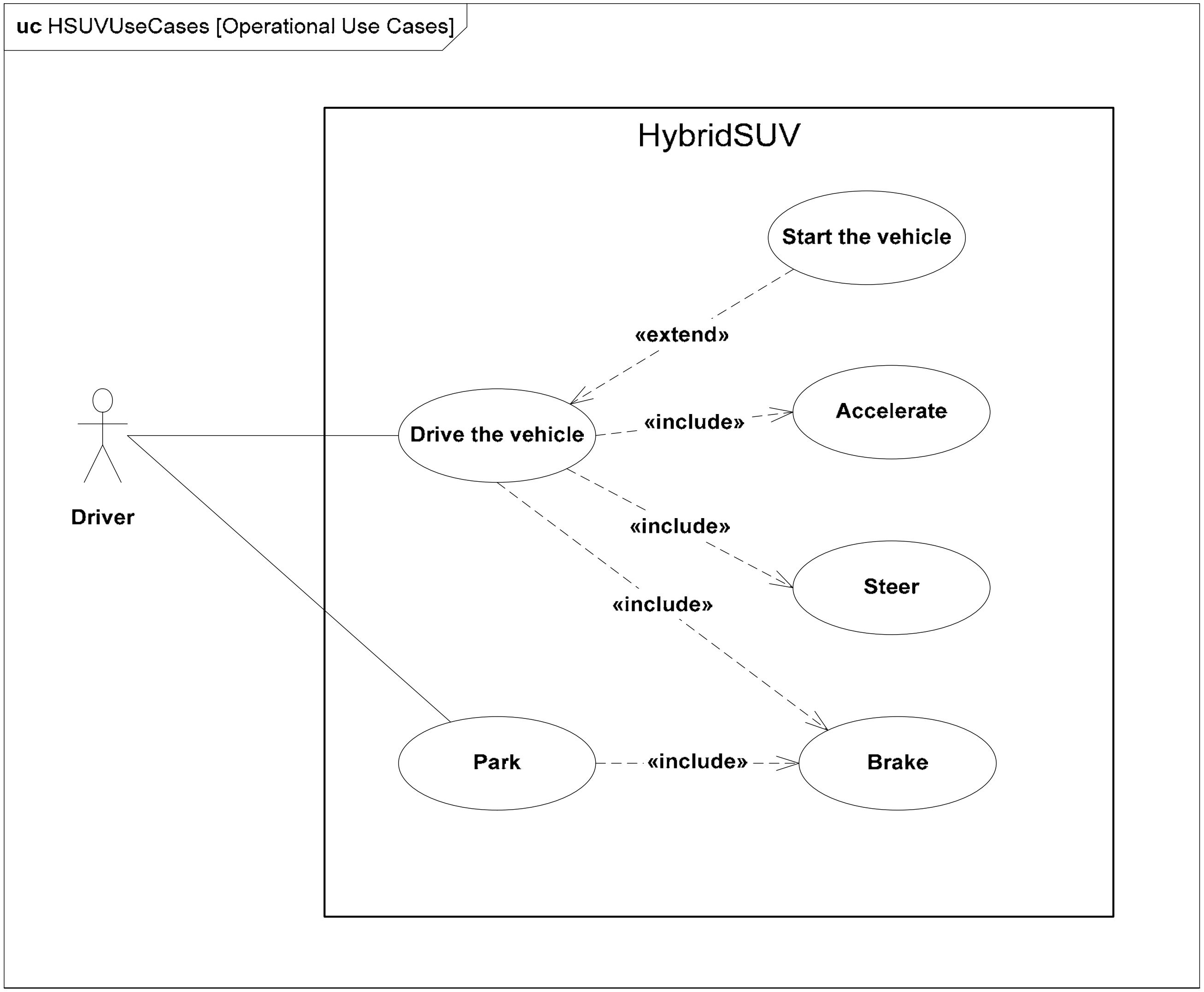


Transition notation: trigger[guard]/action

Use Cases

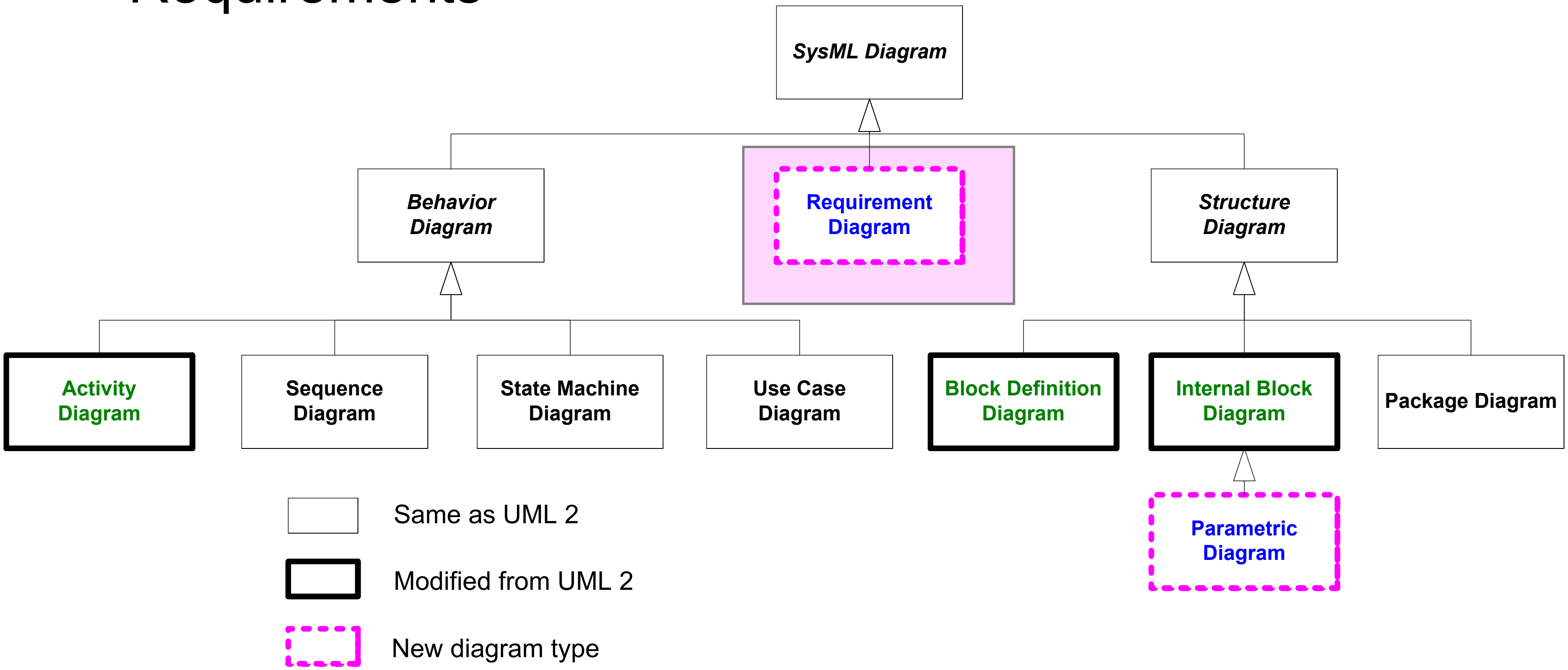
- Provide means for describing basic functionality in terms of usages/goals of the system by actors
- Common functionality can be factored out via include and extend relationships
- Generally elaborated via other behavioral representations to describe detailed scenarios
- No change to UML

Operational Use Cases



Cross-cutting Constructs

- Allocations
- Requirements



SysML Diagram

Behavior Diagram

Requirement Diagram

Structure Diagram

Activity Diagram

Sequence Diagram

State Machine Diagram

Use Case Diagram

Block Definition Diagram

Internal Block Diagram

Package Diagram

Parametric Diagram

Same as UML 2

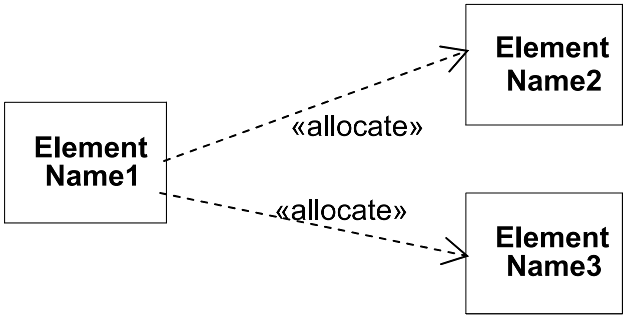
Modified from UML 2

New diagram type

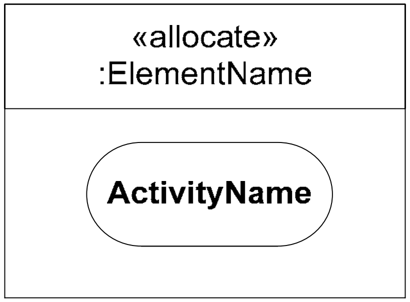
Allocations

- Represent general relationships that map one model element to another
- Different types of allocation are:
  - Behavioral (i.e., function to component)
  - Structural (i.e., logical to physical)
  - Software to Hardware
  - ….
- Explicit allocation of activities to structure via swim lanes (i.e., activity partitions)
- Both graphical and tabular representations are specified

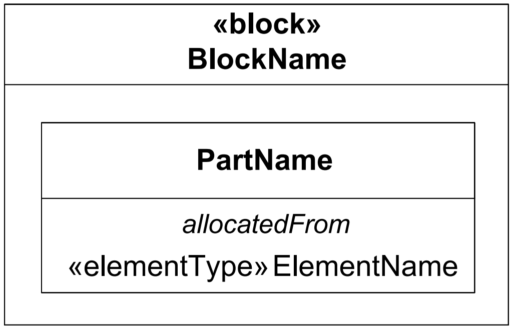
Different Allocation Representations (Tabular Representation Not Shown)



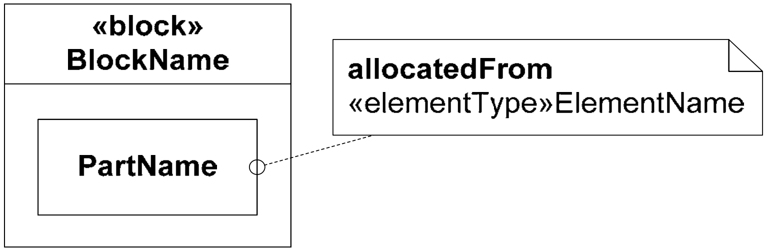
Allocate Relationship



Explicit Allocation of Activity to Swim Lane



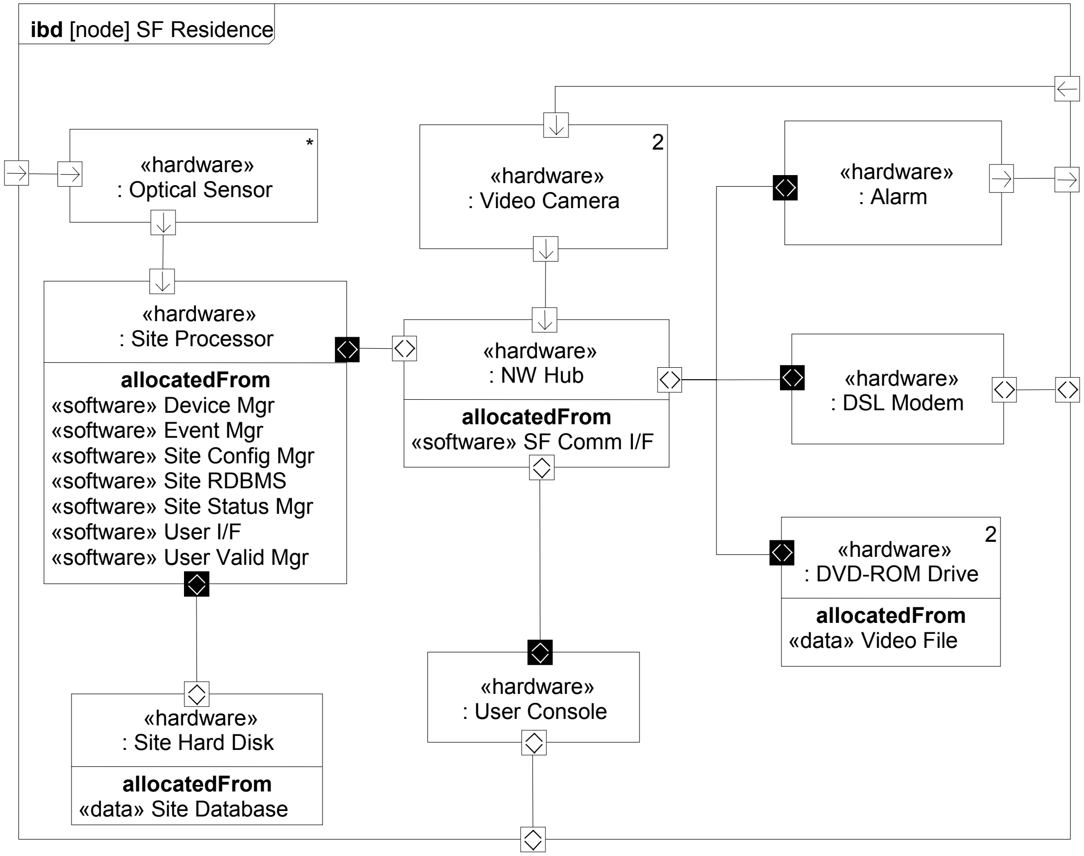
Compartment Notation



Callout Notation

SysML Allocation of SW to HW

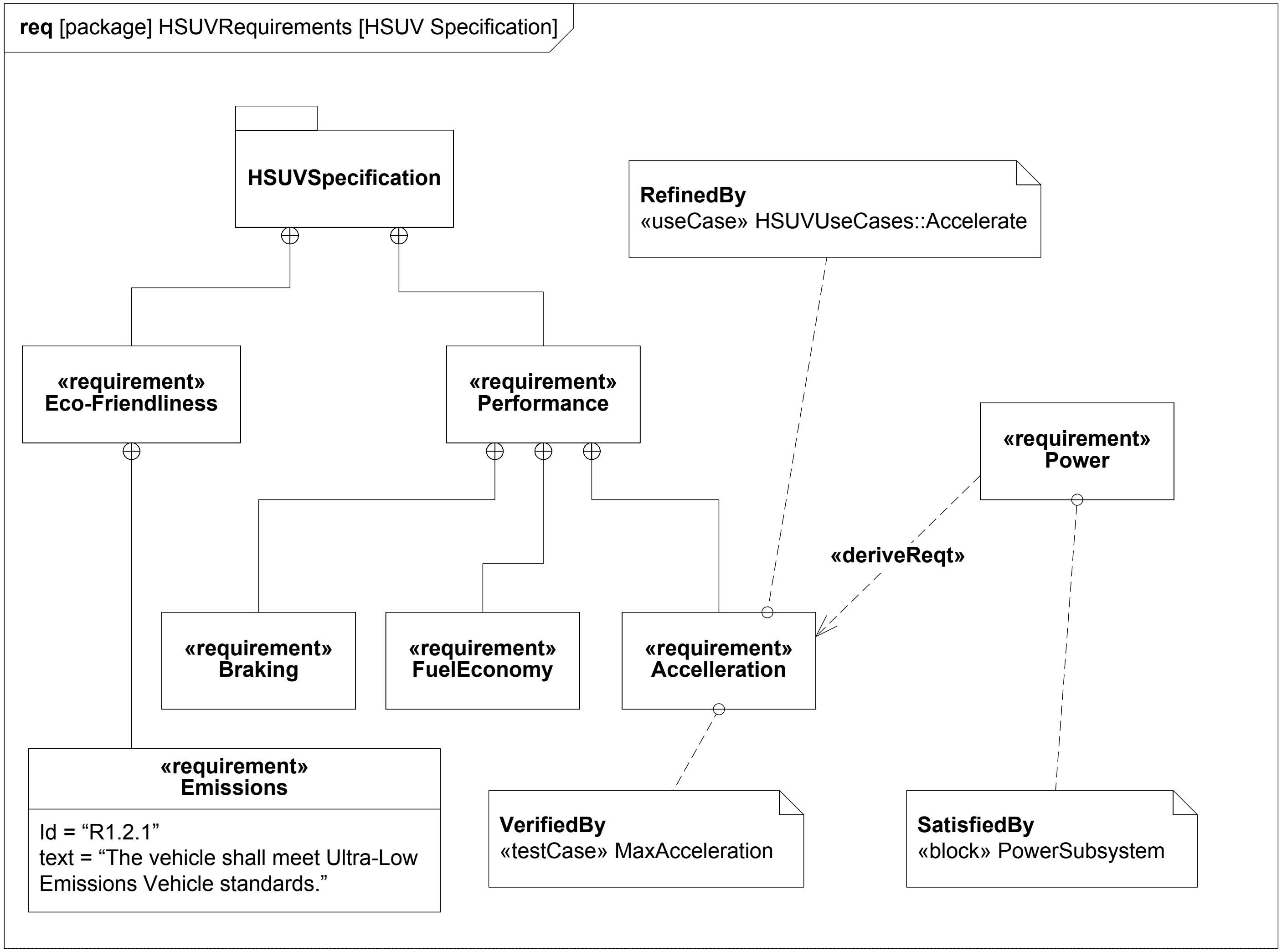
- In UML the deployment diagram is used to deploy artifacts to nodes
- In SysML allocation on ibd and bdd is used to deploy software/data to hardware



Requirements

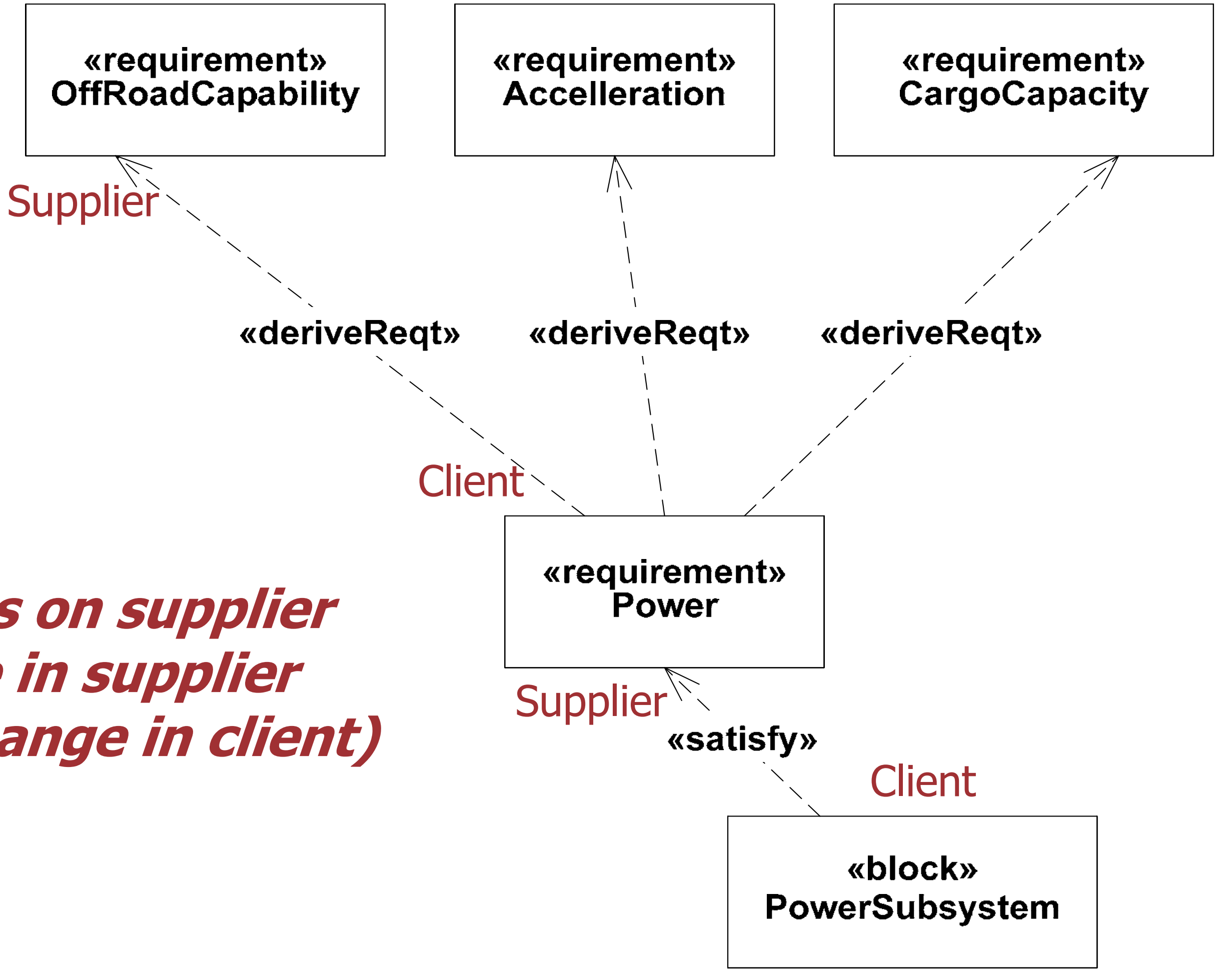
- The «requirement» stereotype represents a text based requirement
  - Includes id and text properties
  - Can add user defined properties such as verification method
  - Can add user defined requirements categories (e.g., functional, interface, performance)
- Requirements hierarchy describes requirements contained in a specification
- Requirements relationships include DeriveReqt, Satisfy, Verify, Refine, Trace, Copy

Requirements Breakdown



Requirement Relationships Model the Content of a Specification

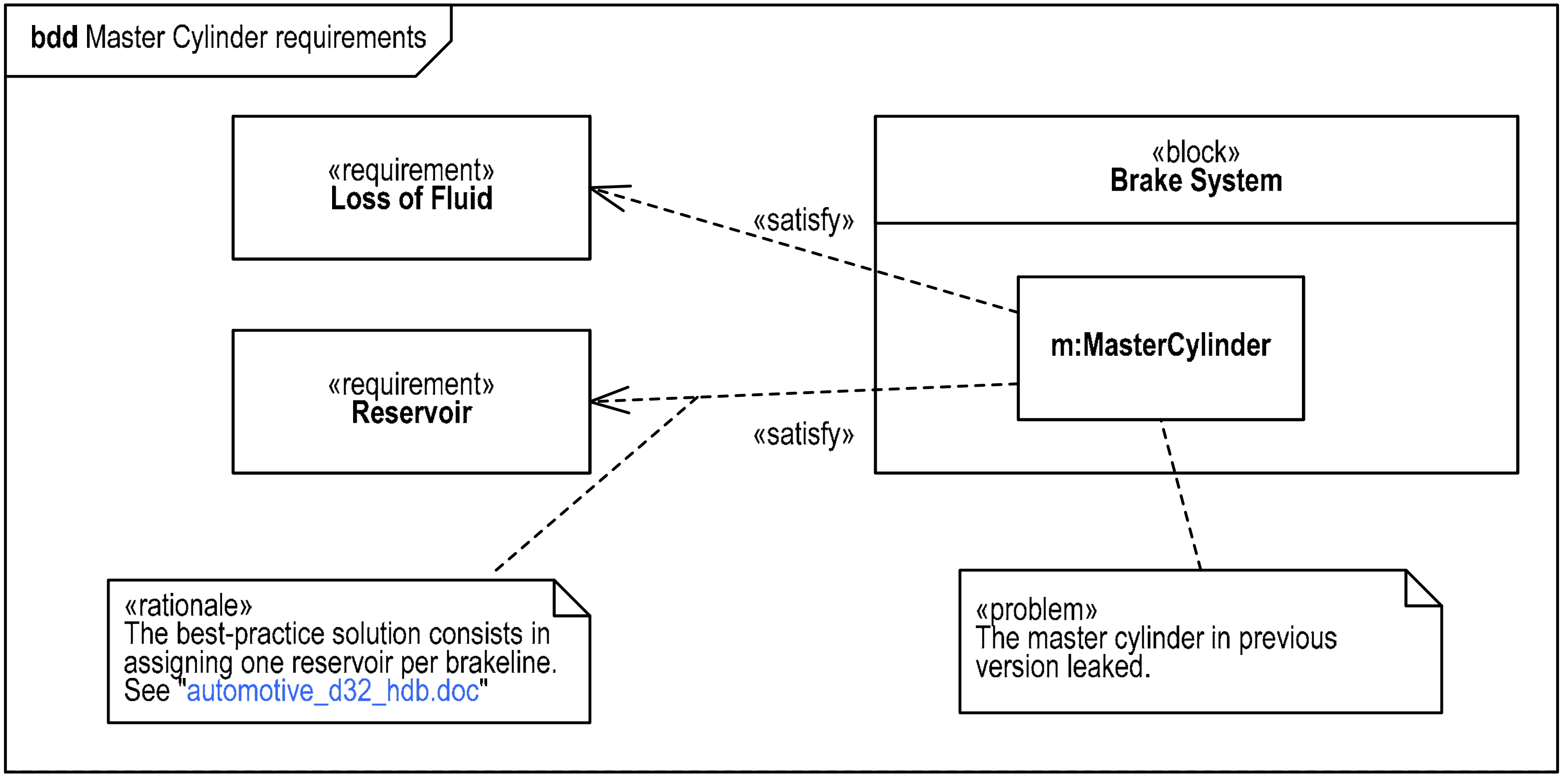
Example of Derive/Satisfy Requirement Dependencies



Client depends on supplier (i.e., a change in supplier results in a change in client)

Arrow Direction Opposite Typical Requirements Flow-Down

Problem and Rationale

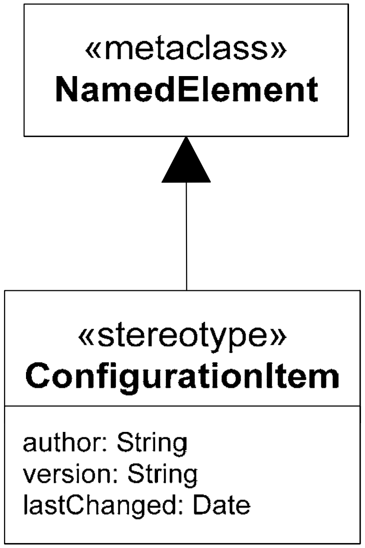

bdd Master Cylinder requirements
«requirement»
Loss of Fluid
«requirement»
Reservoir
«block»
Brake System
m:MasterCylinder
«satisfy»
«satisfy»
«rationale»
The best-practice solution consists in assigning one reservoir per brakeline.
See "automotive_d32_hdb.doc"
«problem»
The master cylinder in previous version leaked.

Problem and Rationale can be attached to any Model Element to Capture Issues and Decisions

Stereotypes & Model Libraries

- Mechanisms for further customizing SysML
- Profiles represent extensions to the language
  - Stereotypes extend meta-classes with properties and constraints
    - Stereotype properties capture metadata about the model element
  - Profile is applied to user model
  - Profile can also restrict the subset of the meta-model used when the profile is applied
- Model Libraries represent reusable libraries of model elements

Stereotypes

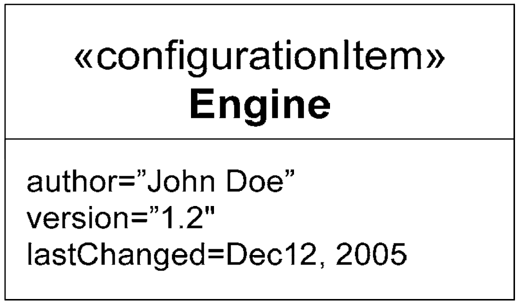


«metaclass»
NamedElement

«stereotype»
ConfigurationItem

author: String
version: String
lastChanged: Date

Defining the Stereotype

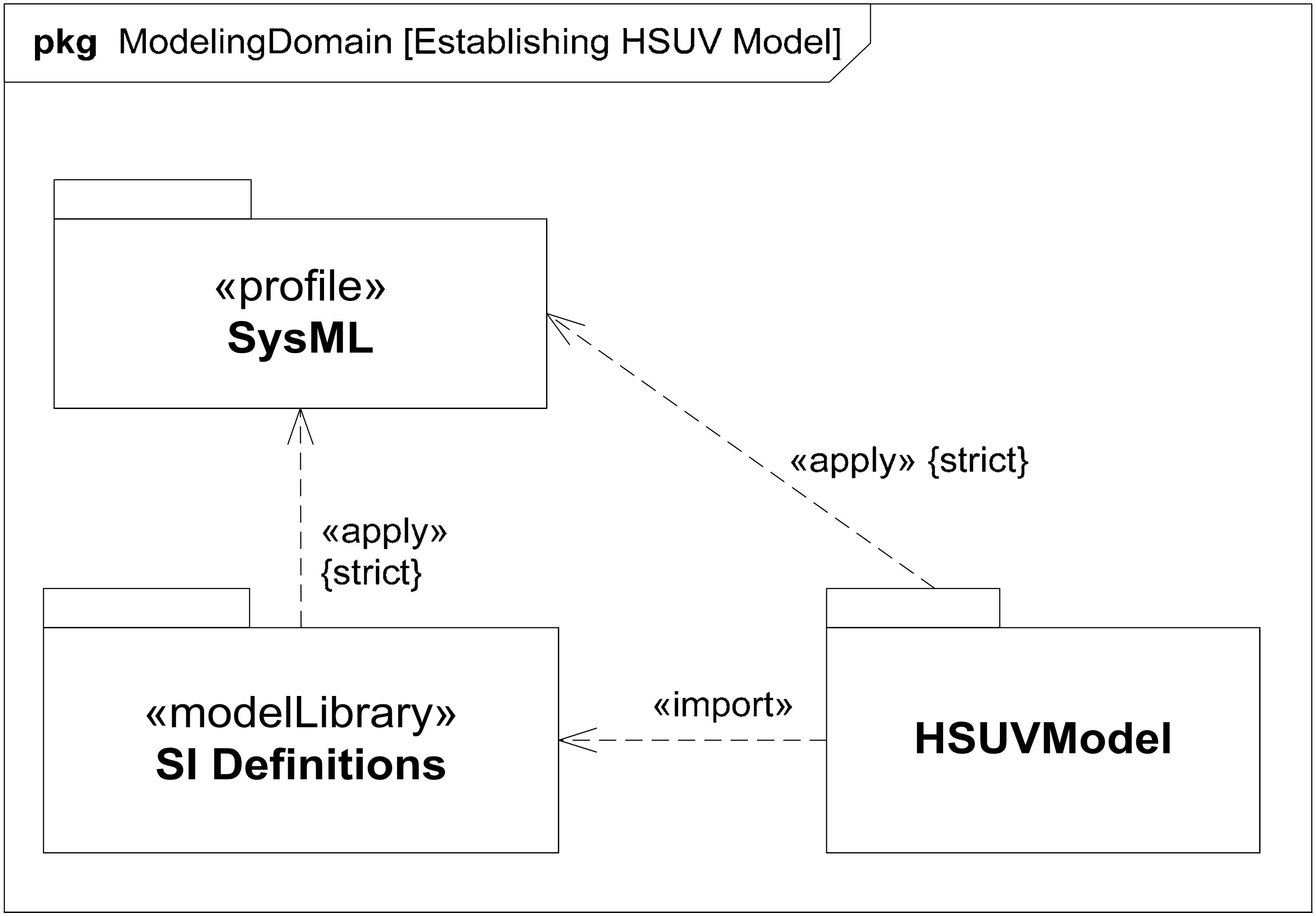


«configurationItem»
Engine

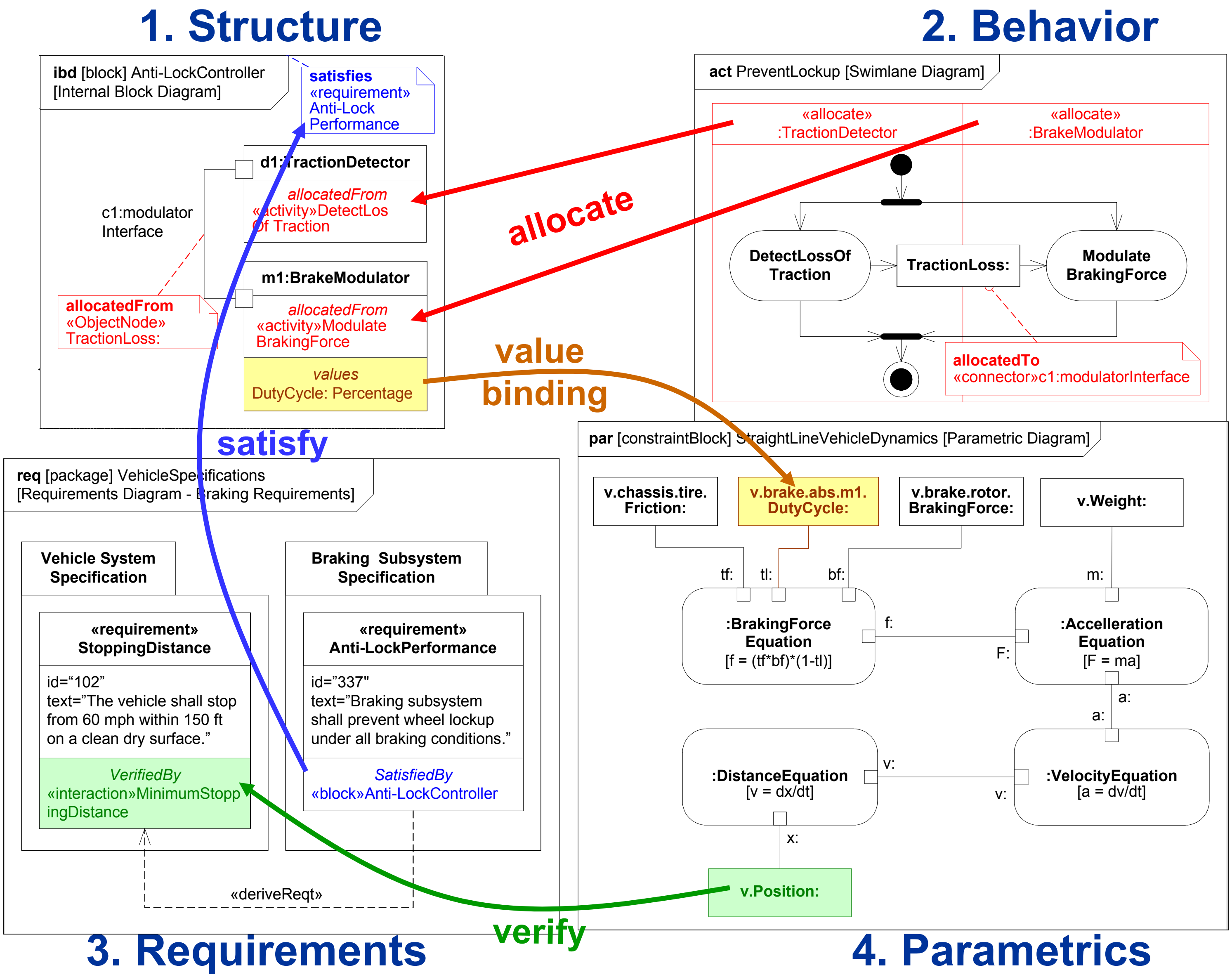
author=”John Doe”
version=”1.2"
lastChanged=Dec12, 2005

Applying the Stereotype

Applying a Profile and Importing a Model Library



Cross Connecting Model Elements



1. Structure

2. Behavior

ibd [block] Anti-LockController
[Internal Block Diagram]

satisfies
«requirement»
Anti-Lock
Performance

d1:TractionDetector

allocatedFrom
«activity»DetectLos
of Traction

c1:modulator
Interface

m1:BrakeModulator

allocatedFrom
«activity»Modulate
BrakingForce

values
DutyCycle: Percentage

allocatedFrom
«ObjectNode»
TractionLoss:

allocate

value
binding

satisfy

act PreventLockup [Swimlane Diagram]

«allocate»
:TractionDetector

«allocate»
:BrakeModulator

DetectLossOf
Traction

TractionLoss:

Modulate
BrakingForce

allocatedTo
«connector»c1:modulatorInterface

req [package] VehicleSpecifications
[Requirements Diagram - Braking Requirements]

Vehicle System
Specification

«requirement»
StoppingDistance

id="102"
text="The vehicle shall stop from 60 mph within 150 ft on a clean dry surface."

VerifiedBy
«interaction»MinimumStoppingDistance

Braking Subsystem
Specification

«requirement»
Anti-LockPerformance

id="337"
text="Braking subsystem shall prevent wheel lockup under all braking conditions."

SatisfiedBy
«block»Anti-LockController

«deriveReqt»

par [constraintBlock] StraightLineVehicleDynamics [Parametric Diagram]

v.chassis.tire.
Friction:

v.brake.abs.m1.
DutyCycle:

v.brake.rotor.
BrakingForce:

v.Weight:

tf: tl: bf:

m:

:BrakingForce
Equation
[f = (tf*bf)*(1-tl)]

f:

F:

:Accelleration
Equation
[F = ma]

a:

a:

:DistanceEquation
[v = dx/dt]

v:

v:

:VelocityEquation
[a = dv/dt]

x:

v.Position:

verify

3. Requirements

4. Parametrics

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International Council on Systems Engineering

INCOSE
2006
Orlando, Florida

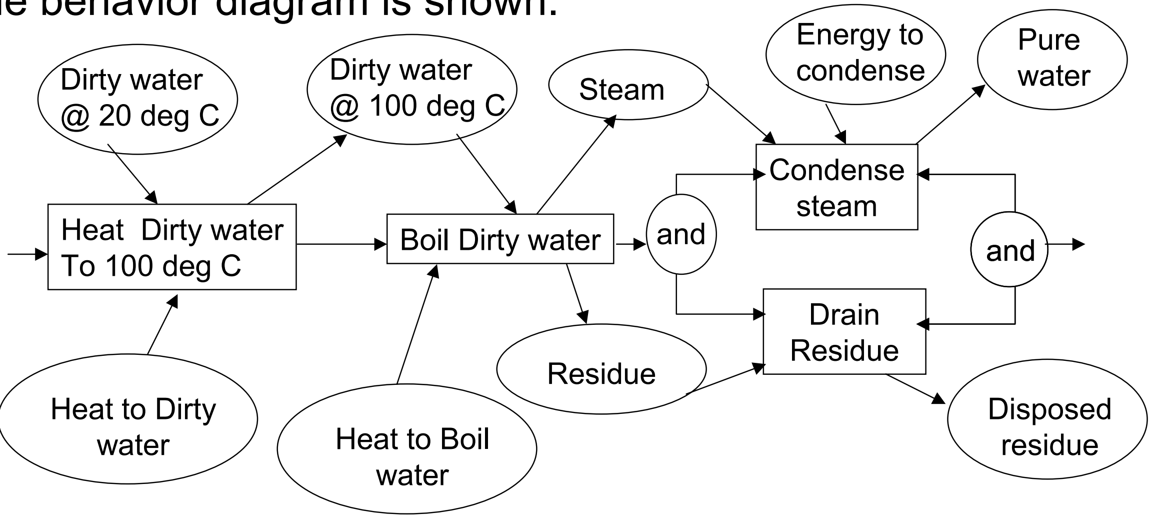
OMG
SYSTEMS
MODELING
LANGUAGE
SYS ML™

SysML Modeling
as Part of the SE Process

Distiller Sample Problem

Distiller Problem Statement

- The following problem was posed to the SysMLteam in Dec '05 by D. Oliver:
- Describe a system for purifying dirty water.
  - Heat dirty water and condense steam are performed by a Counter Flow Heat Exchanger
  - Boil dirty water is performed by a Boiler
  - Drain residue is performed by a Drain
  - The water has properties: vol = 1 liter, density 1 gm/cm3, temp 20 deg C, specific heat 1cal/gm deg C, heat of vaporization 540 cal/gm.
- A crude behavior diagram is shown.

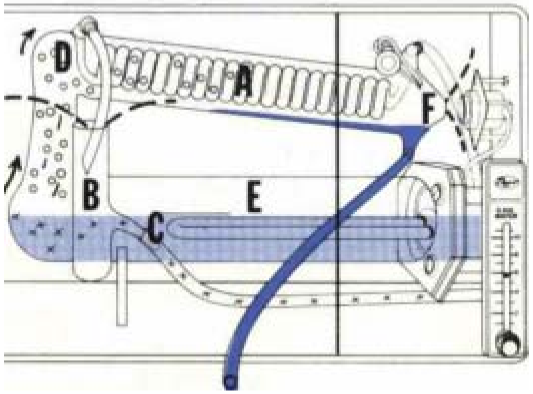


What are the real requirements?
How do we design the system?

Distiller Types

Batch Distiller

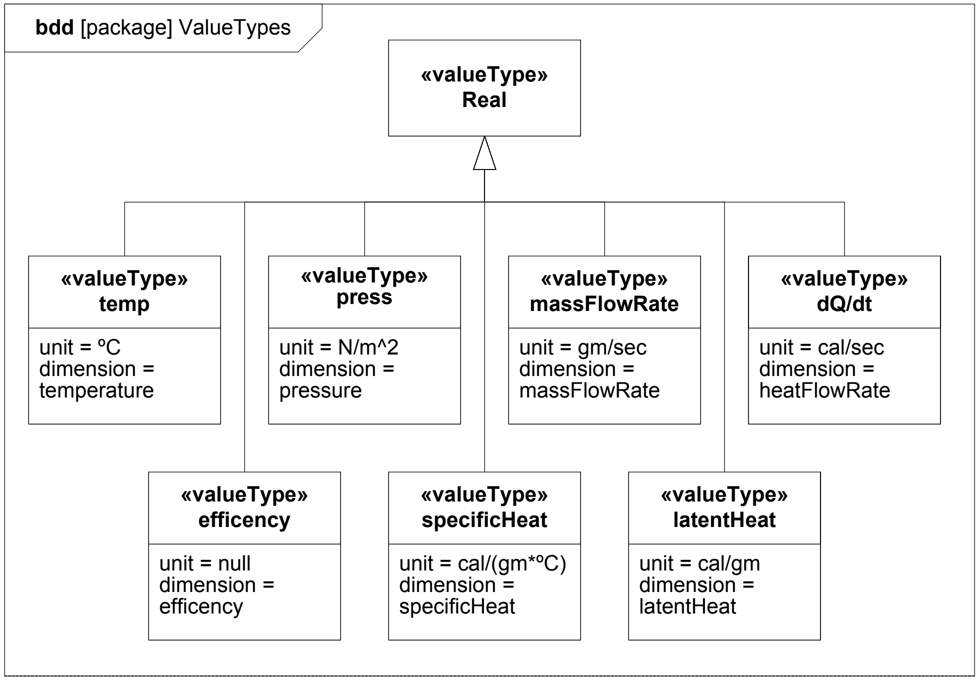
Continuous Distiller



Distiller Problem – Process Used

- Organize the model, identify libraries needed
- List requirements and assumptions
- Model behavior
  - In similar form to problem statement
  - Elaborate as necessary
- Model structure
  - Capture implied inputs and outputs
    - segregate I/O from behavioral flows
  - Allocate behavior onto structure, flow onto I/O
- Capture and evaluate parametric constraints
  - Heat balance equation
- Modify design as required to meet constraints

Distiller Problem – Package Diagram: Model Structure and Libraries



bdd [package] ValueTypes

«valueType» Real

«valueType» temp
unit = ºC
dimension = temperature

«valueType» press
unit = N/m^2
dimension = pressure

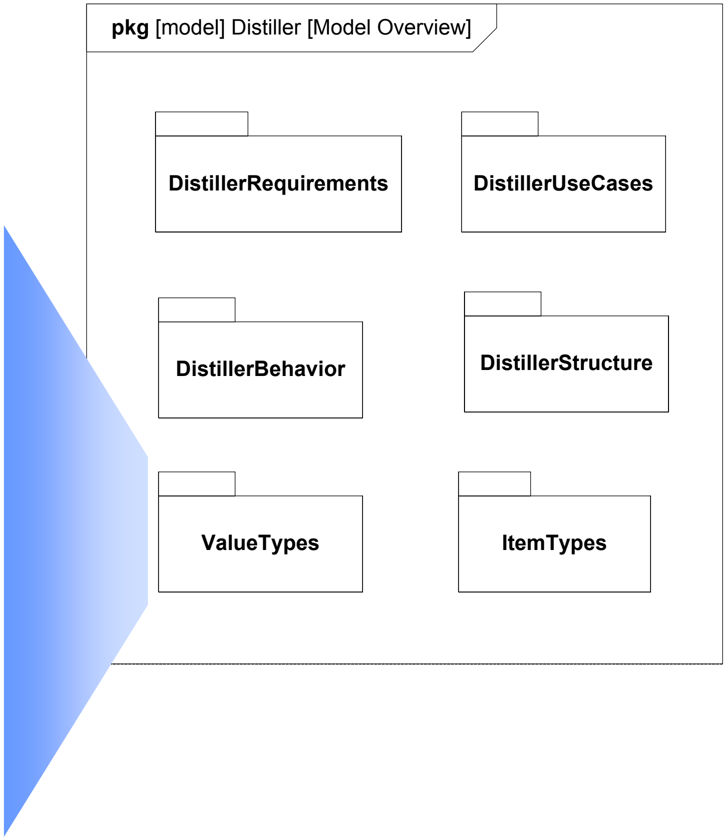
«valueType» massFlowRate
unit = gm/sec
dimension = massFlowRate

«valueType» dQ/dt
unit = cal/sec
dimension = heatFlowRate

«valueType» efficency
unit = null
dimension = efficency

«valueType» specificHeat
unit = cal/(gm*ºC)
dimension = specificHeat

«valueType» latentHeat
unit = cal/gm
dimension = latentHeat



pkg [model] Distiller [Model Overview]

DistillerRequirements

DistillerUseCases

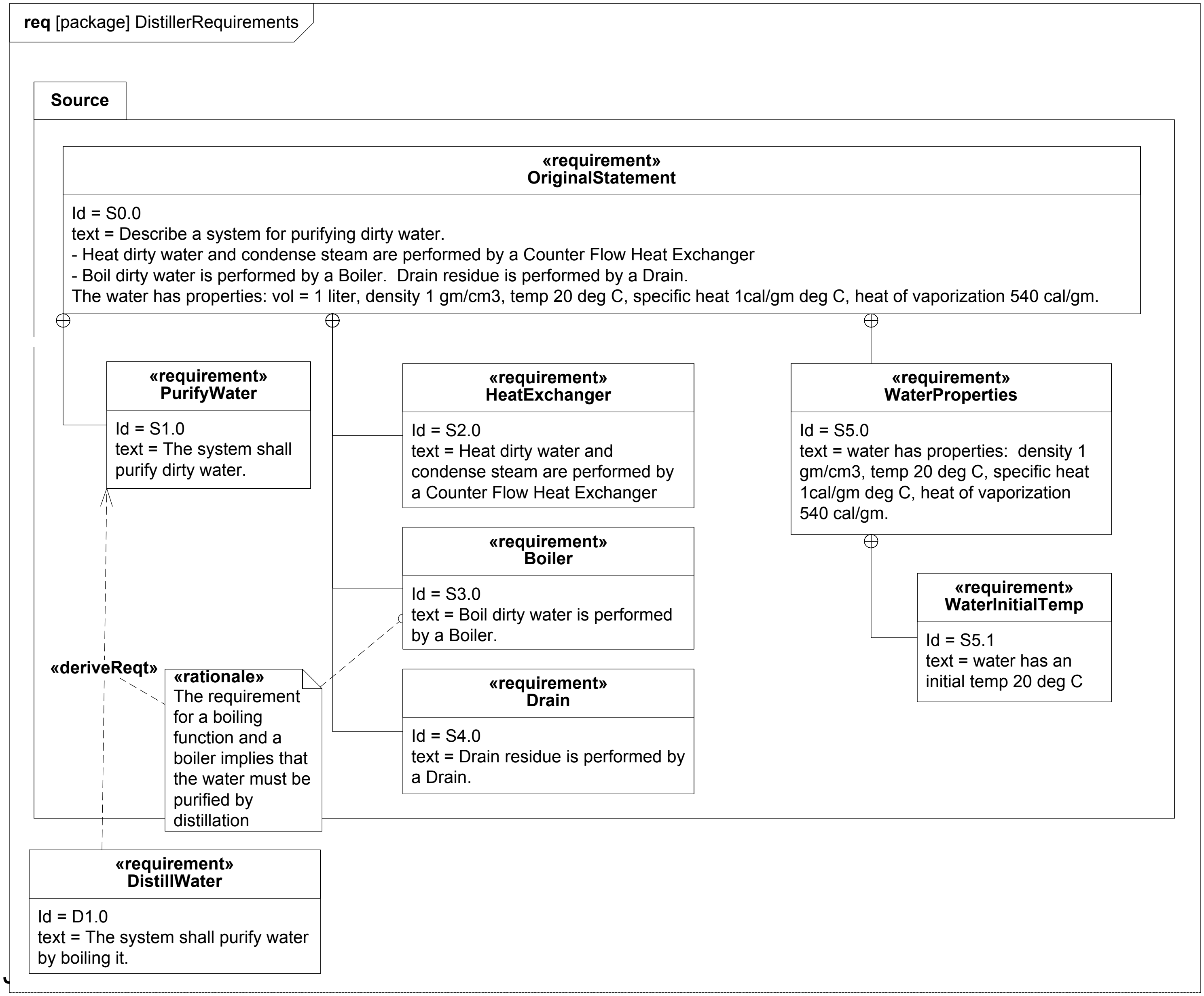
DistillerBehavior

DistillerStructure

ValueTypes

ItemTypes

Distiller Example Requirements Diagram



req [package] DistillerRequirements

Source

«requirement»
OriginalStatement

Id = S0.0
text = Describe a system for purifying dirty water.
- Heat dirty water and condense steam are performed by a Counter Flow Heat Exchanger
- Boil dirty water is performed by a Boiler. Drain residue is performed by a Drain.
The water has properties: vol = 1 liter, density 1 gm/cm3, temp 20 deg C, specific heat 1cal/gm deg C, heat of vaporization 540 cal/gm.

«requirement»
PurifyWater

Id = S1.0
text = The system shall purify dirty water.

«requirement»
HeatExchanger

Id = S2.0
text = Heat dirty water and condense steam are performed by a Counter Flow Heat Exchanger

«requirement»
WaterProperties

Id = S5.0
text = water has properties: density 1 gm/cm3, temp 20 deg C, specific heat 1cal/gm deg C, heat of vaporization 540 cal/gm.

«requirement»
Boiler

Id = S3.0
text = Boil dirty water is performed by a Boiler.

«requirement»
WaterInitialTemp

Id = S5.1
text = water has an initial temp 20 deg C

«deriveReqt»

«rationale»
The requirement for a boiling function and a boiler implies that the water must be purified by distillation

«requirement»
Drain

Id = S4.0
text = Drain residue is performed by a Drain.

«requirement»
DistillWater

Id = D1.0
text = The system shall purify water by boiling it.

Distiller Example: Requirements Tables

table [requirement] OriginalStatement [Decomposition of OriginalStatement]

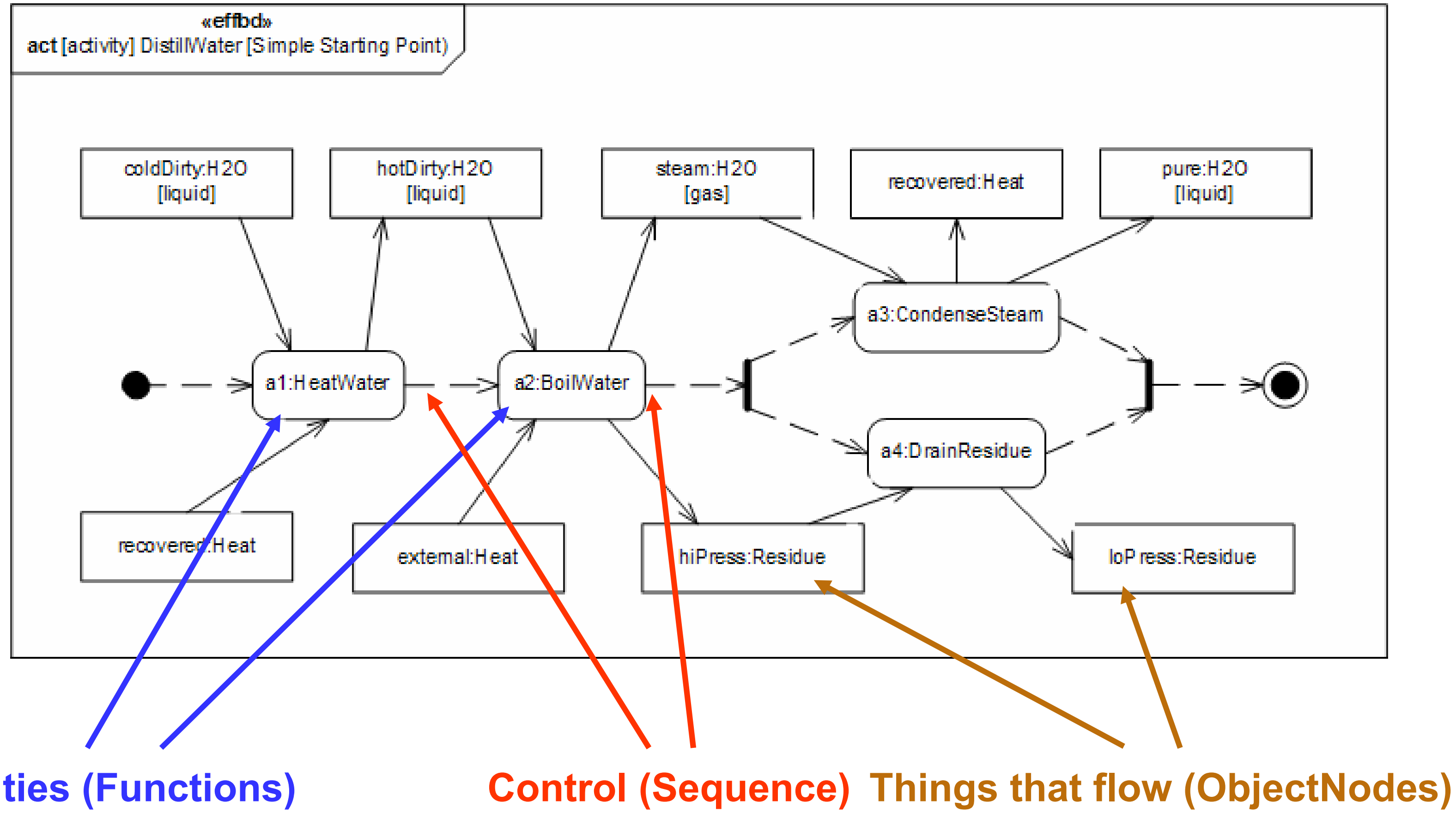
id	name	text
S0.0	OriginalStatement	Describe a system for purifying dirty water. …
S1.0	PurifyWater	The system shall purify dirty water.
S2.0	HeatExchanger	Heat dirty water and condense steam are performed by a …
S3.0	Boiler	Boil dirty water is performed by a Boiler.
S4.0	Drain	Drain residue is performed by a Drain.
S5.0	WaterProperties	water has properties: density 1 gm/cm3, temp 20 deg C, …
S5.1	WaterInitialTemp	water has an initial temp 20 deg C

table [requirement] PurifyWater [Requirements Tree]

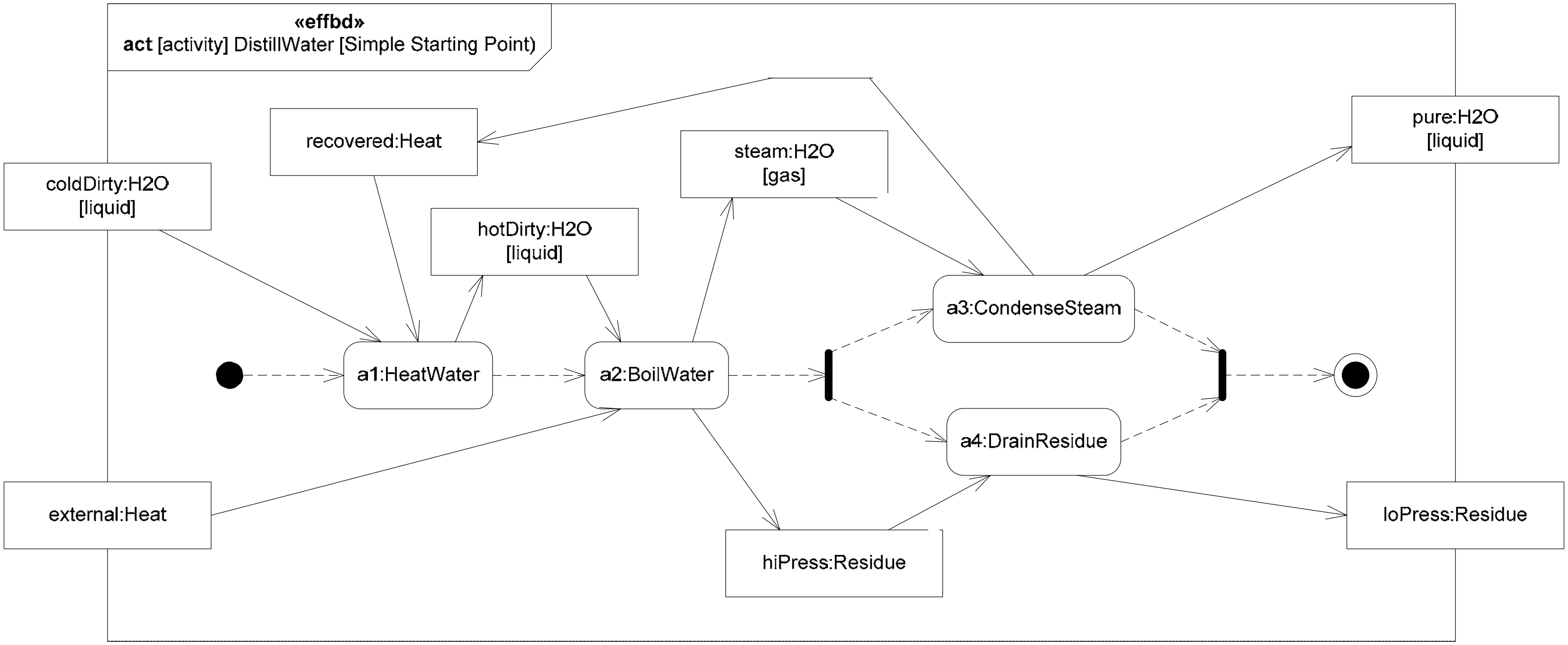
id	name	relation	id	name	Rationale
S1.0	PurifyWater	deriveReqt	D1.0	DistillWater	The requirement for a boiling function and a boiler implies that the water must be purified by distillation

Distiller Example – Activity Diagram: Initial Diagram for DistillWater

- This activity diagram applies the SysML EFFBD profile, and formalizes the diagram in the problem statement.

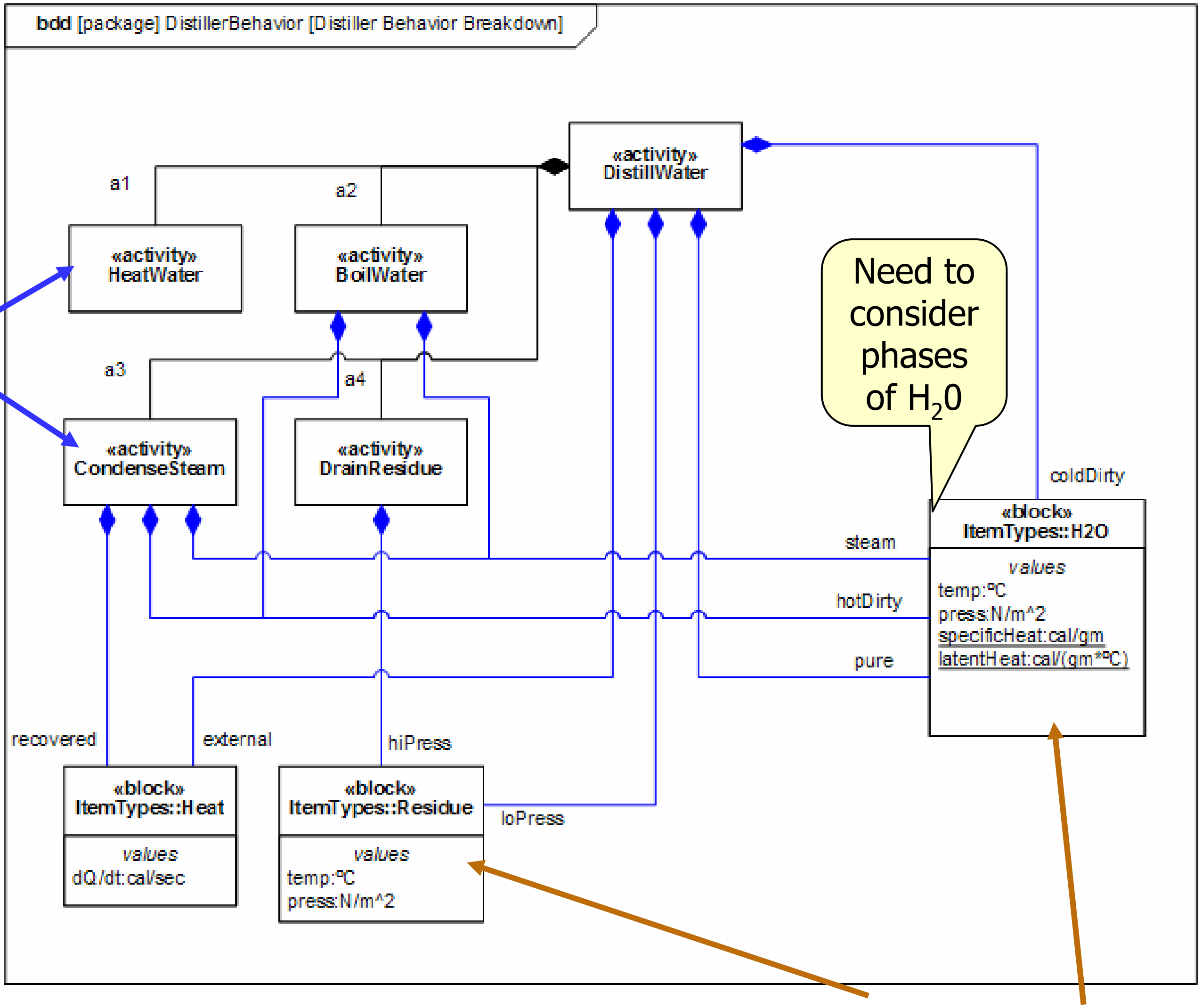


Distiller Example – Activity Diagram: Control-Driven: Serial Behavior



Batch Distiller

Distiller Example – Block Definition Diagram: DistillerBehavior



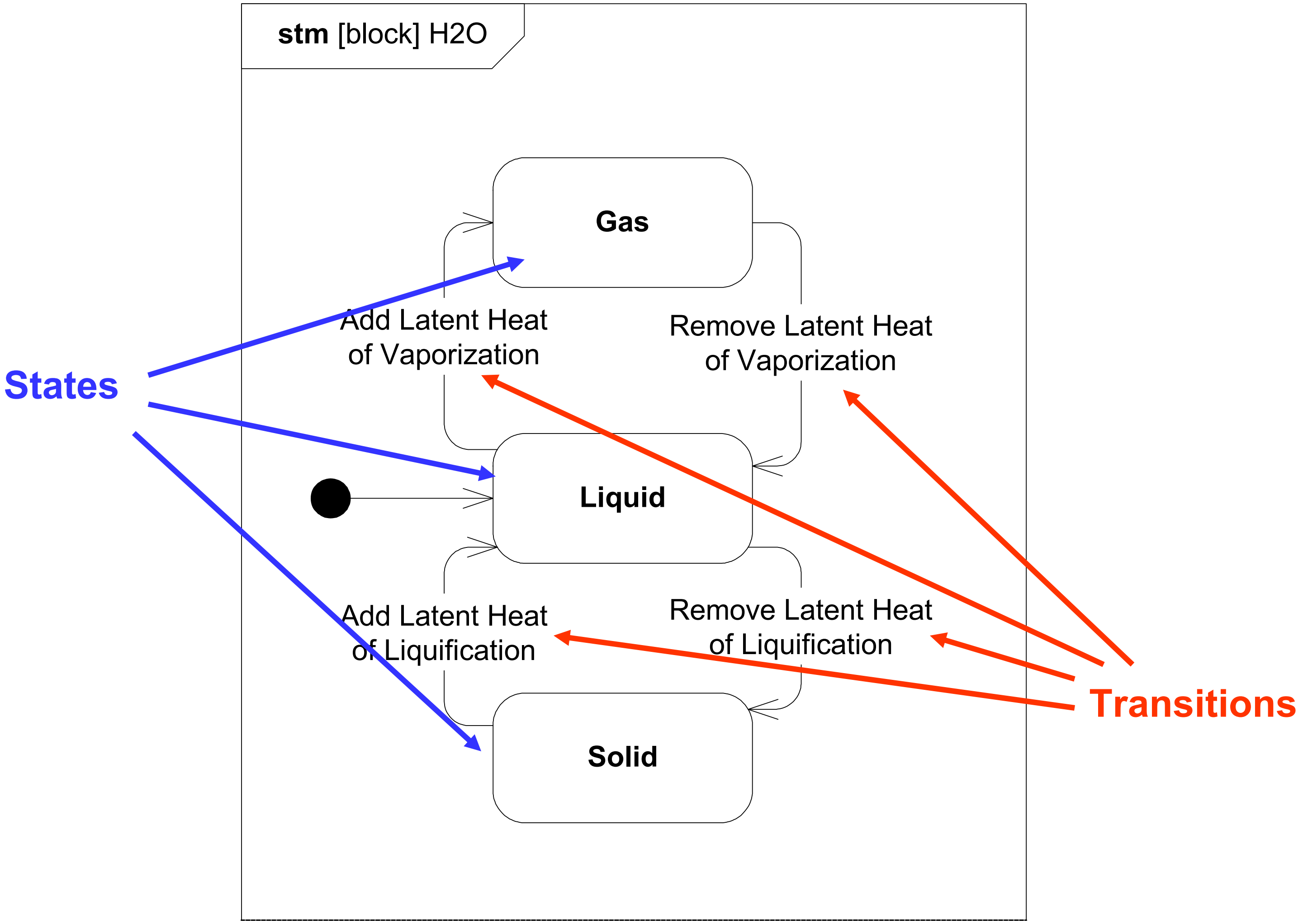
Need to consider phases of $H_2 0$

Activities (Functions)

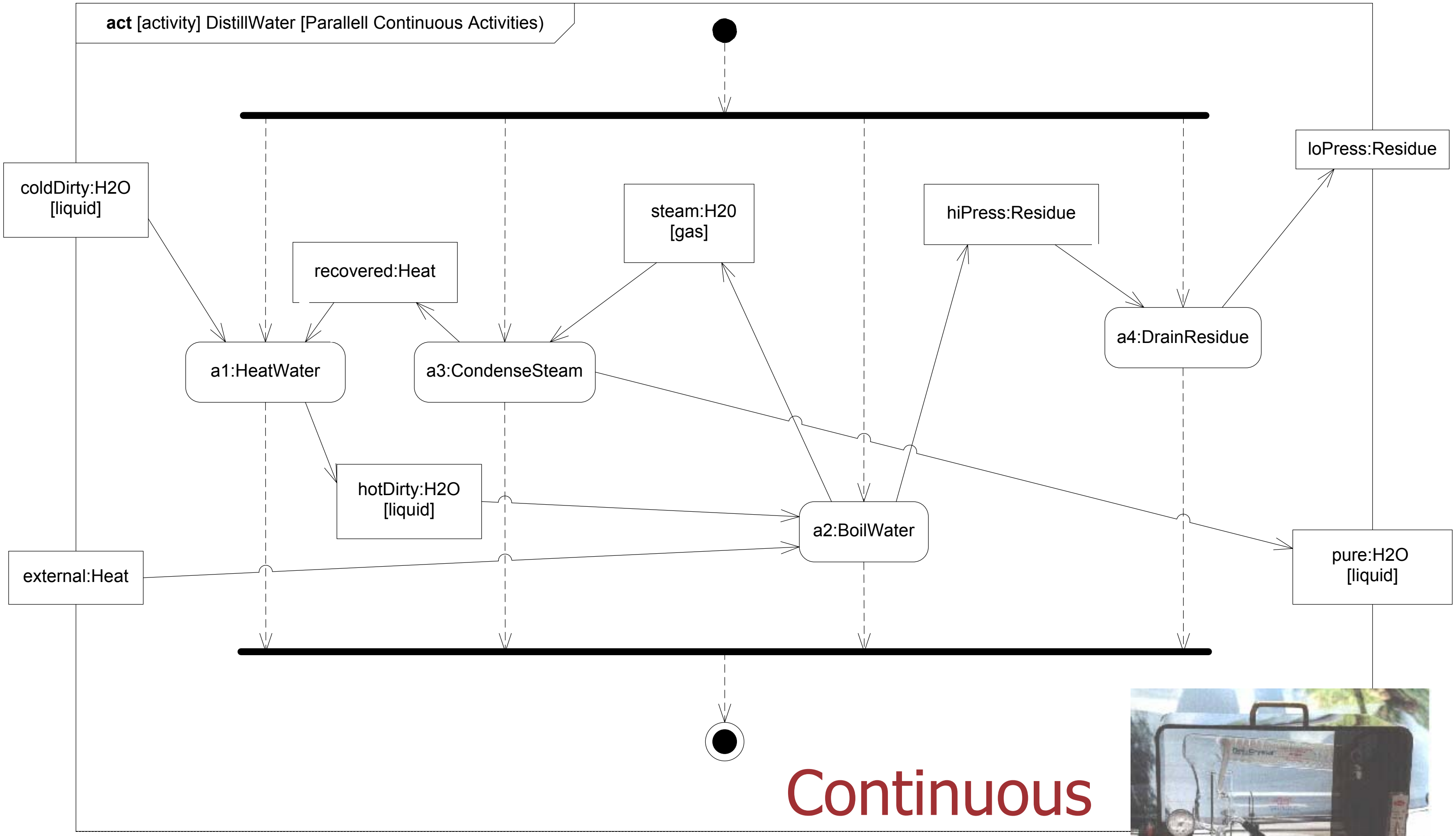
Control (not shown on BDD)

Things that flow (ObjectNodes)

Distiller Example – State Machine Diagram: States of H2O

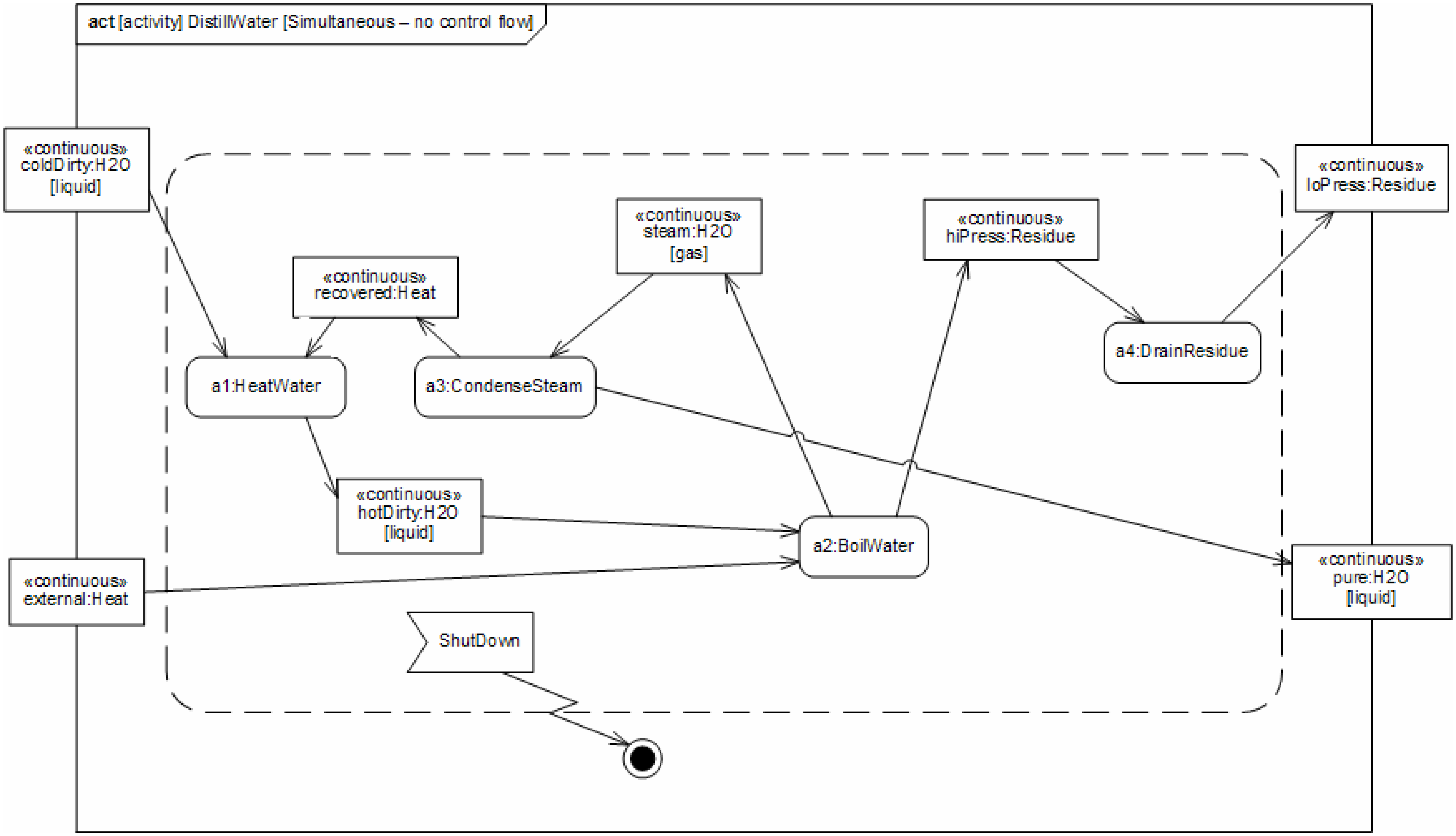

stm [block] H2O
Gas
Liquid
Solid
Add Latent Heat of Vaporization
Remove Latent Heat of Vaporization
Add Latent Heat of Liquification
Remove Latent Heat of Liquification
States
Transitions

Distiller Example – Activity Diagram: I/O Driven: Continuous Parallel Behavior

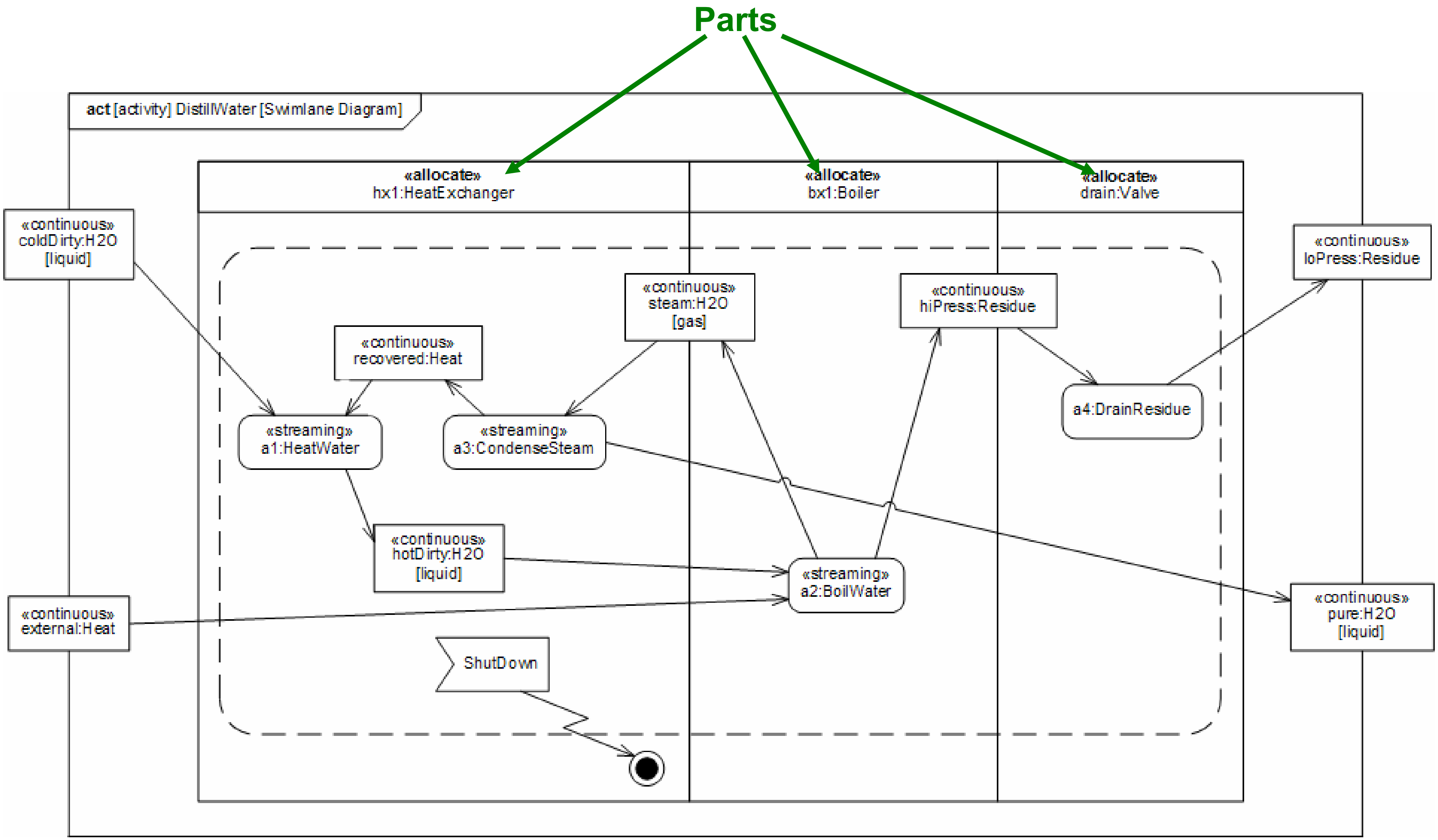


Continuous Distiller

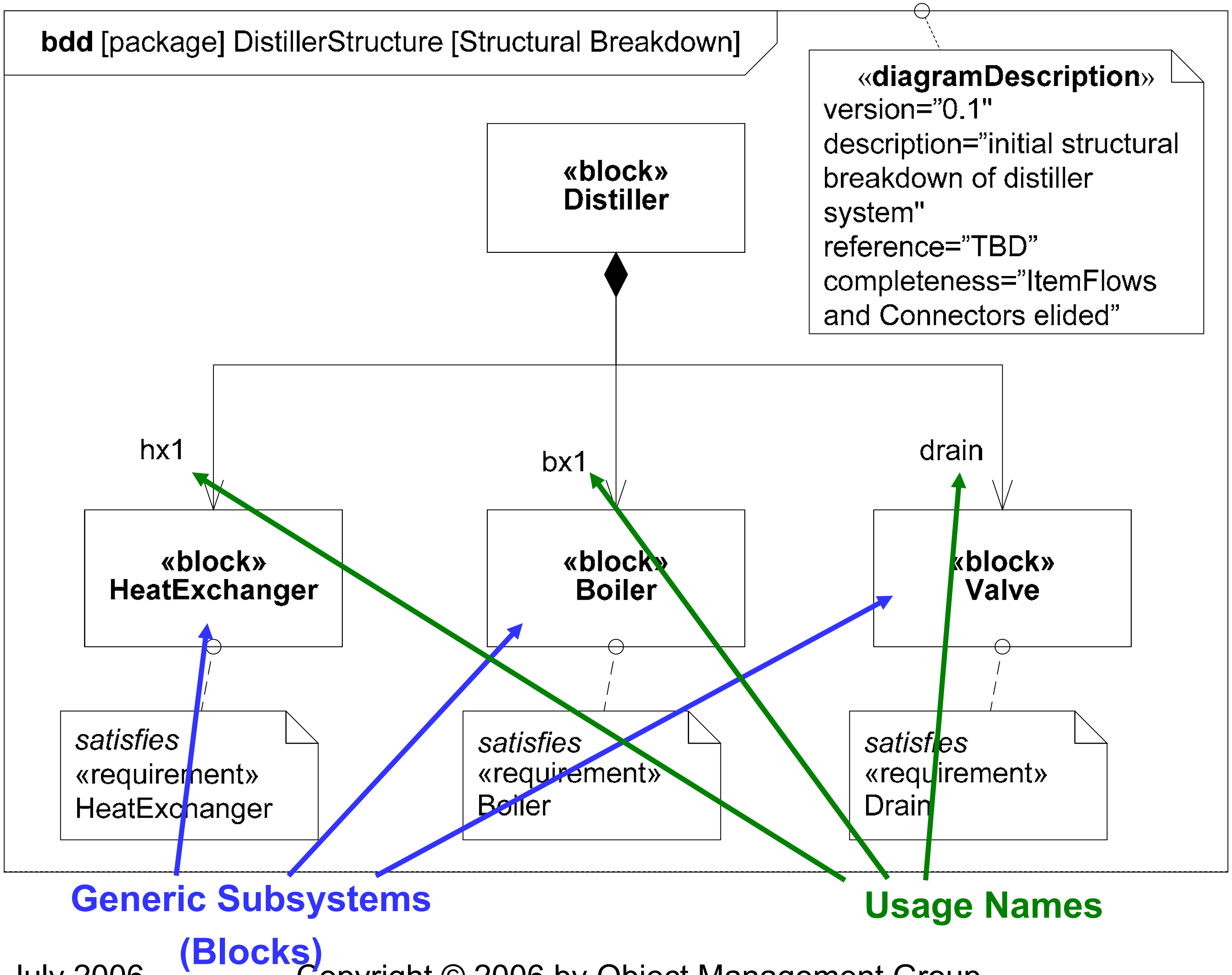
Distiller Example – Activity Diagram: No Control Flow – Simultaneous Behavior


act [activity] DistillWater [Simultaneous – no control flow]
«continuous» coldDirty:H2O [liquid]
«continuous» recovered:Heat
«continuous» steam:H2O [gas]
«continuous» hiPress:Residue
«continuous» loPress:Residue
a1:HeatWater
a3:CondenseSteam
a4:DrainResidue
«continuous» hotDirty:H2O [liquid]
a2:BoilWater
«continuous» external:Heat
«continuous» pure:H2O [liquid]
ShutDown

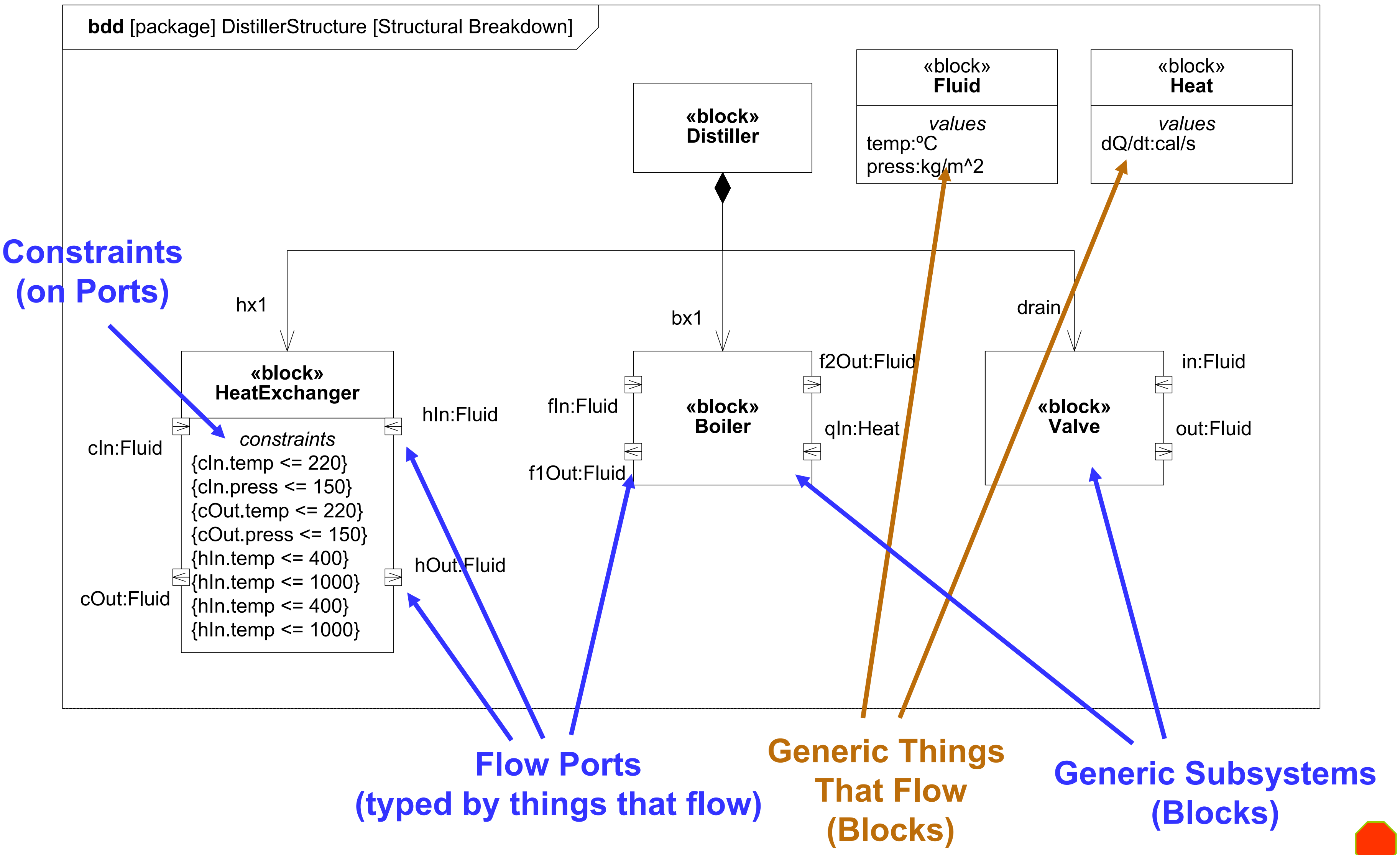
Distiller Example – Activity Diagram (with Swimlanes): DistillWater


Parts
act [activity] DistillWater [Swimlane Diagram]
«allocate» hx1:HeatExchanger
«allocate» bx1:Boiler
«allocate» drain:Valve
«continuous» coldDirty:H2O [liquid]
«continuous» external:Heat
«continuous» recovered:Heat
«continuous» steam:H2O [gas]
«continuous» hiPress:Residue
«continuous» loPress:Residue
«continuous» pure:H2O [liquid]
«streaming» a1:HeatWater
«streaming» a3:CondenseSteam
a4:DrainResidue
«continuous» hotDirty:H2O [liquid]
«streaming» a2:BoilWater
ShutDown

Distiller Example – Block Definition Diagram: DistillerStructure



Distiller Example – Block Definition Diagram: Heat Exchanger Flow Ports



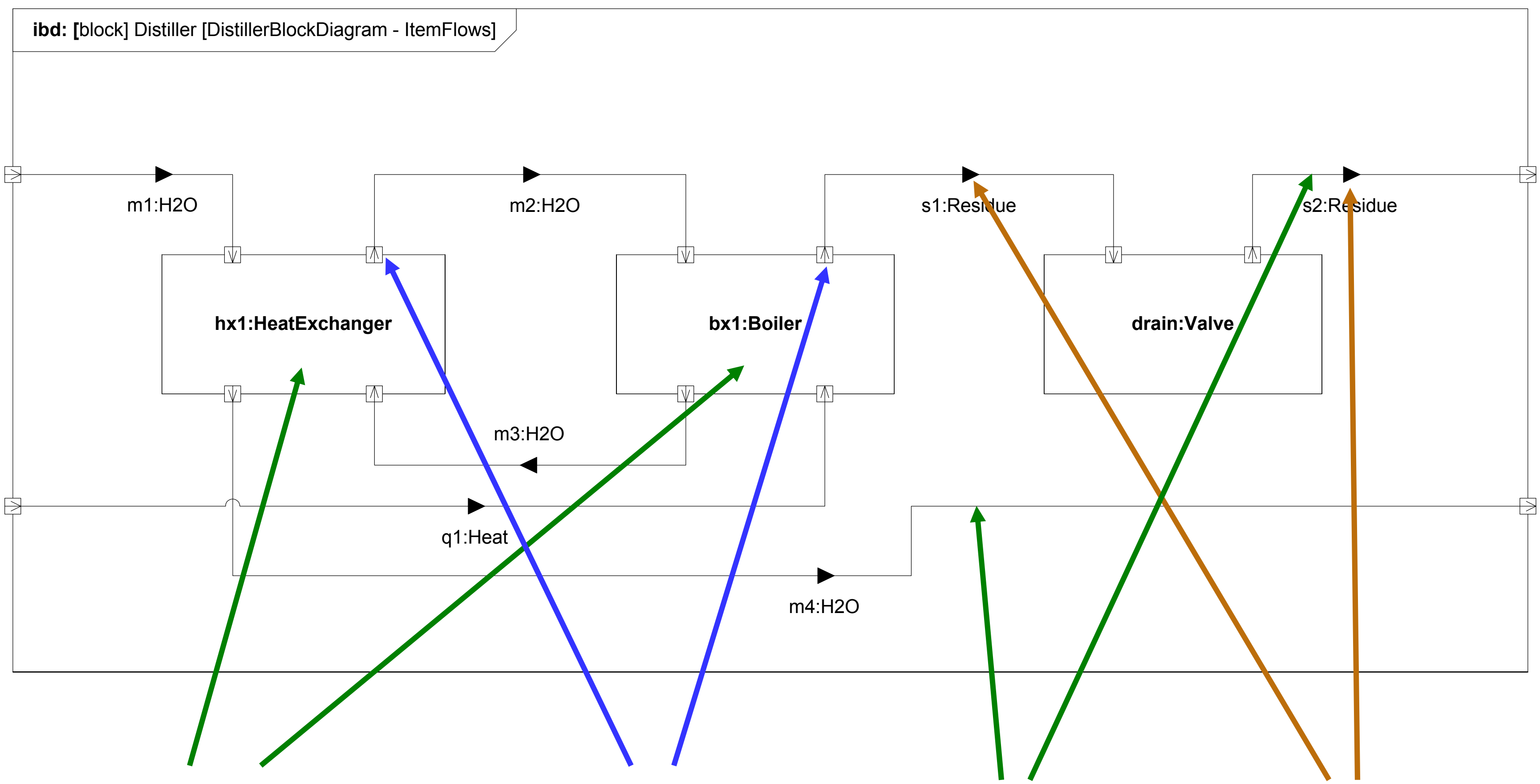
Constraints (on Ports)

Flow Ports (typed by things that flow)

Generic Things That Flow (Blocks)

Generic Subsystems (Blocks)

Distiller Example – Internal Block Diagram: Distiller Initial Design



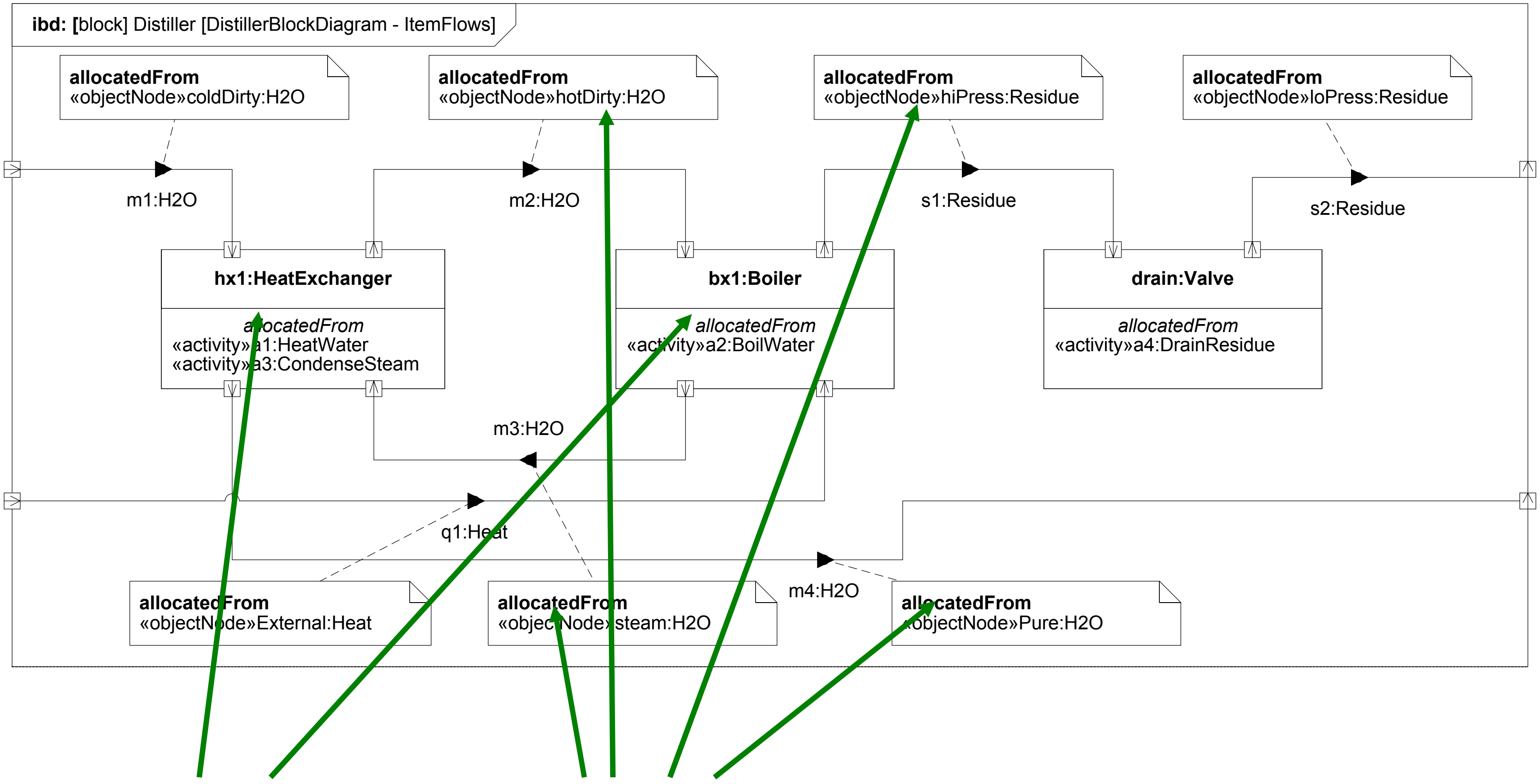
Parts (Blocks used in context)

Flow Ports

Connectors

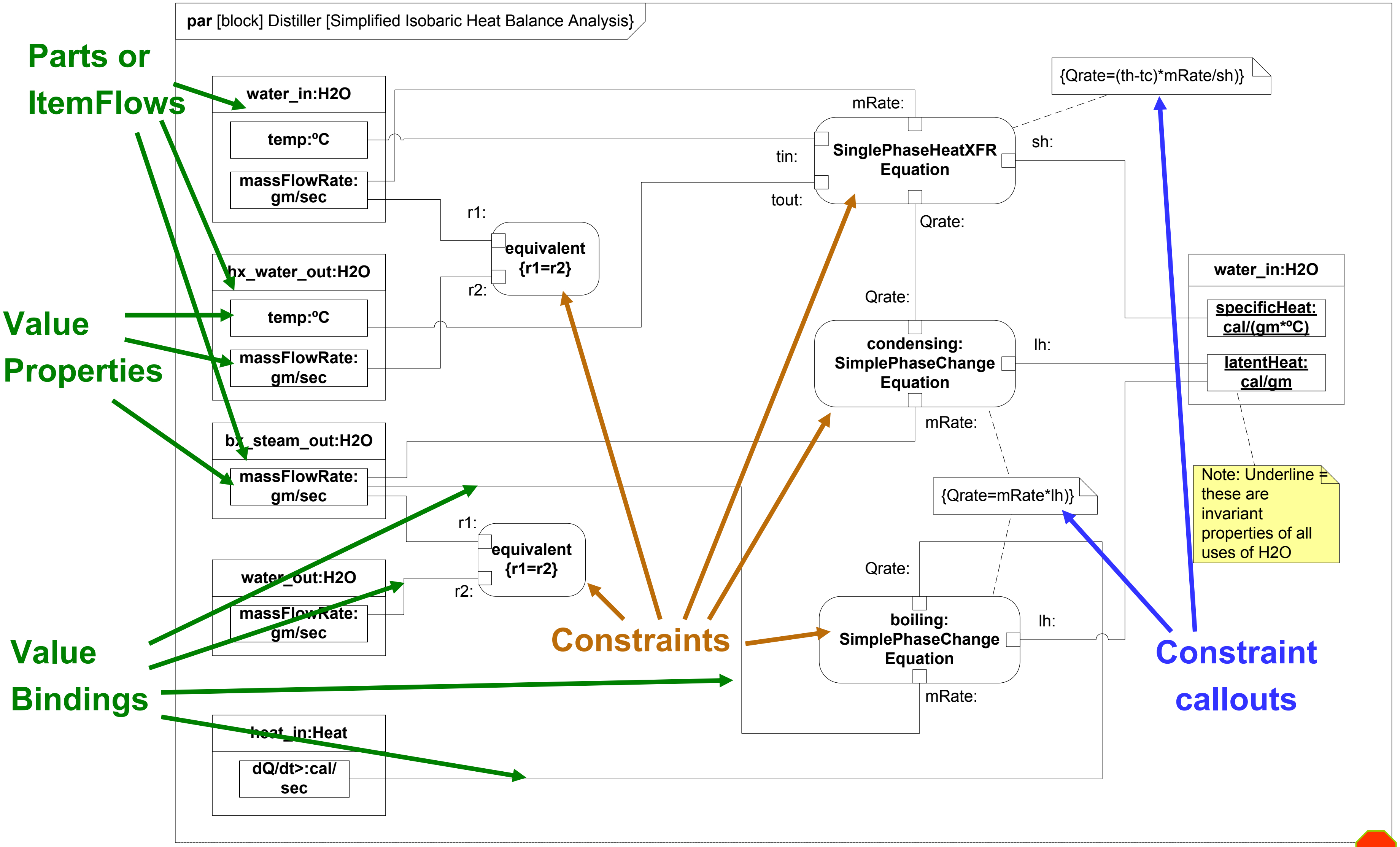
Things That Flow In Context (ItemFlows)

Distiller Example –Internal Block Diagram: Distiller with Allocation



Allocation Compartment **Allocation Callout**

Distiller Example – Parametric Diagram: Heat Balance Equations



Distiller Example – Heat Balance Results

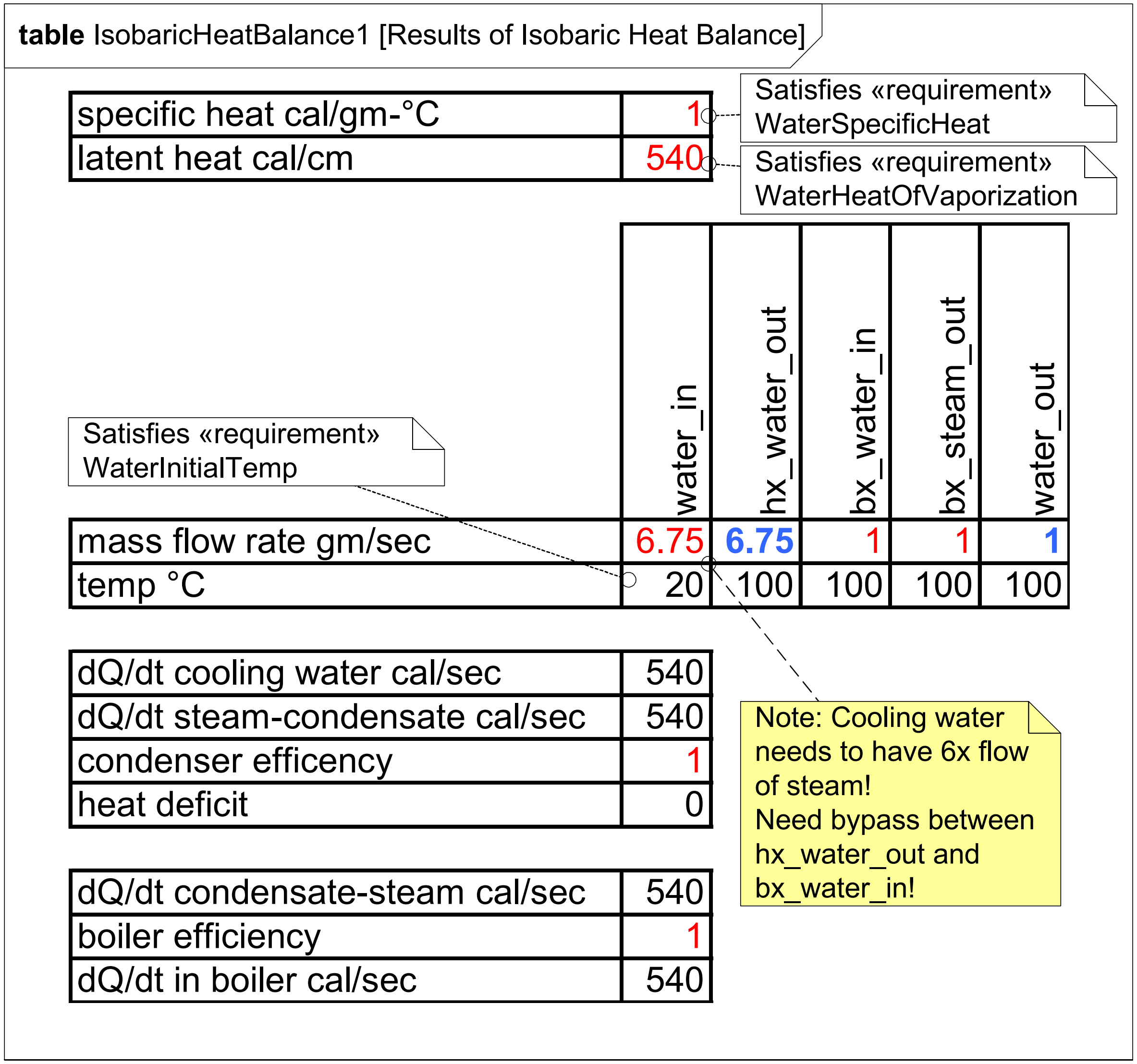


table IsobaricHeatBalance1 [Results of Isobaric Heat Balance]

specific heat cal/gm-°C	1
latent heat cal/cm	540

Satisfies «requirement» WaterSpecificHeat

Satisfies «requirement» WaterHeatOfVaporization

Satisfies «requirement» WaterInitialTemp

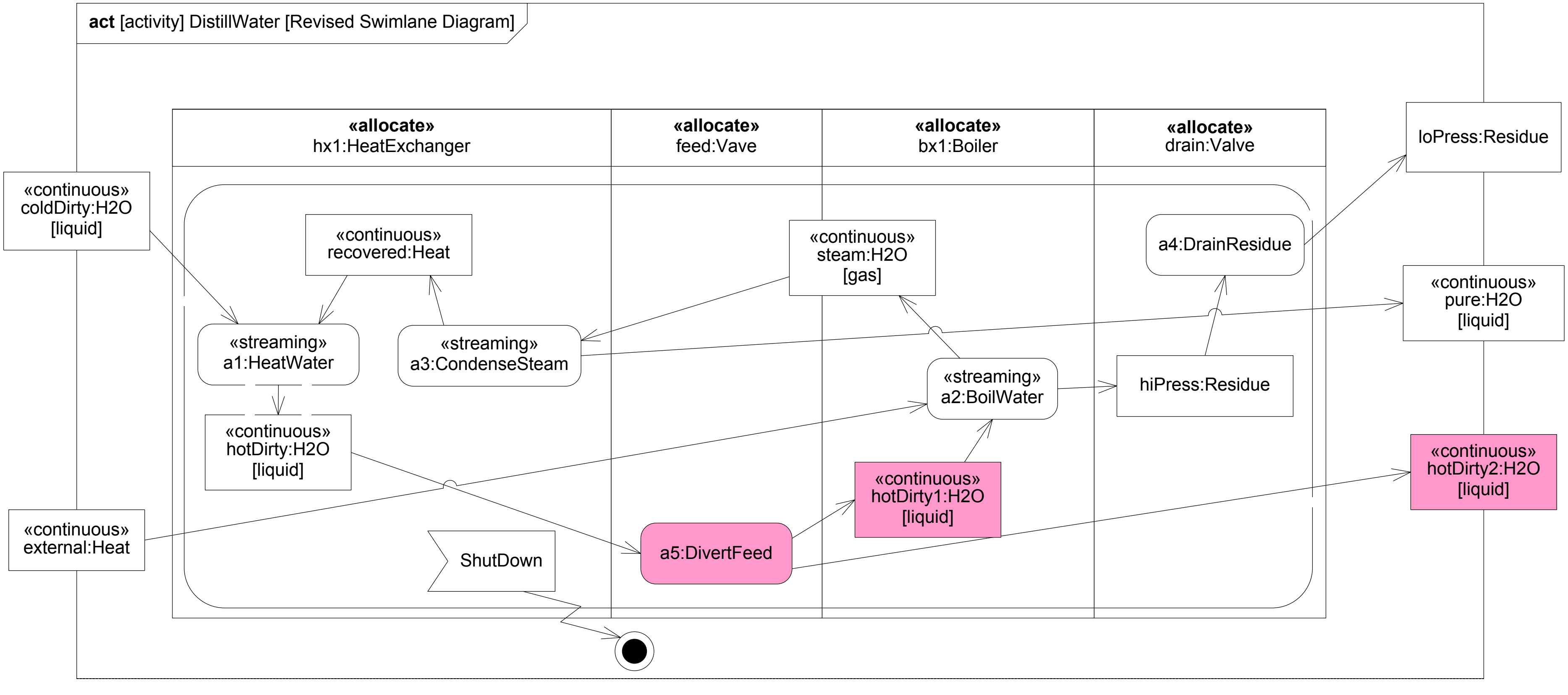
	water_in	hx_water_out	bx_water_in	bx_steam_out	water_out
mass flow rate gm/sec	6.75	**6.75**	1	1	**1**
temp °C	20	100	100	100	100

dQ/dt cooling water cal/sec	540
dQ/dt steam-condensate cal/sec	540
condenser efficency	1
heat deficit	0

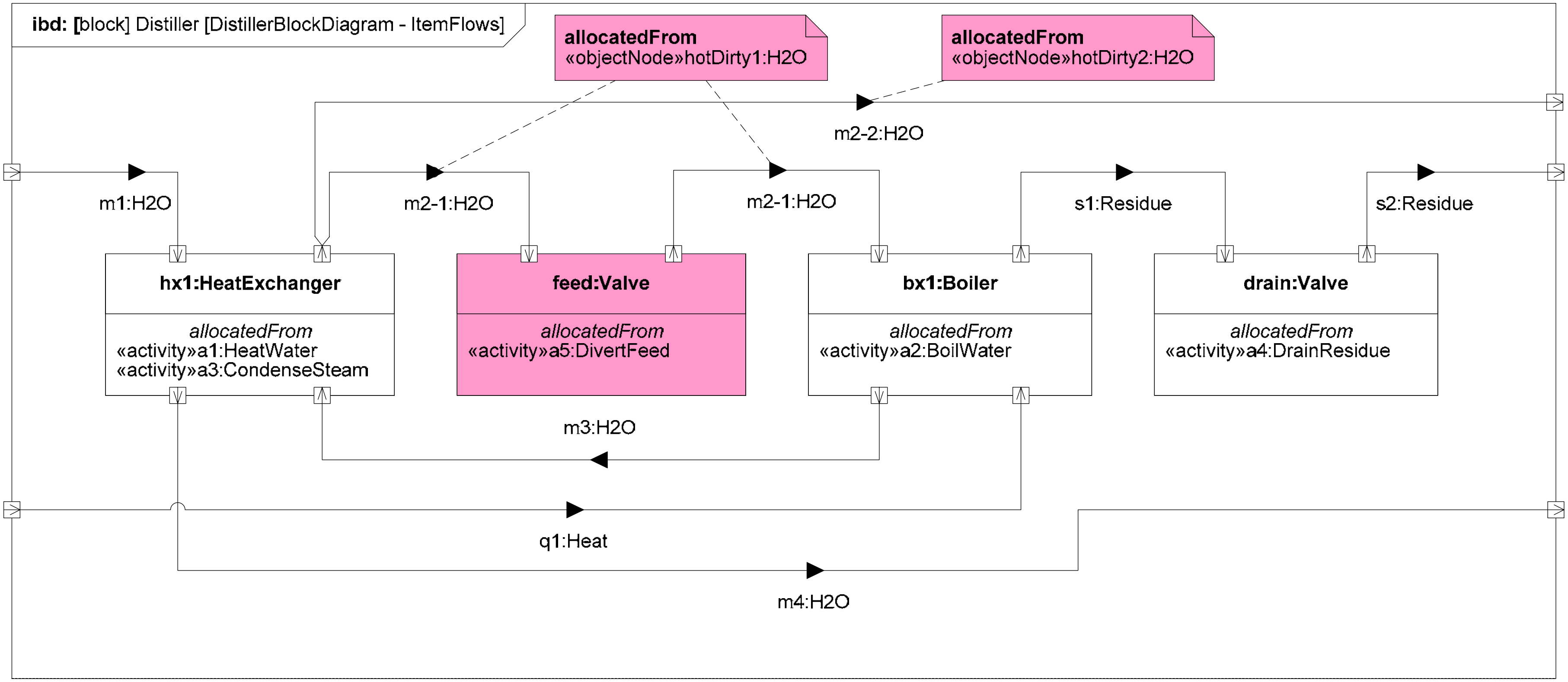
Note: Cooling water needs to have 6x flow of steam!
Need bypass between hx_water_out and bx_water_in!

dQ/dt condensate-steam cal/sec	540
boiler efficiency	1
dQ/dt in boiler cal/sec	540

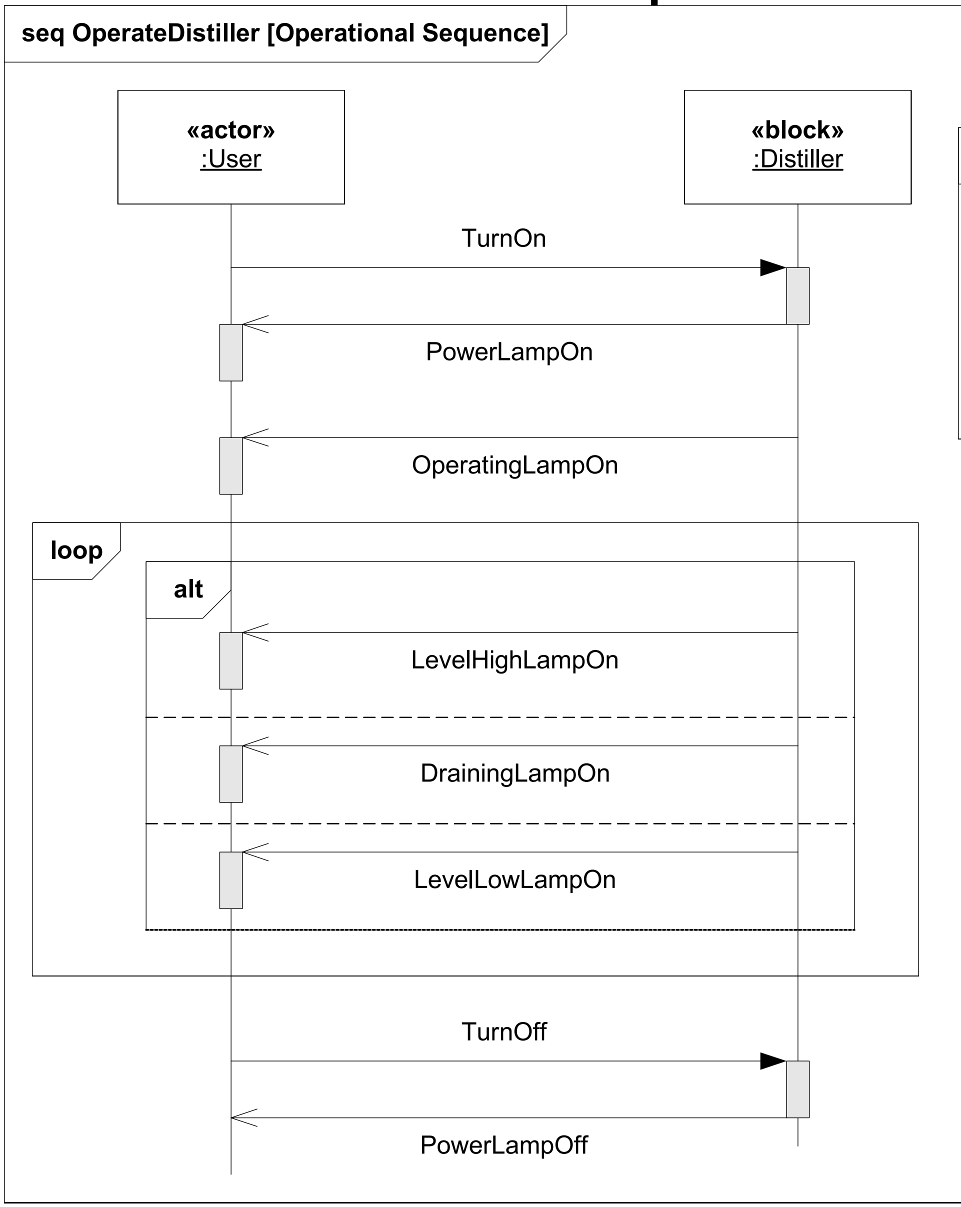
Distiller Example – Activity Diagram: Updated DistillWater

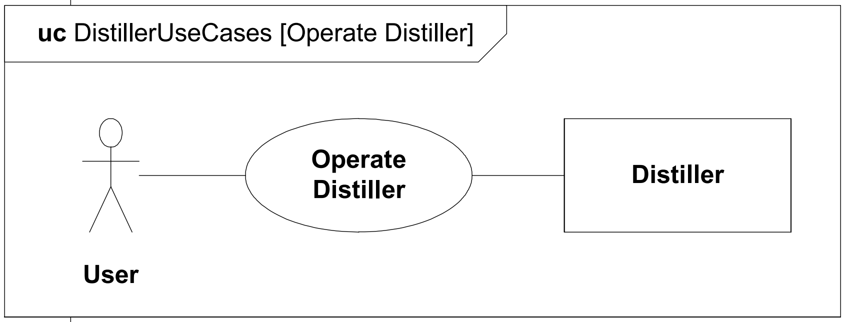


Distiller Example – Internal Block Diagram: Updated Distiller

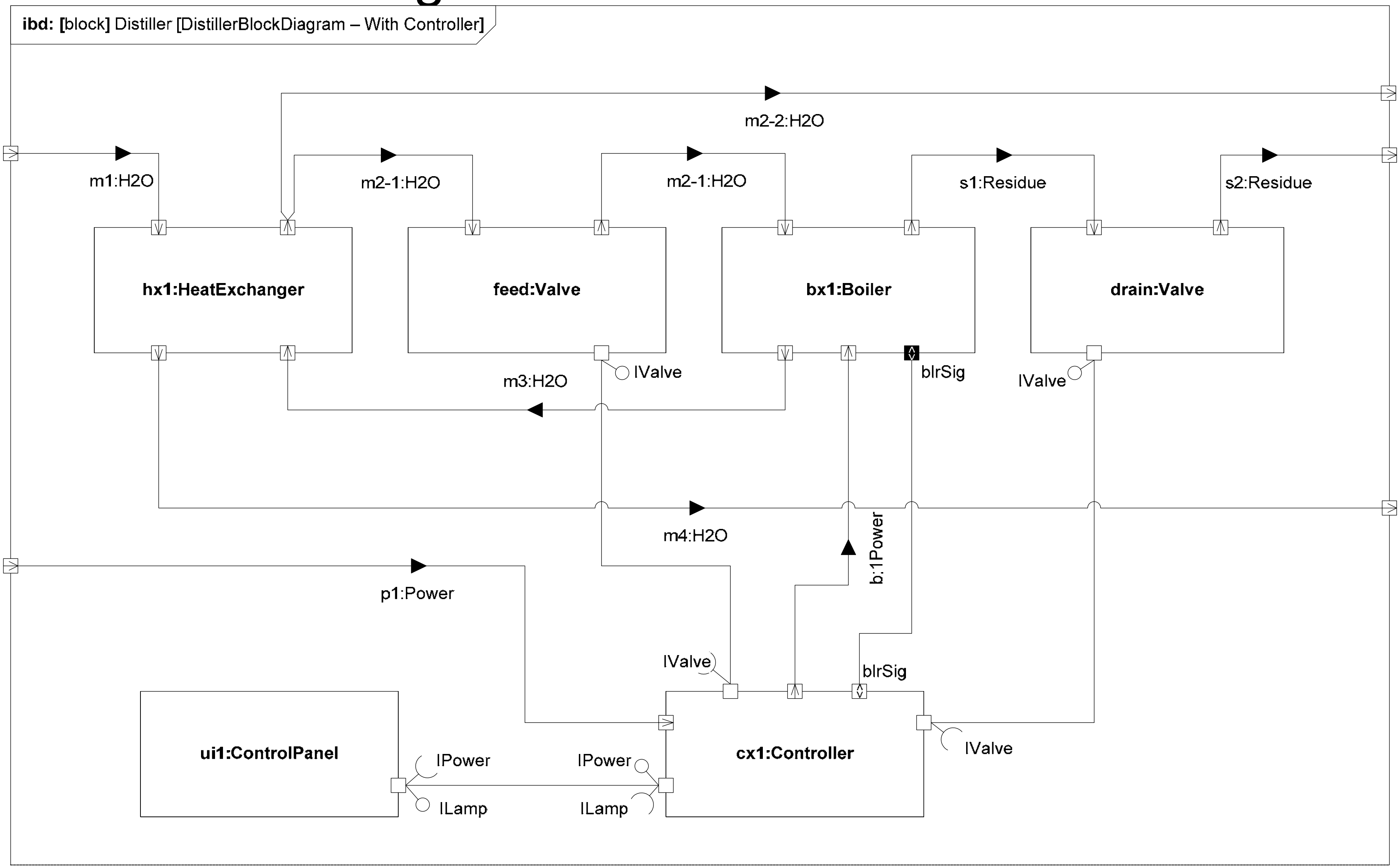


Distiller Example – Use Case and Sequence Diagrams

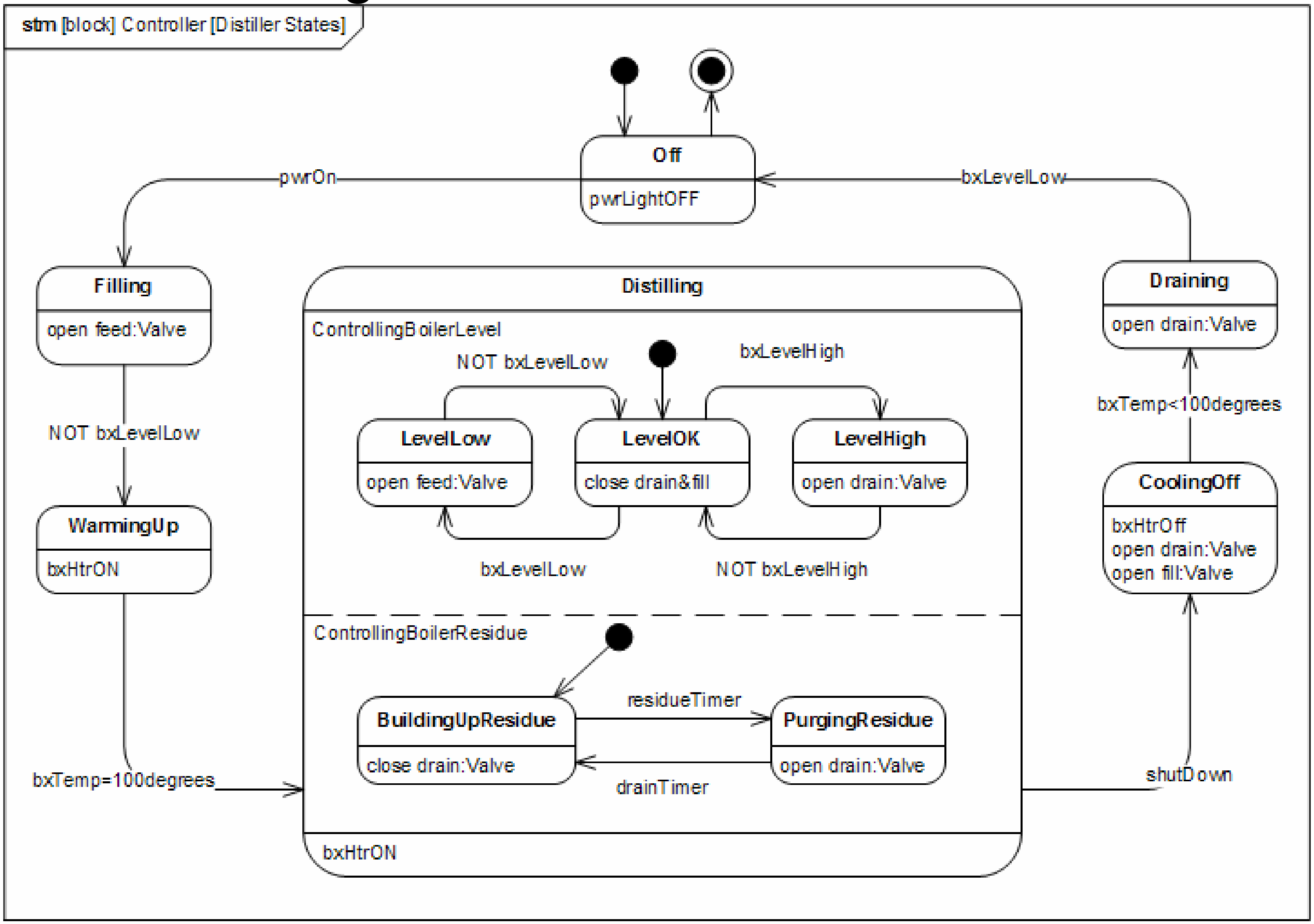


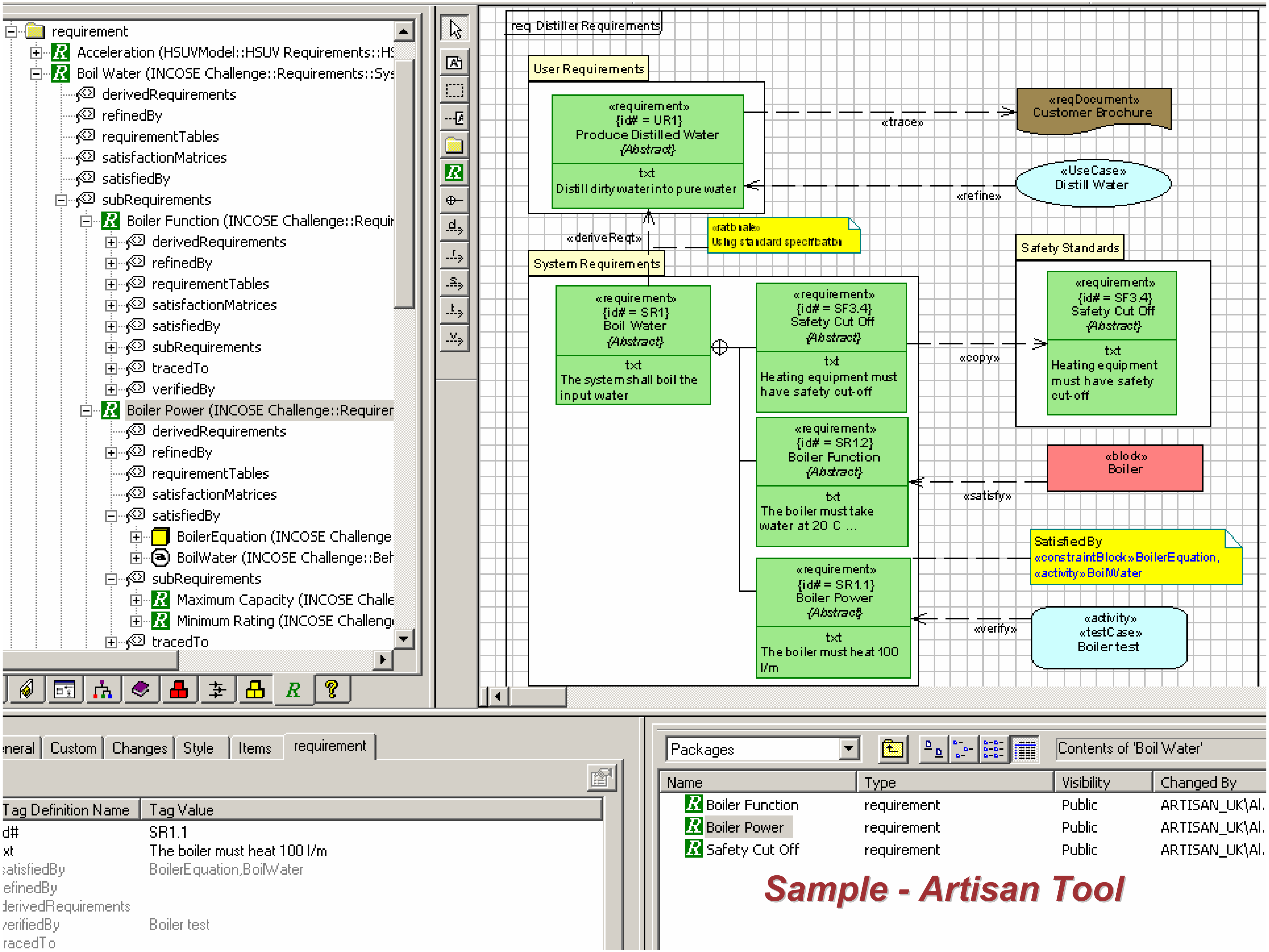


Distiller Example – Internal Block Diagram: Distiller Controller



Distiller Example – State Machine Diagram: Distiller Controller





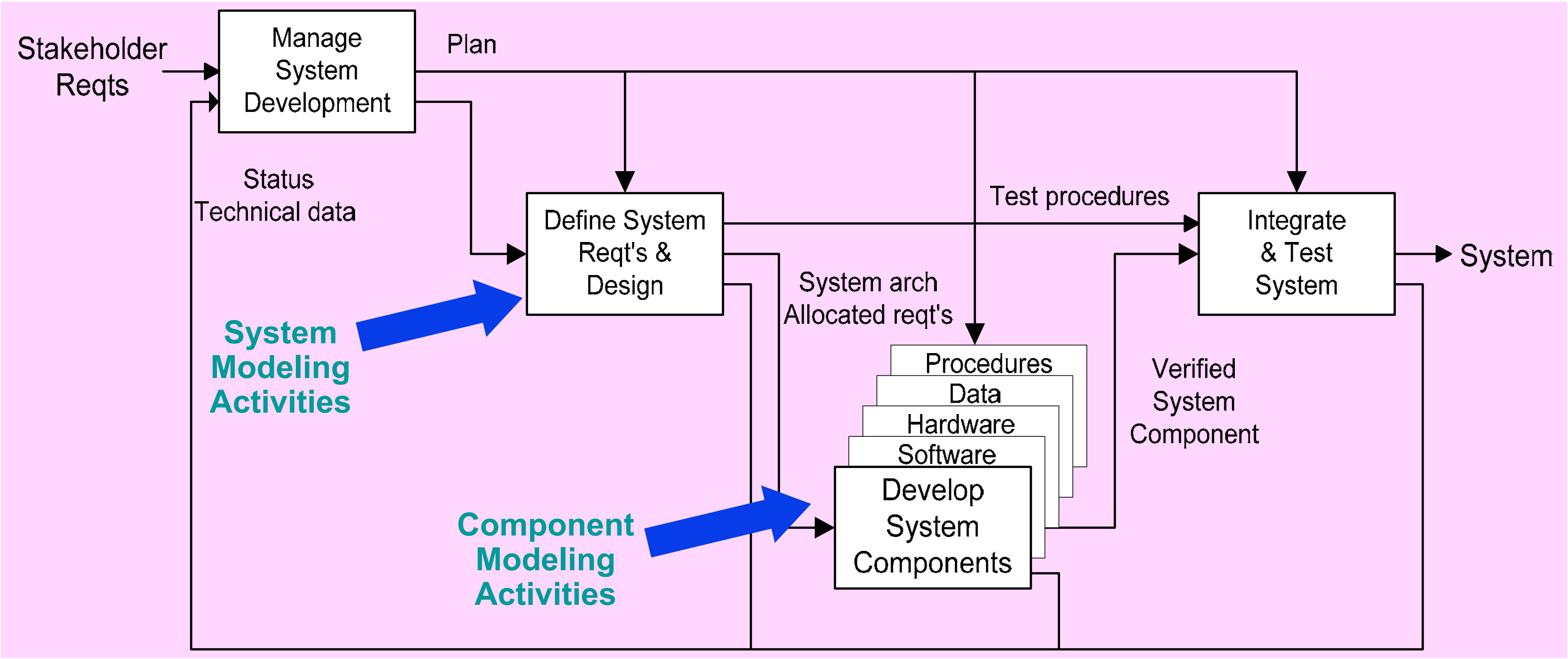
Tag Definition Name	Tag Value
d#	SR1.1
xt	The boiler must heat 100 l/m
satisfiedBy	BoilerEquation,BoilWater
efinedBy	
derivedRequirements	
verifiedBy	Boiler test
racedTo	

Name	Type	Visibility	Changed By
Boiler Function	requirement	Public	ARTISAN_UK\Al.
Boiler Power	requirement	Public	ARTISAN_UK\Al.
Safety Cut Off	requirement	Public	ARTISAN_UK\Al.

Sample - Artisan Tool

OOSEM – ESS Example

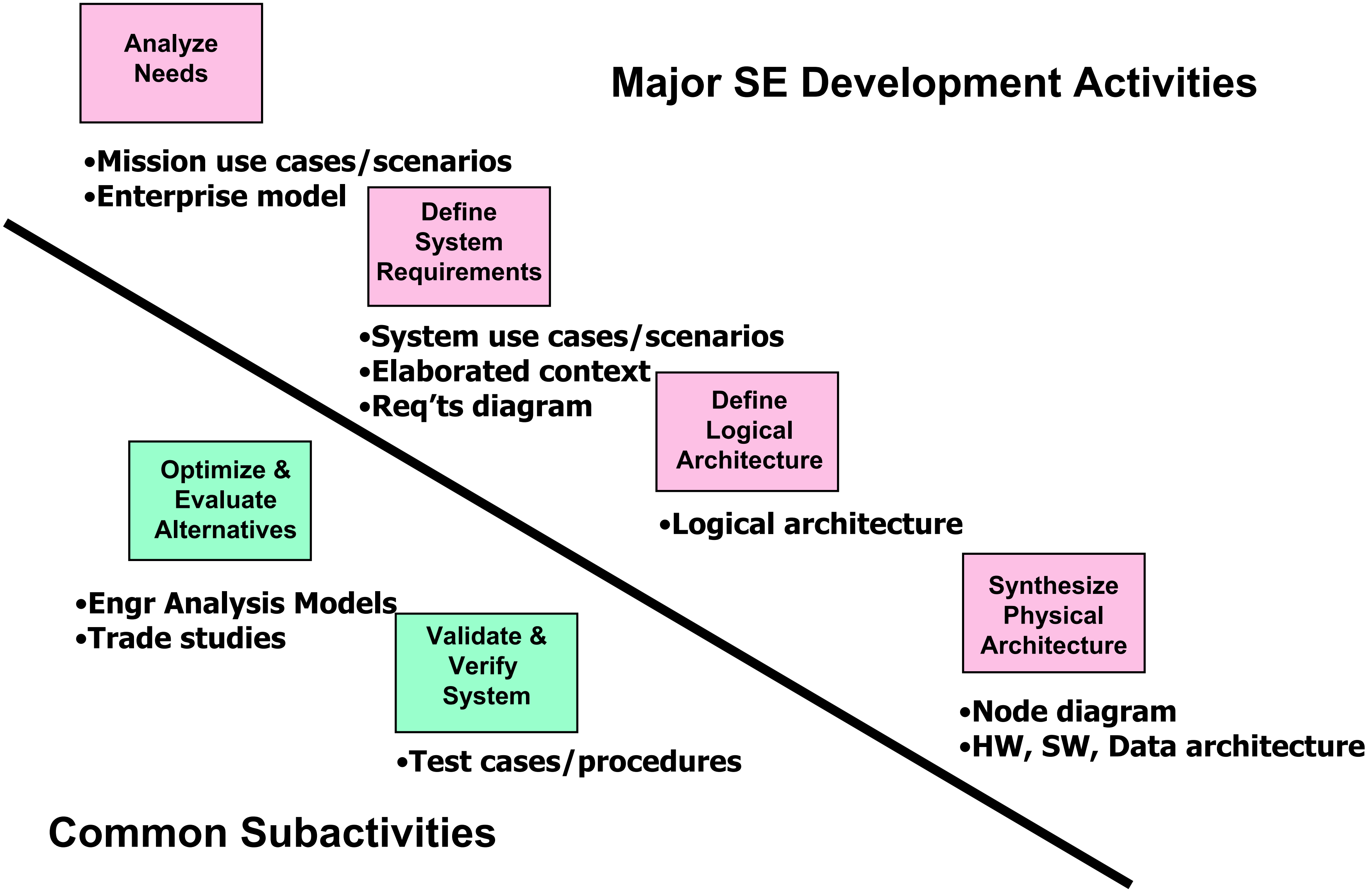
System Development Process


Stakeholder Reqts
Manage System Development
Plan
Status
Technical data
Define System Reqt's & Design
Test procedures
Integrate & Test System
System
System arch
Allocated reqt's
Procedures
Data
Hardware
Software
Develop System Components
Verified System Component
System Modeling Activities
Component Modeling Activities

Integrated Product Development (IPD) is essential to improve communications

A Recursive V process that can be applied to multiple levels of the system hierarchy

Systems Modeling Activities - OOSEM



Analyze Needs

- Mission use cases/scenarios
- Enterprise model

Major SE Development Activities

Define System Requirements

- System use cases/scenarios
- Elaborated context
- Req'ts diagram

Define Logical Architecture

- Logical architecture

Synthesize Physical Architecture

- Node diagram
- HW, SW, Data architecture

Optimize & Evaluate Alternatives

- Engr Analysis Models
- Trade studies

Validate & Verify System

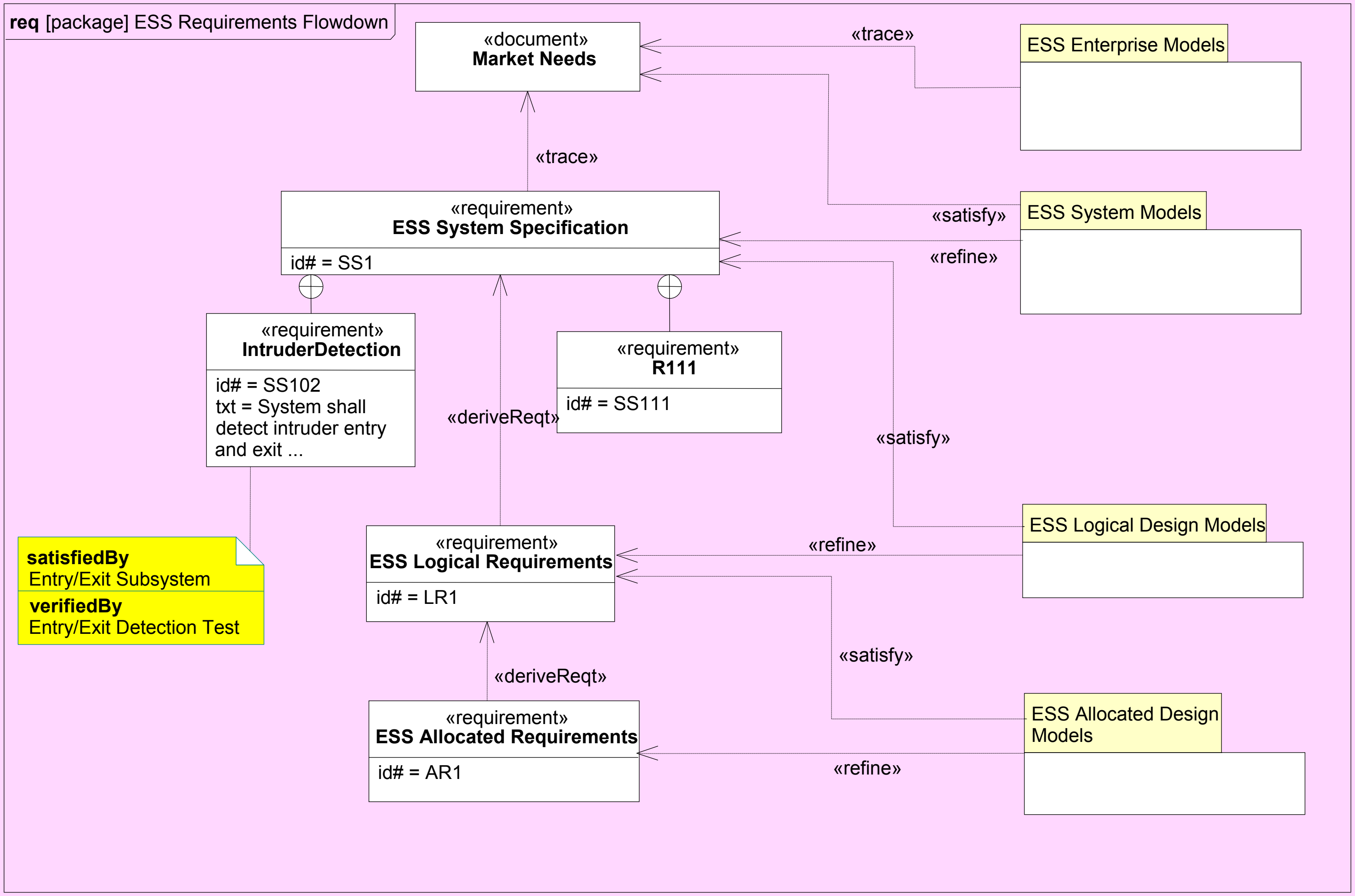
- Test cases/procedures

Common Subactivities

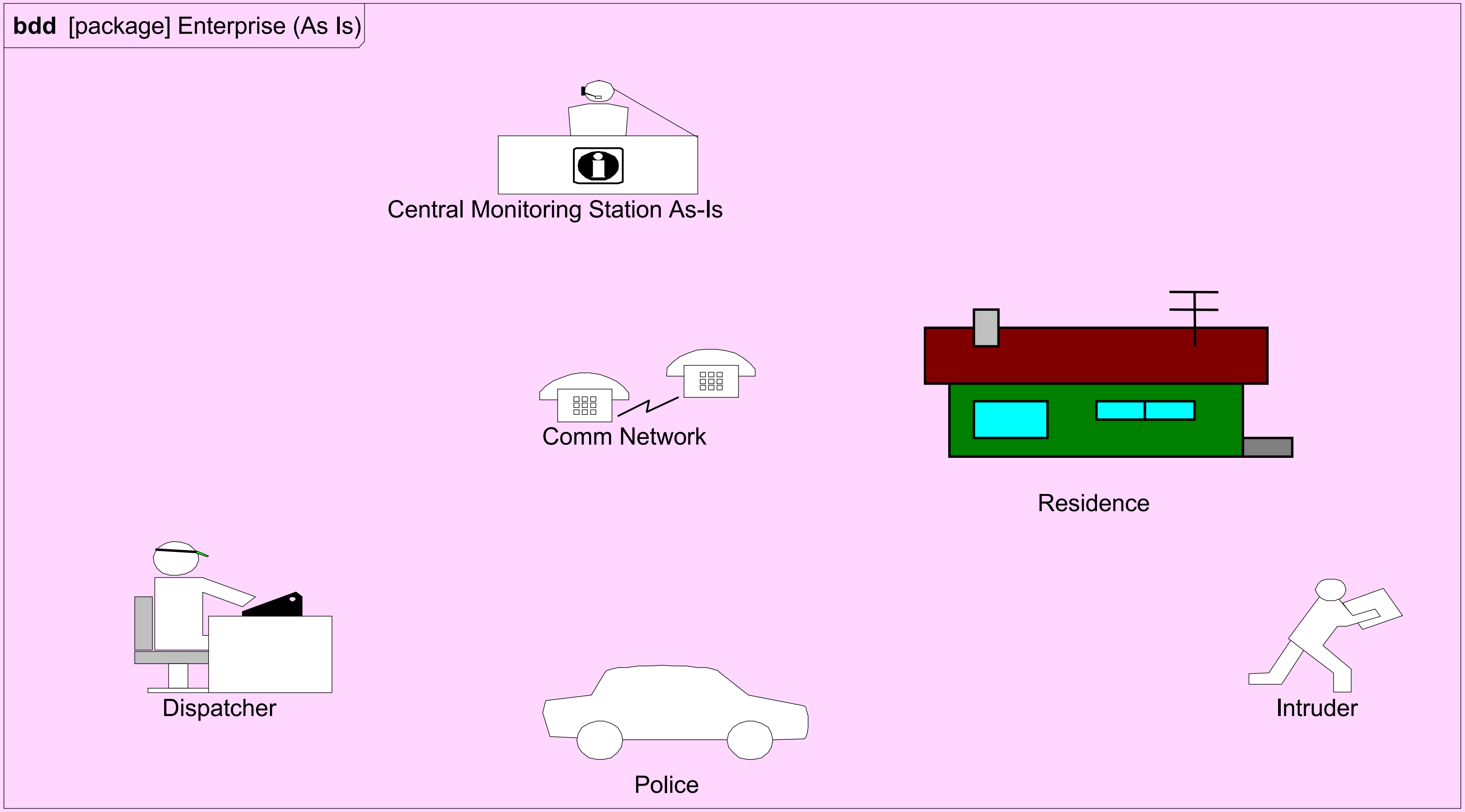
Enhanced Security System Example

- The Enhanced Security System is the example for the OOSEM material
  - Problem fragments used to demonstrate principles
  - Utilizes Artisan RTS™ Tool for the SysML artifacts

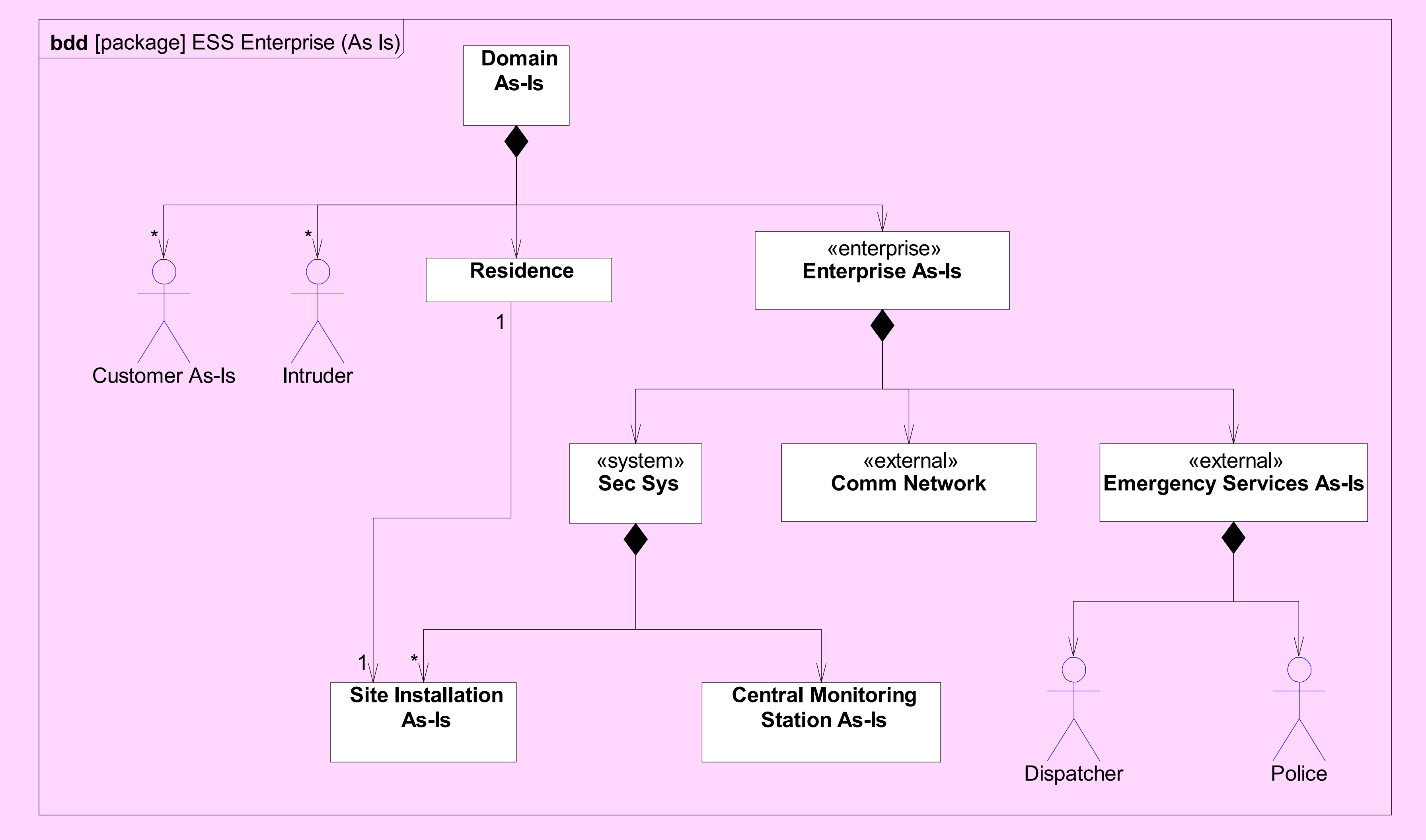
ESS Requirements Flowdown



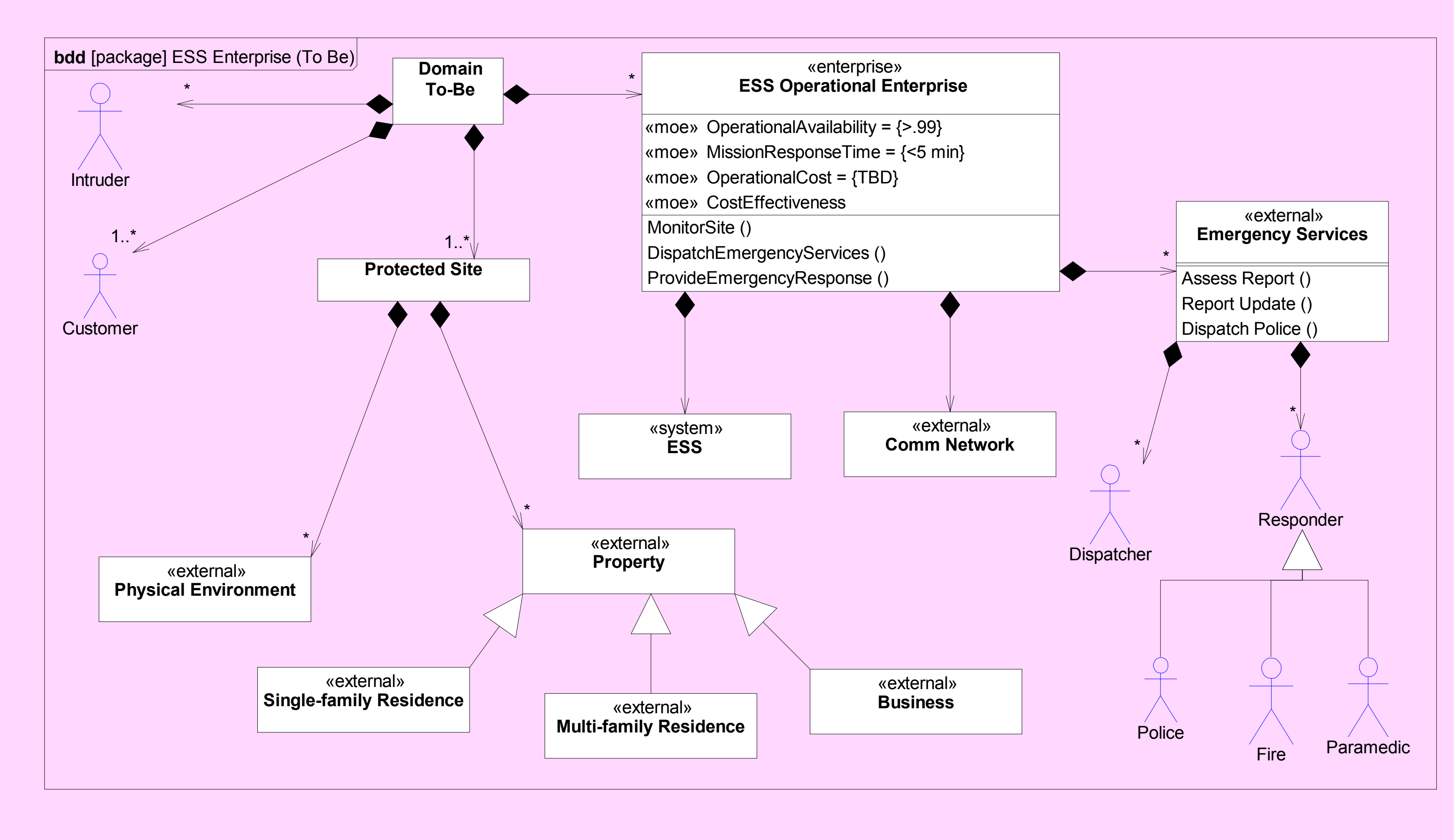
Operational View Depiction


bdd [package] Enterprise (As Is)
Central Monitoring Station As-Is
Comm Network
Residence
Dispatcher
Police
Intruder

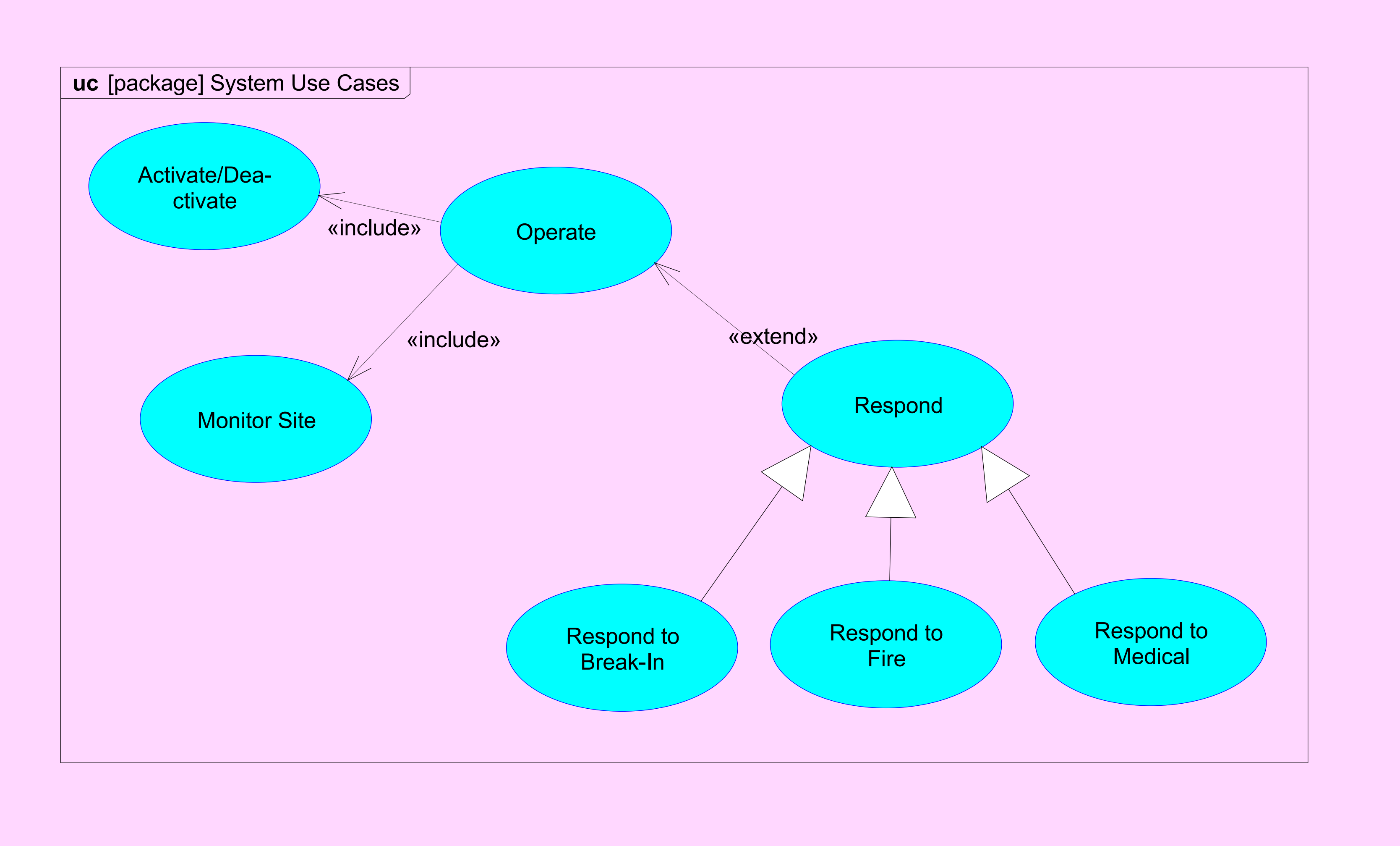
ESS Enterprise As-Is Model


bdd [package] ESS Enterprise (As Is)
Domain As-Is
*
*
Customer As-Is
Intruder
Residence
1
«enterprise» Enterprise As-Is
«system» Sec Sys
«external» Comm Network
«external» Emergency Services As-Is
1
*
Site Installation As-Is
Central Monitoring Station As-Is
Dispatcher
Police

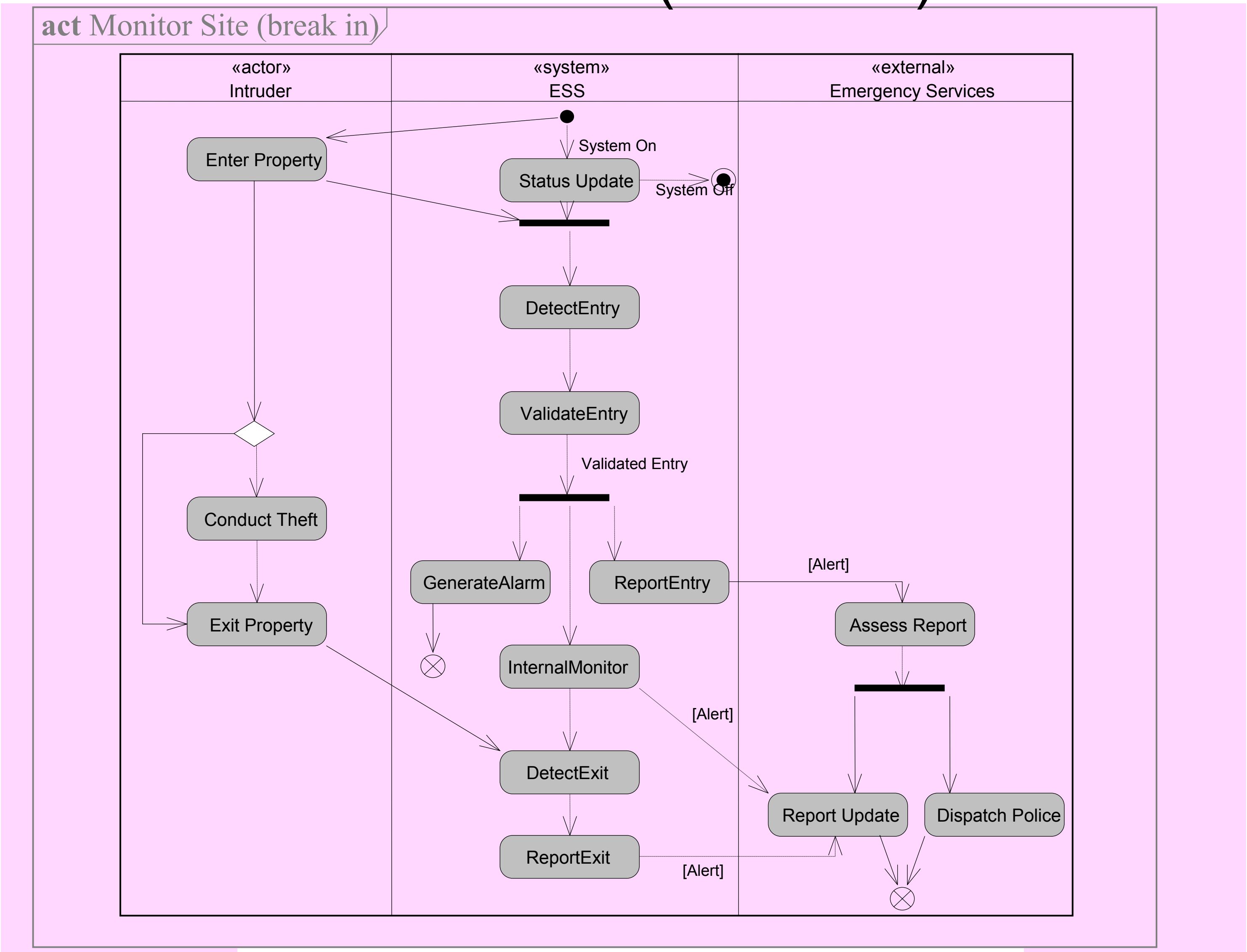
ESS Operational Enterprise To-Be Model


bdd [package] ESS Enterprise (To Be)
Domain To-Be
«enterprise» ESS Operational Enterprise
«moe» OperationalAvailability = {>.99}
«moe» MissionResponseTime = {<5 min}
«moe» OperationalCost = {TBD}
«moe» CostEffectiveness
MonitorSite ()
DispatchEmergencyServices ()
ProvideEmergencyResponse ()
«external» Emergency Services
Assess Report ()
Report Update ()
Dispatch Police ()
Intruder
Customer
Protected Site
«system» ESS
«external» Comm Network
Dispatcher
Responder
«external» Physical Environment
«external» Property
«external» Single-family Residence
«external» Multi-family Residence
«external» Business
Police
Fire
Paramedic
*
1..*
1..*
*
*
*
*
*
*

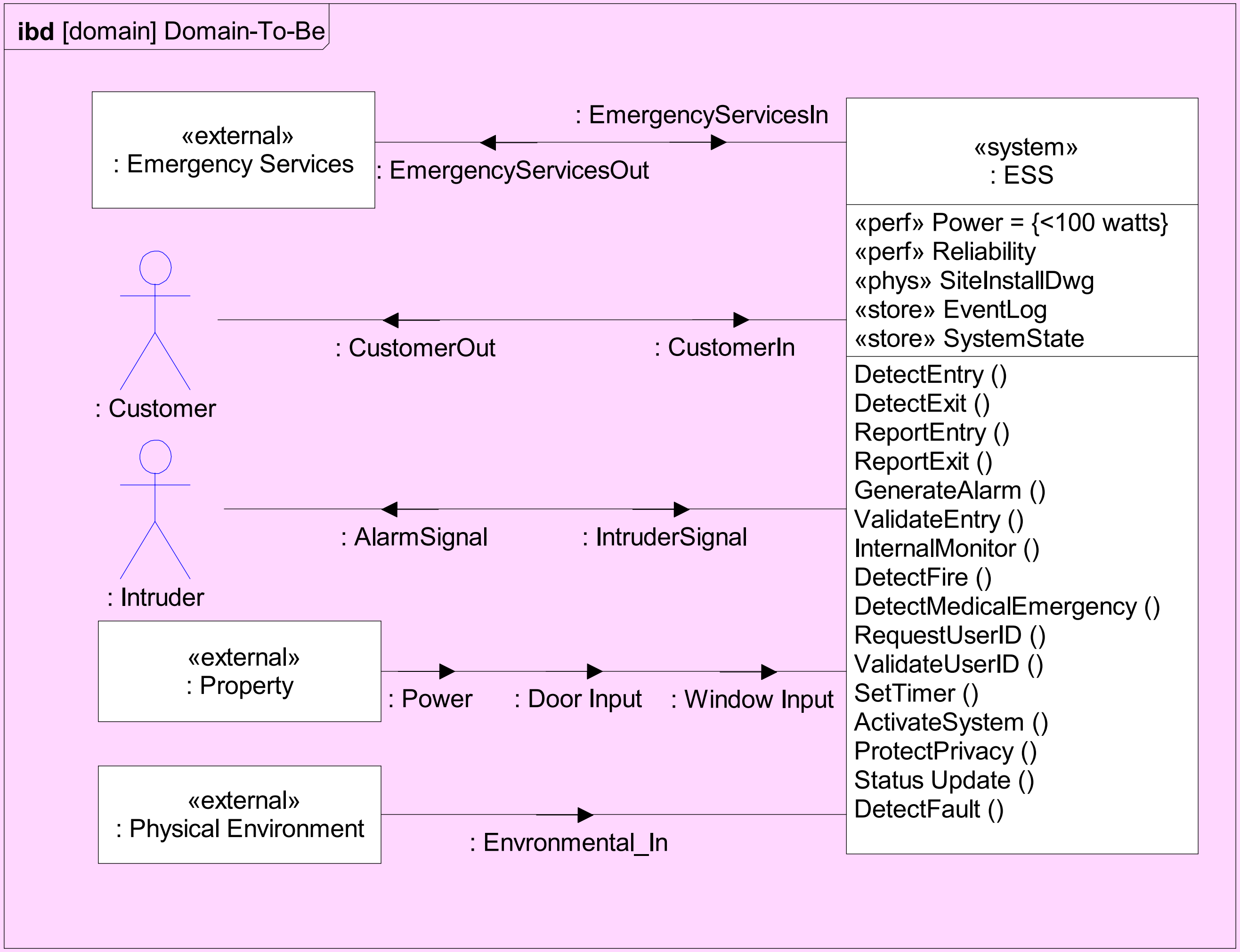
System Use Cases - Operate



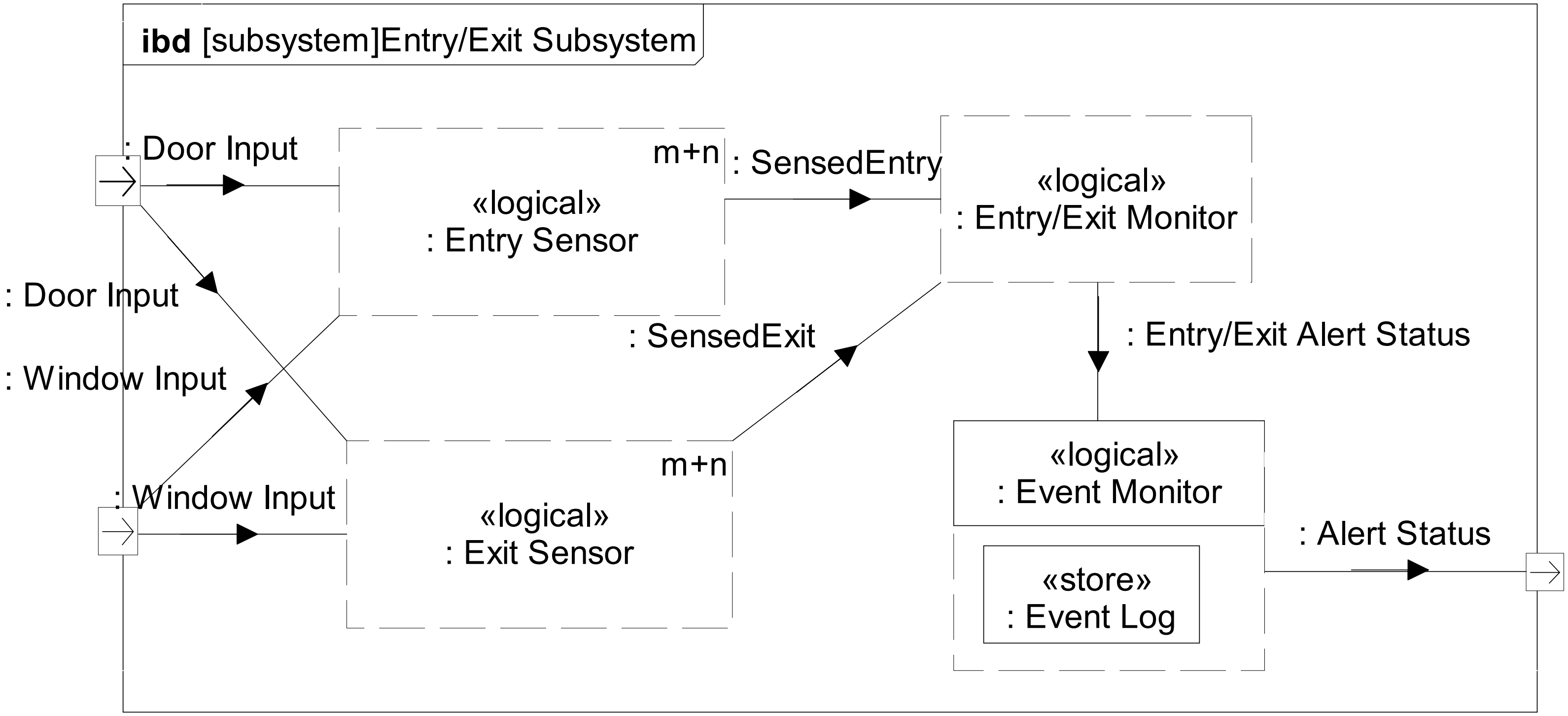
System Scenario: Activity Diagram Monitor Site (Break-In)



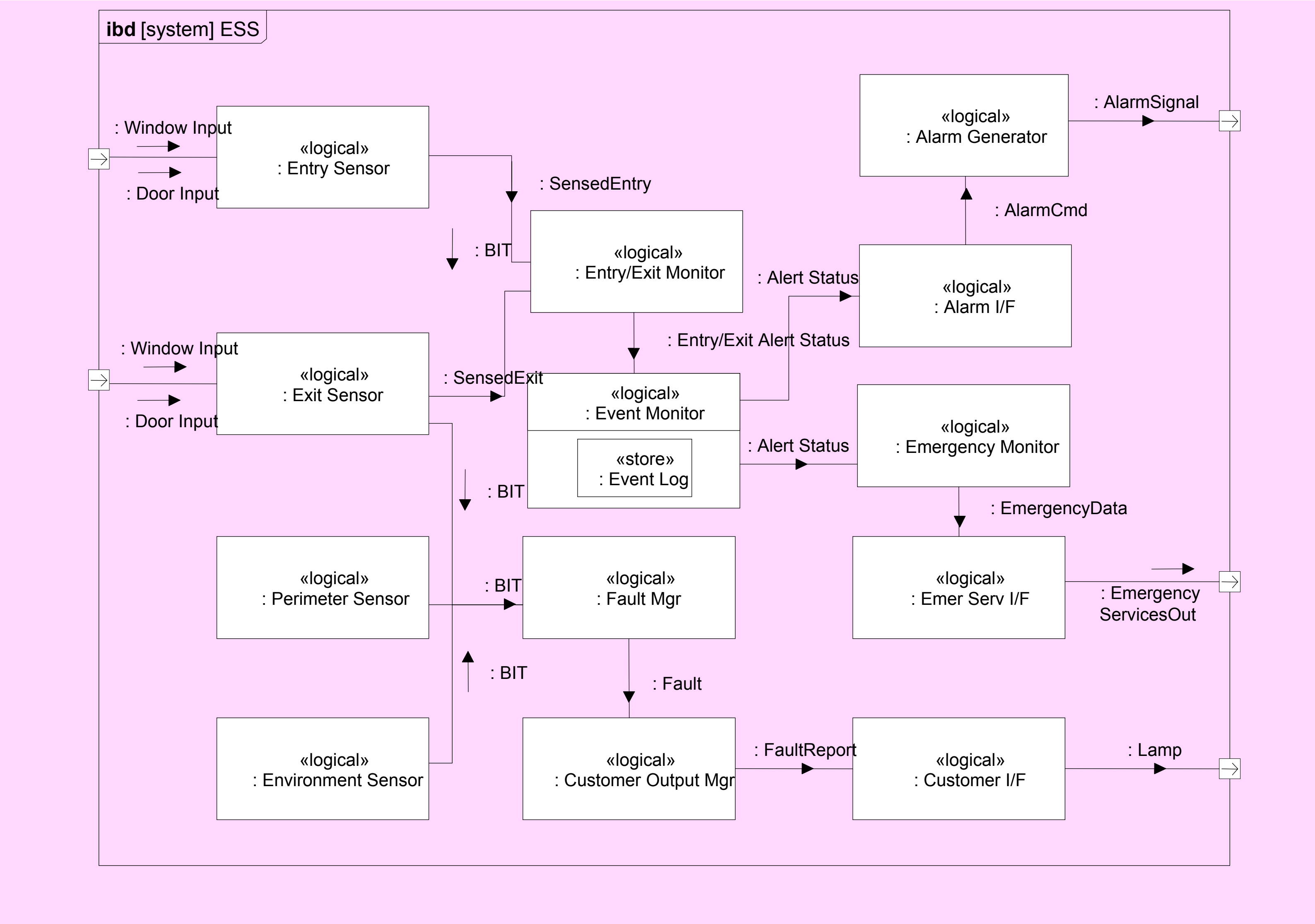
ESS Elaborated Context Diagram



ESS Logical Design – Example Subsystem



ESS Logical Design (Partial)

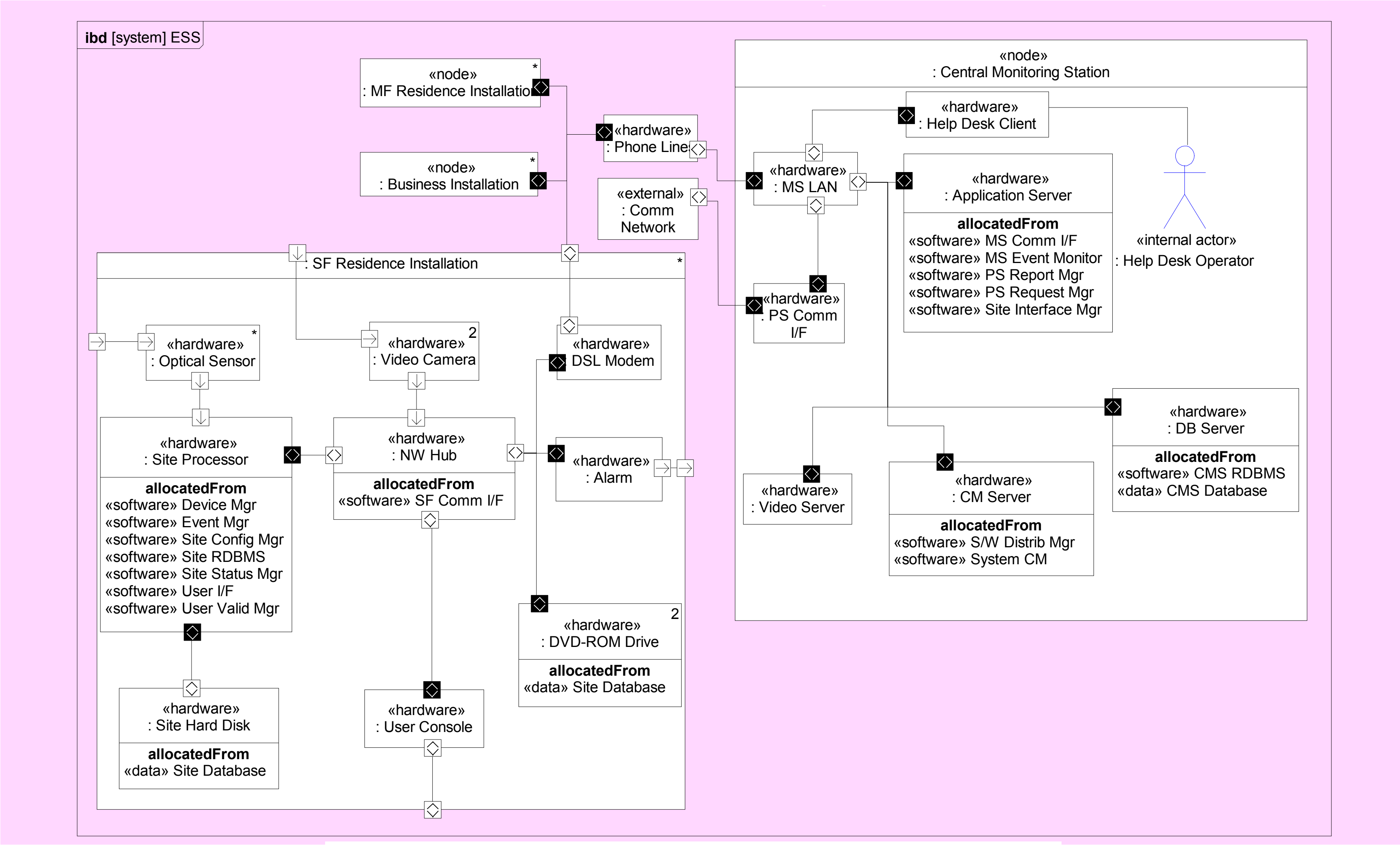


ESS Allocation Table (partial)

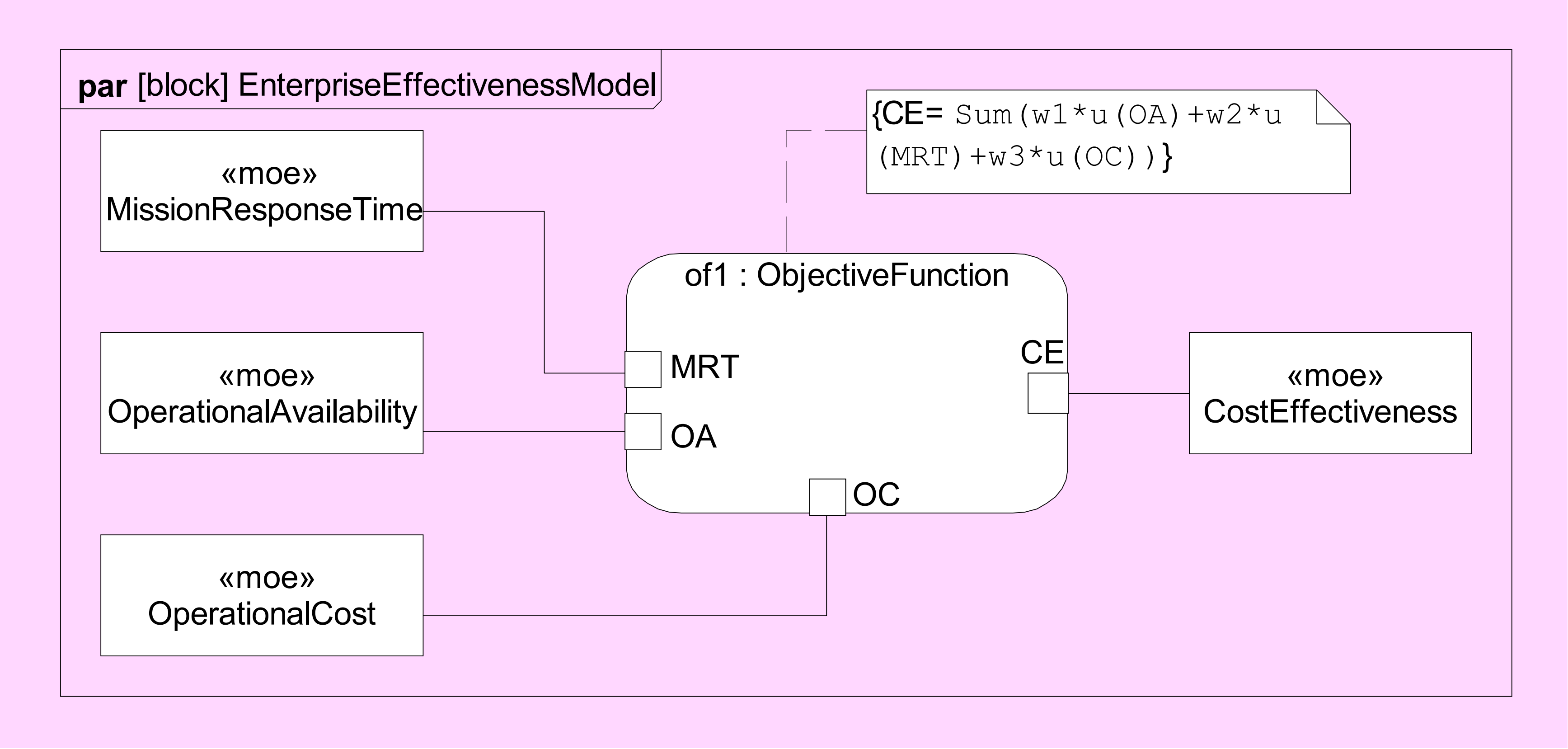
- Allocating Logical Components to HW, SW, Data, and Procedures components

			Logical Components												
Physical Components	Type		Entry Sensor	Exit Sensor	Perimeter Sensor	Entry/Exit Monitor	Event Monitor	Site Comms I/F	Event Log	Customer I/F	Customer Output Mgr	System Status	Fault Mgr	Alarm Generator	Alarm I/F
	«software»	Device Mgr													X
		SF Comm I/F						X							
		User I/F									X				
		Event Mgr				X	X								
		Site Status Mgr											X		
		Site RDBMS							X			X			
		CMS RDBMS							X						
	«data»	Video File							X						
		CMS Database							X						
		Site Database							X			X			
	«hardware»	Optical Sensor	X	X											
		DSL Modem						X							
		User Console								X					
		Video Camera			X										
		Alarm												X	

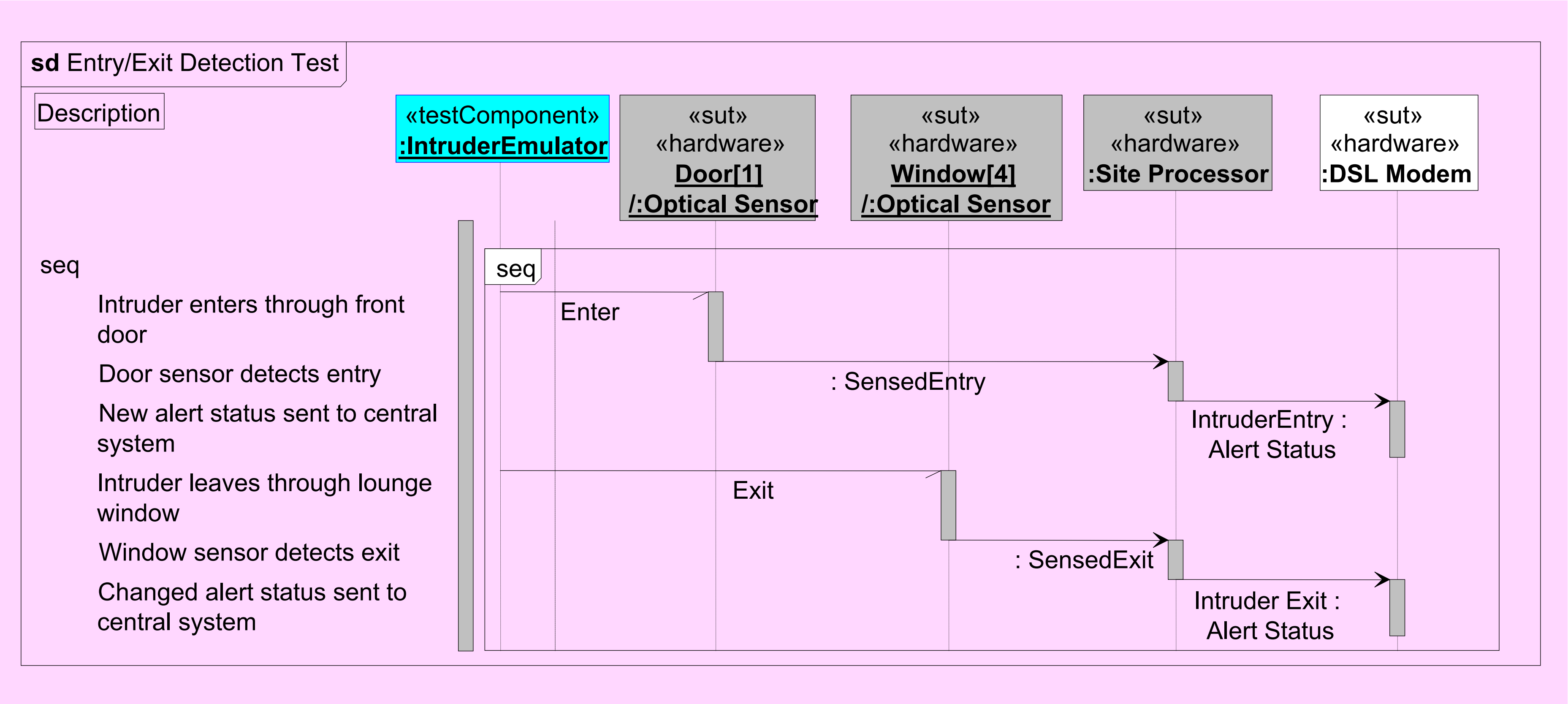
ESS Deployment View



ESS Parametric Diagram To Support Trade-off Analysis


par [block] EnterpriseEffectivenessModel
{CE= Sum(w1*u(OA)+w2*u (MRT)+w3*u(OC))}
«moe» MissionResponseTime
«moe» OperationalAvailability
«moe» OperationalCost
of1 : ObjectiveFunction
MRT
OA
OC
CE
«moe» CostEffectiveness

Entry/Exit Test Case



sd Entry/Exit Detection Test

Description

«testComponent»
:IntruderEmulator

«sut»
«hardware»
Door[1]
/:Optical Sensor

«sut»
«hardware»
Window[4]
/:Optical Sensor

«sut»
«hardware»
:Site Processor

«sut»
«hardware»
:DSL Modem

seq

Intruder enters through front door

Door sensor detects entry

New alert status sent to central system

Intruder leaves through lounge window

Window sensor detects exit

Changed alert status sent to central system

seq

Enter

: SensedEntry

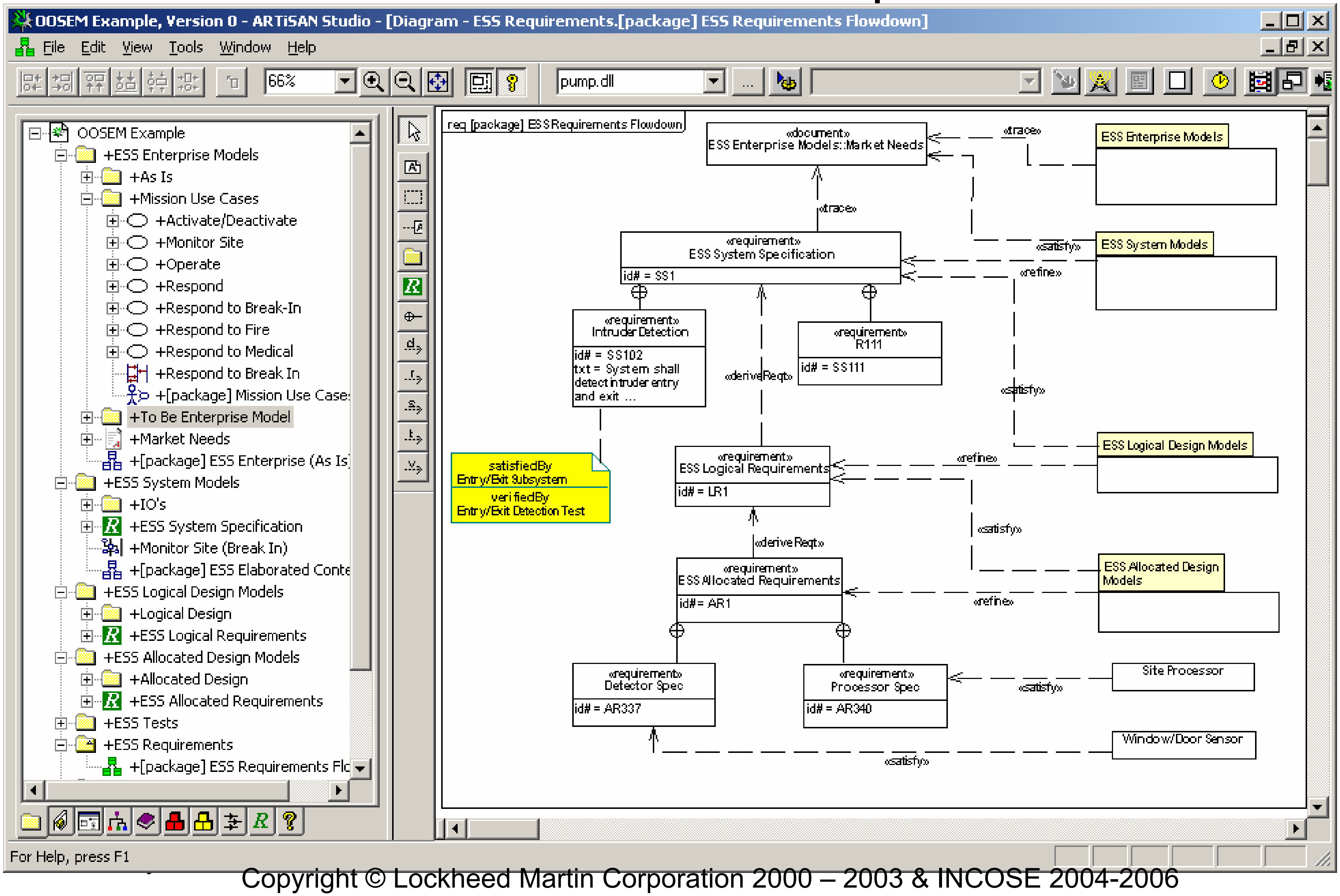
IntruderEntry : Alert Status

Exit

: SensedExit

Intruder Exit : Alert Status

OOSEM Browser View
Artisan Studio™ Example



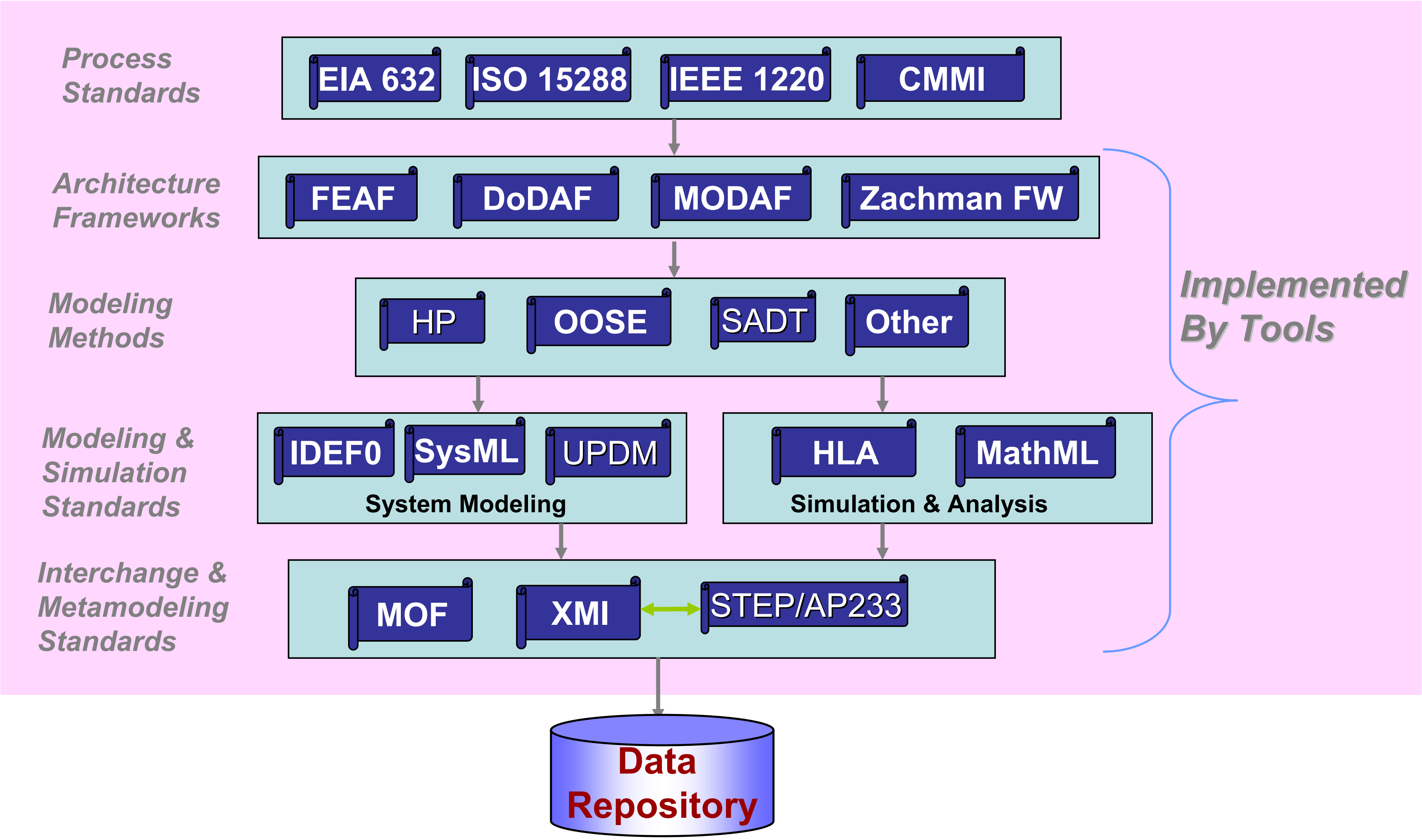
OOSEM Example, Version 0 - ARTiSAN Studio - [Diagram - ESS Requirements.[package] ESS Requirements Flowdown]

- OOSEM Example
  - +ESS Enterprise Models
    - +As Is
    - +Mission Use Cases
      - +Activate/Deactivate
      - +Monitor Site
      - +Operate
      - +Respond
      - +Respond to Break-In
      - +Respond to Fire
      - +Respond to Medical
      - +Respond to Break In
      - +[package] Mission Use Case:
    - +To Be Enterprise Model
    - +Market Needs
    - +[package] ESS Enterprise (As Is]
  - +ESS System Models
    - +IO's
    - +ESS System Specification
    - +Monitor Site (Break In)
    - +[package] ESS Elaborated Conte
  - +ESS Logical Design Models
    - +Logical Design
    - +ESS Logical Requirements
  - +ESS Allocated Design Models
    - +Allocated Design
    - +ESS Allocated Requirements
  - +ESS Tests
  - +ESS Requirements
    - +[package] ESS Requirements Flc

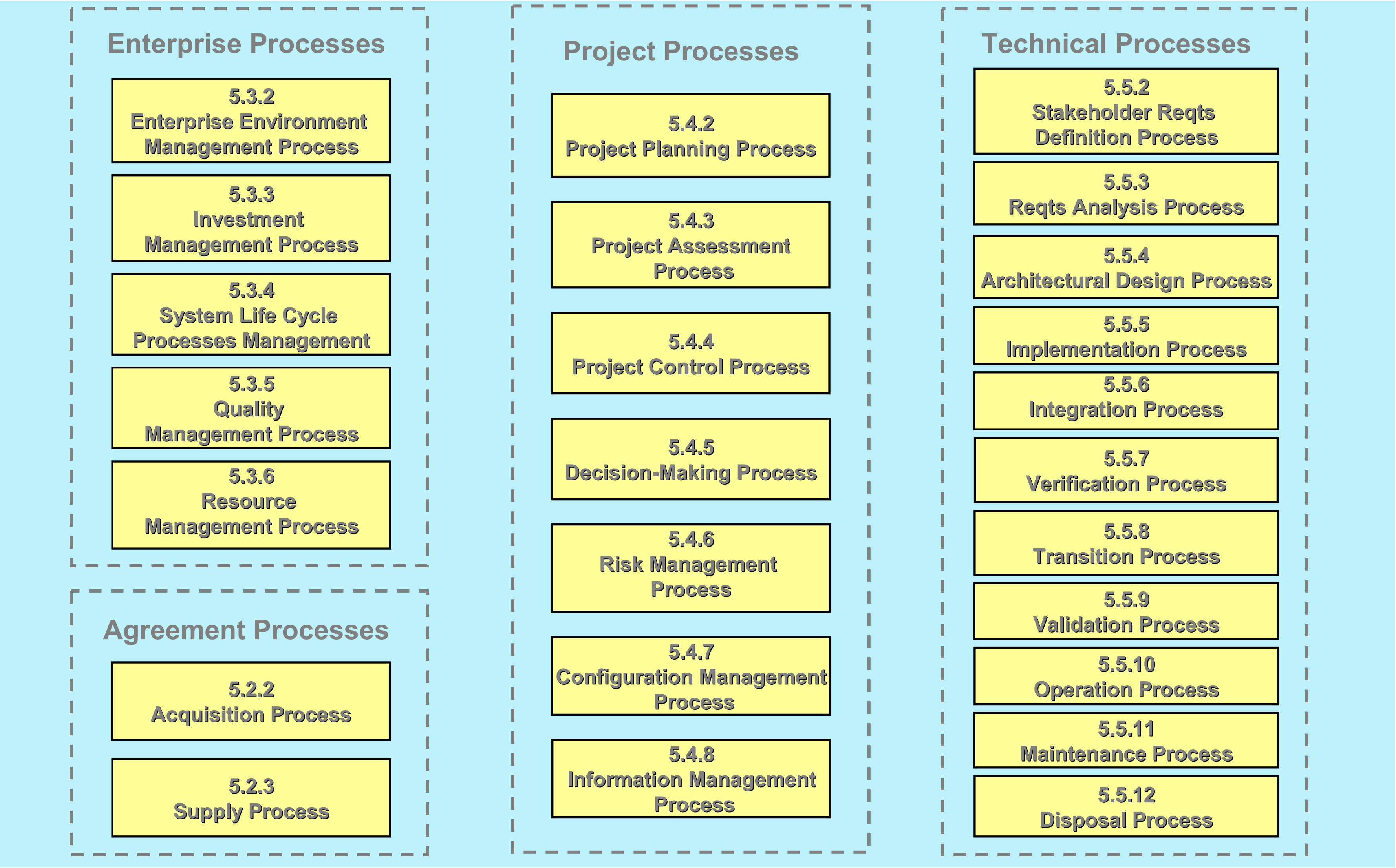
For Help, press F1

SysML in a Standards Framework

Systems Engineering Standards Framework (Partial List)



ISO/IEC 15288
System Life Cycle Processes



Enterprise Processes

5.3.2 Enterprise Environment Management Process

5.3.3 Investment Management Process

5.3.4 System Life Cycle Processes Management

5.3.5 Quality Management Process

5.3.6 Resource Management Process

Agreement Processes

5.2.2 Acquisition Process

5.2.3 Supply Process

Project Processes

5.4.2 Project Planning Process

5.4.3 Project Assessment Process

5.4.4 Project Control Process

5.4.5 Decision-Making Process

5.4.6 Risk Management Process

5.4.7 Configuration Management Process

5.4.8 Information Management Process

Technical Processes

5.5.2 Stakeholder Reqts Definition Process

5.5.3 Reqts Analysis Process

5.5.4 Architectural Design Process

5.5.5 Implementation Process

5.5.6 Integration Process

5.5.7 Verification Process

5.5.8 Transition Process

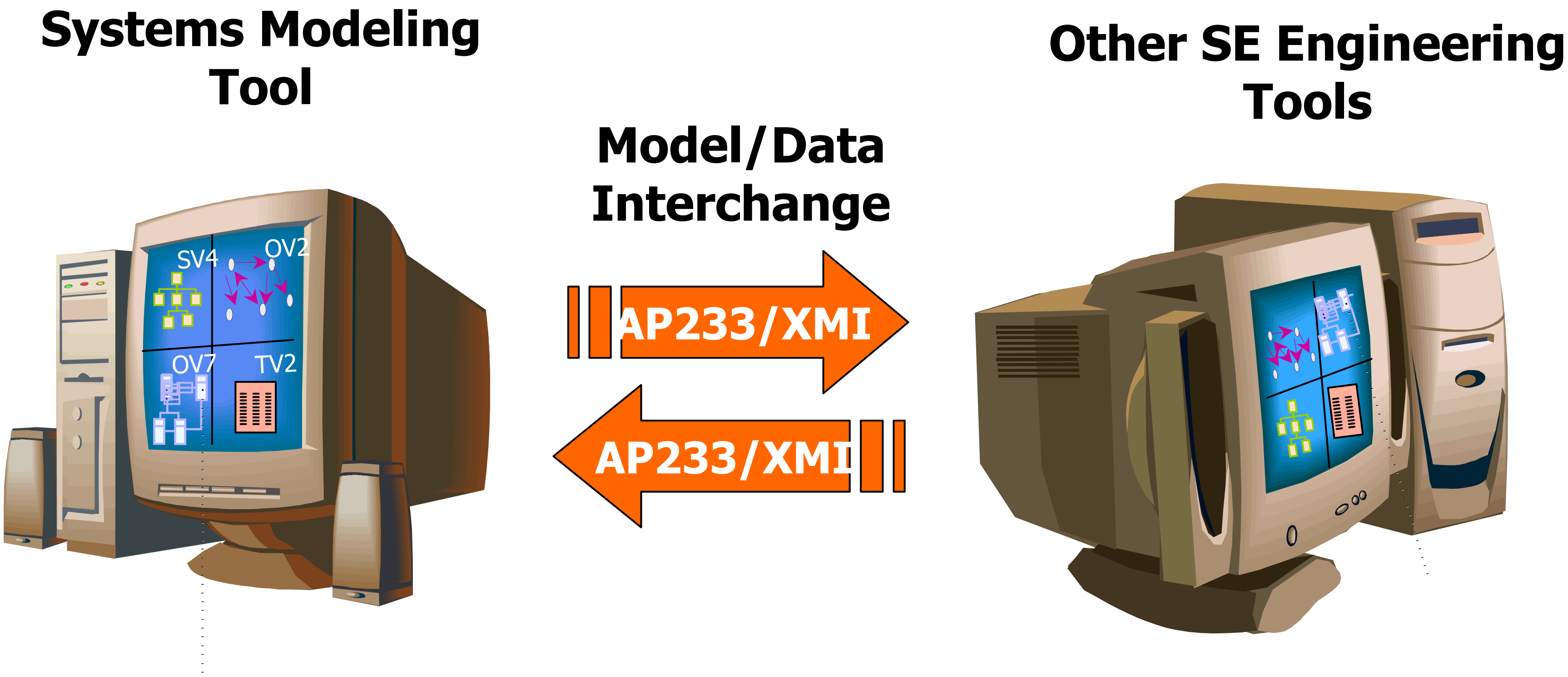
5.5.9 Validation Process

5.5.10 Operation Process

5.5.11 Maintenance Process

5.5.12 Disposal Process

Standards-based Tool Integration with SysML



Systems Modeling Tool

Model/Data Interchange

AP233/XMI

AP233/XMI

Other SE Engineering Tools

Participating SysML Tool Vendors

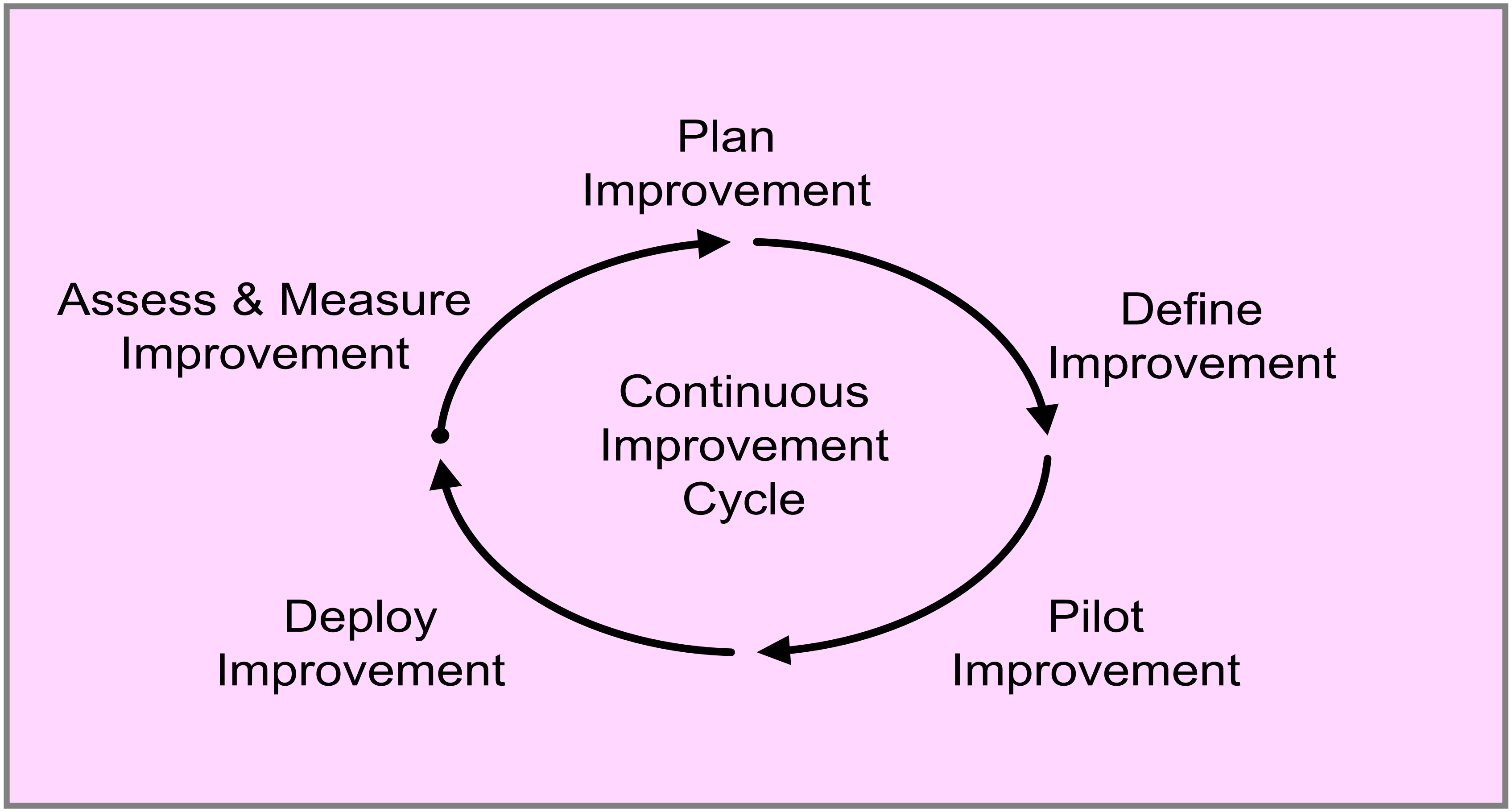
- Artisan
- EmbeddedPlus
  - 3rd party IBM vendor
- Sparx Systems
- Telelogic (includes I-Logix)
- Vitech

UML Profile for DoDAF/MODAF (UPDM) Standardization

- Current initiative underway to develop standard profile for representing DODAF and MODAF products
  - Requirements for profile issued Sept 05
  - Final submissions expected Dec ‘06
- Multiple vendors and users participating
- Should leverage SysML

Transitioning to SysML

Using Process Improvement To Transition to SysML



Plan Improvement

Define Improvement

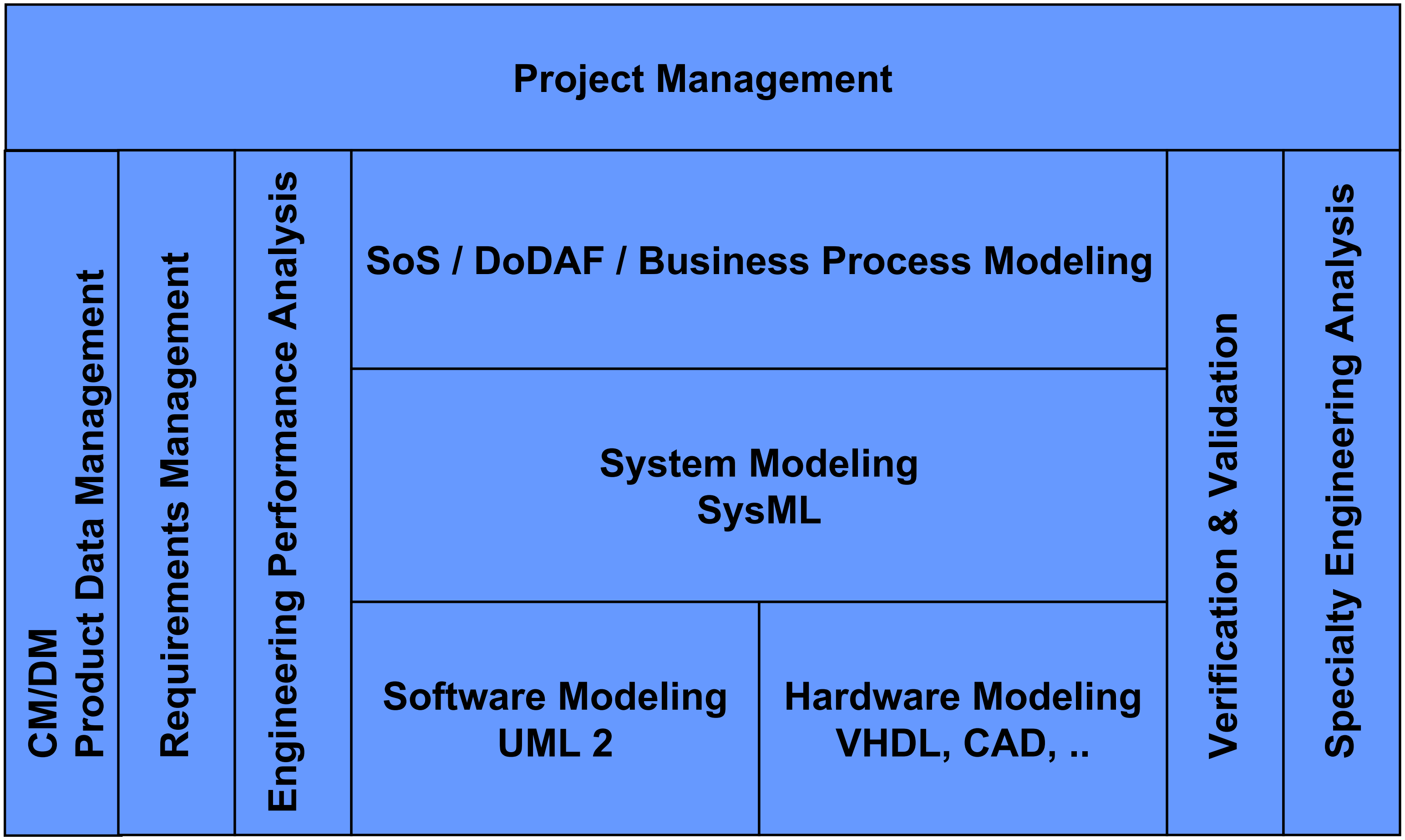
Pilot Improvement

Deploy Improvement

Assess & Measure Improvement

Continuous Improvement Cycle

Integrated Tool Environment



Project Management

CM/DM
Product Data Management

Requirements Management

Engineering Performance Analysis

SoS / DoDAF / Business Process Modeling

System Modeling
SysML

Software Modeling
UML 2

Hardware Modeling
VHDL, CAD, ..

Verification & Validation

Specialty Engineering Analysis

Summary and Wrap up

Summary

- SysML sponsored by INCOSE/OMG with broad industry and vendor participation
- SysML provides a general purpose modeling language to support specification, analysis, design and verification of complex systems
  - Subset of UML 2 with extensions
  - 4 Pillars of SysML include modeling of requirements, behavior, structure, and parametrics
- OMG SysML Adopted in May 2006
- Multiple vendor implementations announced
- Standards based modeling approach for SE expected to improve communications, tool interoperability, and design quality

References

- OMG SysML website
  - http://www.omgsysml.org
- UML for Systems Engineering RFP
  - OMG doc# ad/03-03-41
- UML 2 Superstructure
  - OMG doc# formal/05-07-04
- UML 2 Infrastructure
  - OMG doc# ptc/04-10-14