Modeling with SysML

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OBJECT MANAGEMENT GROUP • CERTIFICATION PROGRAM •
SM

APL
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APPLIED PHYSICS LABORATORY

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OMG SysML™ Specification

- Specification status
  - Adopted by OMG in May ’06
  - Available Specification v1.0 in Sept ’07
  - Available Specification v1.1 in Nov ‘08
  - Available Specification for v1.2 in March ‘10
  - Revision Task Force for v1.3 in process
- Multiple vendor implementations available
- This tutorial is based on:
  - OMG SysML available specification (formal/2007-09-01) and
  - OMG/INCOSE tutorial by Friedenthal, Moore, and Steiner
  - “A Practical Guide to SysML” by Friedenthal, Moore, and Steiner
  - Tutorial Material from JHU/APL Course developed by Joe Wolfrom
- This OMG tutorial, specifications, papers, and vendor info can be found on the OMG SysML Website at http://www.omgsysml.org/

Agenda

- Introduction
- SysML Diagram Overview
- Introduction to a Modeling Tool
- Language Concepts and Constructs
- Class Exercise
- Process Summary
- Tools Overview
- Wrap-up

Objectives & Intended Audience

At the end of this tutorial, you should have an awareness of:

- Motivation of model-based systems engineering approach
- SysML diagrams and basic language concepts
- How SysML is used as part of an MBSE process

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

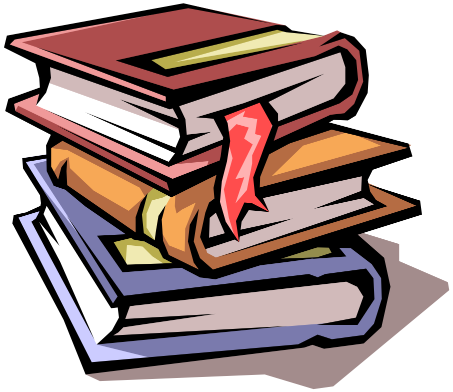
Intended Audience:

- Practicing Systems Engineers interested in system modeling
- Software Engineers who want to better understand how to integrate software and system models
- Familiarity with UML is not required, but it helps

INTRODUCTION

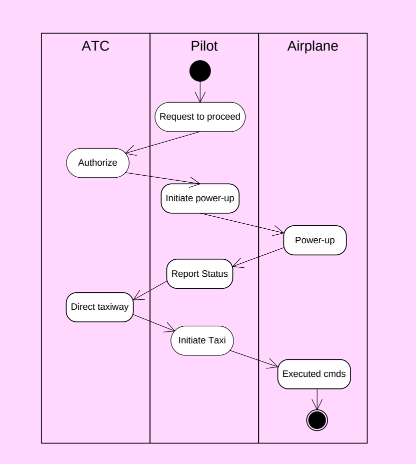
SE Practices for Describing Systems

Past



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

Future

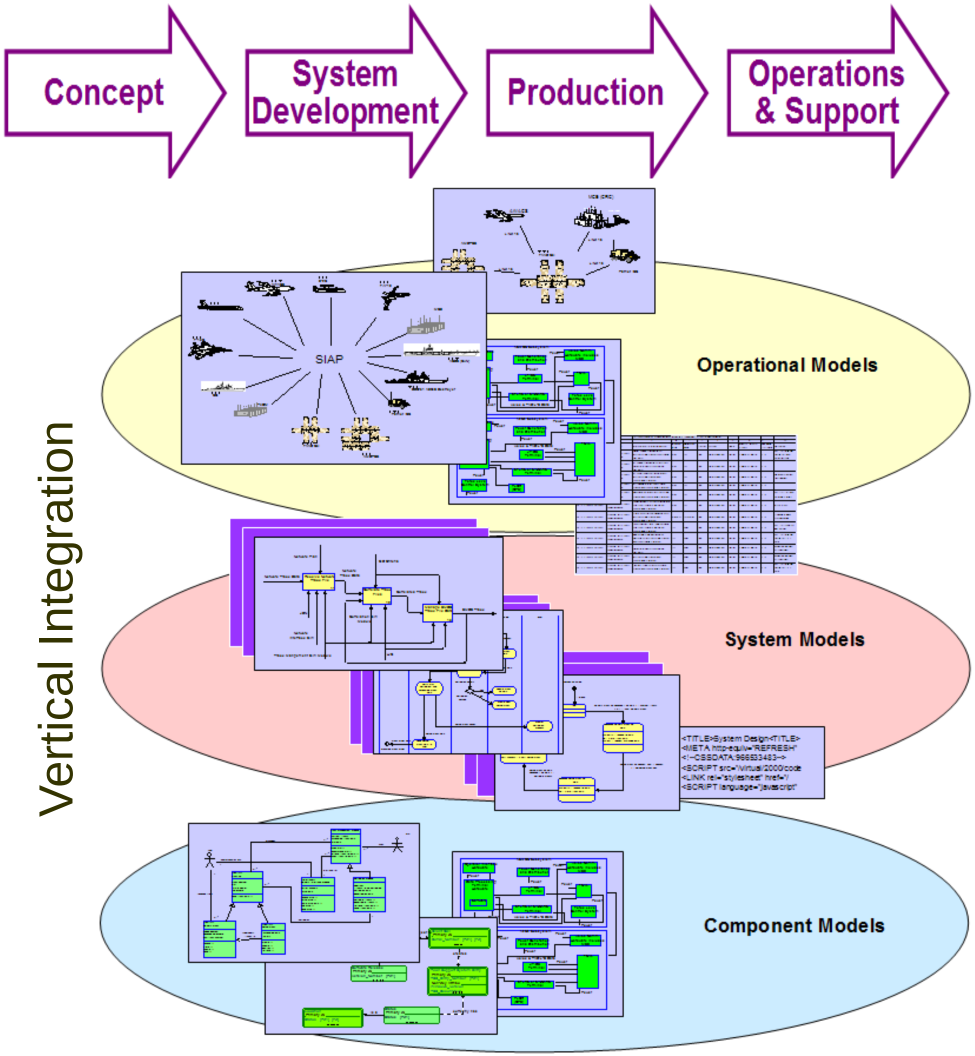


Moving from Document centric to Model centric

Model-based Systems Engineering (MBSE)

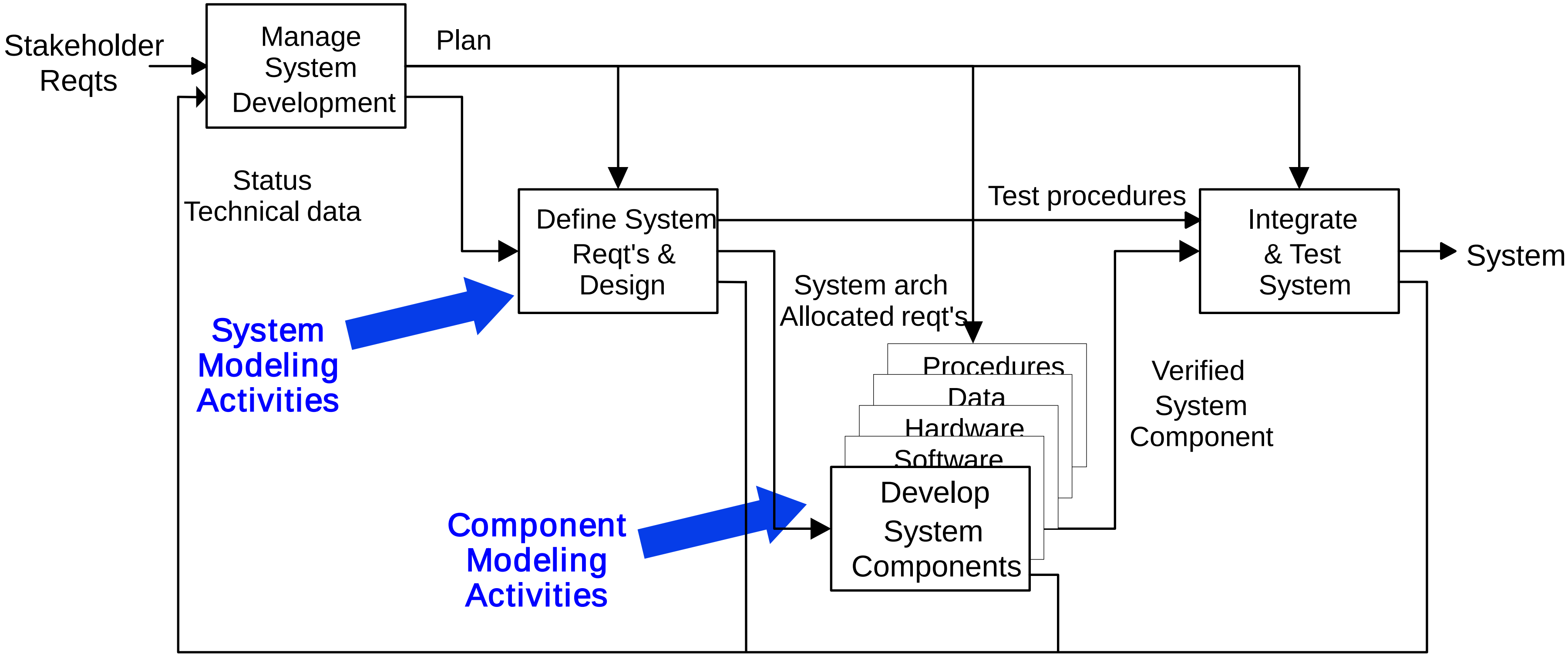
- Formalizes the practice of systems development through use of models
- Broad in scope
  - Integrates with multiple modeling domains across life cycle from system of systems to component
- Results in quality/productivity improvements & lower risk
  - Rigor and precision
  - Communications among system/project stakeholders
  - Management of complexity

Life Cycle Support



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

System Development Process

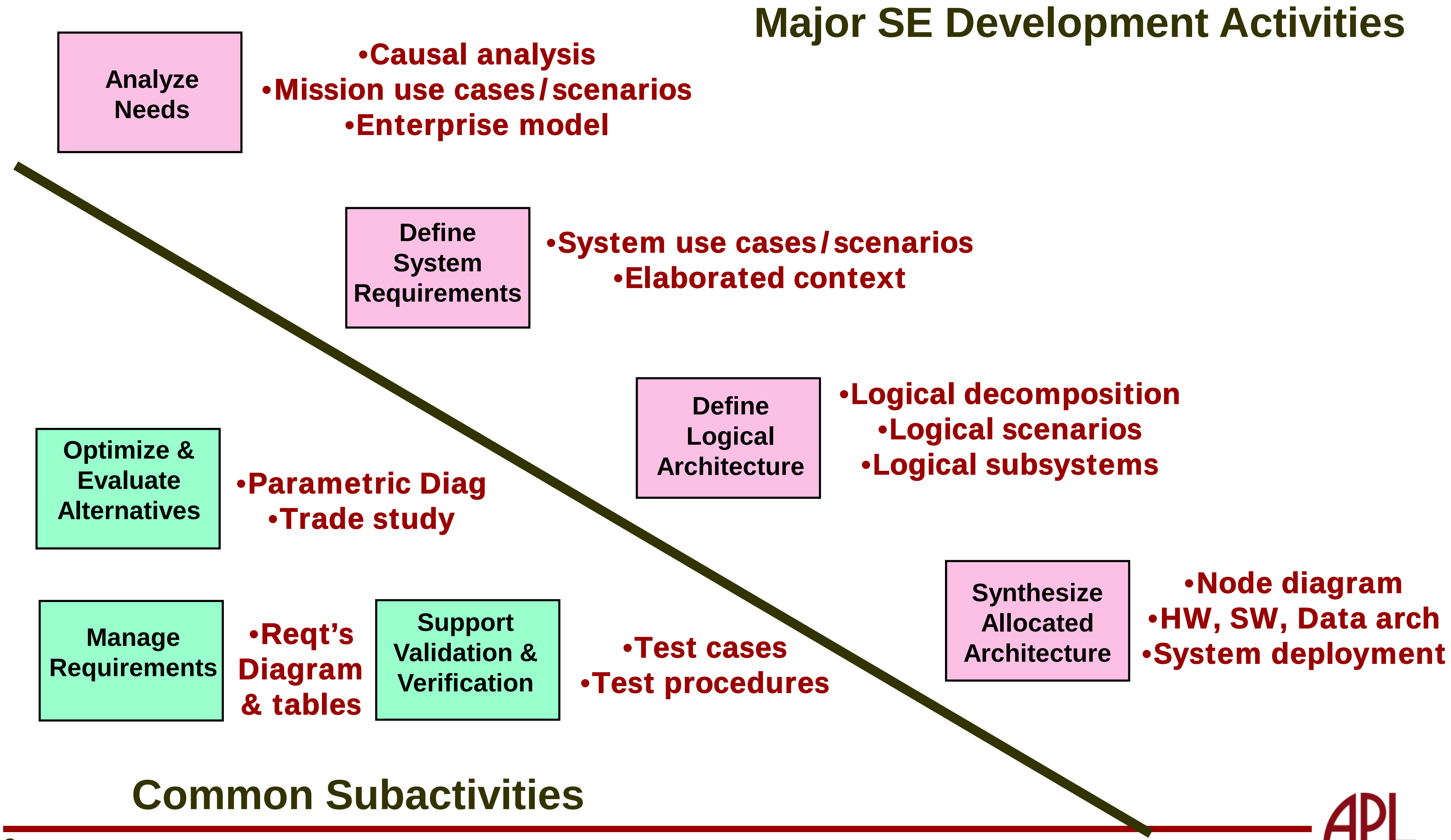

Stakeholder Reqts
Manage System Development
Plan
Status Technical data
Define System Reqt's & Design
Test procedures
Integrate & Test System
System
System arch Allocated reqt's
Procedures
Data
Hardware
Software
Develop System Components
Verified System Component
System Modeling Activities
Component Modeling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

System Modeling Activities – OOSEM

Integrating MBSE into the SE Process



Major SE Development Activities

Analyze Needs

- •Causal analysis
- •Mission use cases/scenarios
- •Enterprise model

Define System Requirements

- •System use cases/scenarios
- •Elaborated context

Define Logical Architecture

- •Logical decomposition
- •Logical scenarios
- •Logical subsystems

Synthesize Allocated Architecture

- •Node diagram
- •HW, SW, Data arch
- •System deployment

Optimize & Evaluate Alternatives

- •Parametric Diag
- •Trade study

Manage Requirements

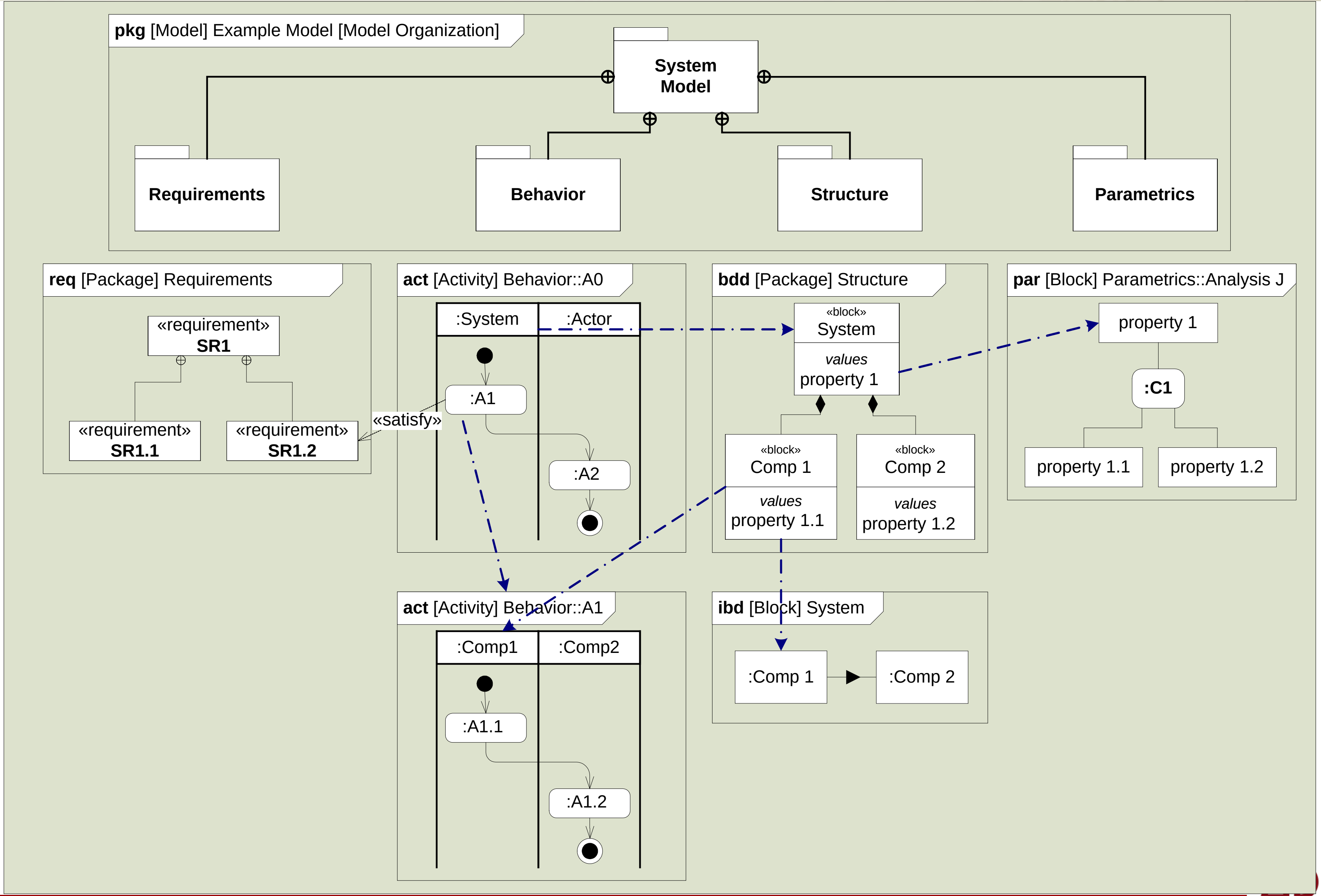
- •Reqt's Diagram & tables

Support Validation & Verification

- •Test cases
- •Test procedures

Common Subactivities

4 Pillars of SysML



SysML Diagram Types

SysML includes nine diagrams as shown in this diagram:

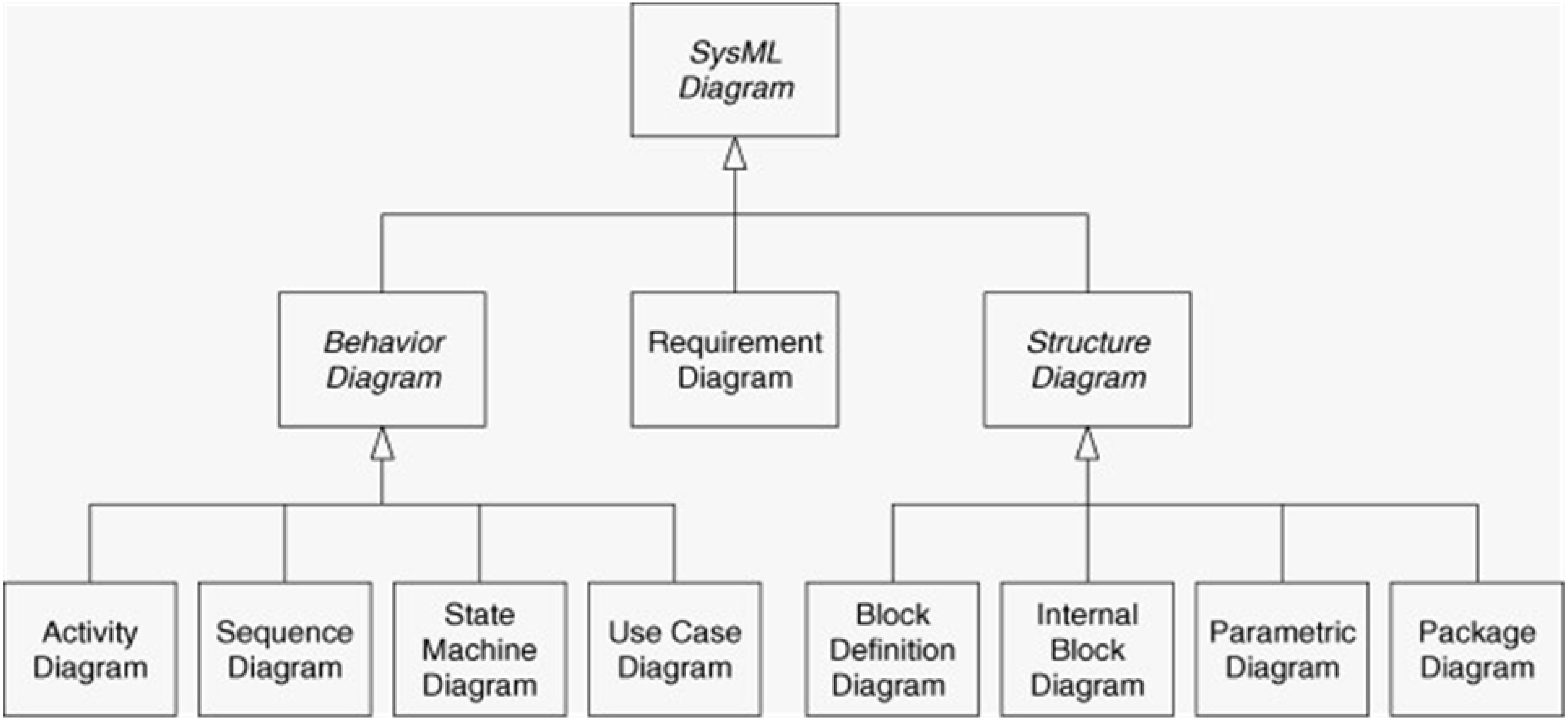


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FIGURE 3.1

4 Pillars of SysML – ABS Example

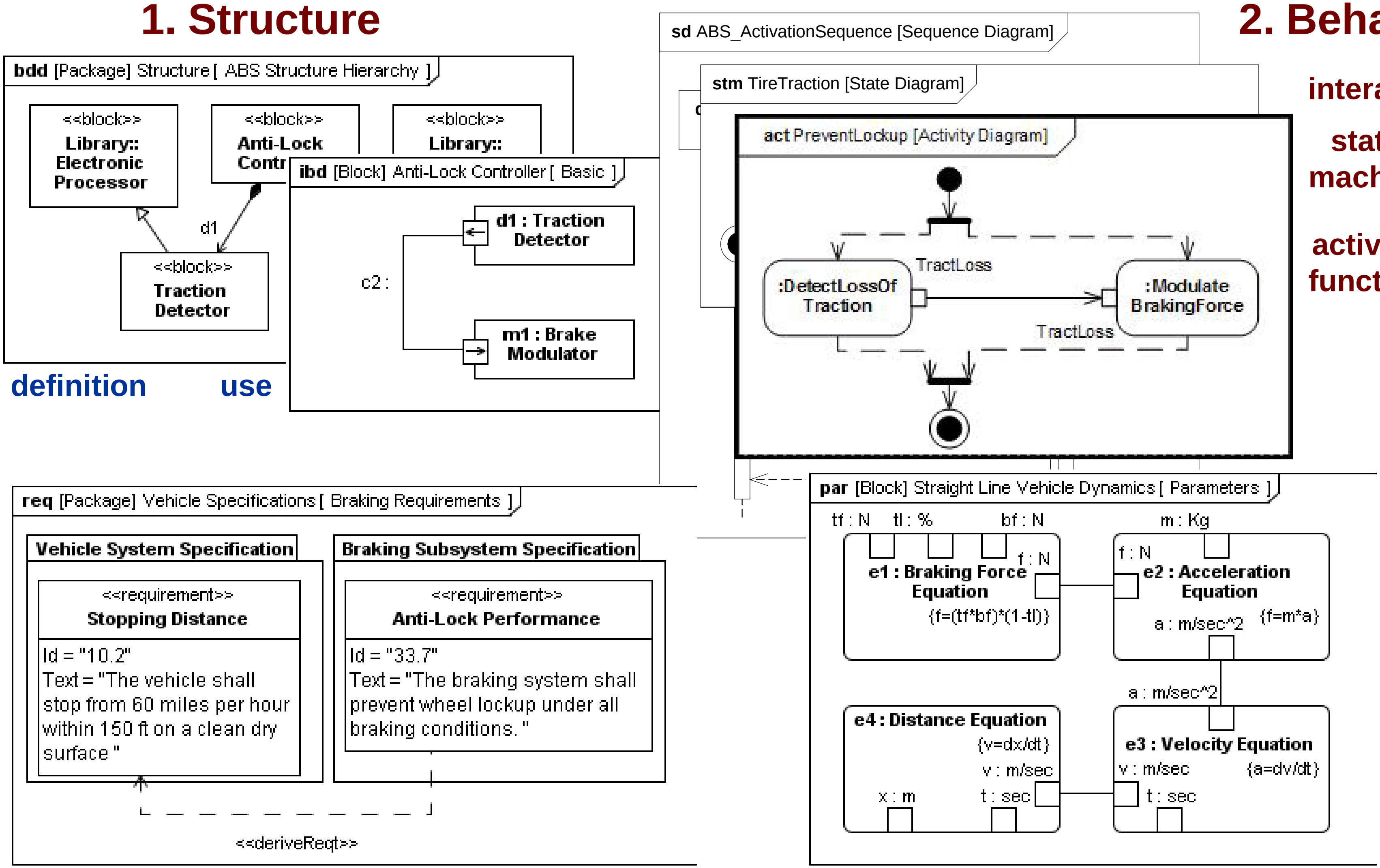
1. Structure

2. Behavior

interaction

state machine

activity/ function


bdd [Package] Structure [ABS Structure Hierarchy]
<<block>> Library:: Electronic Processor
<<block>> Anti-Lock Contr
<<block>> Library::
d1
<<block>> Traction Detector
ibd [Block] Anti-Lock Controller [Basic]
d1 : Traction Detector
c2 :
m1 : Brake Modulator
sd ABS_ActivationSequence [Sequence Diagram]
stm TireTraction [State Diagram]
act PreventLockup [Activity Diagram]
:DetectLossOf Traction
TractLoss
:Modulate BrakingForce
TractLoss
req [Package] Vehicle Specifications [Braking Requirements]
Vehicle System Specification
Braking Subsystem Specification
<<requirement>> Stopping Distance
<<requirement>> Anti-Lock Performance
<<deriveReqt>>
par [Block] Straight Line Vehicle Dynamics [Parameters]
tf : N
tl : %
bf : N
f : N
e1 : Braking Force Equation
{f=(tf*bf)*(1-tl)}
m : Kg
f : N
e2 : Acceleration Equation
a : m/sec^2
{f=m*a}
a : m/sec^2
e4 : Distance Equation
{v=dx/dt}
v : m/sec
x : m
t : sec
e3 : Velocity Equation
v : m/sec
{a=dv/dt}
t : sec

Id = "10.2"
Text = "The vehicle shall stop from 60 miles per hour within 150 ft on a clean dry surface "

Id = "33.7"
Text = "The braking system shall prevent wheel lockup under all braking conditions. "

definition use

3. Requirements

•4. Parametrics

SYSML DIAGRAM OVERVIEW

SysML Diagram Frames

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

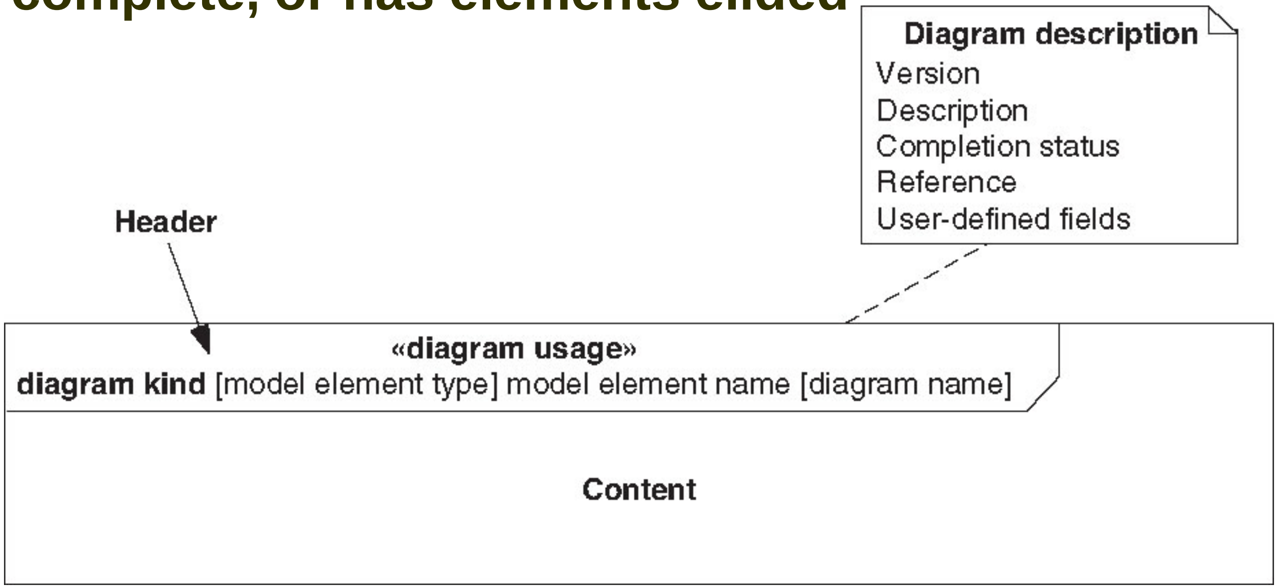


FIGURE 4.8

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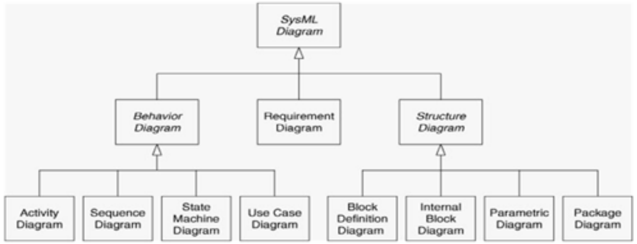
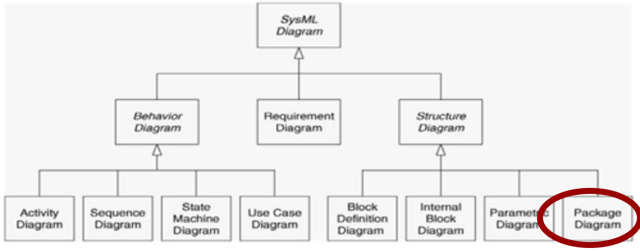
SysML Diagrams



- Package diagram
- Requirement diagram
- Use Case diagram
- Block Definition diagram
- Internal Block diagram
- Activity diagram
- Sequence diagram
- State Machine diagram
- Parametric diagram

Package Diagram



- **Represents the organization of a model in terms of packages that contain model elements**

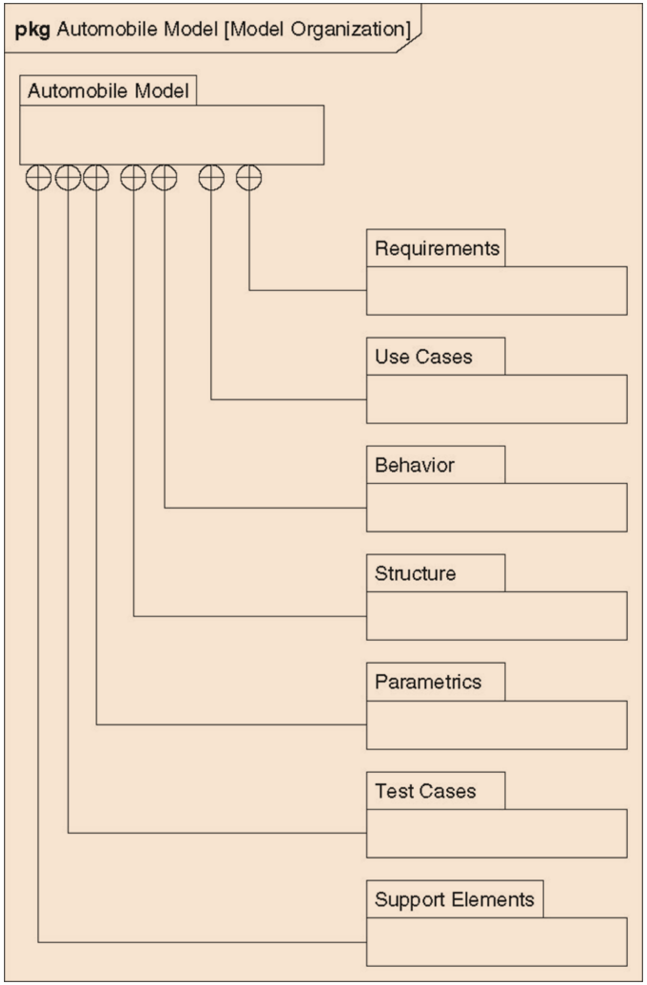


FIGURE 3.19

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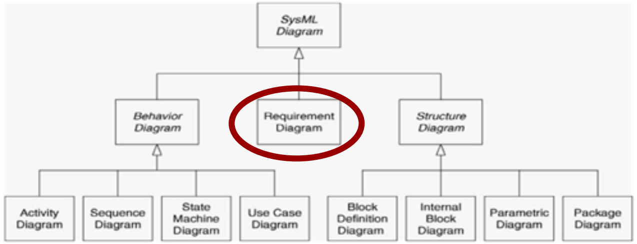

Requirement Diagram

- **Represents text-based requirements and their relationship with other requirements, design elements, and test cases to support requirements traceability**

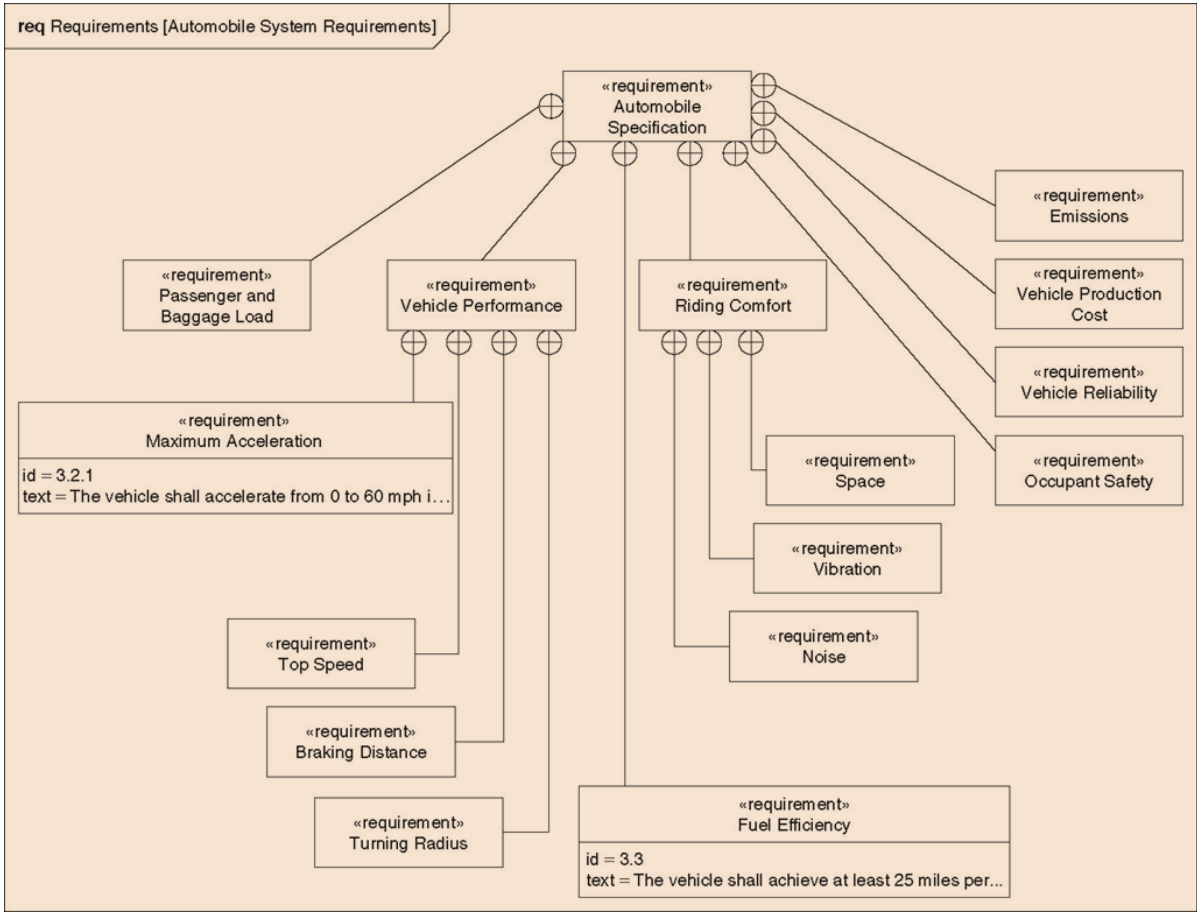
req Requirements [Automobile System Requirements]
«requirement» Automobile Specification
«requirement» Passenger and Baggage Load
«requirement» Vehicle Performance
«requirement» Riding Comfort
«requirement» Emissions
«requirement» Vehicle Production Cost
«requirement» Vehicle Reliability
«requirement» Occupant Safety
«requirement» Maximum Acceleration
id = 3.2.1
text = The vehicle shall accelerate from 0 to 60 mph i...
«requirement» Space
«requirement» Vibration
«requirement» Noise
«requirement» Top Speed
«requirement» Braking Distance
«requirement» Turning Radius
«requirement» Fuel Efficiency
id = 3.3
text = The vehicle shall achieve at least 25 miles per...

FIGURE 3.2

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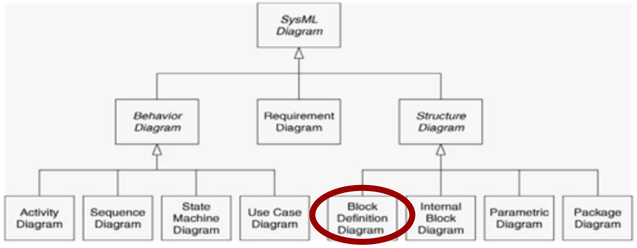
Block Definition Diagram



- **Represents structural elements called blocks, and their composition and classification**

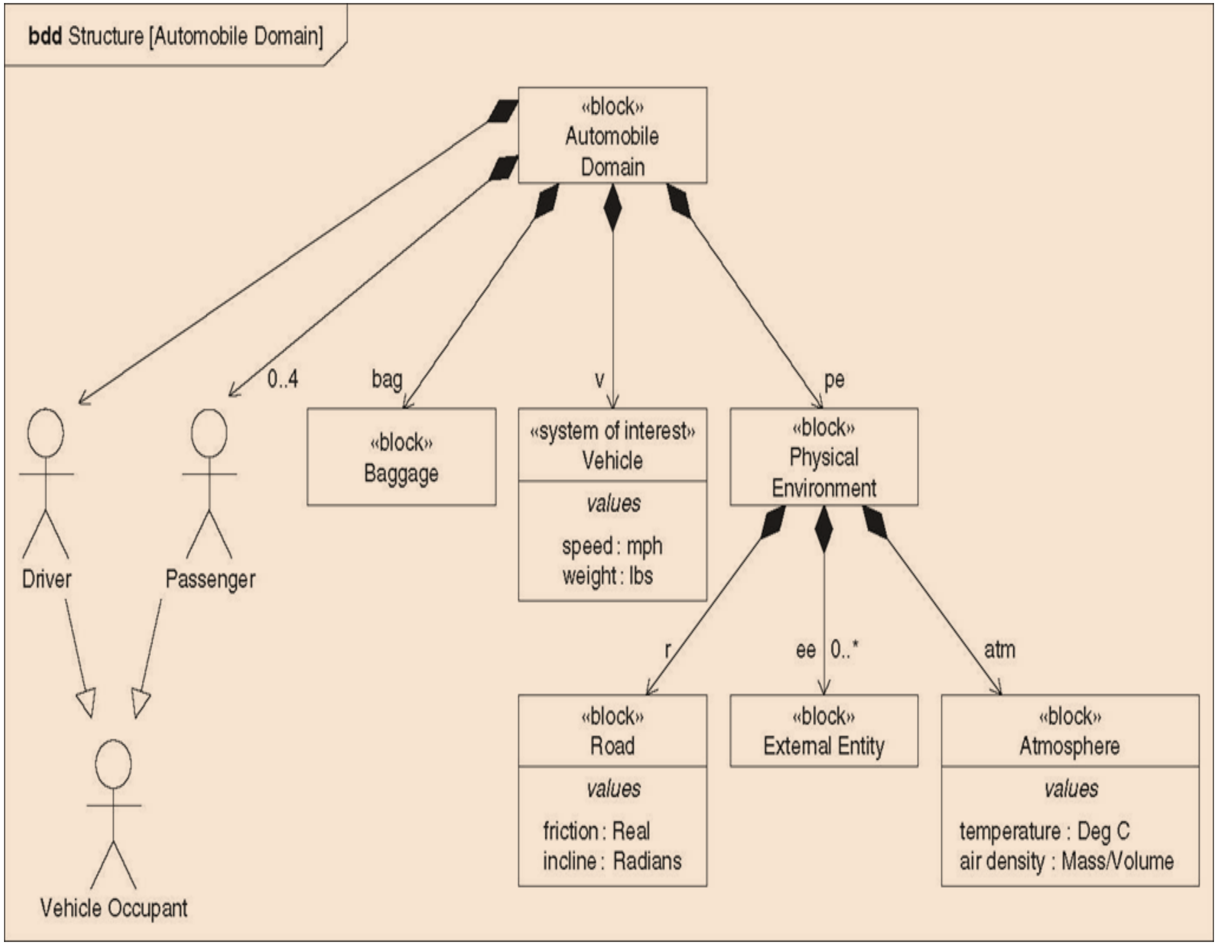


FIGURE 3.3

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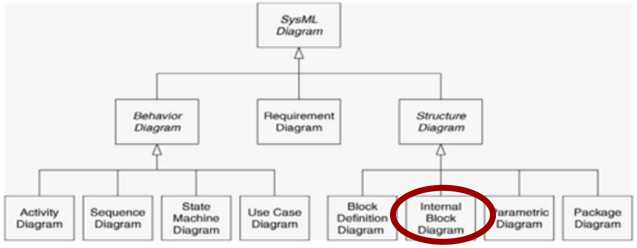
Internal Block Diagram



- Represents interconnection and interfaces between the parts of a block

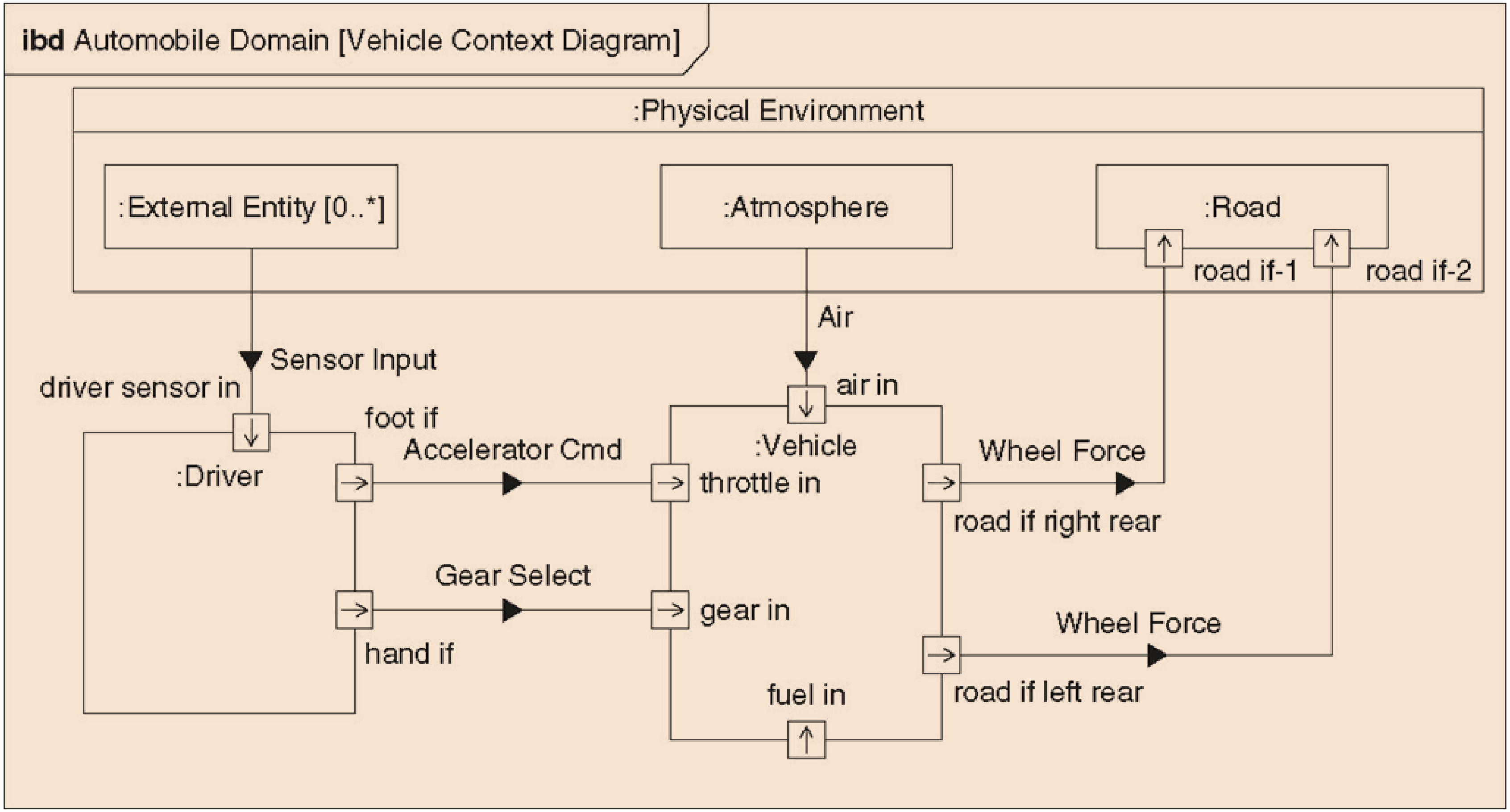


FIGURE 3.9

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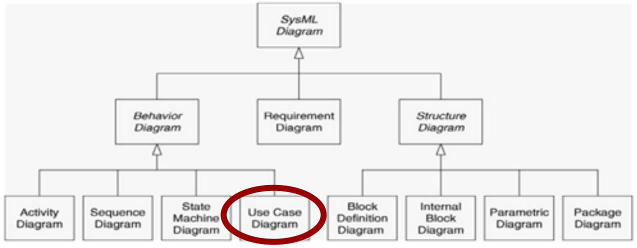
Use Case Diagram



- **Represents functionality in terms of how a system or other entity is used by external entities (i.e., actors) to accomplish a set of goals**

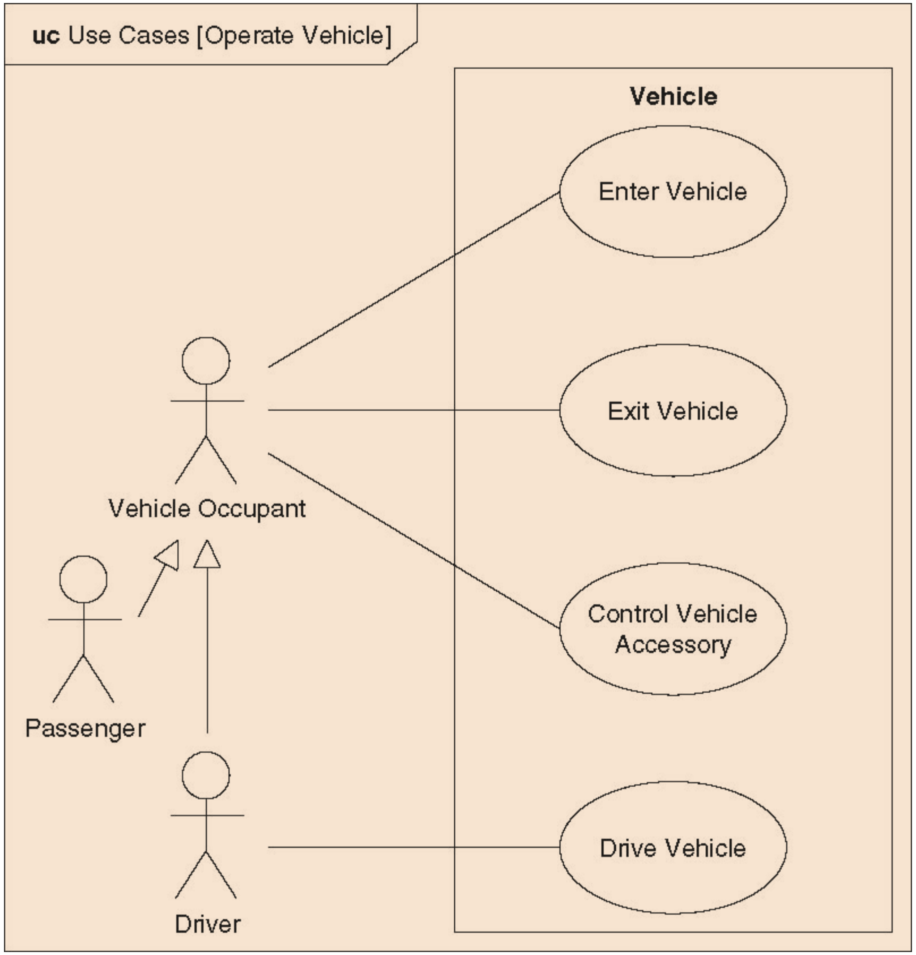


FIGURE 3.4

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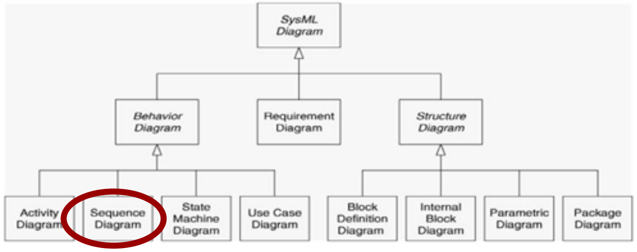
Drive Vehicle Sequence Diagram



- Represents behavior in terms of a sequence of messages exchanged between parts

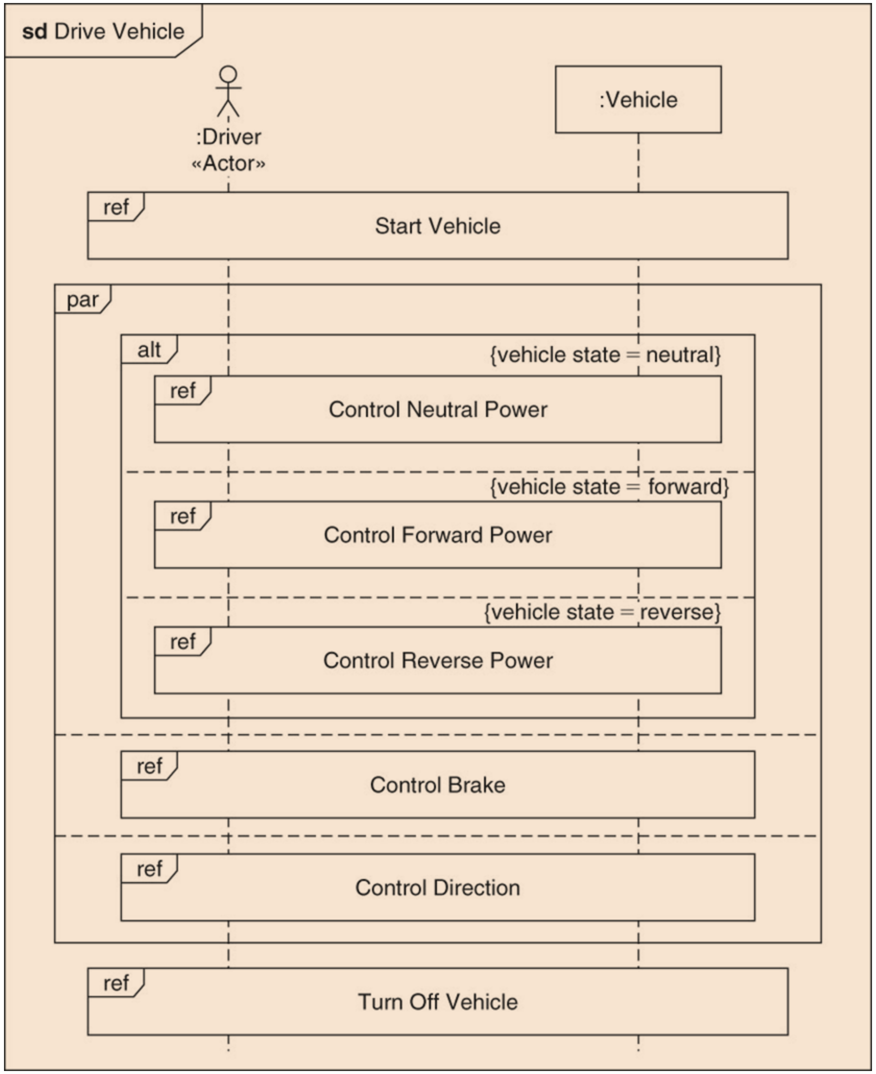


FIGURE 3.5

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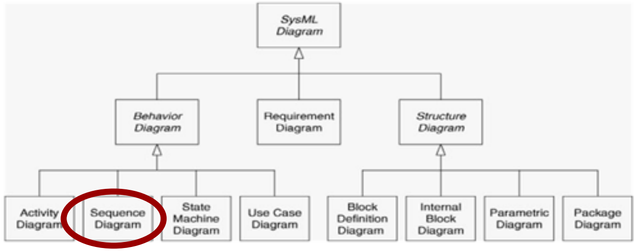
Start Vehicle Sequence Diagram



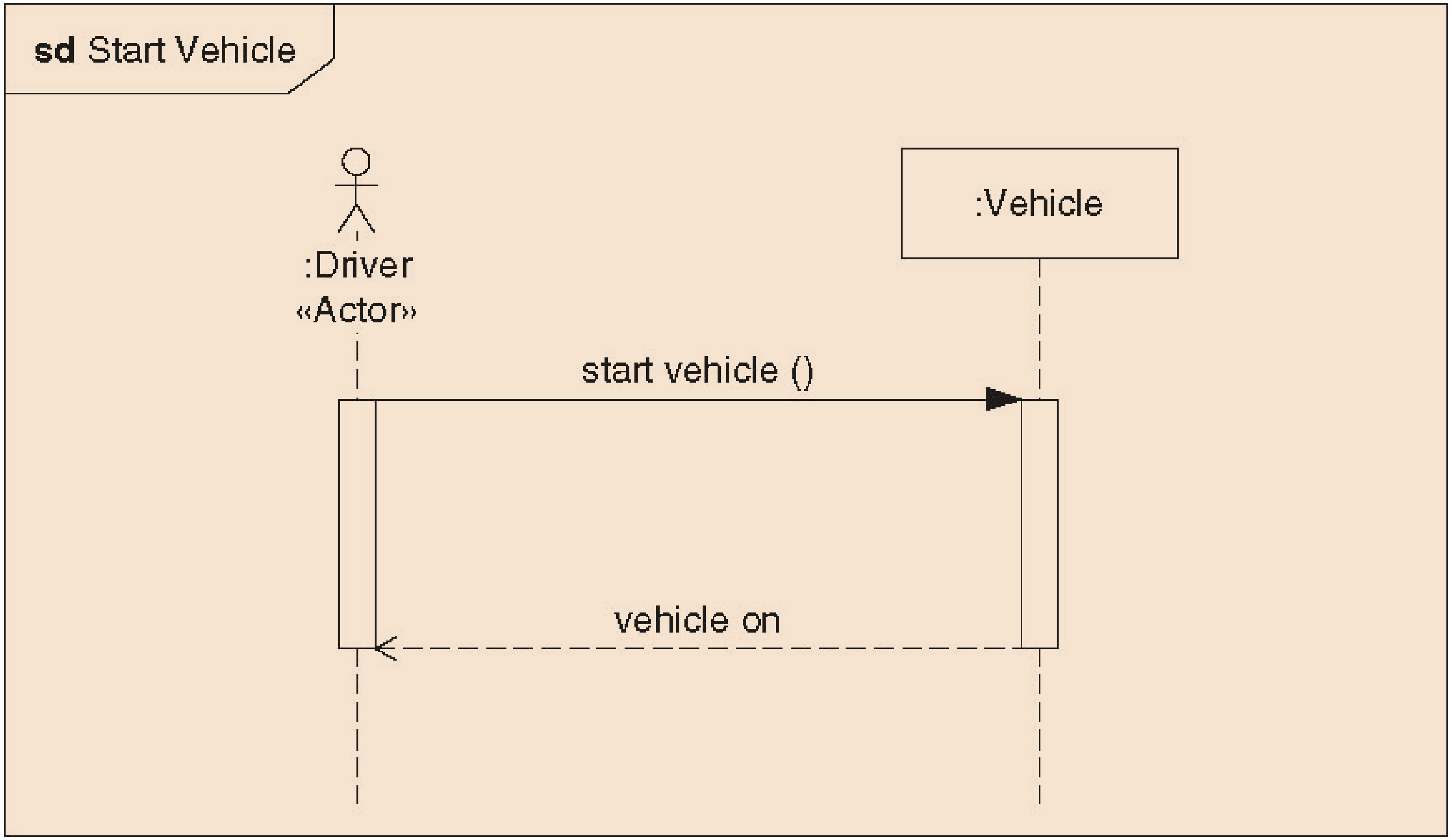


FIGURE 3.6

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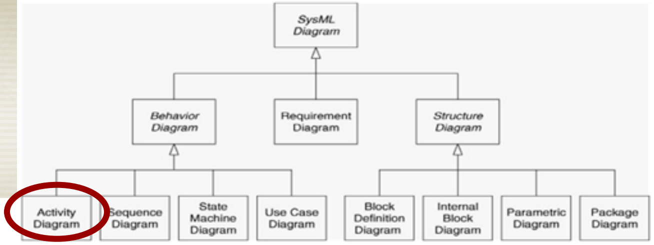
Activity Diagram



- Represents behavior in terms of the ordering of actions based on the availability of inputs, outputs, and control, and how the actions transform the inputs to outputs

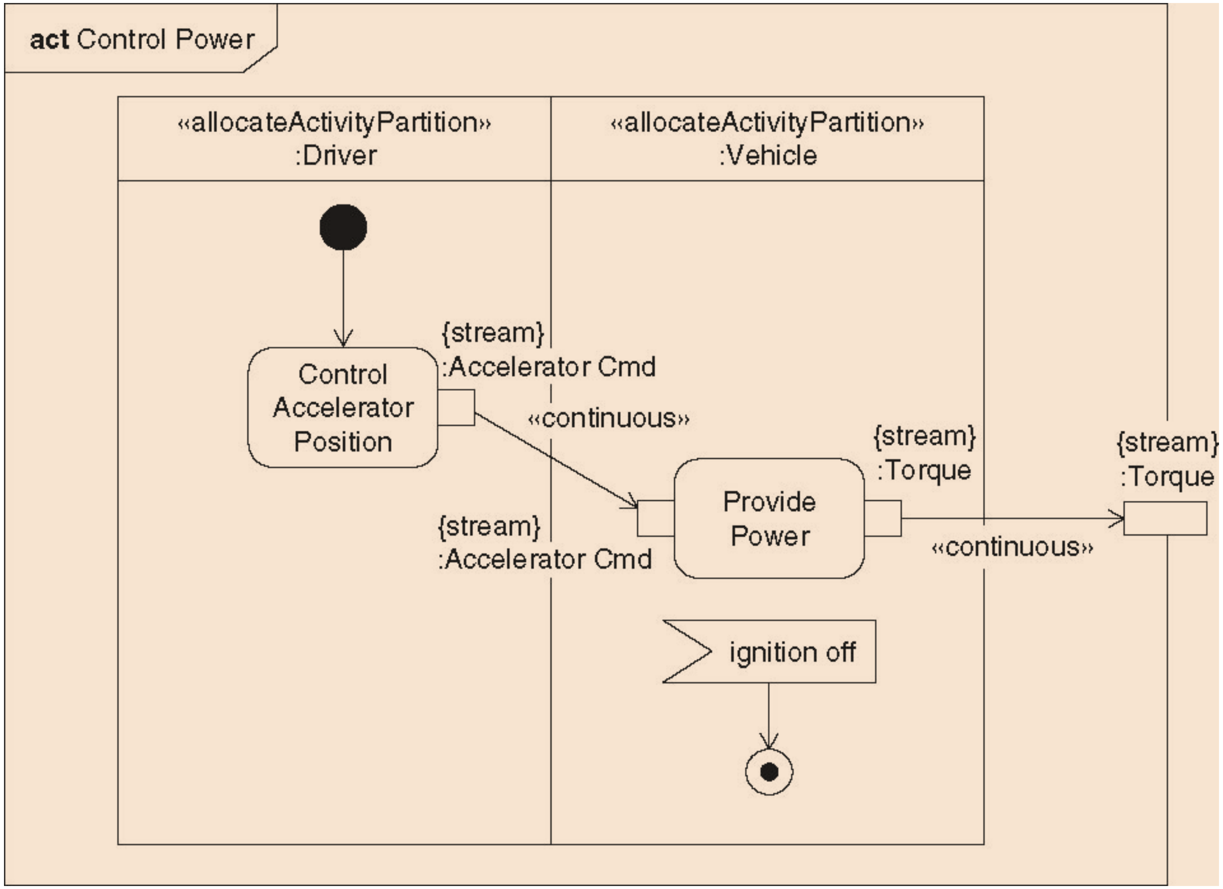

act Control Power
«allocateActivityPartition» :Driver
«allocateActivityPartition» :Vehicle
Control Accelerator Position
{stream} :Accelerator Cmd
«continuous»
{stream} :Torque
Provide Power
{stream} :Accelerator Cmd
{stream} :Torque
«continuous»
ignition off

FIGURE 3.7

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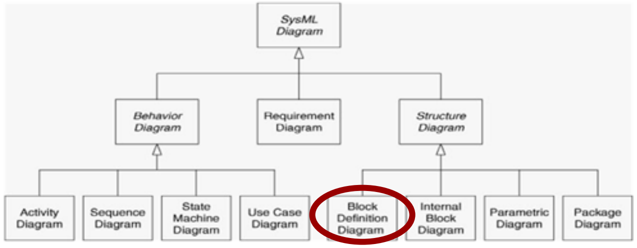
Vehicle System Hierarchy Block Definition Diagram



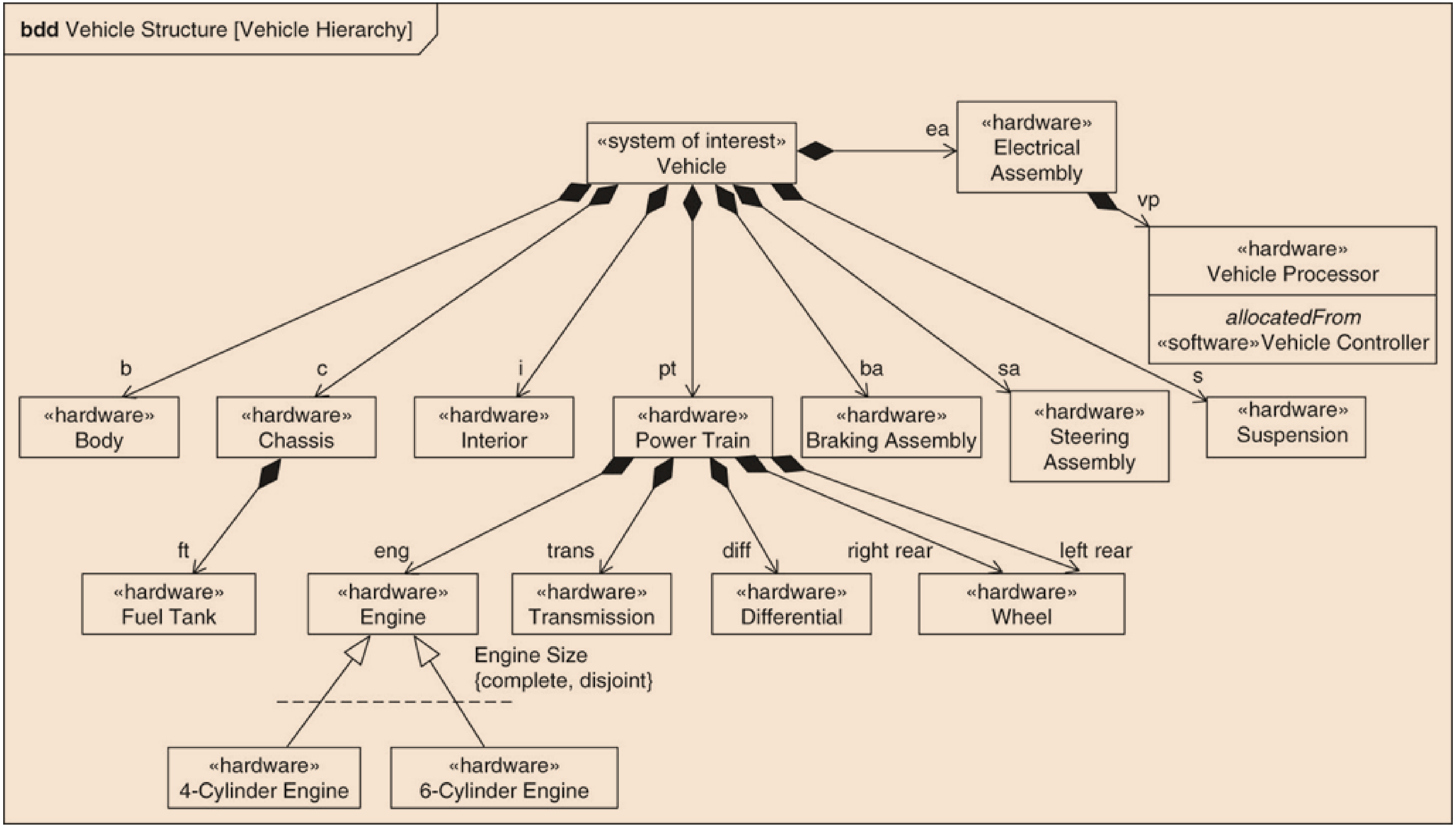


FIGURE 3.10

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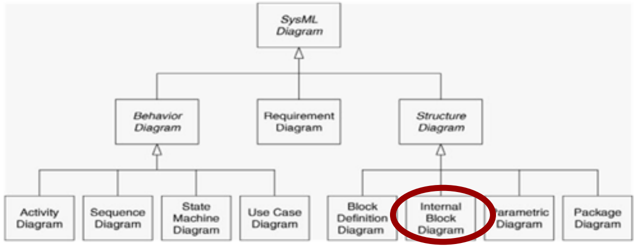
Power Subsystem Internal Block Diagram



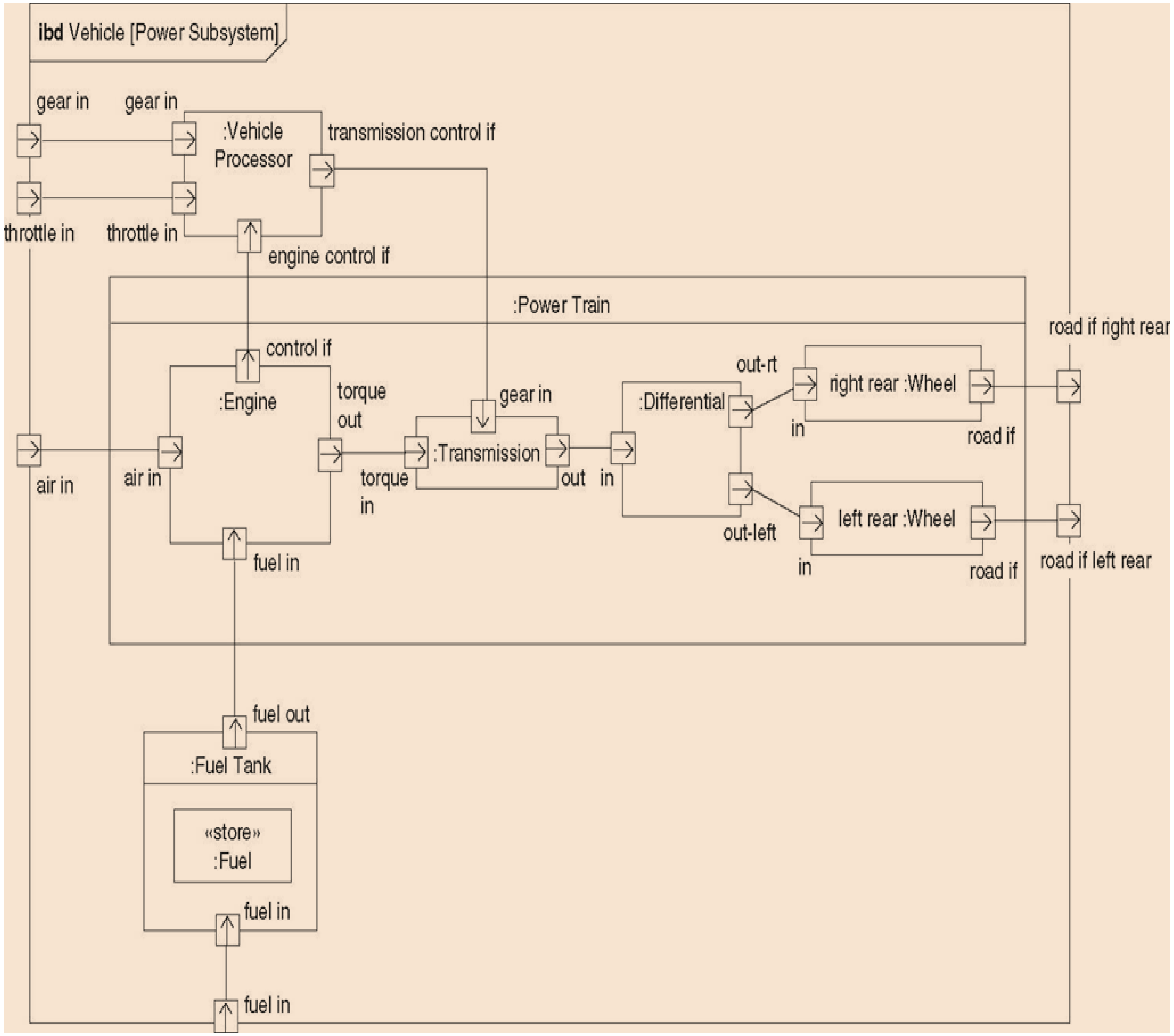


FIGURE 3.12

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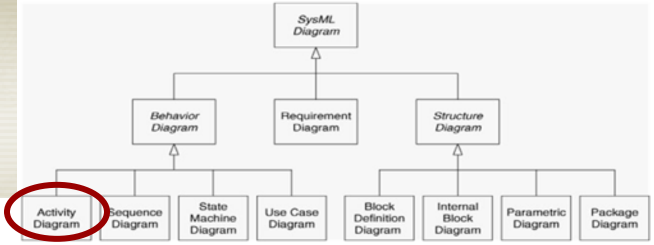
Provide Power Activity Diagram



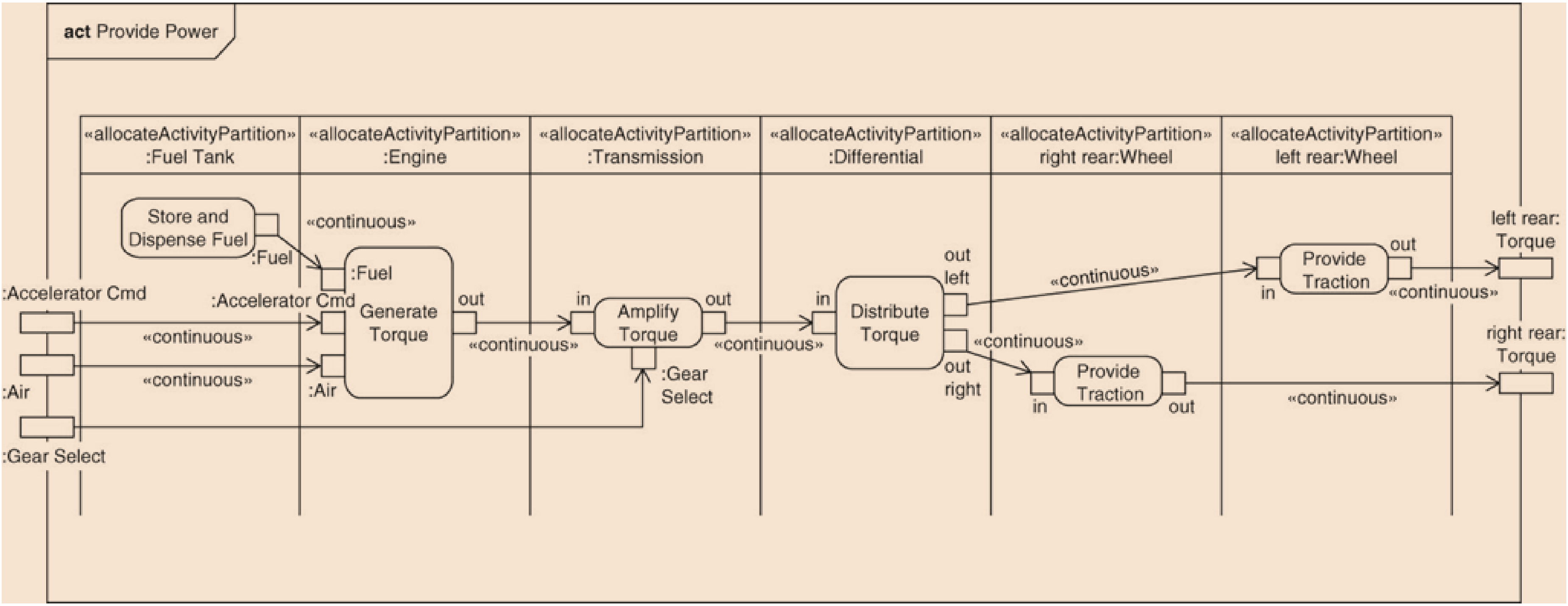


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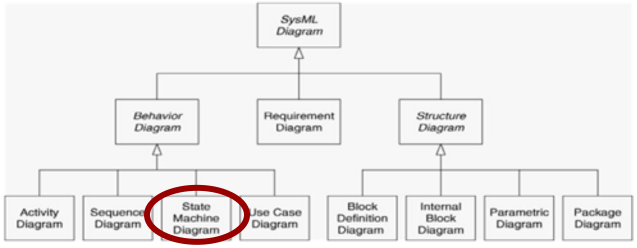
FIGURE 3.11

State Machine Diagram



- **Represents behavior of an entity in terms of its transitions between states triggered by events**

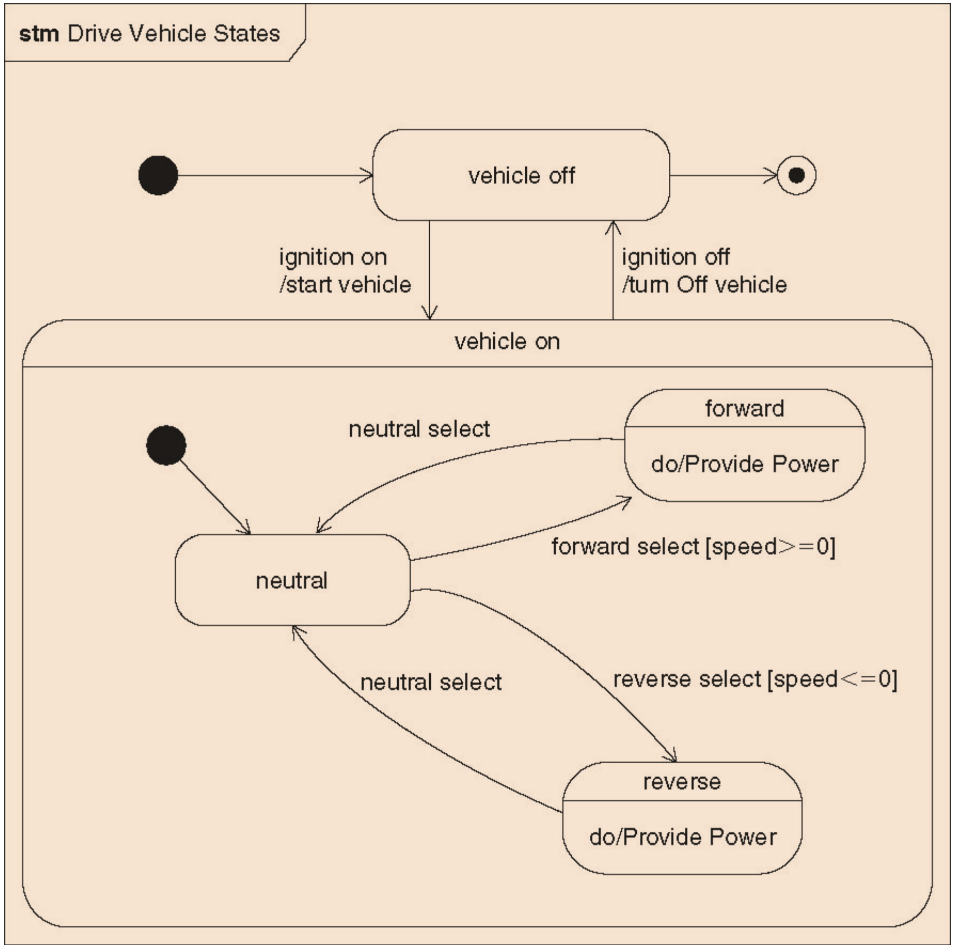


FIGURE 3.8

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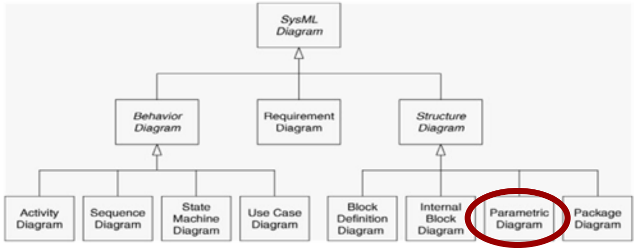
Parametric Diagram



- **Represents constraints on property values, such as F=m*a, used to support engineering analysis**

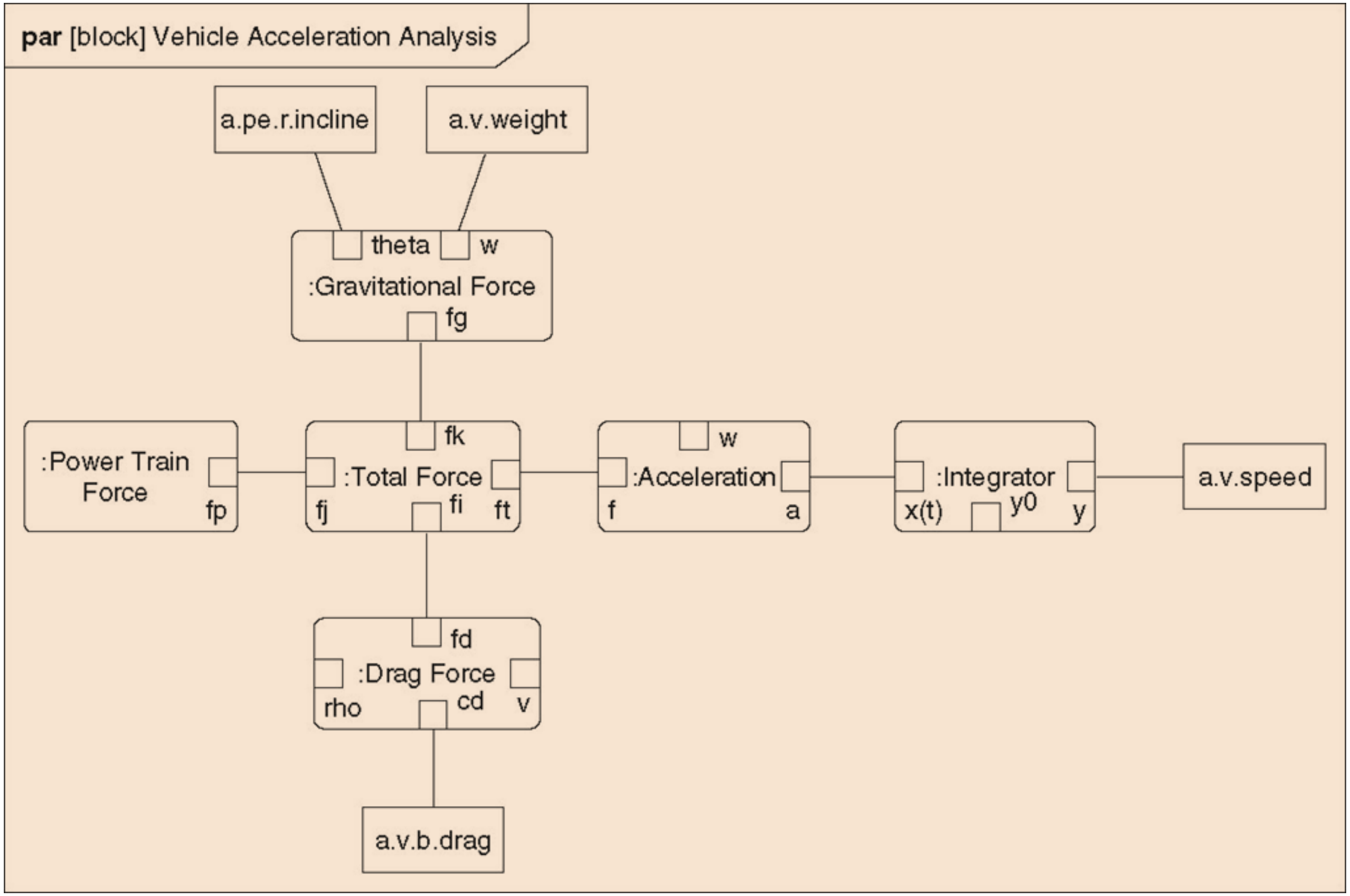


FIGURE 3.14

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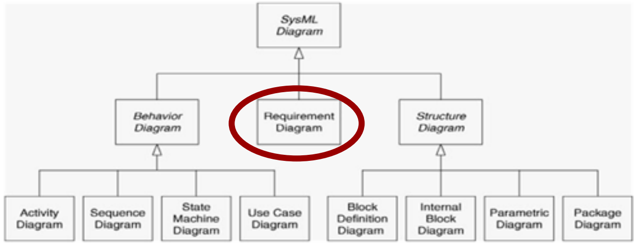
Requirements Traceability



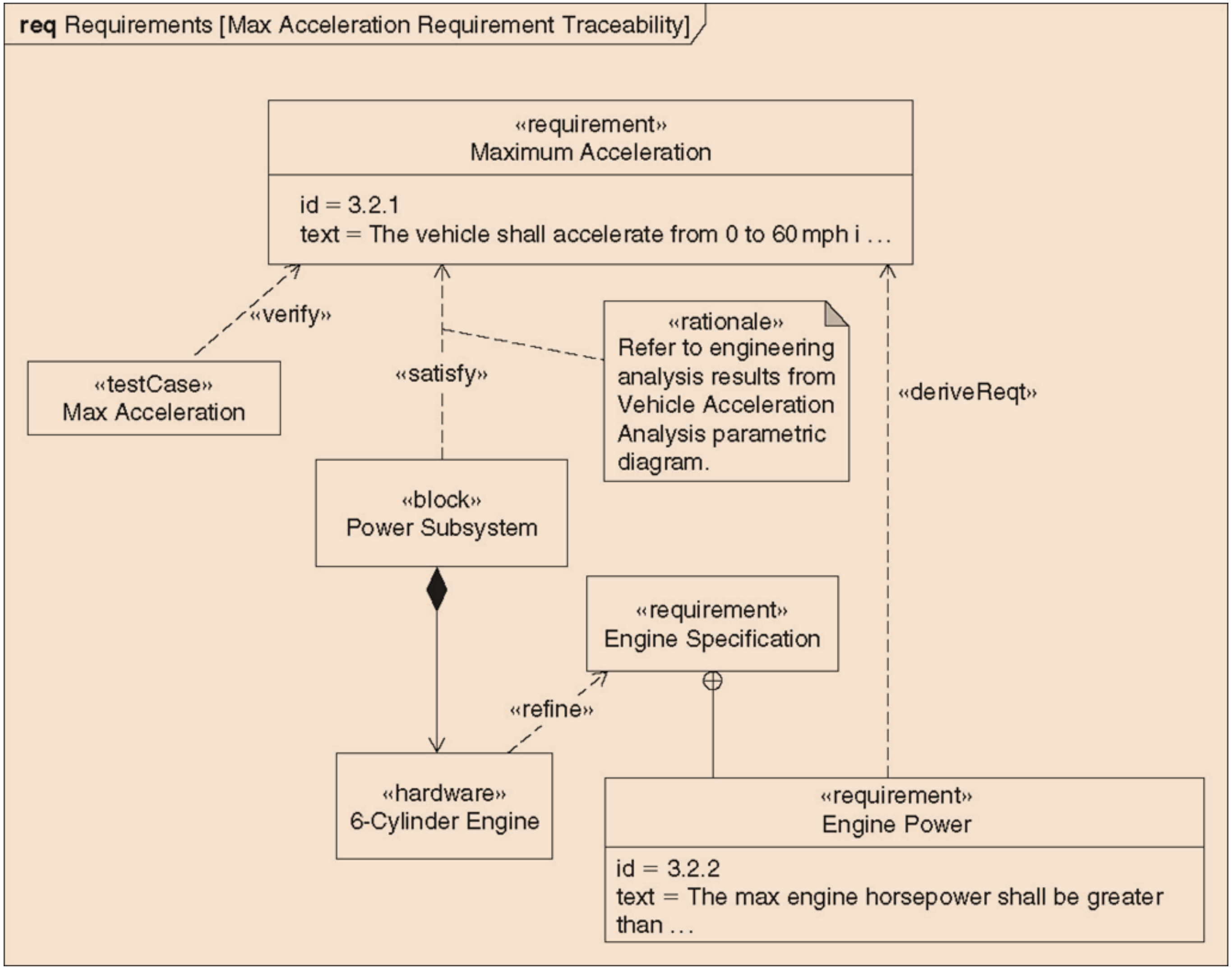

req Requirements [Max Acceleration Requirement Traceability]
«requirement»
Maximum Acceleration
id = 3.2.1
text = The vehicle shall accelerate from 0 to 60 mph i . . .
«verify»
«testCase»
Max Acceleration
«satisfy»
«rationale»
Refer to engineering analysis results from Vehicle Acceleration Analysis parametric diagram.
«deriveReqt»
«block»
Power Subsystem
«requirement»
Engine Specification
«refine»
«hardware»
6-Cylinder Engine
«requirement»
Engine Power
id = 3.2.2
text = The max engine horsepower shall be greater than . . .

FIGURE 3.18

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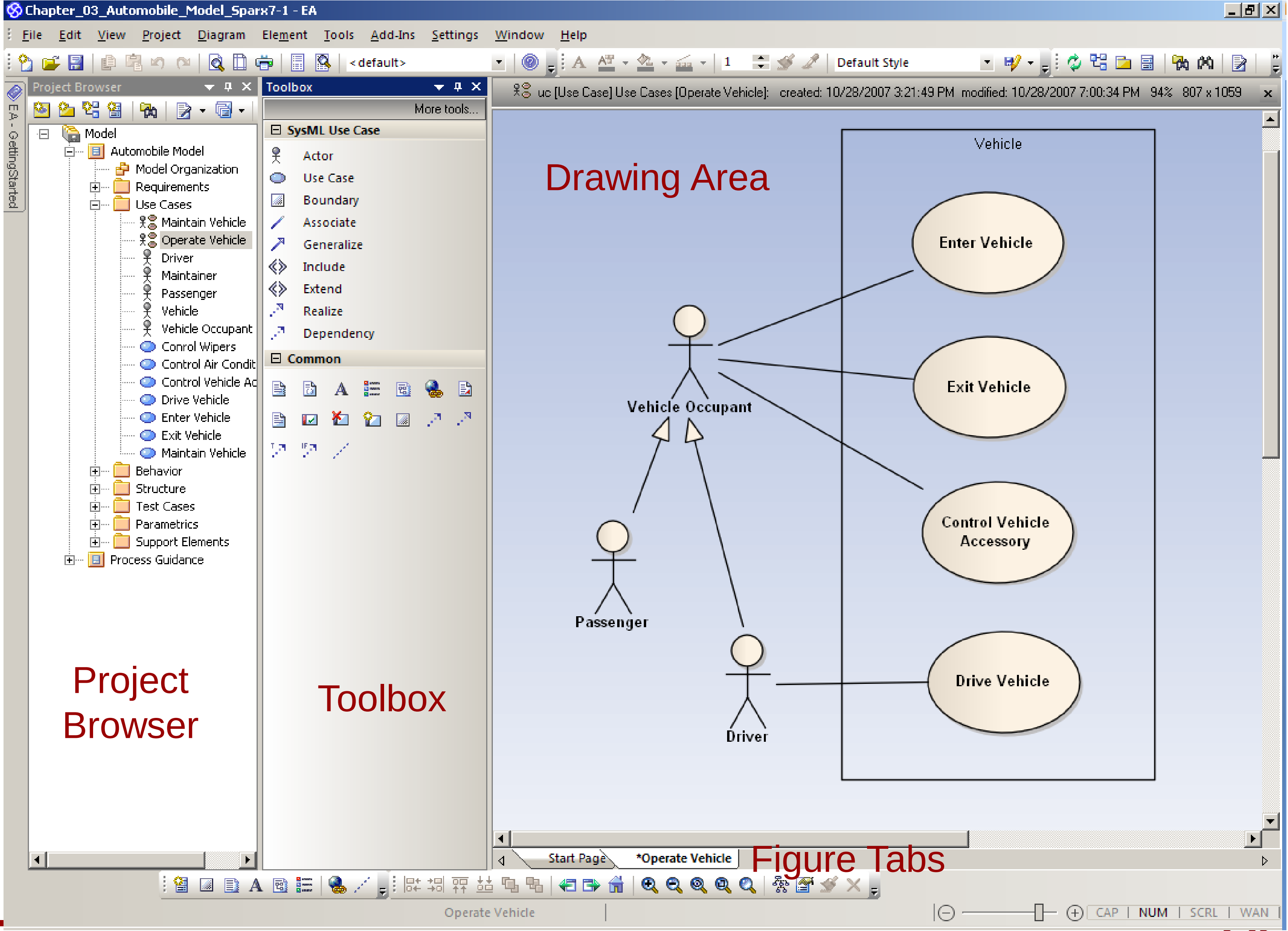
INTRODUCTION TO A MODELING TOOL

Typical Work Area Components



LANGUAGE CONCEPTS AND CONSTRUCTS

Agenda

- **Language Concepts and Constructs**
  - Organizing the Model with Packages
  - Capturing Text-Based Requirements in the Model
  - Modeling High Level Functionality with Use Cases
  - Modeling Structure With Blocks
    - Modeling Blocks and Their Relationships on a BDD
    - Modeling Part Interconnection on an IBD
  - Modeling Behavior
    - Flow-based Behavior with Activities
    - Message-based Behavior with Interactions
    - Event-based Behavior with State Machines
  - Modeling Constraints with Parametrics
  - Modeling Cross Cutting Relationships with Allocations

ORGANIZING THE MODEL WITH PACKAGES

Packages

- Packages are used to organize the model
  - Groups model elements into a name space
  - Often represented in tool browser
  - Supports model configuration management (check-in/out)
- Model can be organized in multiple ways
  - By System hierarchy (e.g., enterprise, system, component)
  - By diagram kind (e.g., requirements, use cases, behavior)
  - Use viewpoints to augment model organization
- Package Diagrams provide a graphical depiction of the model organization and/or package content

Package Diagram for Automobile Model

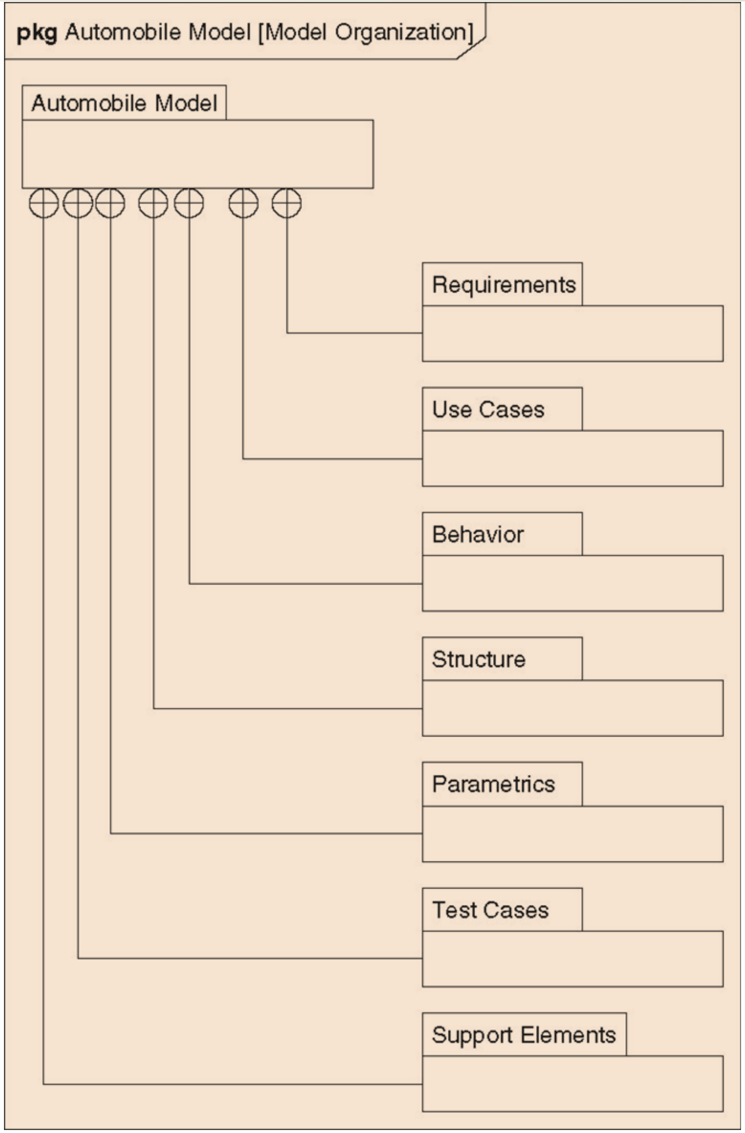


FIGURE 3.19

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Package Diagram Containment Relationship

- Depicts Package Hierarchy
- Three techniques (displayed below)
  - Packages contained within ‘frame’ of parent package
  - Packages contained within a package
  - Crosshair pointing to the parent package

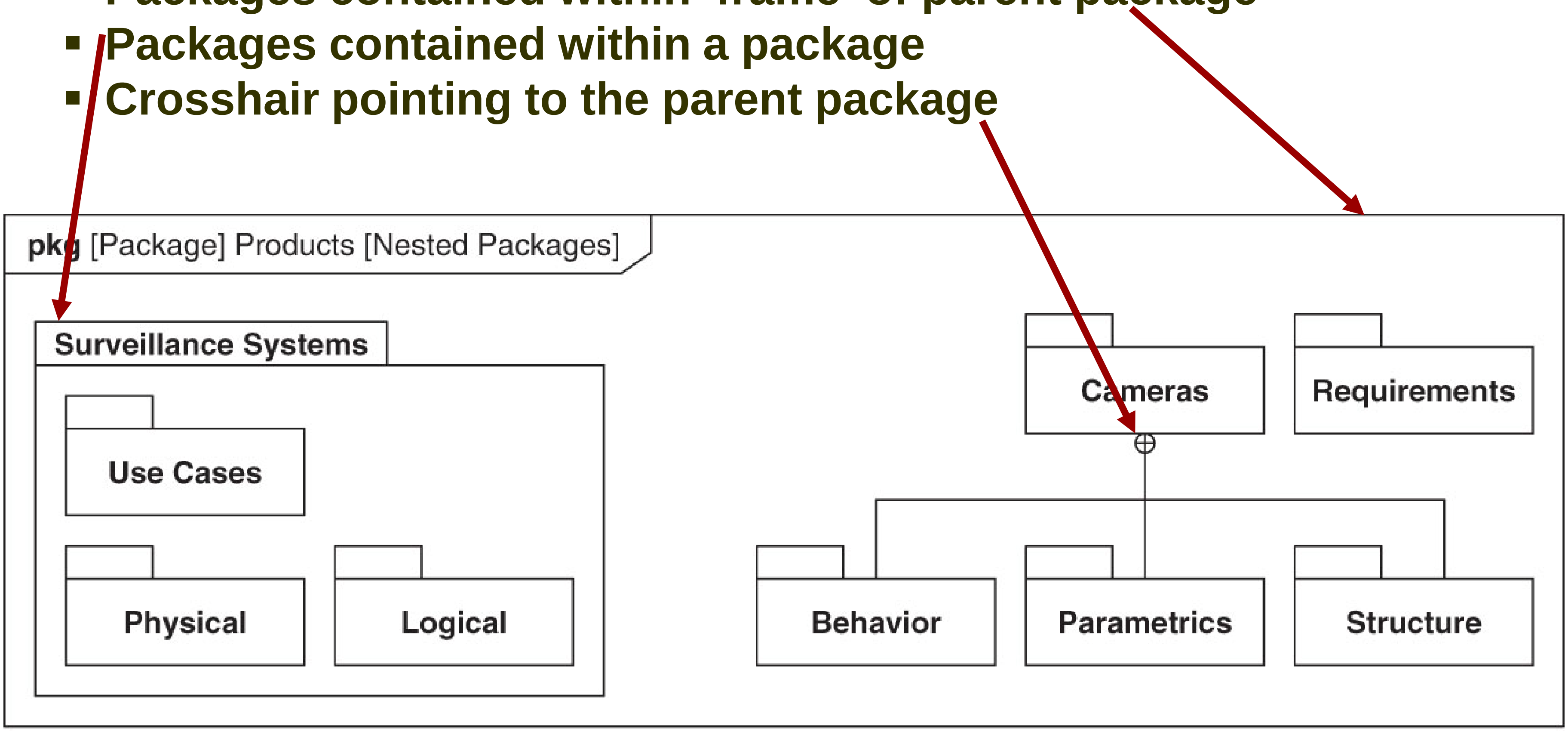
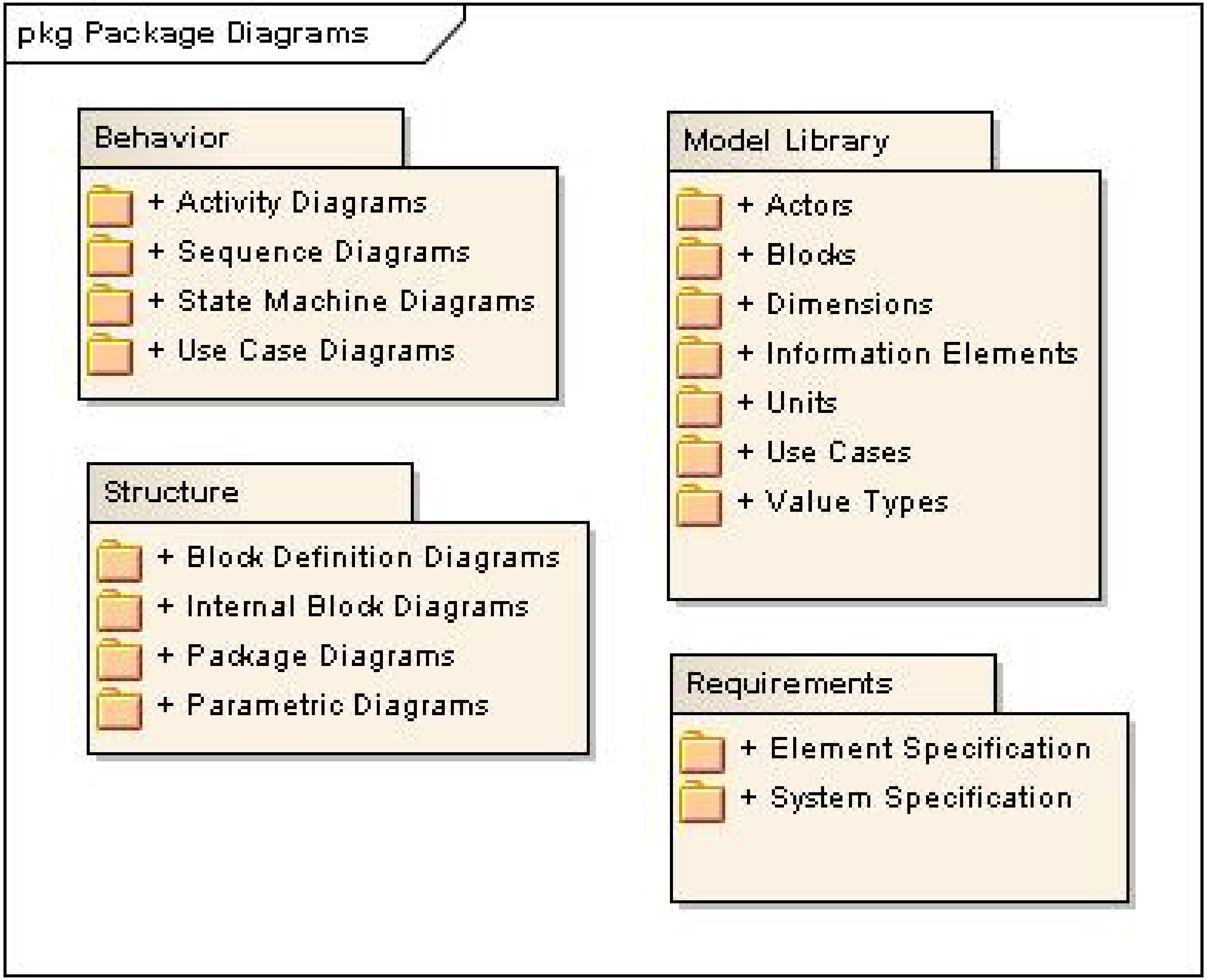


FIGURE 5.1

Package Organization for Parking Garage Gate



Summary

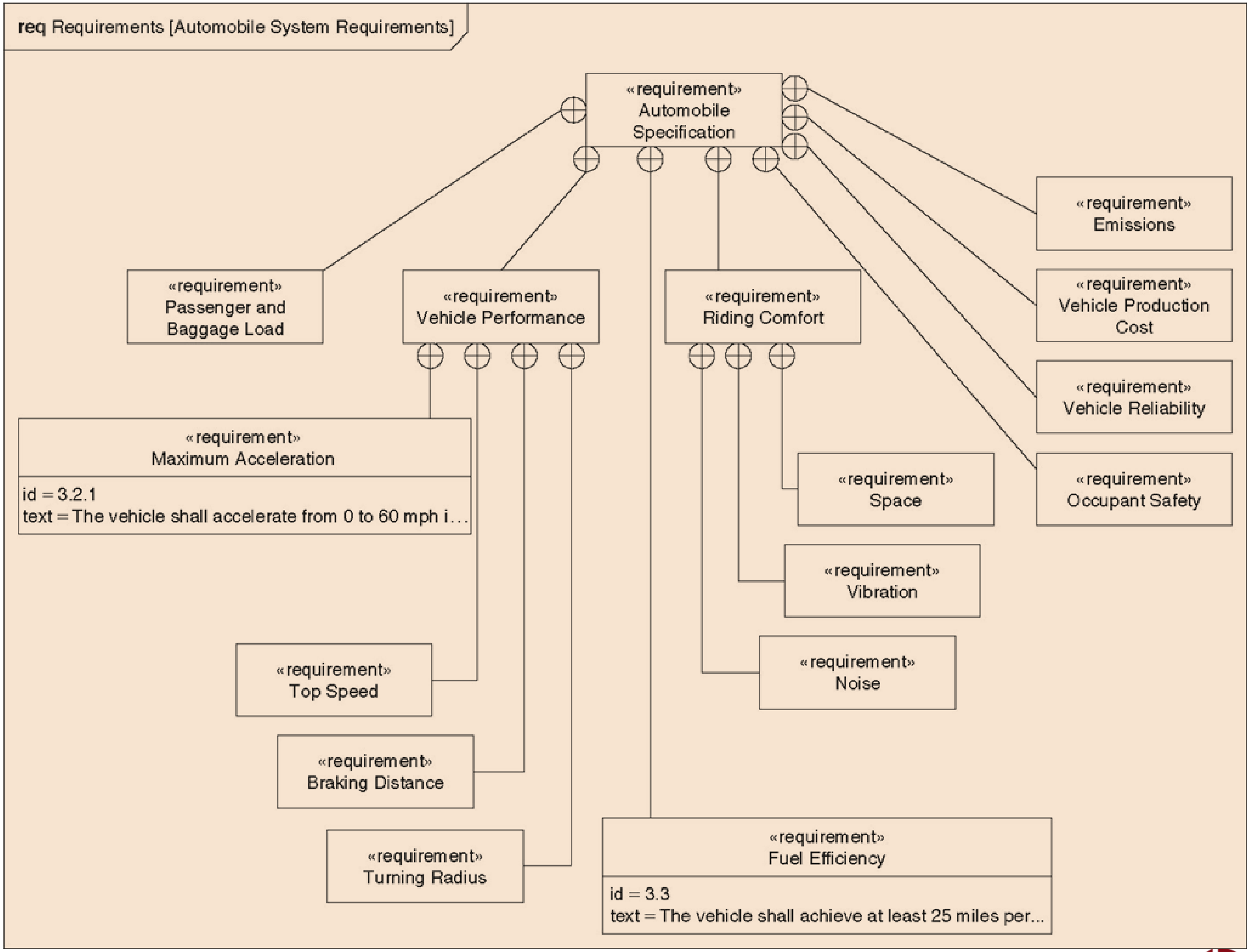
- Packages are used for Model Organization
- Package Diagrams are used to depict how the model is organized
- Packages can contain:
  - Other packages
  - Model elements
- Models may be organized using a variety of methods

CAPTURING TEXT-BASED REQUIREMENTS IN THE MODEL

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 Containment, DeriveReqt, Satisfy, Verify, Refine, Trace, Copy
  - SysML provides a graphical depiction of these relationships
  - SysML also provides a means to capture rationale for a specific requirement or relationship

Automobile Specification Requirements Diagram



req Requirements [Automobile System Requirements]
«requirement» Automobile Specification
«requirement» Passenger and Baggage Load
«requirement» Vehicle Performance
«requirement» Riding Comfort
«requirement» Emissions
«requirement» Vehicle Production Cost
«requirement» Vehicle Reliability
«requirement» Occupant Safety
«requirement» Maximum Acceleration
id = 3.2.1
text = The vehicle shall accelerate from 0 to 60 mph i…
«requirement» Space
«requirement» Vibration
«requirement» Noise
«requirement» Top Speed
«requirement» Braking Distance
«requirement» Turning Radius
«requirement» Fuel Efficiency
id = 3.3
text = The vehicle shall achieve at least 25 miles per...

FIGURE 3.2

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Requirements Traceability

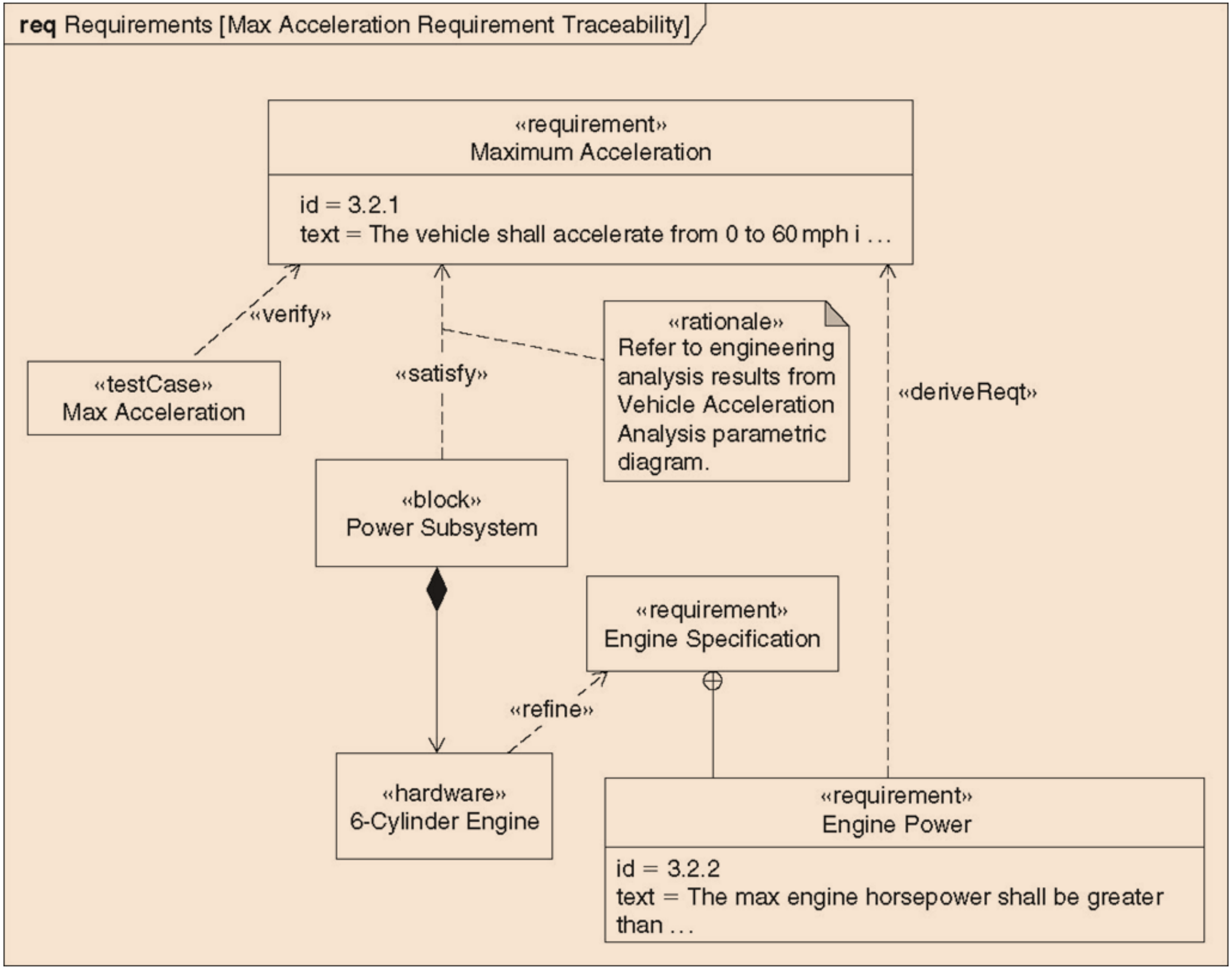
req Requirements [Max Acceleration Requirement Traceability]
«requirement»
Maximum Acceleration
id = 3.2.1
text = The vehicle shall accelerate from 0 to 60 mph i . . .
«verify»
«testCase»
Max Acceleration
«satisfy»
«rationale»
Refer to engineering analysis results from Vehicle Acceleration Analysis parametric diagram.
«deriveReqt»
«block»
Power Subsystem
«requirement»
Engine Specification
«refine»
«hardware»
6-Cylinder Engine
«requirement»
Engine Power
id = 3.2.2
text = The max engine horsepower shall be greater than . . .

FIGURE 3.18

Representing Relationships

- Three ways to depict requirement relationships in SysML:
  - Direct
  - Compartment
  - Callout

Direct Notation

- Used when the requirement and the related model element appear on the same diagram
- Establishes dependency of model element to requirement in model
- Read figure below as: “The camera satisfies the Sensor Decision requirement”.

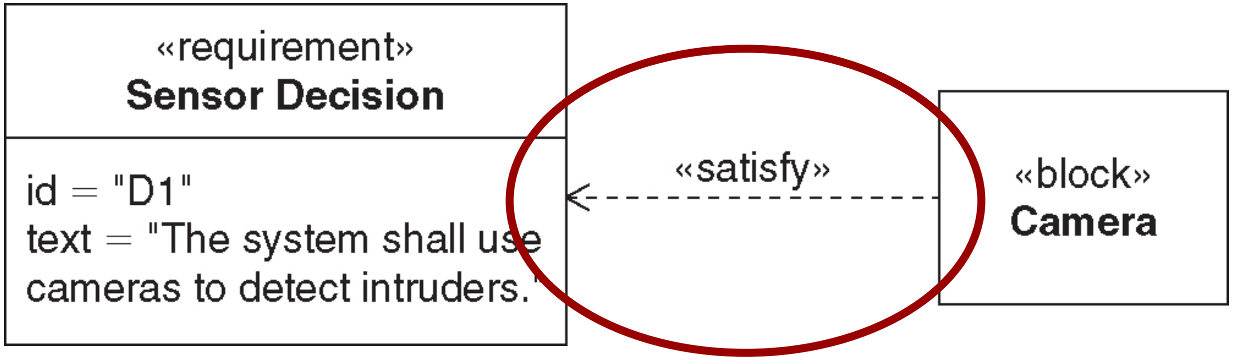

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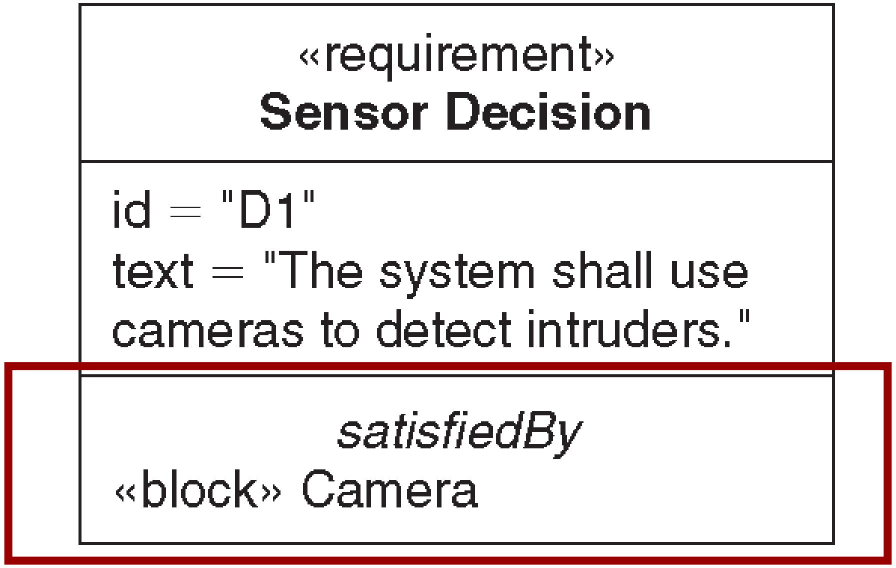
FIGURE 12.3

Compartment Notation

- Used when the requirement and model element do not appear on the same diagram.
- Used for model elements such as blocks or requirements that support compartments.



«requirement»
Sensor Decision

id = "D1"
text = "The system shall use cameras to detect intruders."

satisfiedBy
«block» Camera

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FIGURE 12.4

Callout Notation

- Used when the requirement and model element do not appear on the same diagram
  - Uses ‘Note’ box, rather than model element
- Can be used when the model element or tool does not support compartments

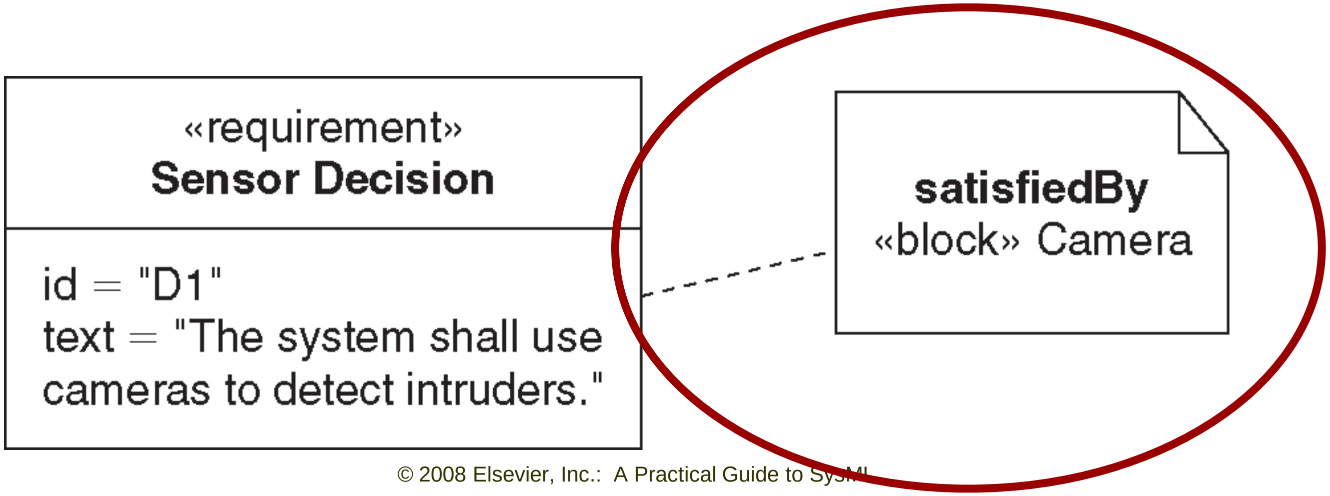

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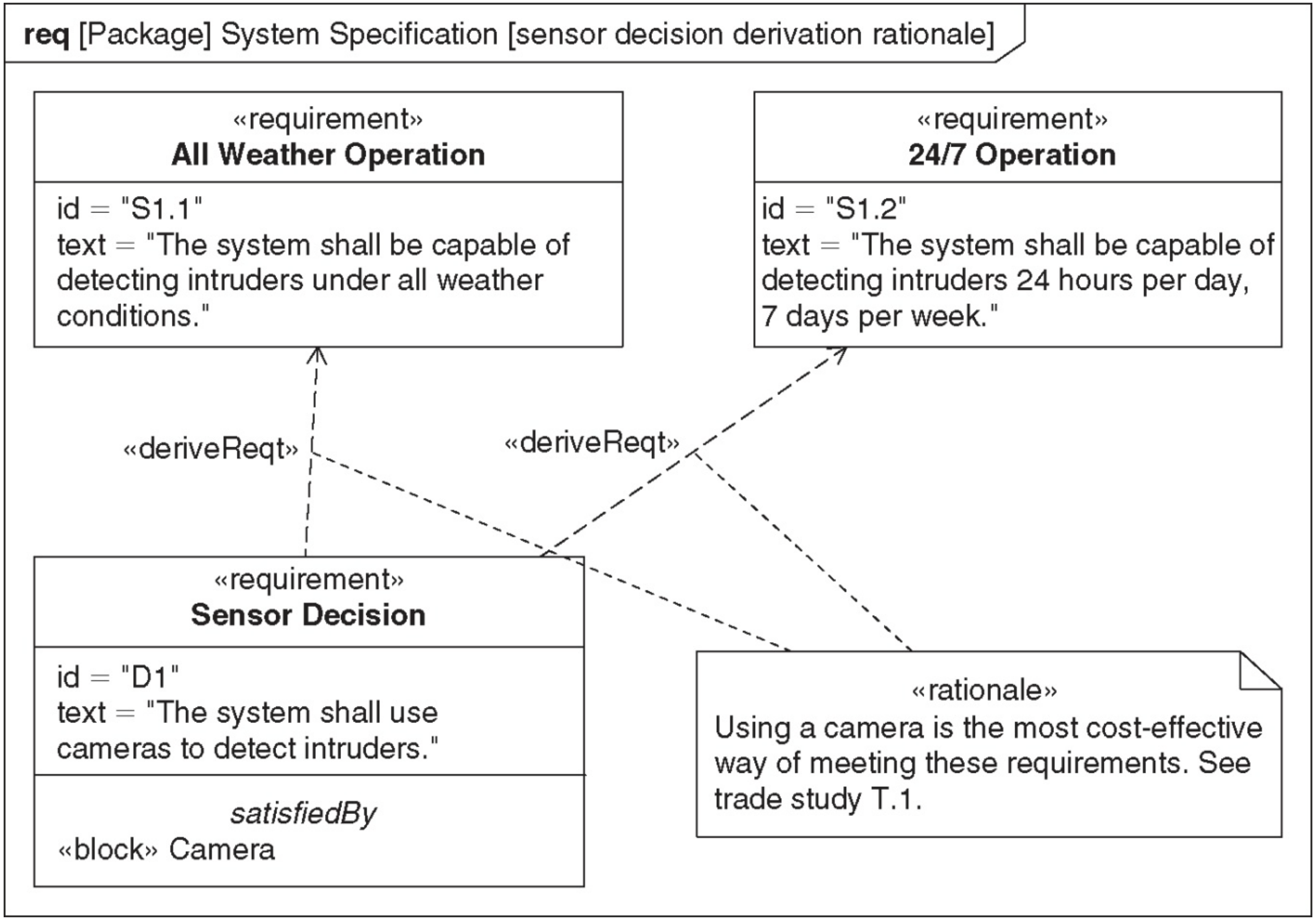
FIGURE 12.5

Depicting Rationale

- Used to explain or justify a requirement or a requirement relationship



req [Package] System Specification [sensor decision derivation rationale]
«requirement»
All Weather Operation
id = "S1.1"
text = "The system shall be capable of detecting intruders under all weather conditions."
«requirement»
24/7 Operation
id = "S1.2"
text = "The system shall be capable of detecting intruders 24 hours per day, 7 days per week."
«deriveReqt»
«deriveReqt»
«requirement»
Sensor Decision
id = "D1"
text = "The system shall use cameras to detect intruders."
satisfiedBy
«block» Camera
«rationale»
Using a camera is the most cost-effective way of meeting these requirements. See trade study T.1.

FIGURE 12.14

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Tabular Format

- **Requirements and their relationships can be represented in a tabular format**

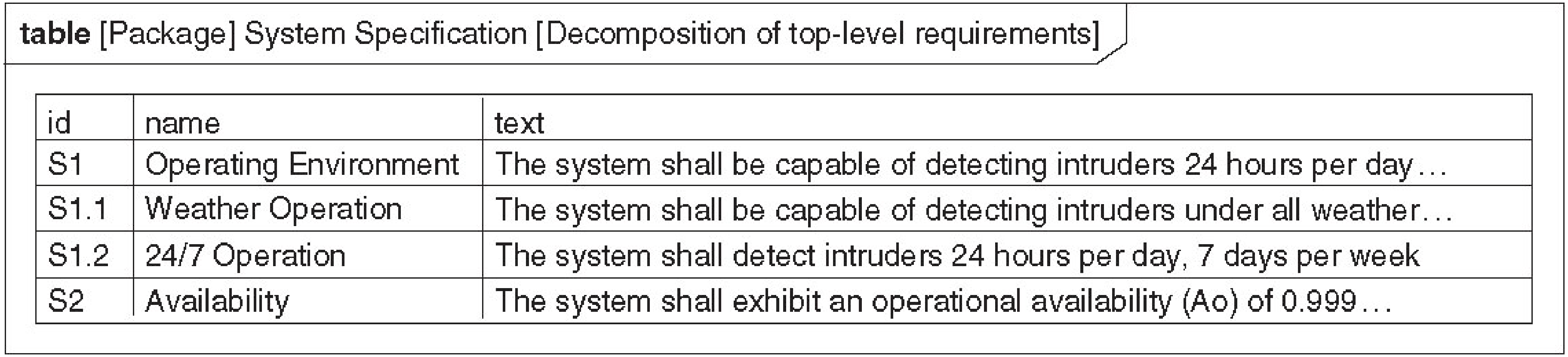

table [Package] System Specification [Decomposition of top-level requirements]

id	name	text
S1	Operating Environment	The system shall be capable of detecting intruders 24 hours per day…
S1.1	Weather Operation	The system shall be capable of detecting intruders under all weather…
S1.2	24/7 Operation	The system shall detect intruders 24 hours per day, 7 days per week
S2	Availability	The system shall exhibit an operational availability (Ao) of 0.999…

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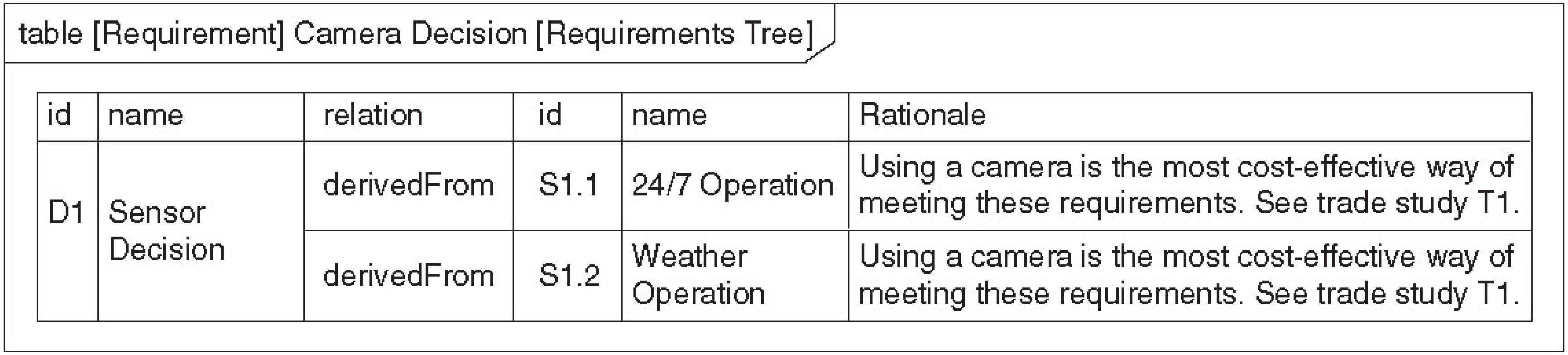

table [Requirement] Camera Decision [Requirements Tree]

id	name	relation	id	name	Rationale
D1	Sensor Decision	derivedFrom	S1.1	24/7 Operation	Using a camera is the most cost-effective way of meeting these requirements. See trade study T1.
		derivedFrom	S1.2	Weather Operation	Using a camera is the most cost-effective way of meeting these requirements. See trade study T1.

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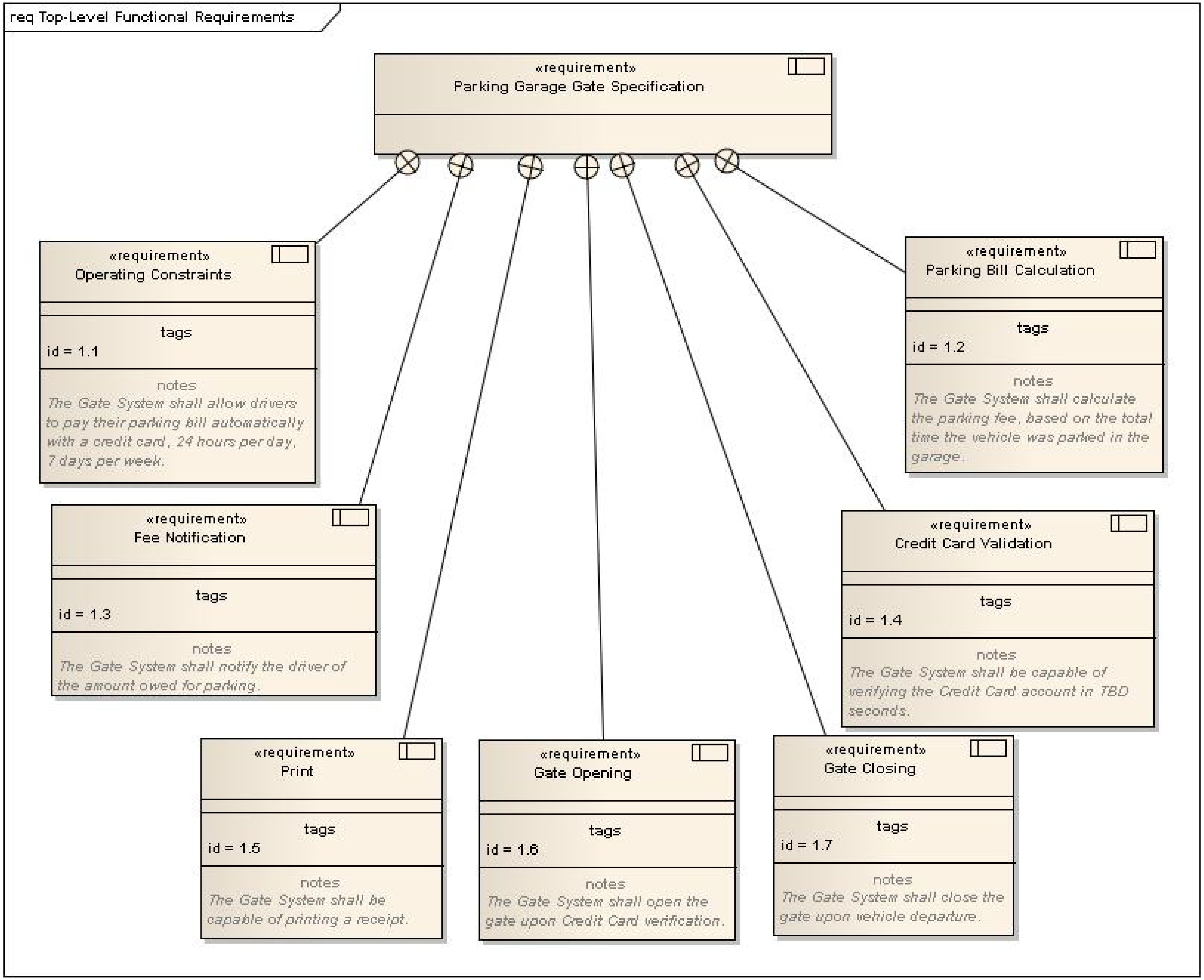
Parking Garage Requirements Model



req Top-Level Functional Requirements

«requirement»
Parking Garage Gate Specification

«requirement»
Operating Constraints

tags
id = 1.1

notes
The Gate System shall allow drivers to pay their parking bill automatically with a credit card, 24 hours per day, 7 days per week.

«requirement»
Parking Bill Calculation

tags
id = 1.2

notes
The Gate System shall calculate the parking fee, based on the total time the vehicle was parked in the garage.

«requirement»
Fee Notification

tags
id = 1.3

notes
The Gate System shall notify the driver of the amount owed for parking.

«requirement»
Credit Card Validation

tags
id = 1.4

notes
The Gate System shall be capable of verifying the Credit Card account in TBD seconds.

«requirement»
Print

tags
id = 1.5

notes
The Gate System shall be capable of printing a receipt.

«requirement»
Gate Opening

tags
id = 1.6

notes
The Gate System shall open the gate upon Credit Card verification.

«requirement»
Gate Closing

tags
id = 1.7

notes
The Gate System shall close the gate upon vehicle departure.

Summary

- Requirement modeling graphically depicts:
  - Hierarchy between requirements
  - Traceability between requirements and the rest of the model elements
- There are three types of notation used to depict requirement relationships: Direct, Compartment, and Callout
- There are seven types of requirement relationships in SysML:
  - Containment
  - Satisfy
  - Verify
  - Derive
  - Refine
  - Trace
  - Copy

MODELING HIGH LEVEL FUNCTIONALITY WITH USE CASES

Use Cases

- Provide means for describing basic functionality in terms of usages/goals of the system by actors
  - Use is methodology dependent
  - Often accompanied by use case descriptions
- Common functionality can be factored out via «include» and «extend» relationships
- Elaborated via other behavioral representations to describe detailed scenarios
- No change to UML

Operate Vehicle Use Case Diagram

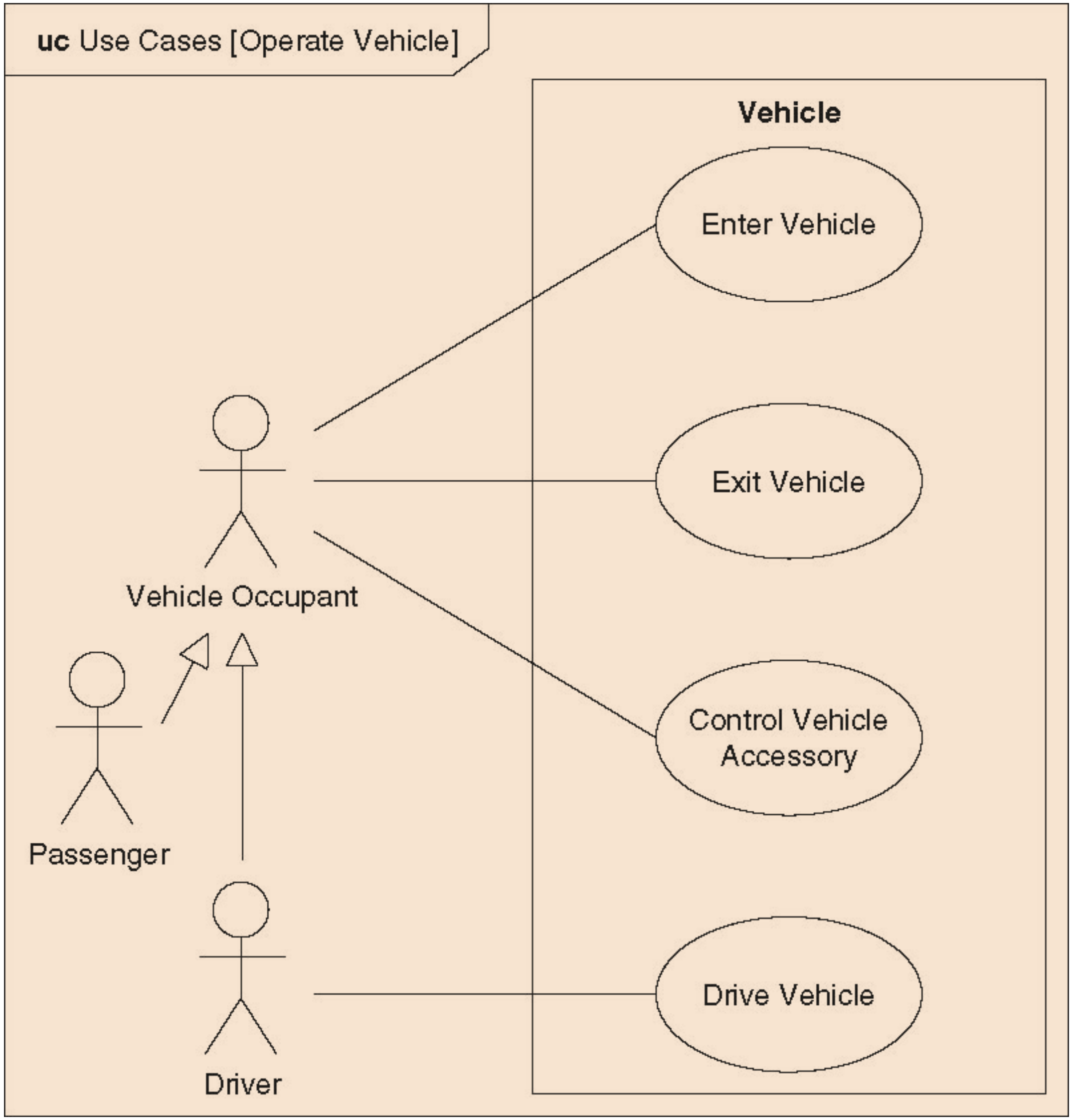


FIGURE 3.4

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Use Case Diagram Components

- Use Case diagrams are comprised of the following:
  - Subject
  - Actors
  - Use Cases
  - Relationships

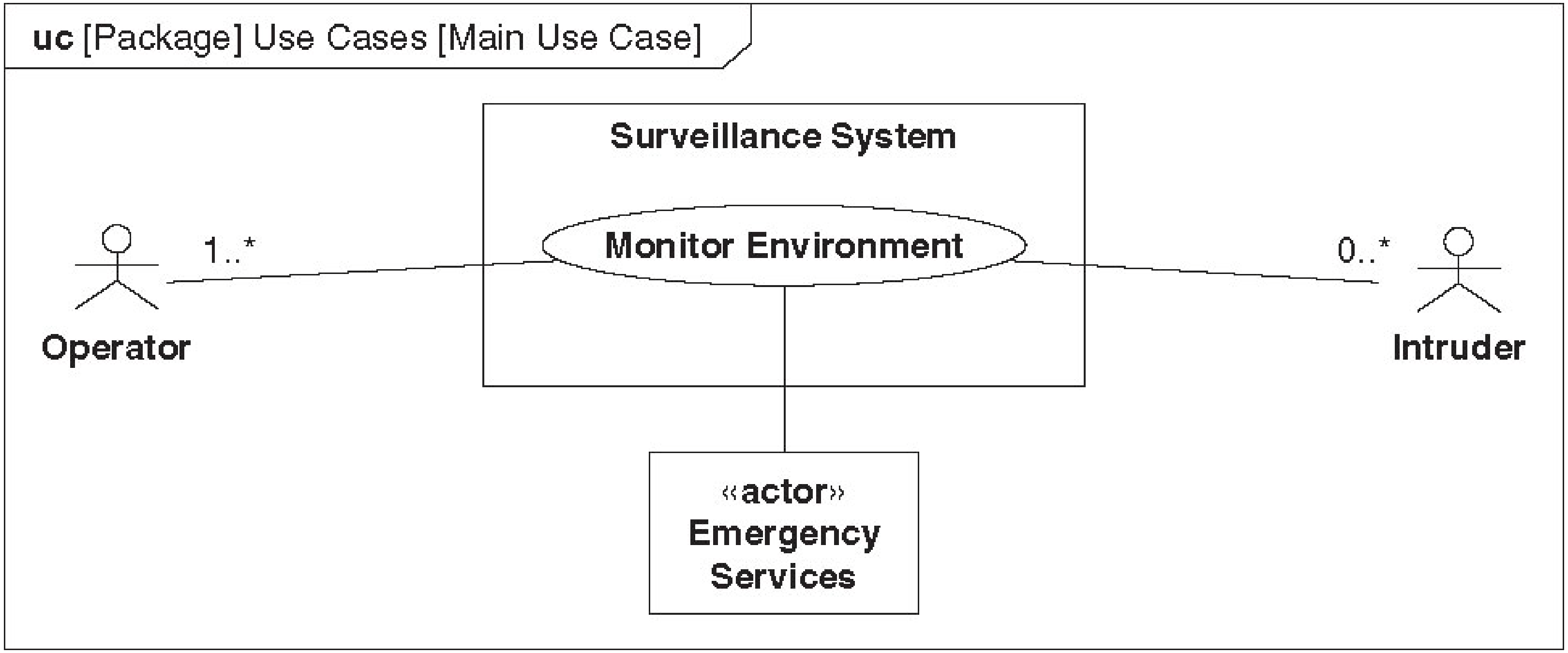

FIGURE 11.1

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Subject

- Provides the functionality in support of the use cases
- Represents a system being developed
- Also called the ‘system under consideration’
- Represented by a rectangle on the use case diagram

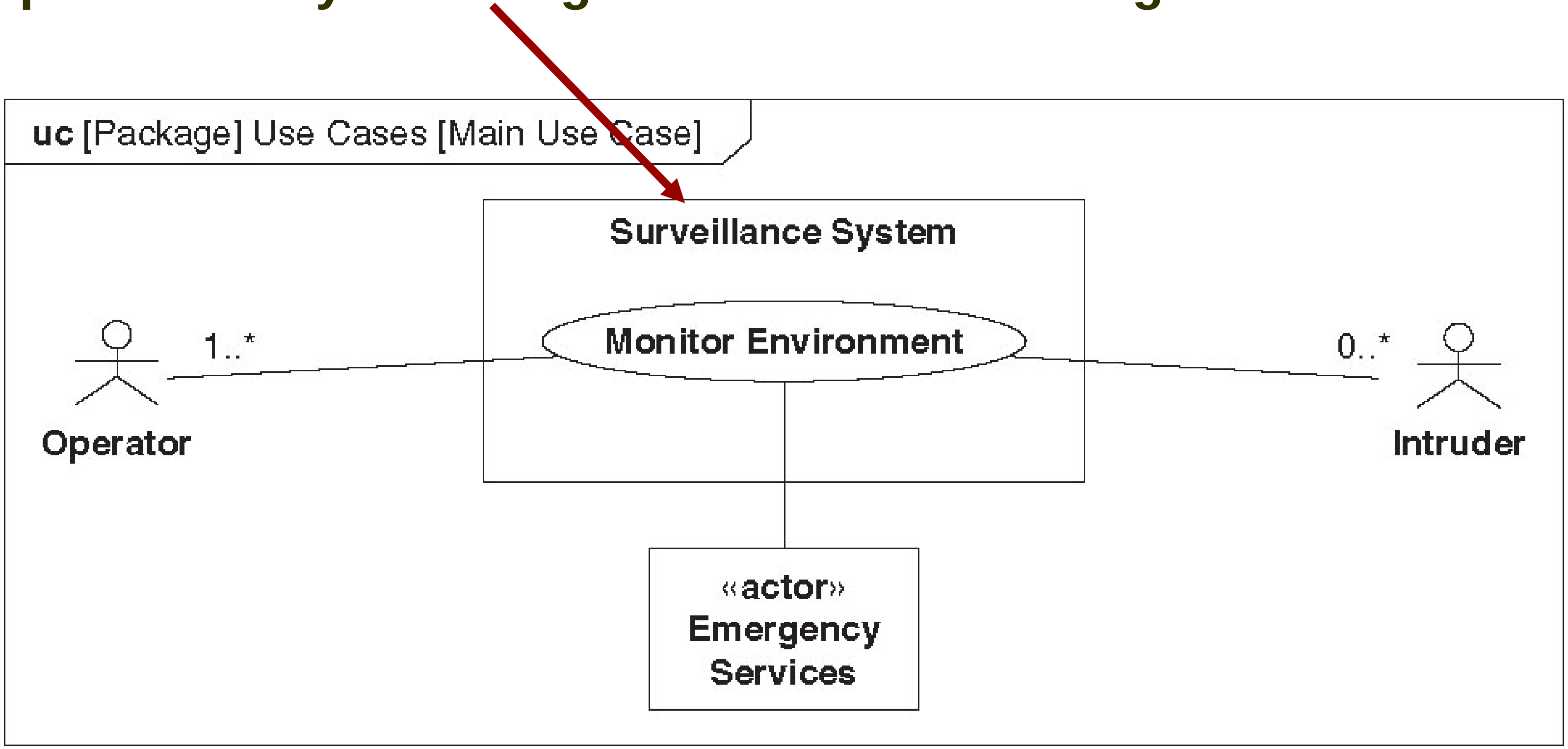

FIGURE 11.1

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Actors

- Used to represent something that uses the system
  - Not ‘part’ of the system
    - Depicted outside of the system ‘box’
  - Actors interface with the system
- Can be a person or another system
- Usually depicted by a stick figure and/or block with <<actor>> label
- Name the Actors based on the role they perform as a user of the system (e.g. Operator, Customer, etc)

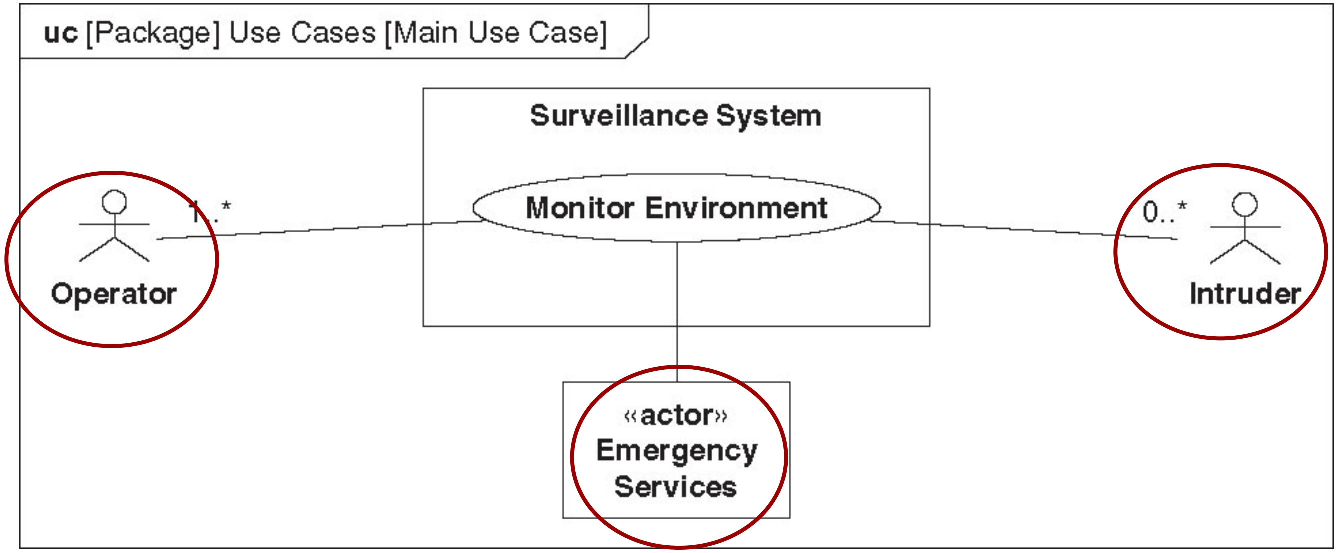

FIGURE 11.1

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Use Cases

- Represent the goals that a system will support
- Depicted by an oval with the Use Case name inside
- Name should consist of a verb and a noun that describe the functionality of the system (e.g. Record Grades, Monitor Environment)

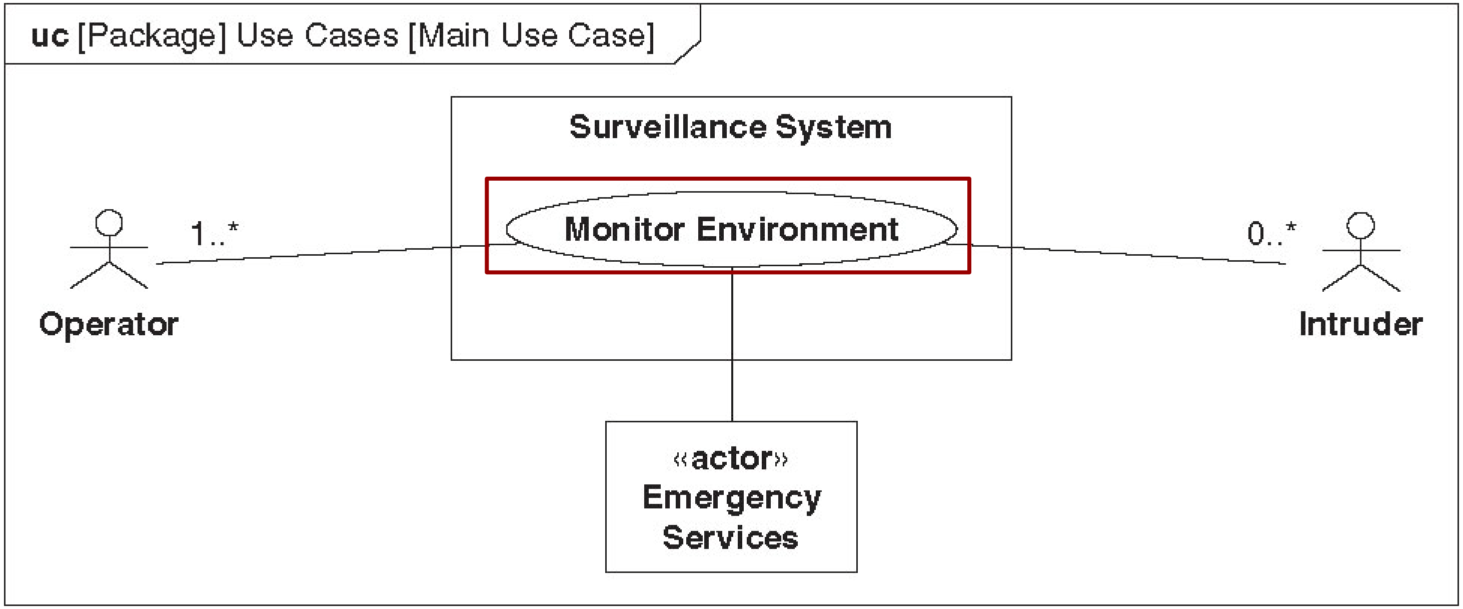

FIGURE 11.1

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Relationships on a Use Case Diagram

- Relationships between Actors and Use Cases
- Relationships between Use Cases
  - Include
  - Extend
  - Classification

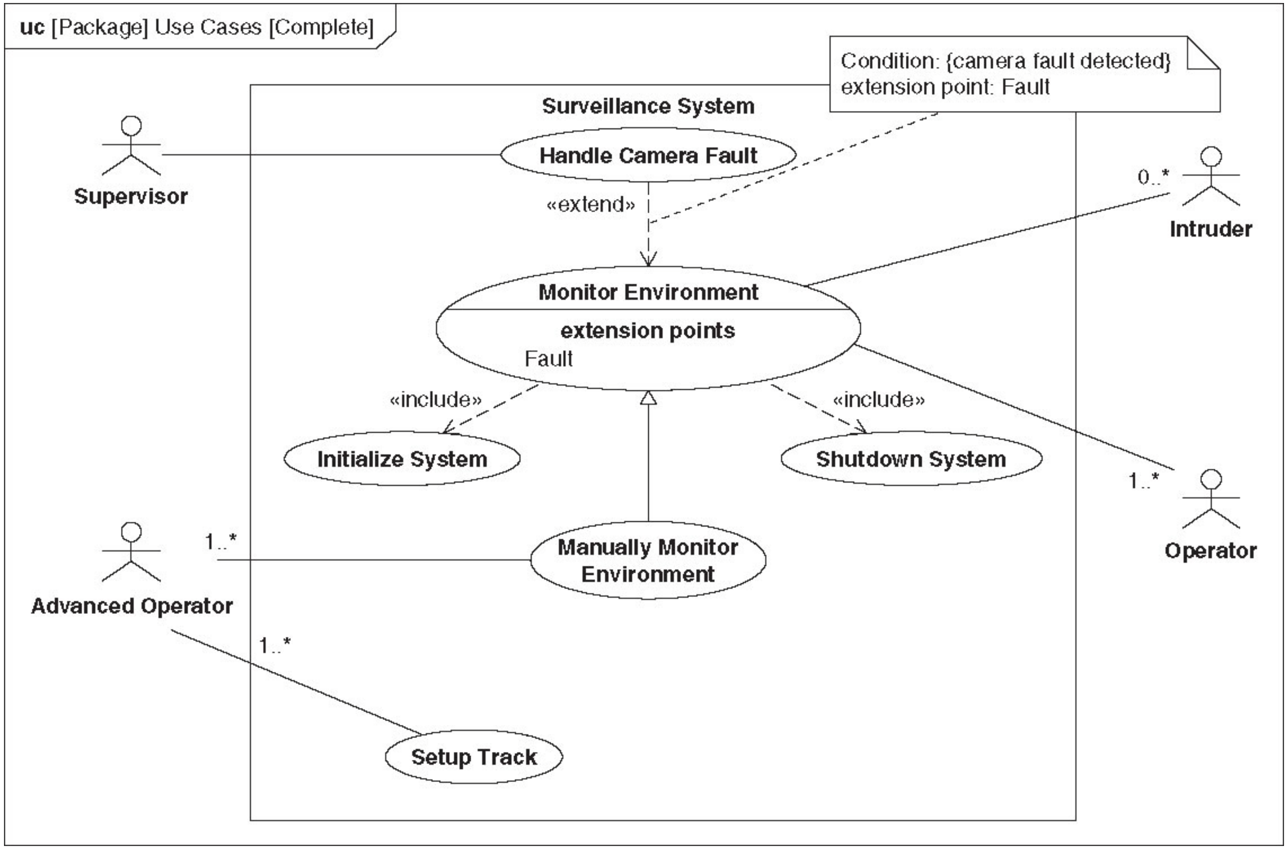

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FIGURE 11.4

Relationships Between Use Cases

- Include - depicts shared (or re-used) functionality
- Extend – depicts optional functionality, performed when a particular condition is met
- Classification – indicates that the specialized Use Case inherits functionality from the general Use Case

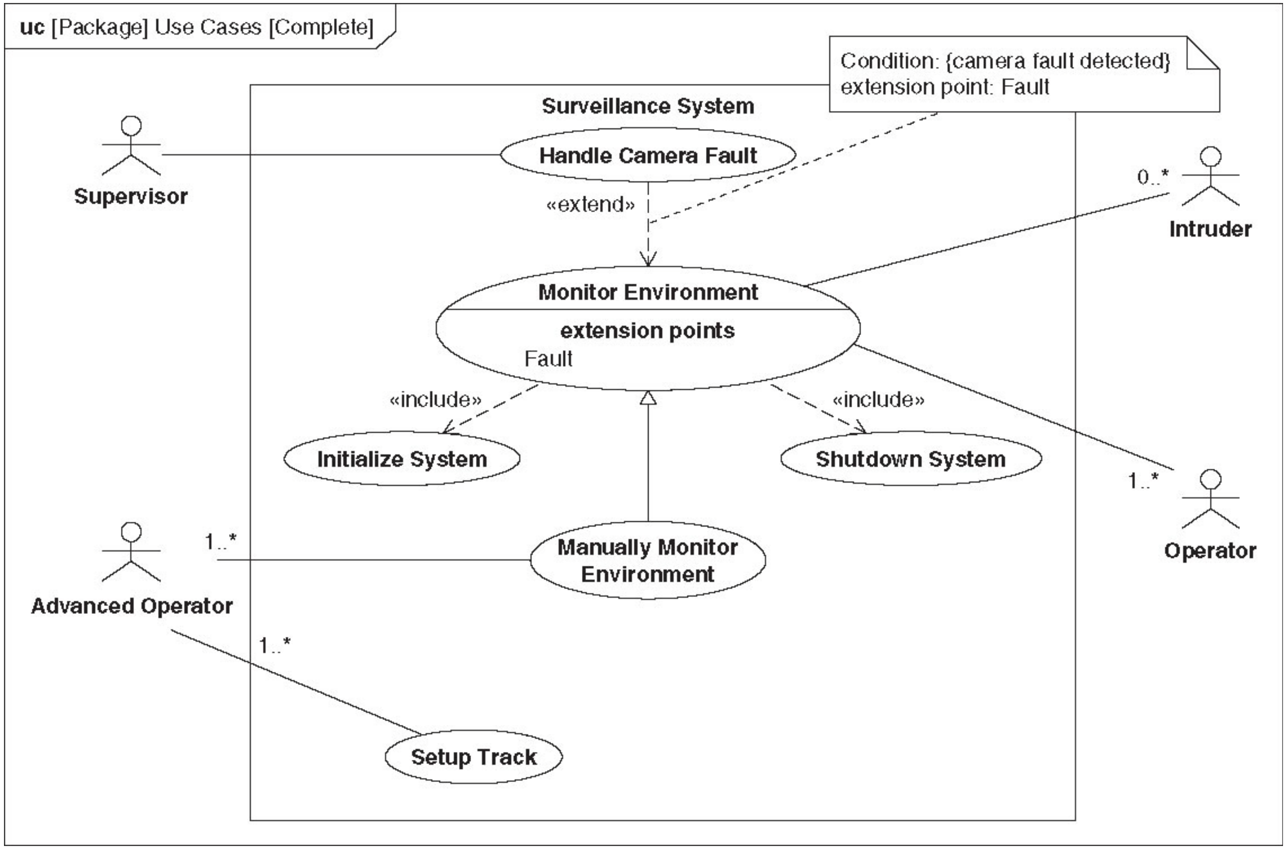

FIGURE 11.4

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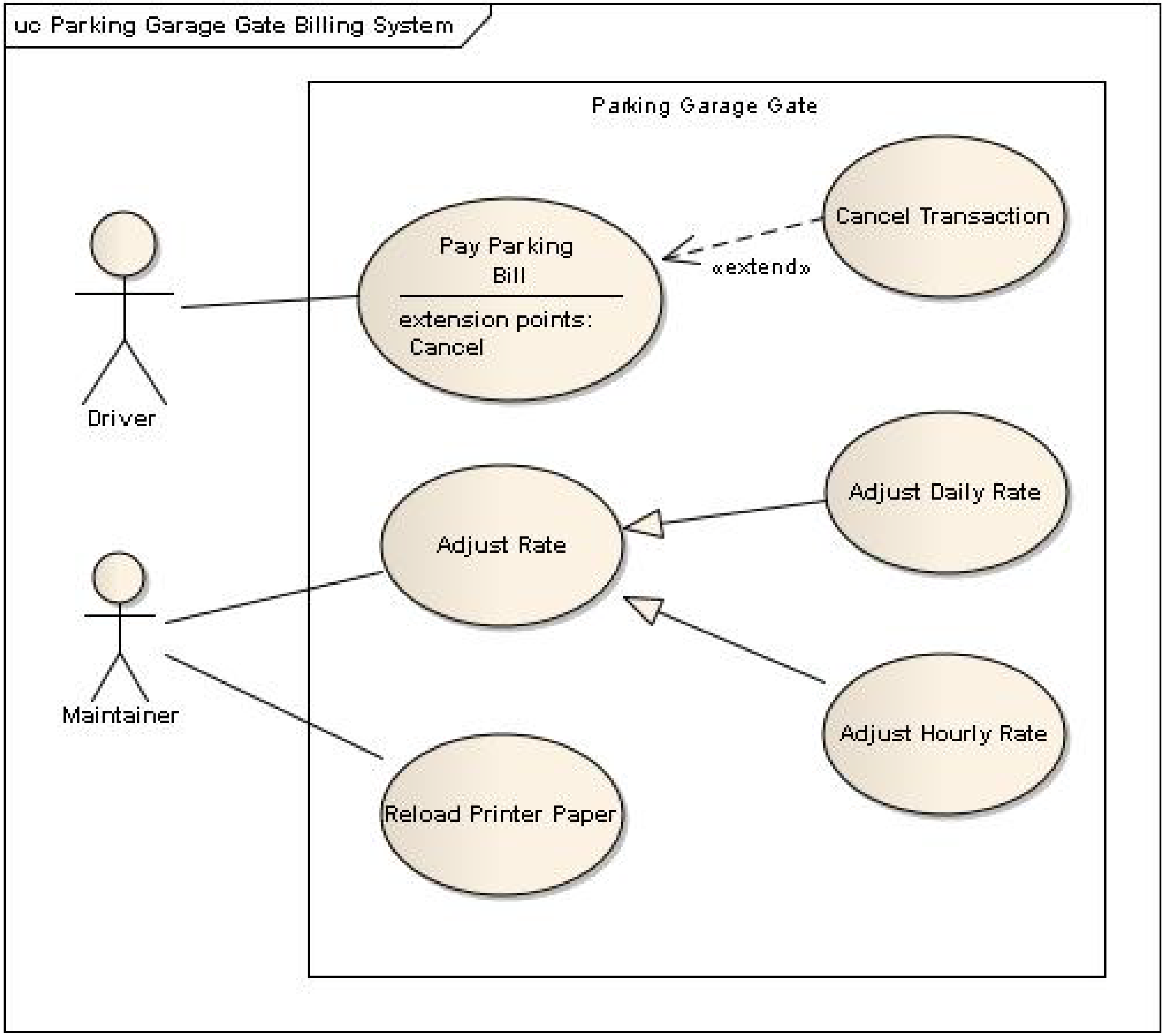
Use Case Model for Parking Garage Gate



Summary

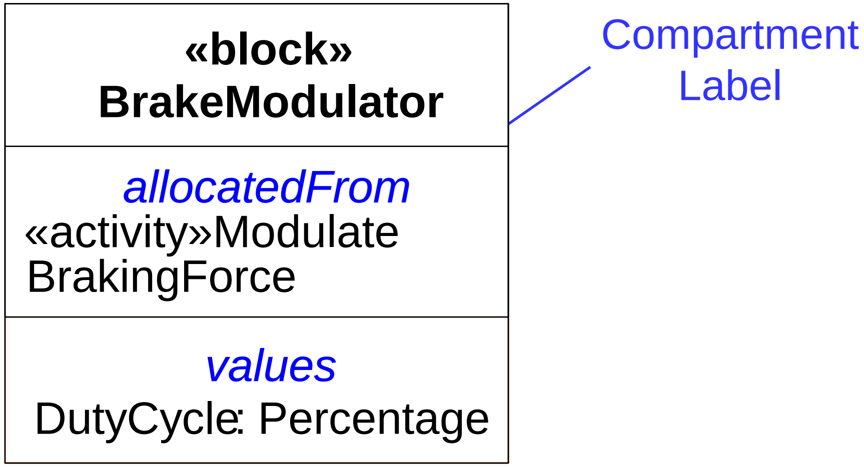
- Use Cases capture the functionality a system must provide to achieve user goals
- Use Case diagrams are made up of:
  - Subject
  - Actors
  - Use Cases
  - Relationships
- Use Case can be elaborated through:
  - Activity diagrams
  - Sequence diagrams
  - State machine diagrams

MODELING STRUCTURE WITH BLOCKS

MODELING BLOCKS AND THEIR RELATIONSHIPS ON A BDD

Blocks are Basic Structural Elements

- Provides a unifying concept for describing the structure of an entity
  - System
  - Hardware
  - Software
  - Data
  - Procedure
  - Facility
  - Person



«block»
BrakeModulator

allocatedFrom
«activity»Modulate BrakingForce

values
DutyCycle: Percentage

Compartment Label

- Multiple standard compartments can describe the block characteristics
  - Properties (parts, references, values, ports)
  - Operations
  - Constraints
  - Allocations from/to other model elements (e.g. activities)
  - Requirements the block satisfies
  - User defined compartments

Top Level Block Definition Diagram

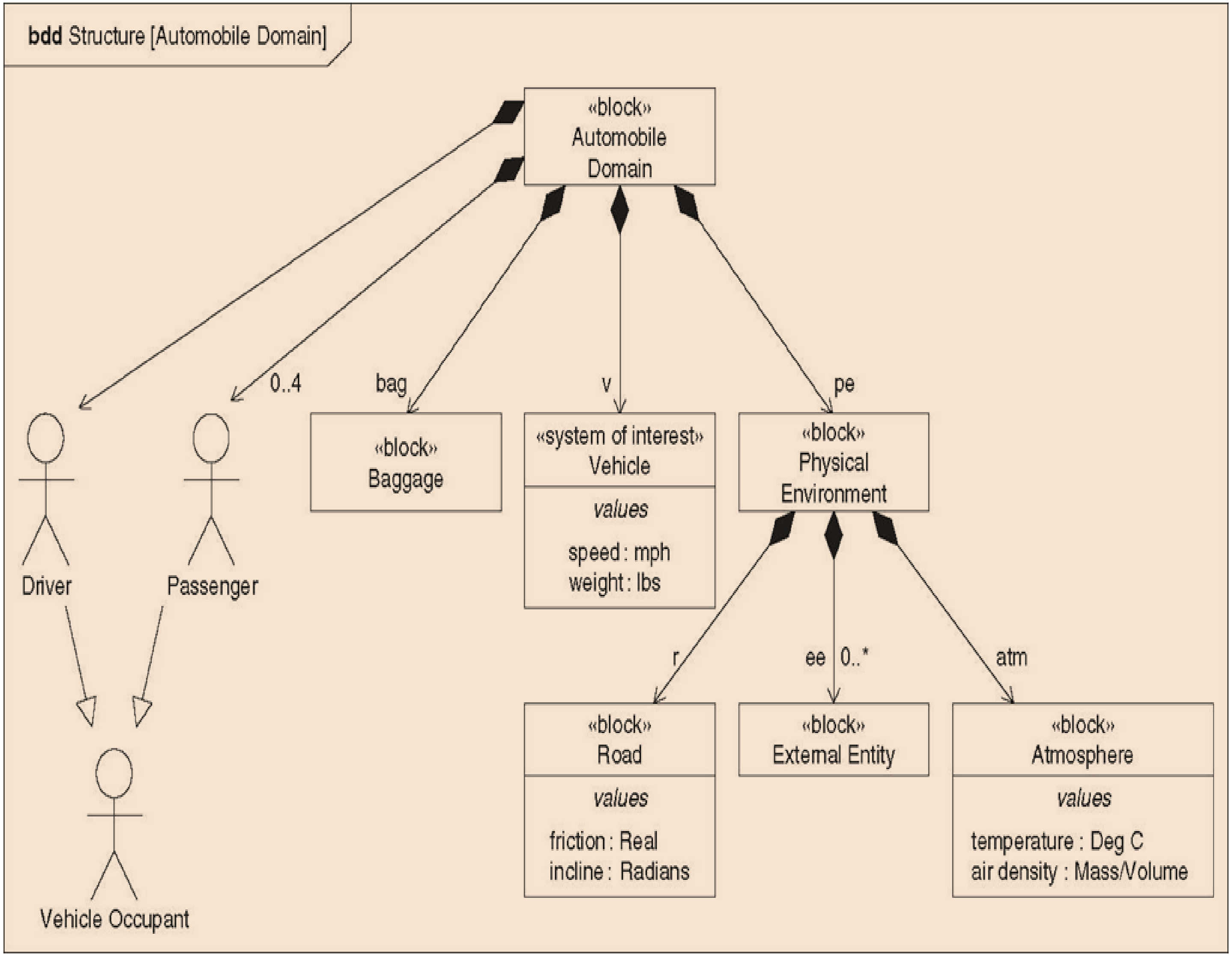


FIGURE 3.3

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Vehicle System Hierarchy

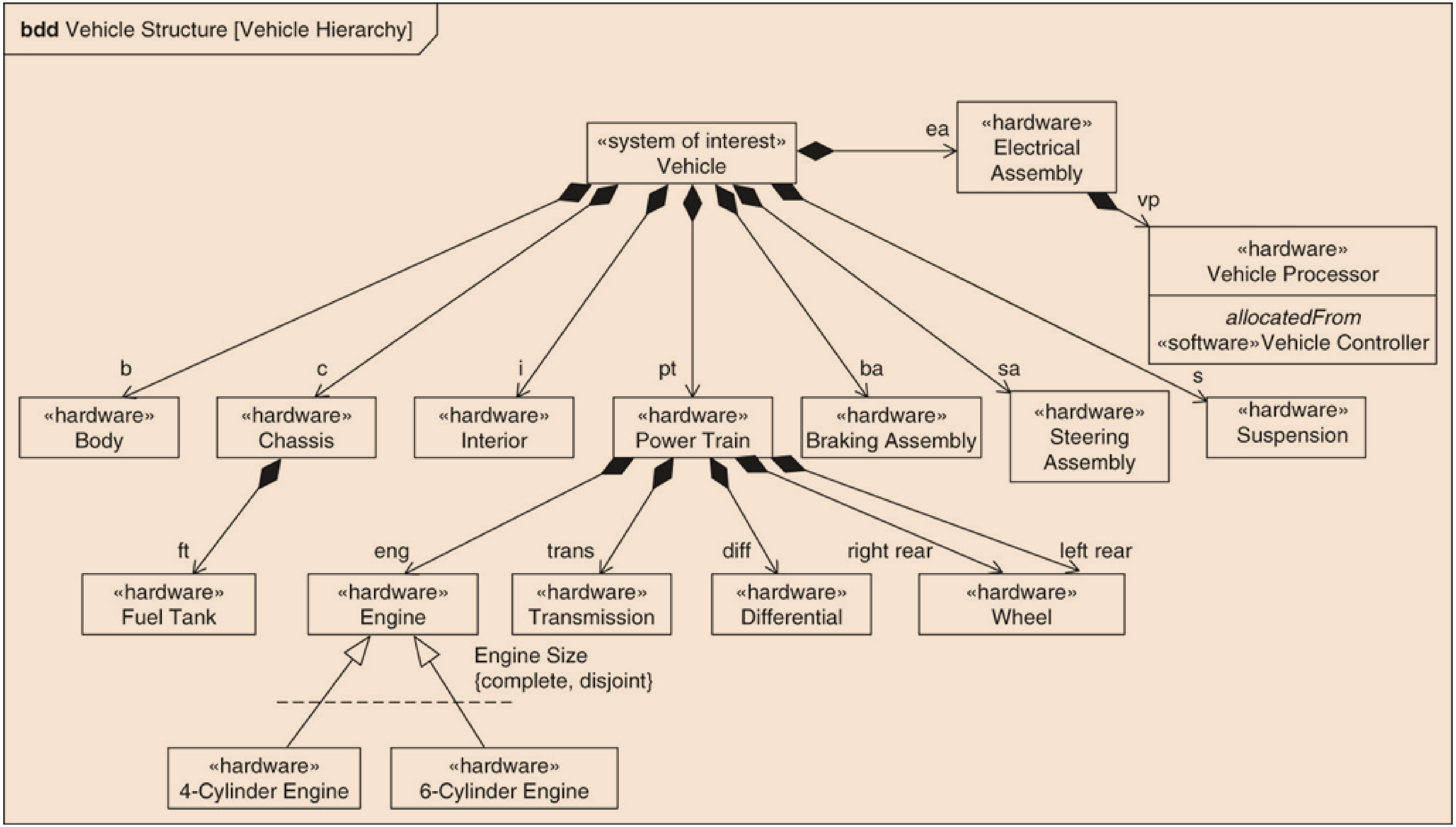

FIGURE 3.10

Purpose of Block Definition Diagrams

- Depicting Relationships between Blocks
  - Composite Association
  - Generalization
- Depicting Structural Features of Blocks
  - Part Properties
  - Value Properties
  - Ports
    - Flow Ports
    - Standard Ports
- Depicting Behavioral Characteristics of Blocks
    - Operations

Composite Association

- Composite Associations depict parts that make up the Whole
  - Black diamond on the Whole end
  - Role names can appear on the part end

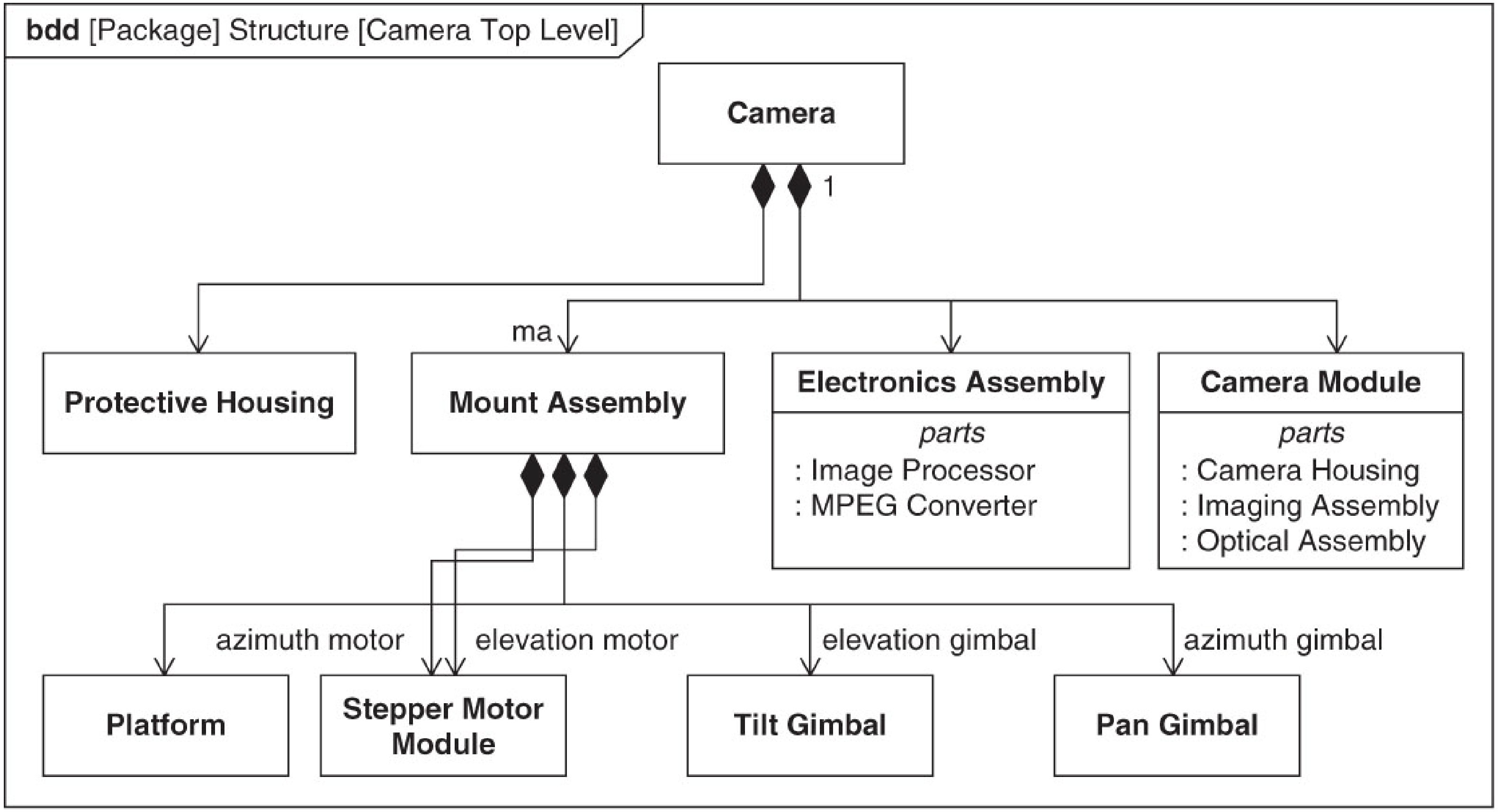

FIGURE 6.5

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Generalization

- Block Definition Diagrams can be used to depict generalization and specialization relationships
- Facilitates reuse
    - The specialized block (subclass) reuses (inherits) the features of a generalized block (superclass), and adds its own features
- Depicts an ‘is-a’ relationship
- Depicted with a closed arrowhead pointing toward the generalized block

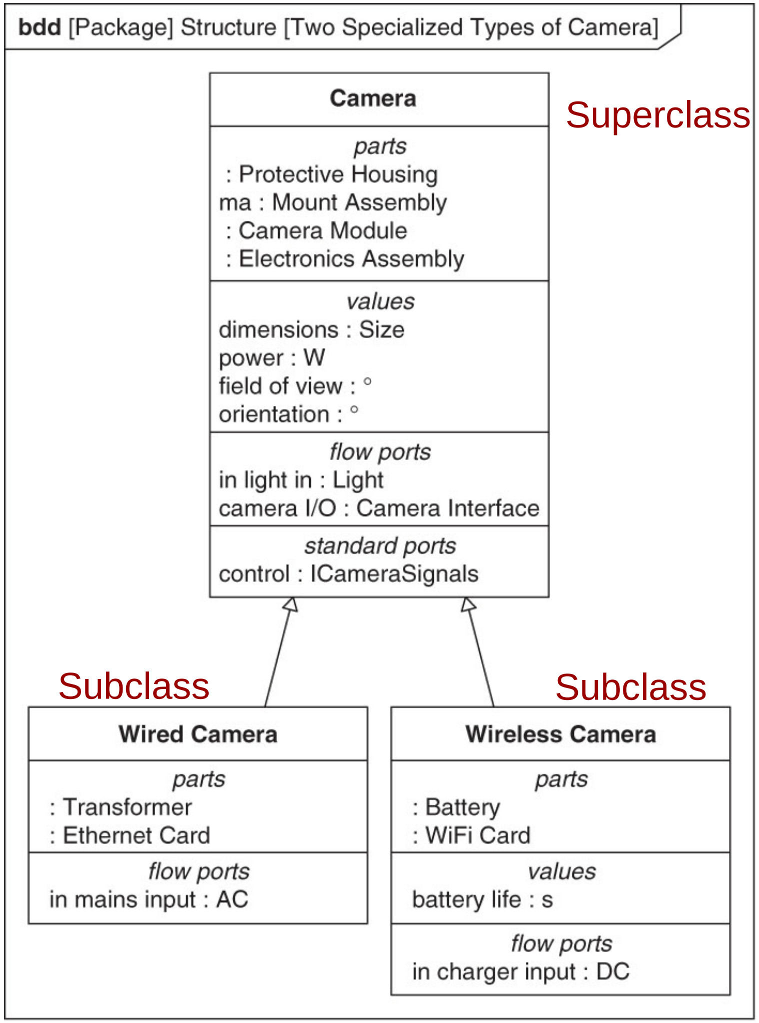

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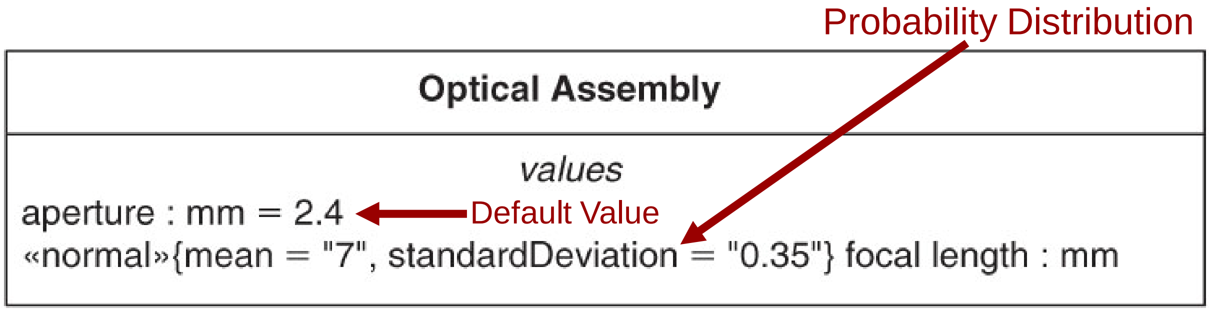
FIGURE 6.35

Value Properties

- **Used to model quantifiable block characteristics or attributes**
- **Based on a Value Type, which describe the values for quantities**
- **Listed in compartments using the following syntax:**
  - **value property name: value type name**
- **Value Properties:**
  - **can have default values**
  - **can also define a probability distribution for their values**



Probability Distribution

Optical Assembly

values

aperture : mm = 2.4

Default Value

«normal»{mean = "7", standardDeviation = "0.35"} focal length : mm

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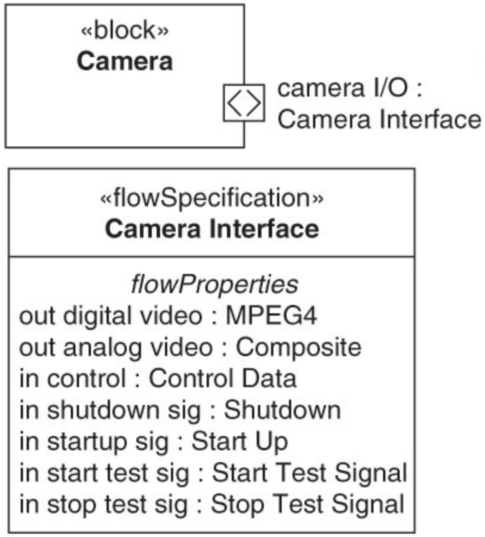
FIGURE 6.22

Ports

- Specifies interaction points on blocks
- Kinds of Ports
  - Flow Port
    - Specifies what can flow in or out of a block
  - Standard Port
    - Specifies a set of required or provided operations

Flow Ports

- Flow Ports – used to describe an interaction point for items flowing in or out of a block
- Two types:
  - Atomic Ports
  - Non-atomic Ports
- Depicted as a box on the block border



«block»
Camera
camera I/O :
Camera Interface
«flowSpecification»
Camera Interface
flowProperties
out digital video : MPEG4
out analog video : Composite
in control : Control Data
in shutdown sig : Shutdown
in startup sig : Start Up
in start test sig : Start Test Signal
in stop test sig : Stop Test Signal

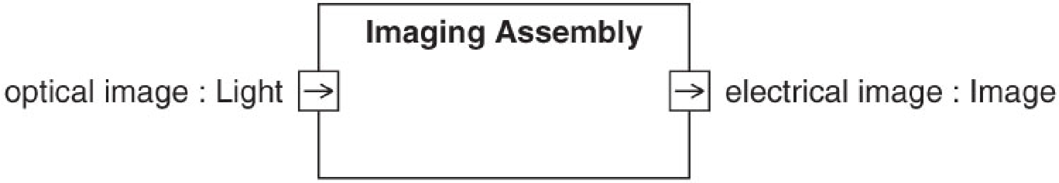


FIGURE 6.25

FIGURE 6.26

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Standard Ports and Interfaces

- Standard Ports – depict interfaces that specify the behavioral features (services) that a block either provides or requires
- Provided Interface – specifies operations that a block provides
  - Depicted by a ‘ball’
- Required Interface – specifies operations required by the block
  - Depicted by a ‘socket’

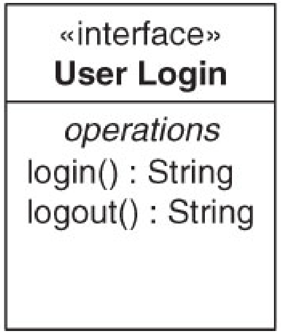

FIGURE 6.32

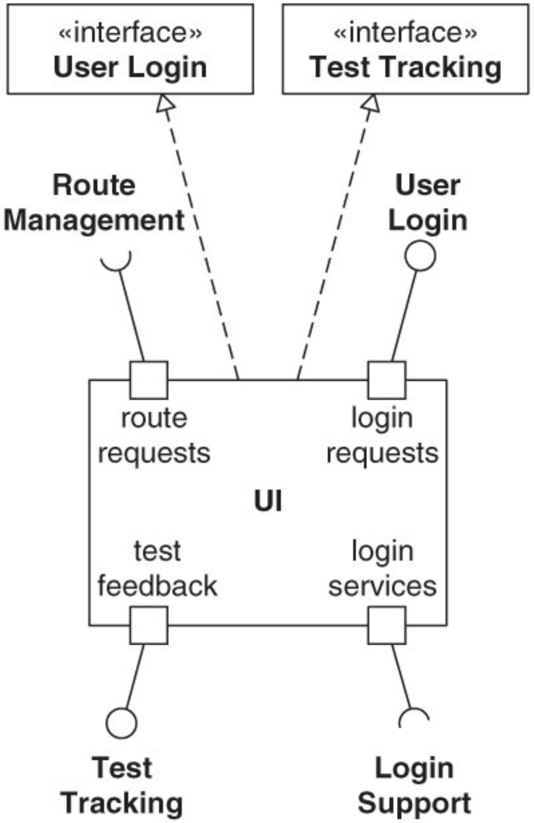

FIGURE 6.33

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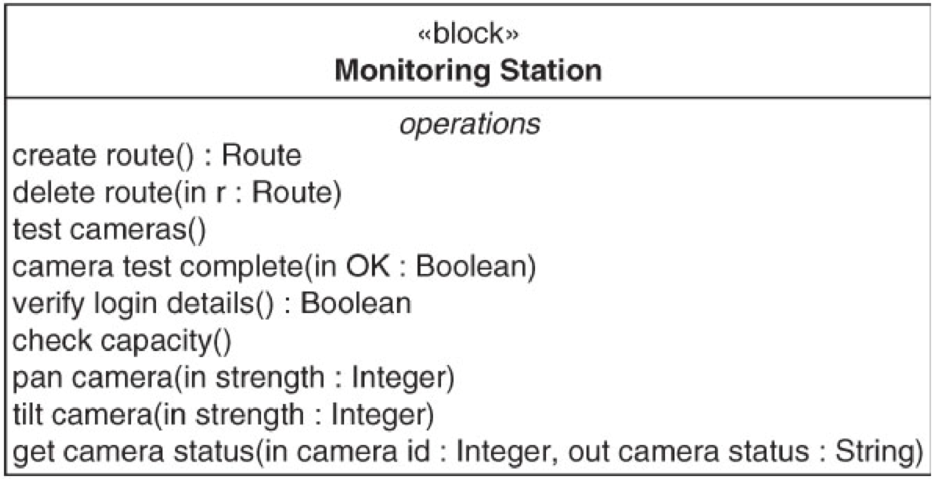
Operations

- Operations describe something that a block can do
- Operations can have parameters that are passed into or out of the operation
- Operations are typically synchronous, (i.e. requestor waits for a response)
- Operations are listed in the ‘operations’ compartment of a block, as follows:
  - operation name (parameter list): return type



«block»
Monitoring Station

operations

create route() : Route
delete route(in r : Route)
test cameras()
camera test complete(in OK : Boolean)
verify login details() : Boolean
check capacity()
pan camera(in strength : Integer)
tilt camera(in strength : Integer)
get camera status(in camera id : Integer, out camera status : String)

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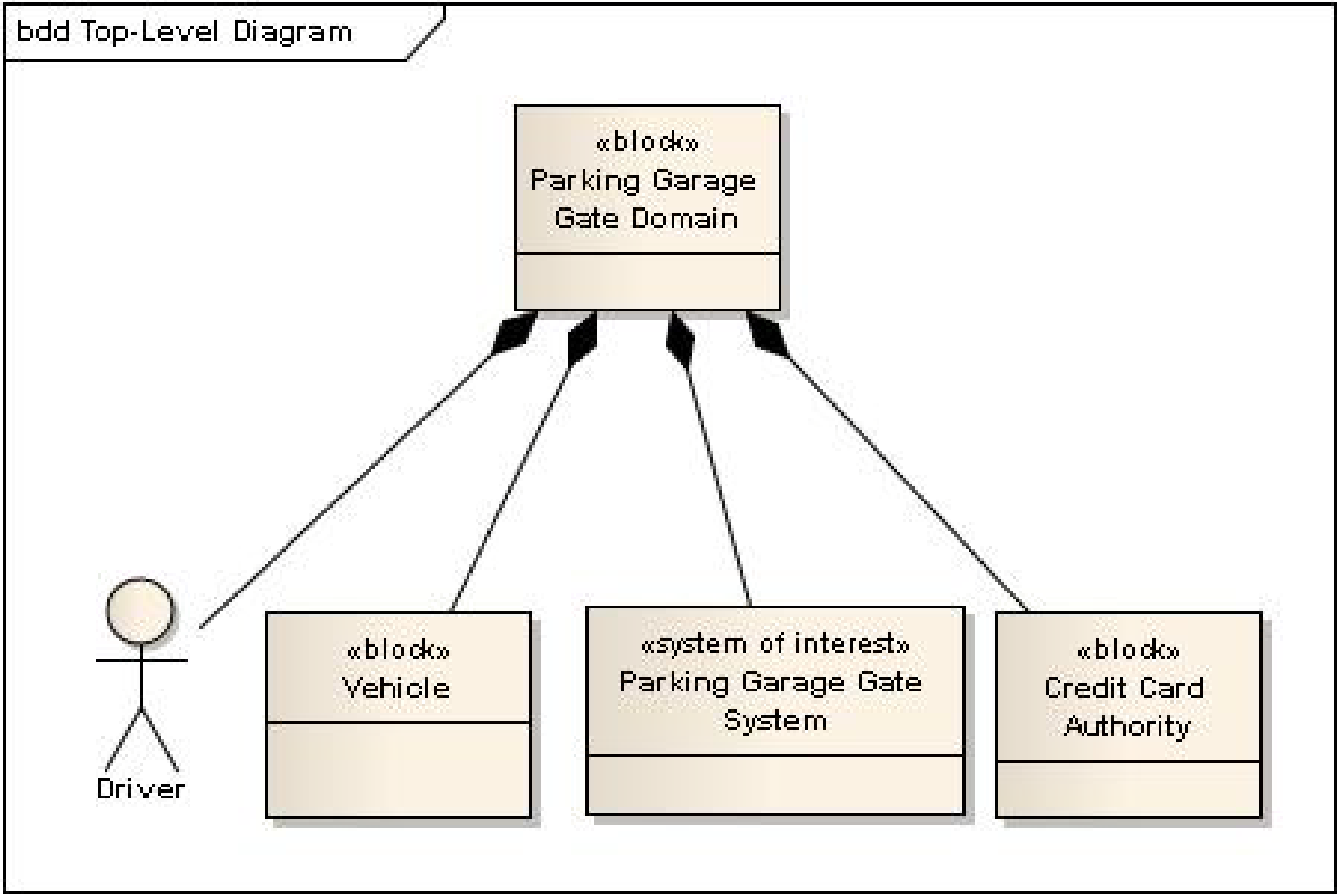
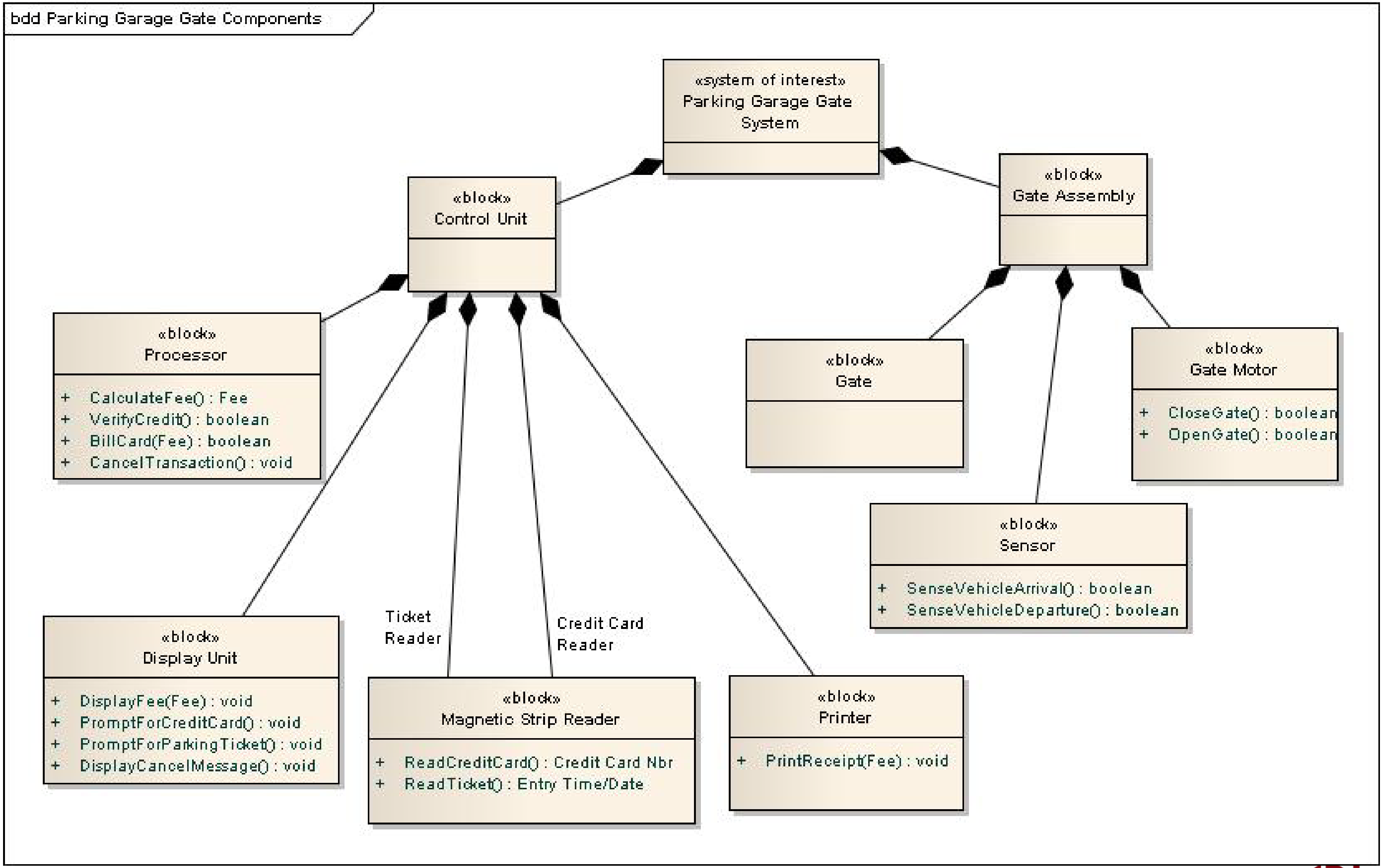
FIGURE 6.31

Top Level Block Definition Diagram for Parking Garage Gate Domain



Block Definition Diagram for Gate System



bdd Parking Garage Gate Components

«system of interest»
Parking Garage Gate System

«block»
Control Unit

«block»
Gate Assembly

«block»
Processor

+ CalculateFee() : Fee
+ VerifyCredit() : boolean
+ BillCard(Fee) : boolean
+ CancelTransaction() : void

«block»
Gate

«block»
Gate Motor

+ CloseGate() : boolean
+ OpenGate() : boolean

«block»
Sensor

+ SenseVehicleArrival() : boolean
+ SenseVehicleDeparture() : boolean

«block»
Display Unit

+ DisplayFee(Fee) : void
+ PromptForCreditCard() : void
+ PromptForParkingTicket() : void
+ DisplayCancelMessage() : void

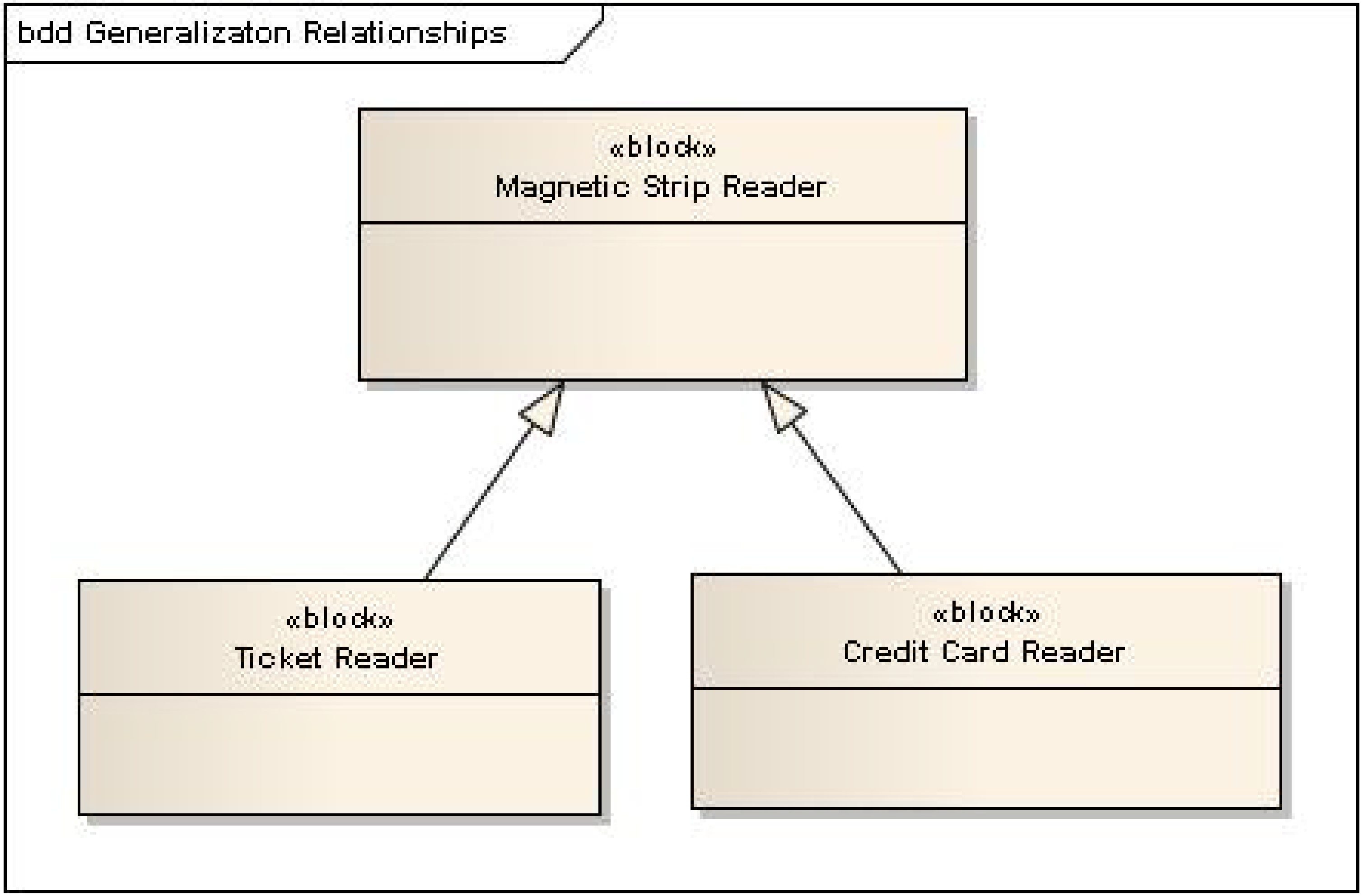
«block»
Magnetic Strip Reader

+ ReadCreditCard() : Credit Card Nbr
+ ReadTicket() : Entry Time/Date

«block»
Printer

+ PrintReceipt(Fee) : void

Generalization/Specialization Relationship



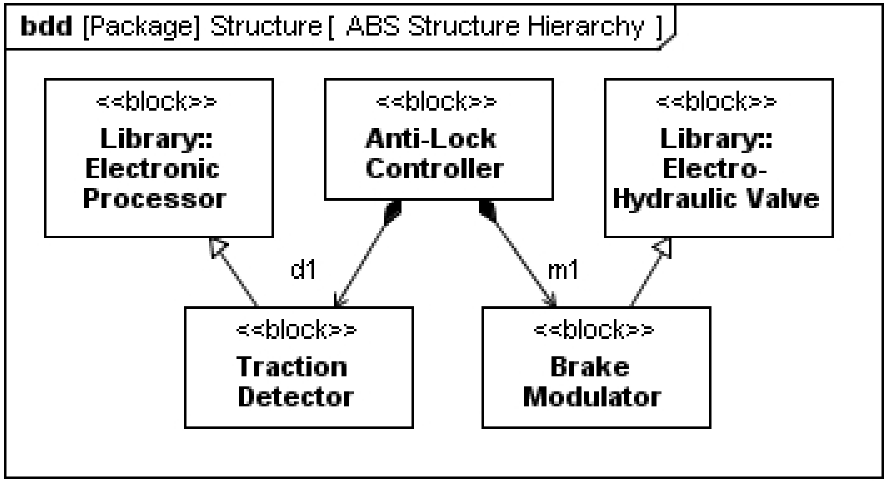
Summary

- A Block is the basic structural element used to model the system's structure
- Block Definition Diagrams are used to depict
  - Definition of blocks
  - How blocks relate to each other
- Block structural characteristics include part properties, value properties, and ports
- Block functional characteristics include operations and receptions
- Block relationships include associations and generalizations

MODELING PART INTERCONNECTION ON AN IBD

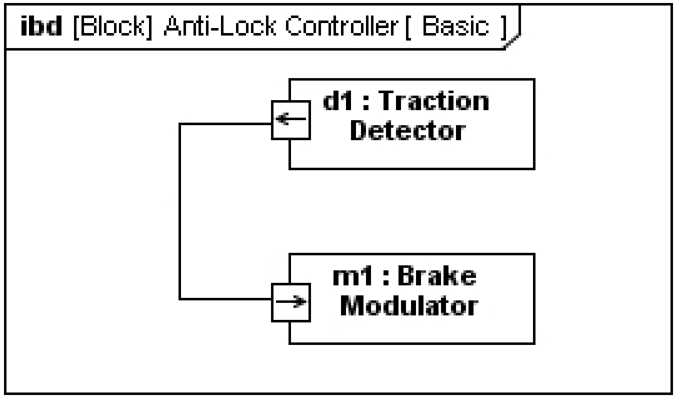
Block Definition vs. Usage

Block Definition Diagram



bdd [Package] Structure [ABS Structure Hierarchy]
<<block>> Library:: Electronic Processor
<<block>> Anti-Lock Controller
<<block>> Library:: Electro-Hydraulic Valve
d1
m1
<<block>> Traction Detector
<<block>> Brake Modulator

Internal Block Diagram



Definition

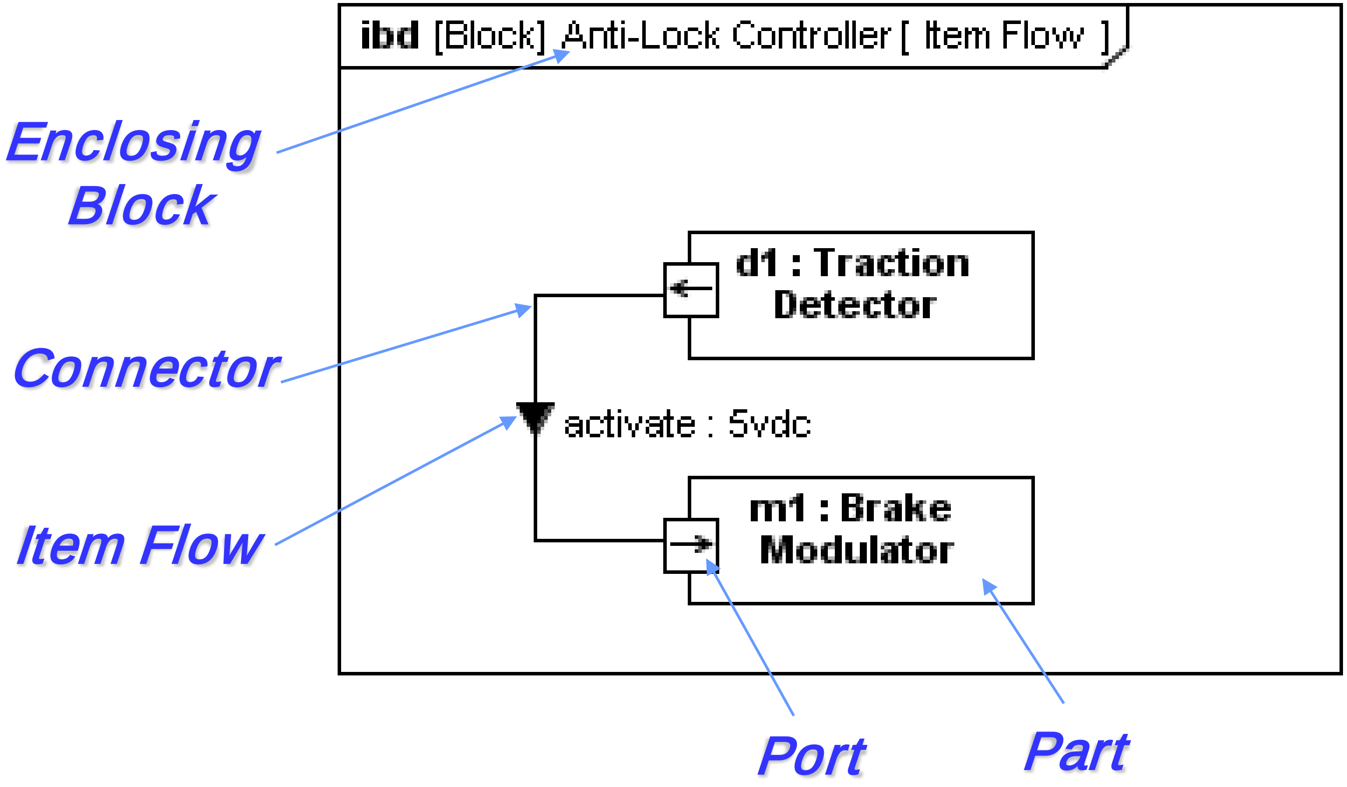
- Block is a definition/type
- Captures properties, etc.
- Reused in multiple contexts

Usage

- Part is the usage of a block in the context of a composing block
- Also known as a role

Internal Block Diagram (ibd)

Blocks, Parts, Ports, Connectors & Flows



Internal Block Diagram Specifies Interconnection of Parts

Vehicle System Context Showing External Interfaces

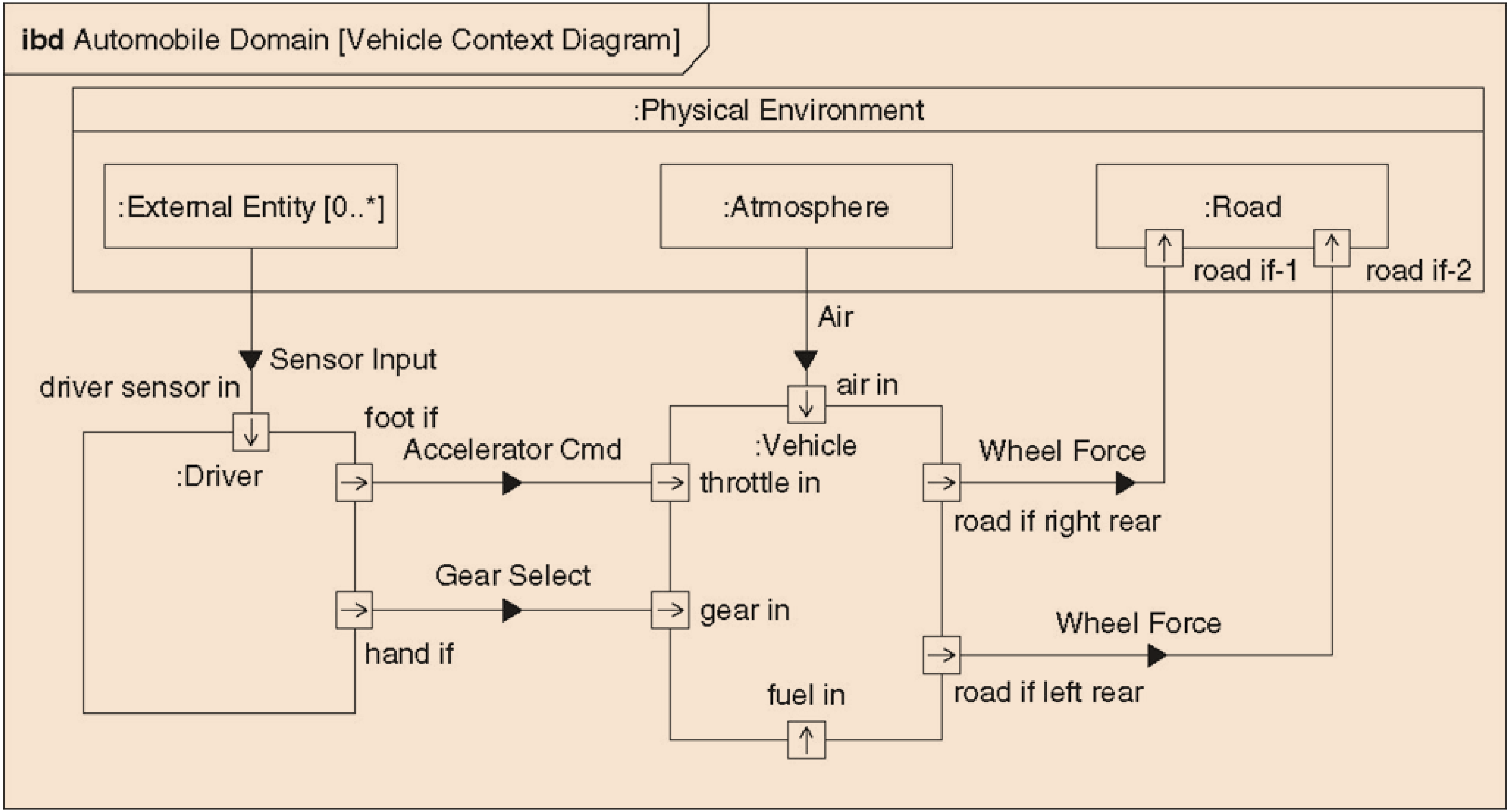


FIGURE 3.9

Power Subsystem Internal Block Diagram

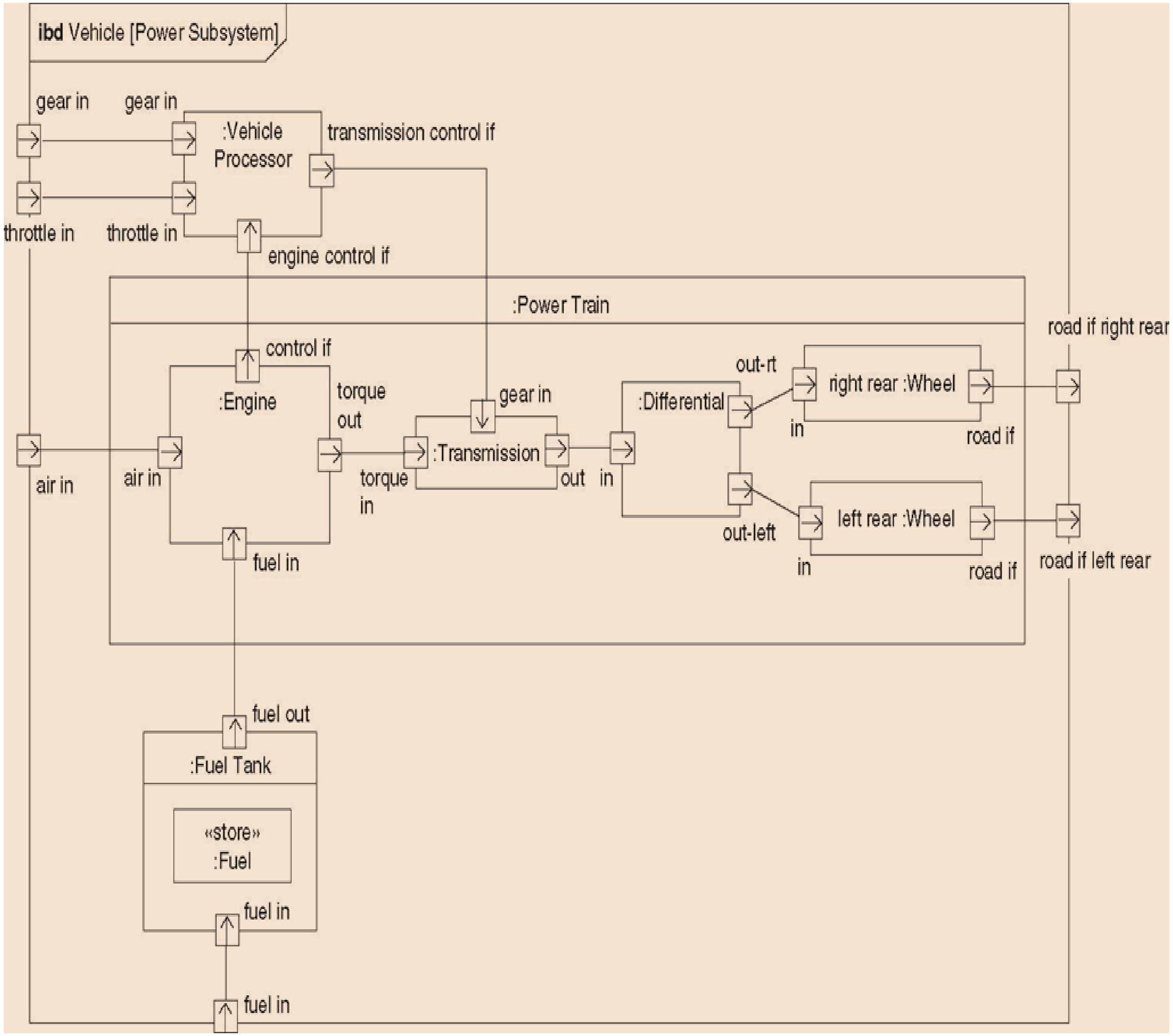


FIGURE 3.12

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Modeling Standard Ports and their Connectors on an IBD

- Standard ports specify interactions as services
  - Required interface specifies requests for services (socket symbol)
  - Provided interface specifies provided services (ball symbol)

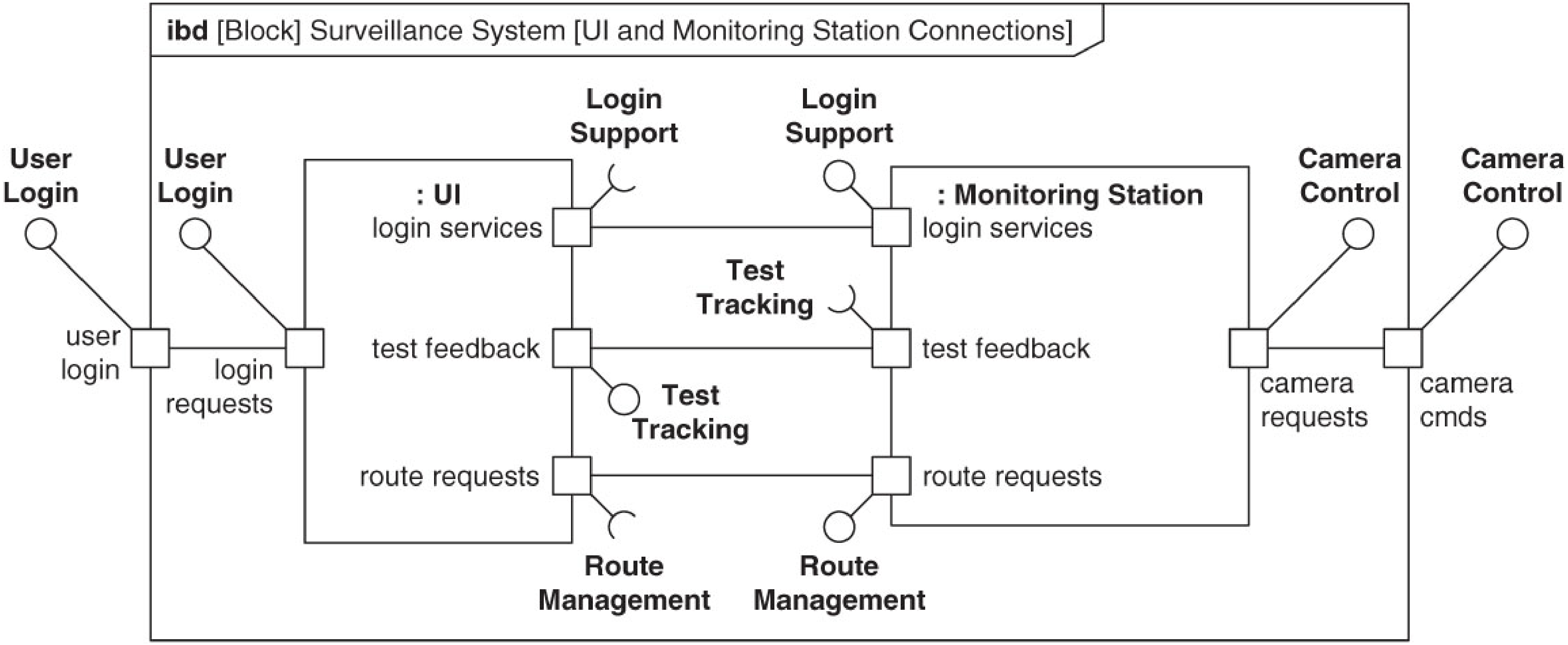

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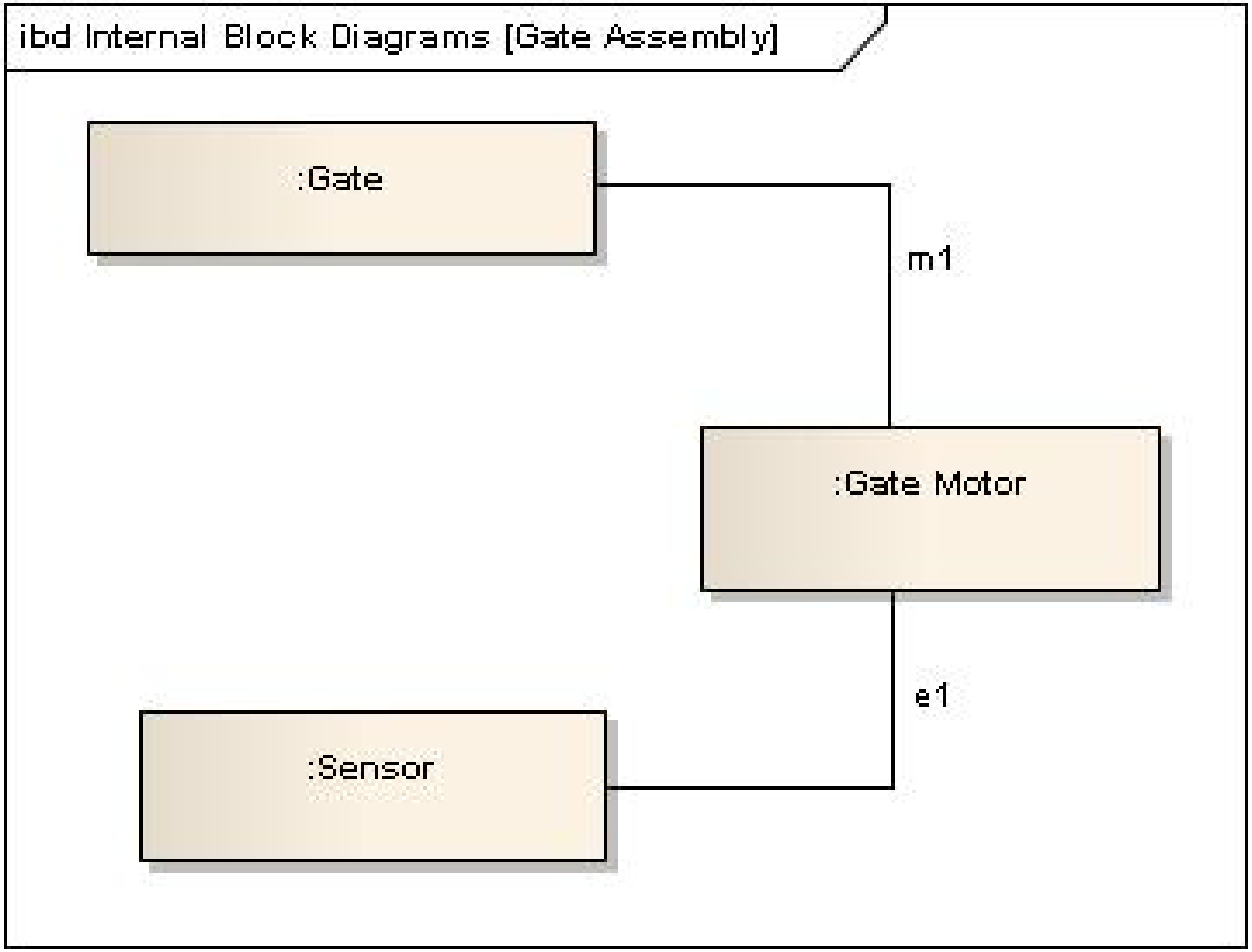
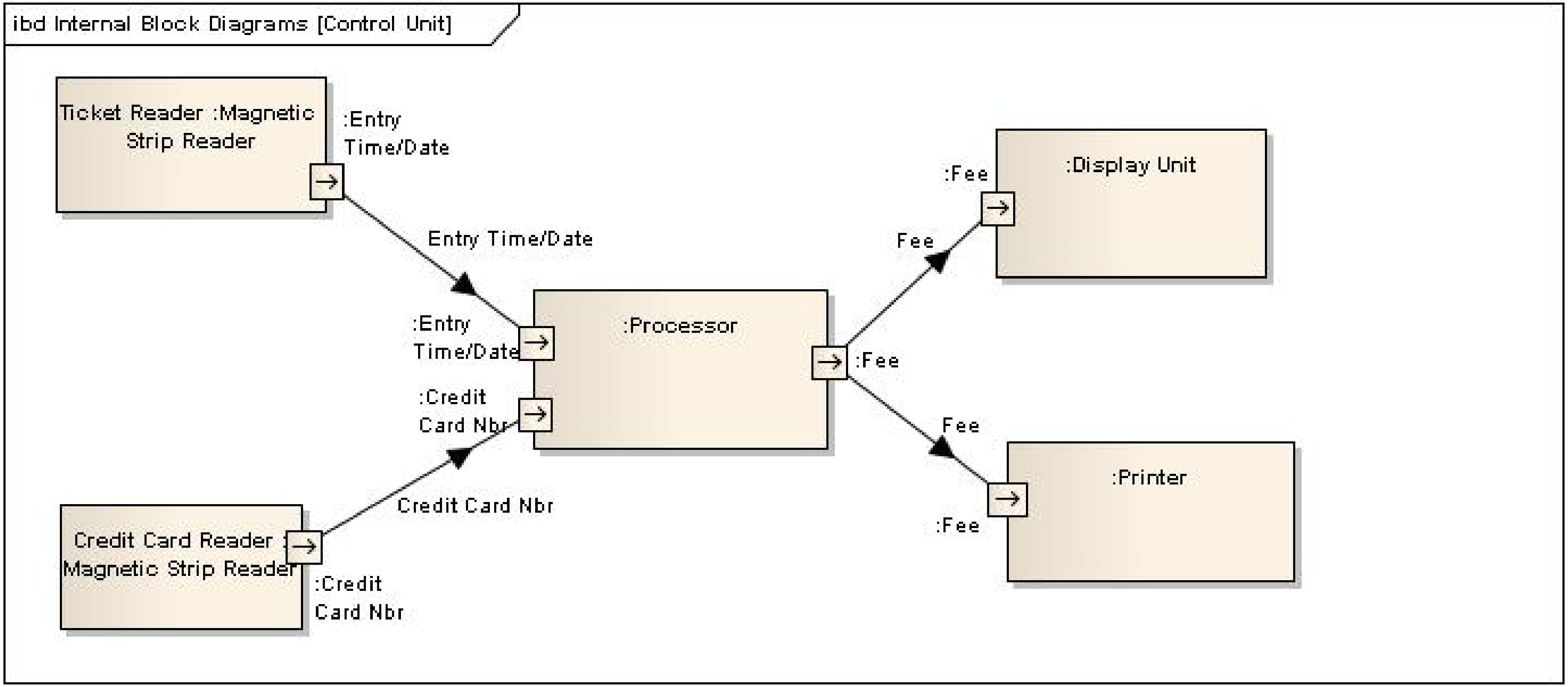
FIGURE 6.34

Internal Block Diagram for Gate Assembly



Internal Block Diagram for Control Unit



Summary

- Internal Block Diagrams are used to depict the internal structure of a block
- The frame of an IBD represents the enclosing block
- Internal Block Diagrams depict:
  - The usage of a block in a specific context
  - How parts/ports are connected
  - What flows between parts/ports
- Standard ports are used on an IBD to depict interfaces that specify the behavioral features (services) that a block either provides or requires

MODELING BEHAVIOR

MODELING FLOW-BASED BEHAVIOR WITH ACTIVITIES

Activities

- Activity specifies transformation of inputs to outputs through a controlled sequence of actions
- Secondary constructs show responsibilities for the activities using activity partitions (i.e., swim lanes)
- SysML extensions to Activities
  - Support for continuous flow modeling
  - Alignment of activities with Enhanced Functional Flow Block Diagram (EFFBD)

Control Power Activity Diagram

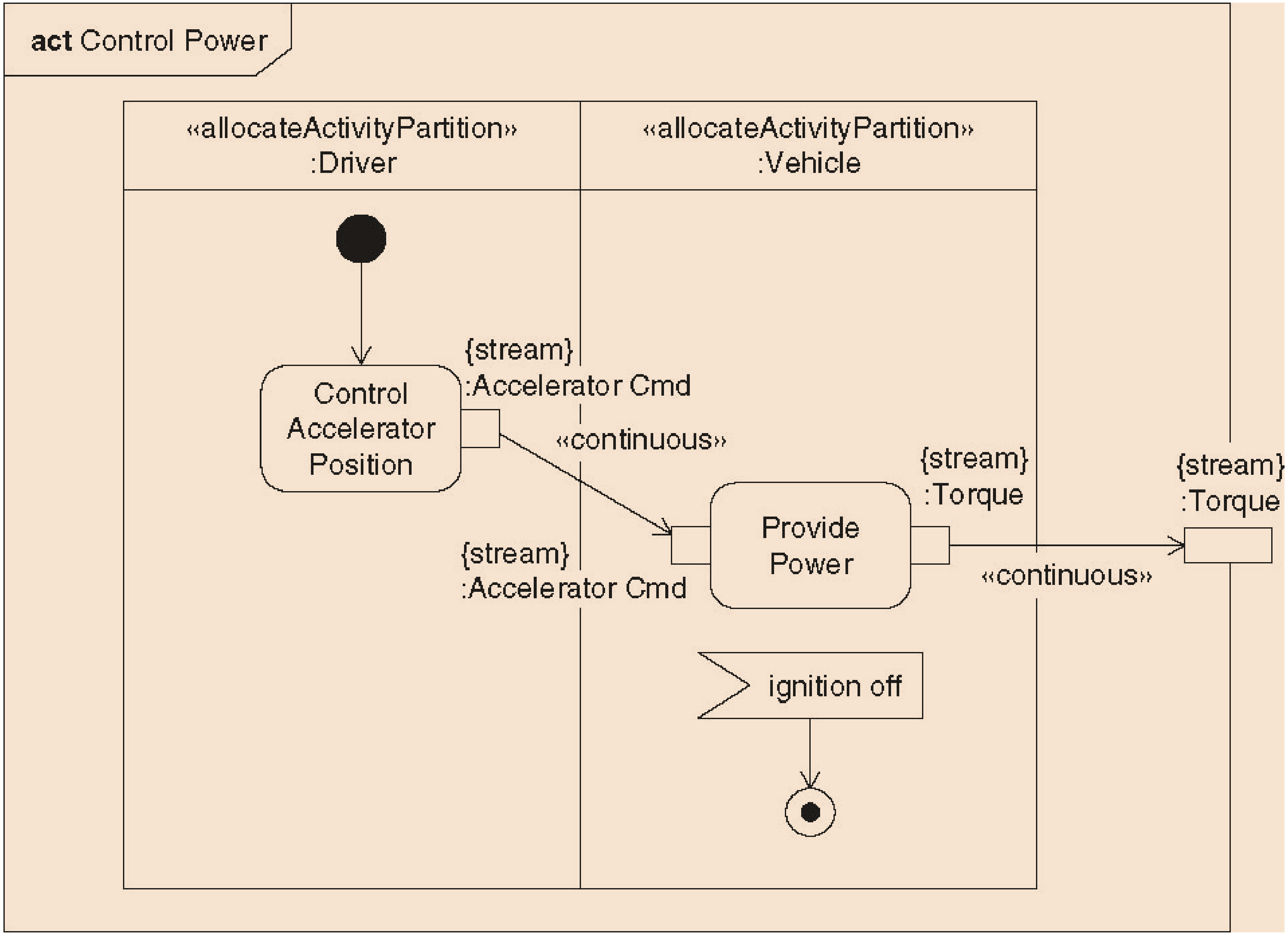


FIGURE 3.7

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Provide Power Activity Diagram

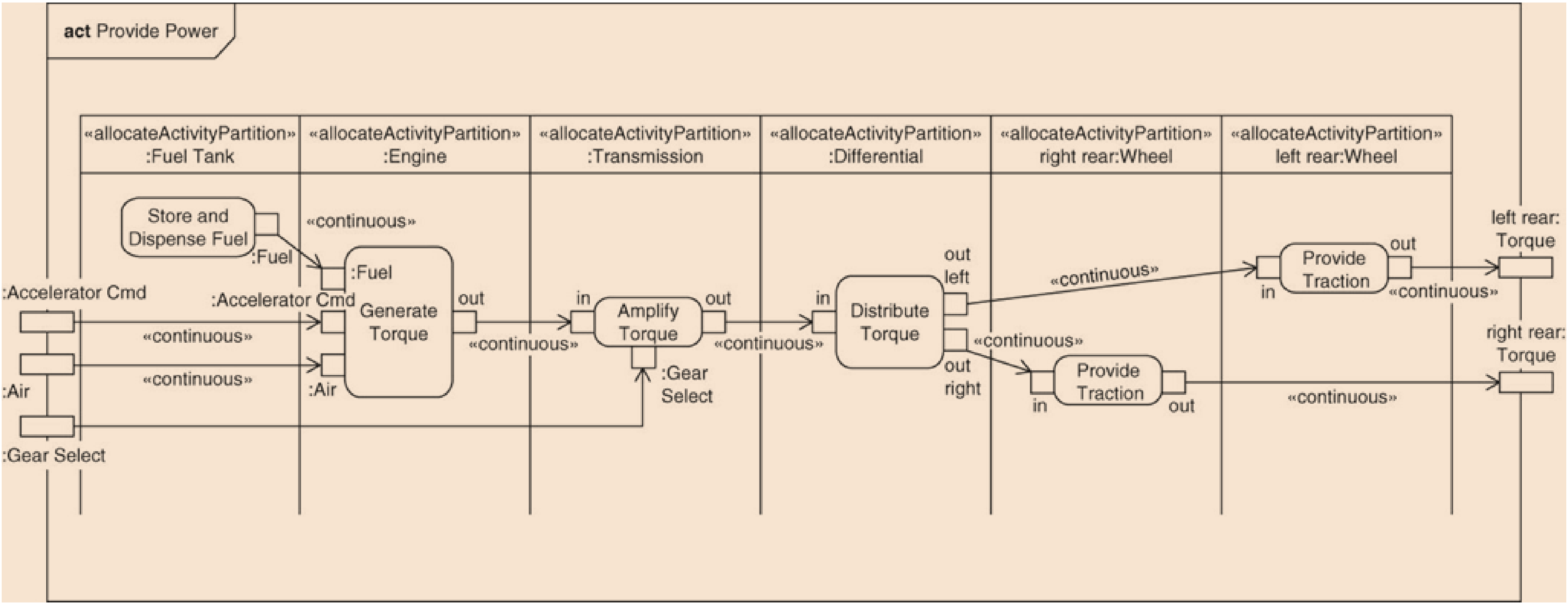

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FIGURE 3.11

Actions

- Actions – describe how activities execute
  - Used to model the steps of the activity
  - Accept inputs and create outputs (depicted by ‘pins’)
  - Call Actions – represent activities that can be further decomposed into other actions
    - Allows for hierarchical modeling of activities

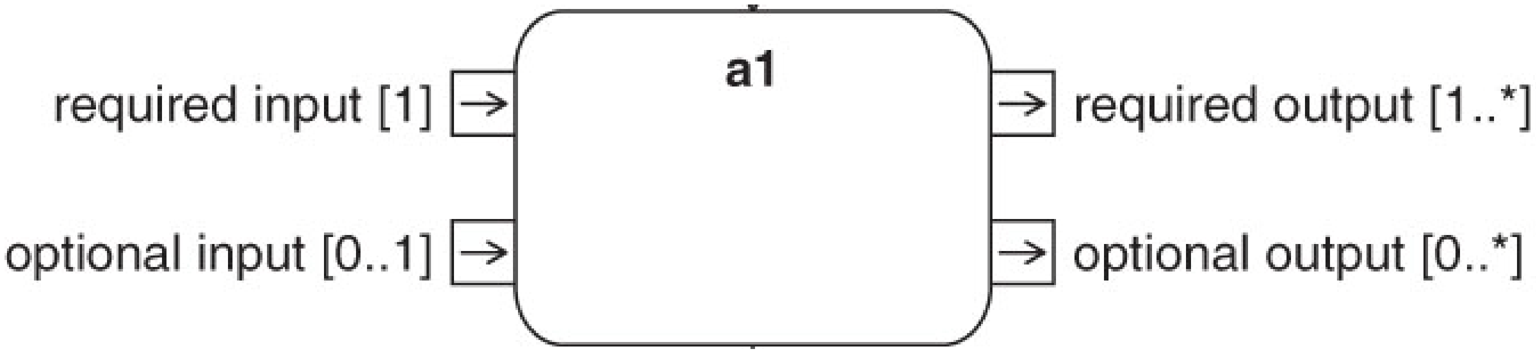

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FIGURE 8.3

Decomposing an Activity Diagram with Call Behavior Actions

- Pins match Parameters in number and type
- Rake symbol denotes details are depicted on another diagram

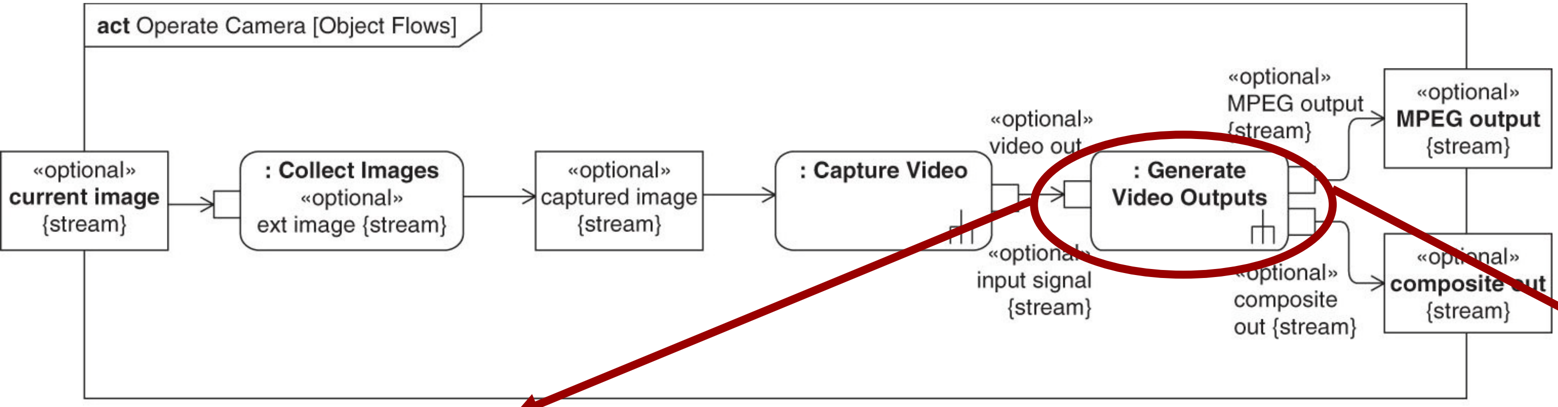
act Operate Camera [Object Flows]
«optional» current image {stream}
: Collect Images
«optional» ext image {stream}
«optional» captured image {stream}
: Capture Video
«optional» video out
«optional» input signal {stream}
: Generate Video Outputs
«optional» MPEG output {stream}
«optional» composite out {stream}
«optional» MPEG output {stream}
«optional» composite out {stream}

FIGURE 8.6

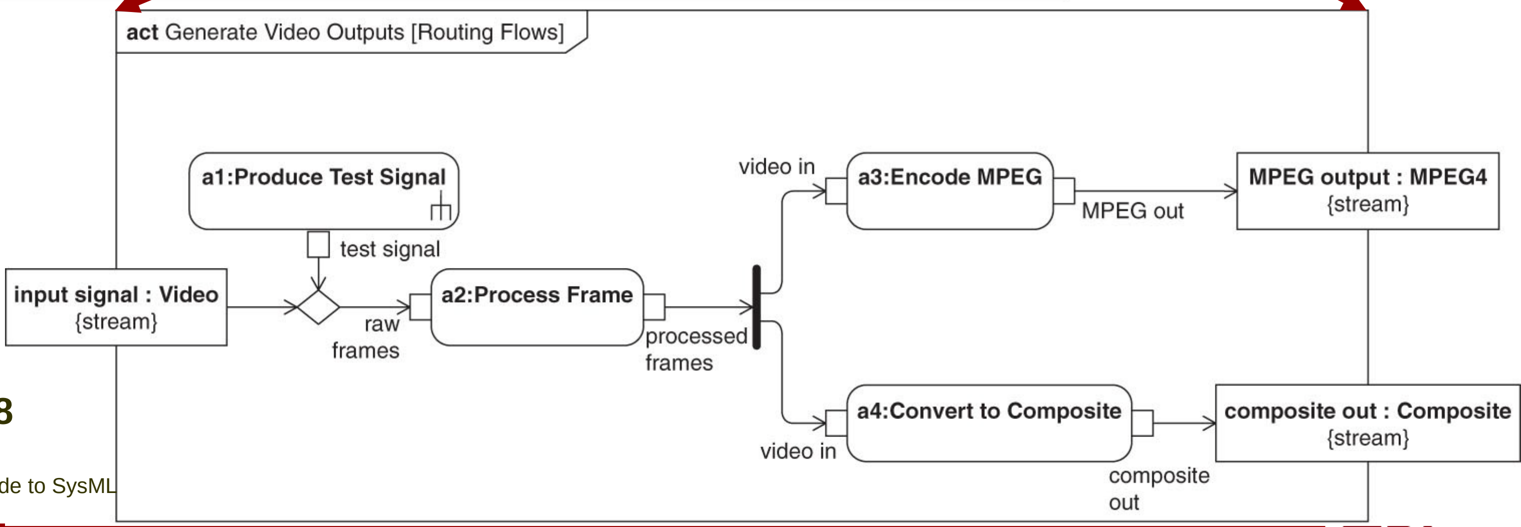

FIGURE 8.8

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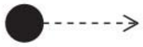
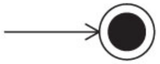
Initial, Activity Final, and Flow Final Nodes

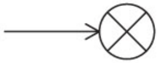
- Initial Node – denotes where execution begins
  - Depicted by black circle



- Activity Final Node – denotes where execution terminates
  - Depicted by a bulls-eye



- Flow Final Node – terminates a particular sequence of actions without terminating the entire activity
  - Depicted by circle with cross-hair



Fork Nodes and Join Nodes

- Fork Node – one input flow, multiple output flows
  - Output flows are independent and concurrent
- Join Node – multiple input flows, one output flow
  - Output occurs, only when all input tokens are available (default)
- Join Specification may override default

Fork Node

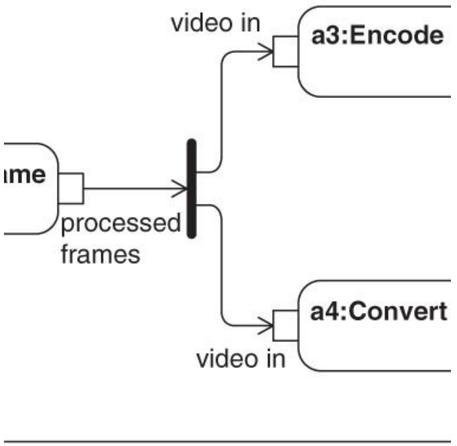


FIGURE 8.1

Join Node with Join Specification

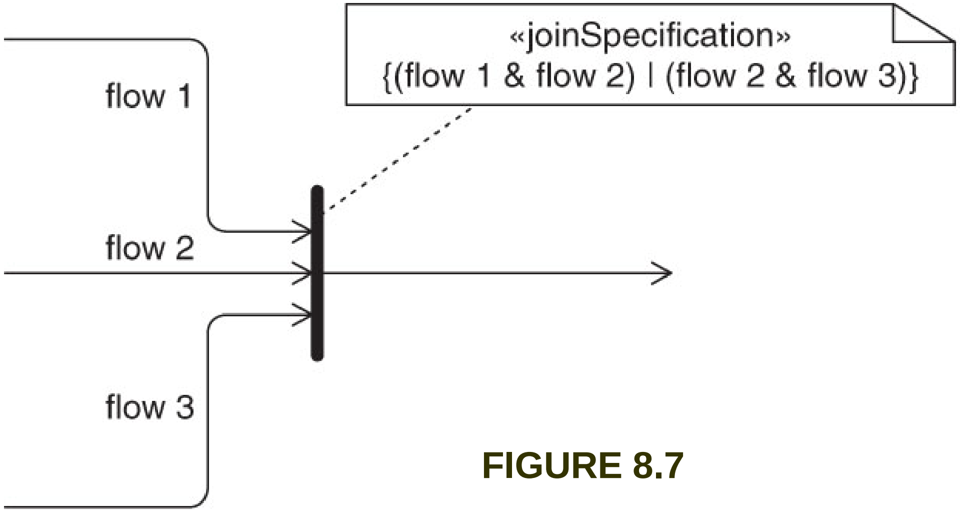


FIGURE 8.7

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Decision Nodes and Merge Nodes

- Decision Nodes – one input, multiple output paths
  - Only one output path is valid, based on ‘guard’ conditions
  - Guards must be mutually exclusive
- Merge Node – multiple inputs, one output flow
  - Output flow is triggered upon arrival of any of the input flows

Decision Node

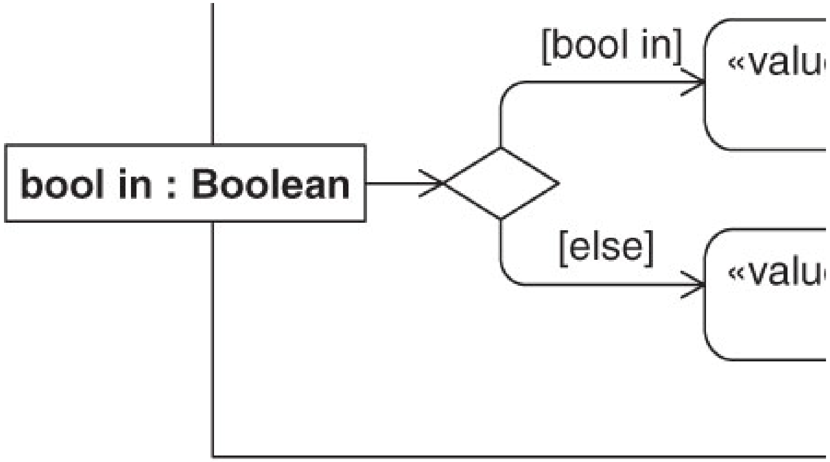

FIGURE 8.13

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Merge Node

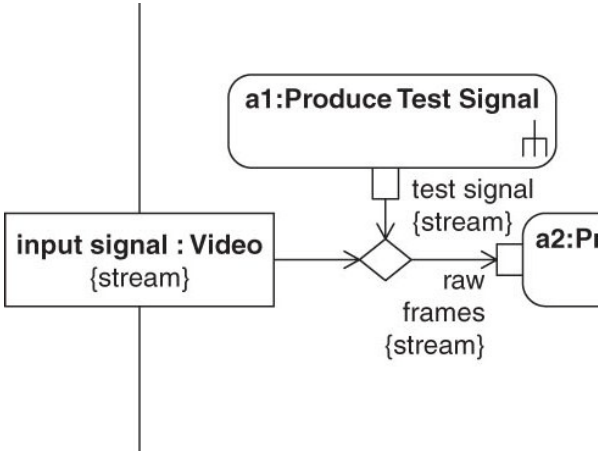

FIGURE 8.8

Control Flow

- Used to show sequence of actions
- Represents a control token
  - An action cannot start until it receives a control token on all input control flows
  - When an action is completed, it places control tokens on all outgoing control flows
- Can be depicted with a dashed arrow, to distinguish it from object flows
- Like object flow, can be used with:
  - Forks and Joins
  - Decision Nodes and Merges

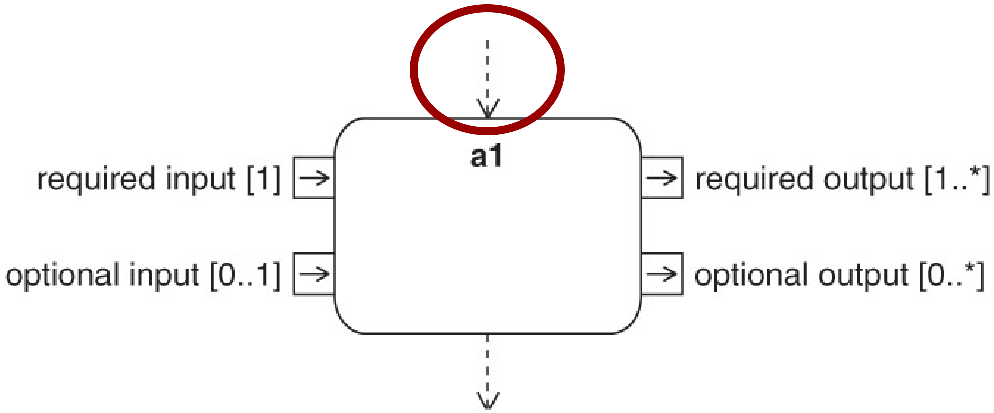

FIGURE 8.3 © 2008 Elsevier, Inc.: A Practical Guide to SysML

Partitions (aka Swimlanes)

- Allocates actions to an entity responsible for performing the action
- Can be used to specify functional requirements of an actor, component, or part
- Can be depicted horizontally or vertically

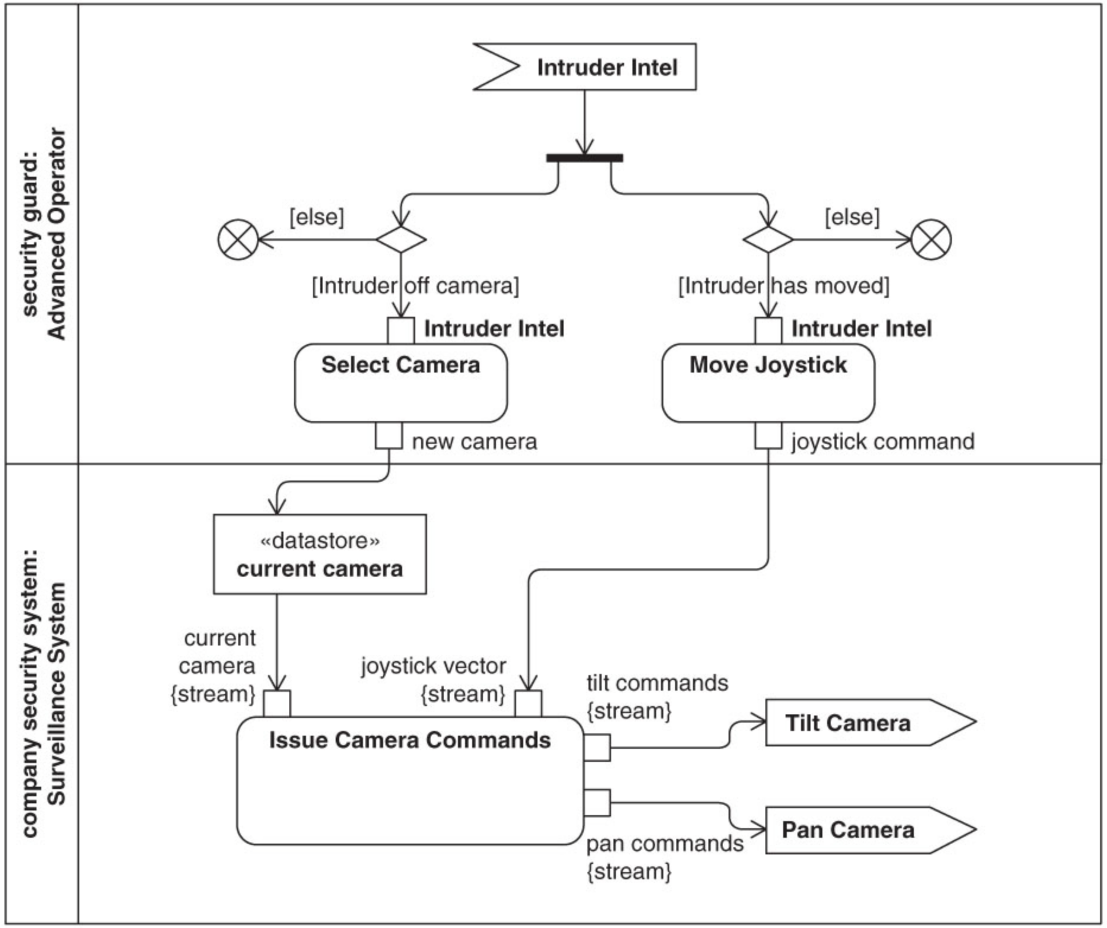

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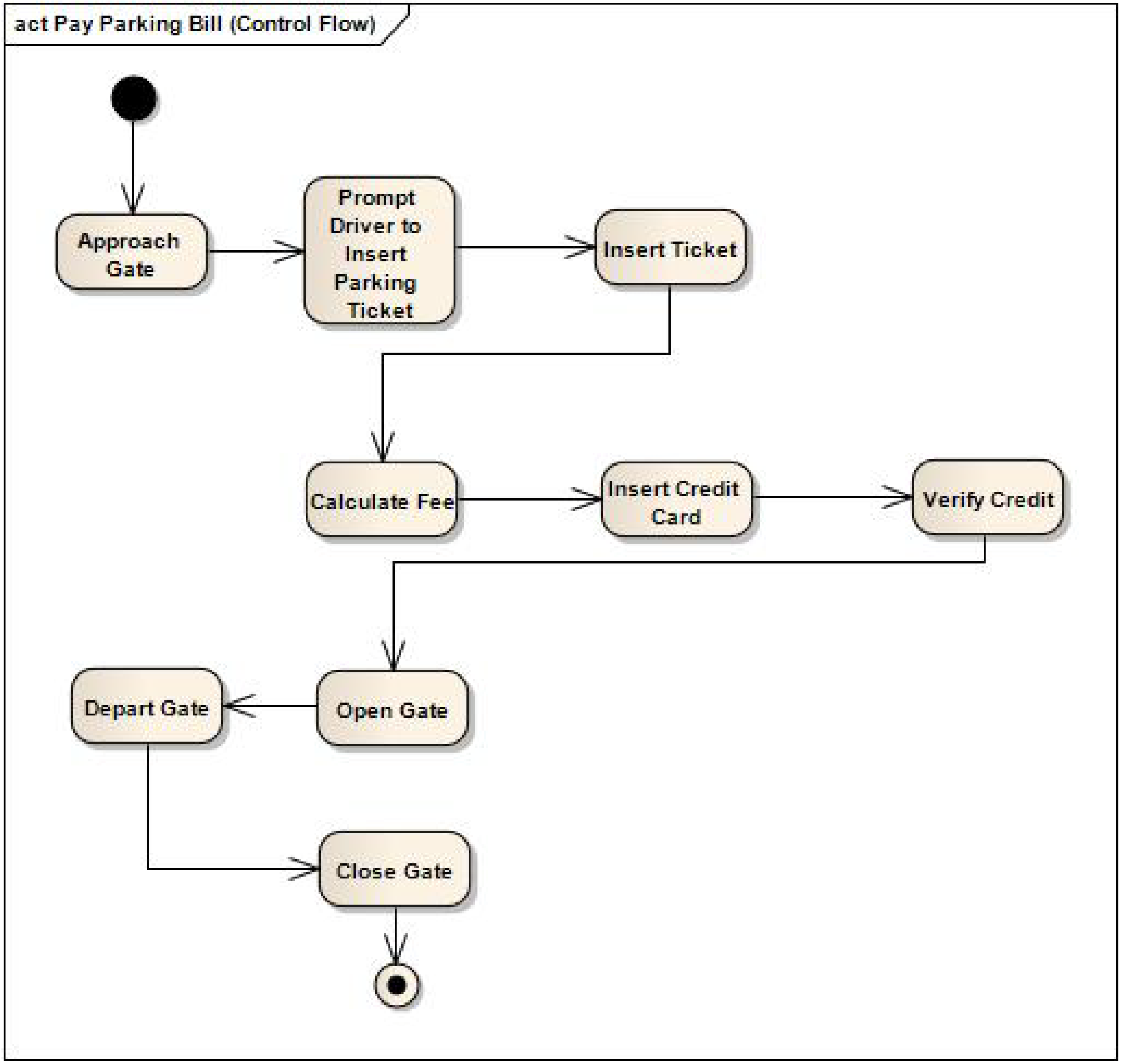
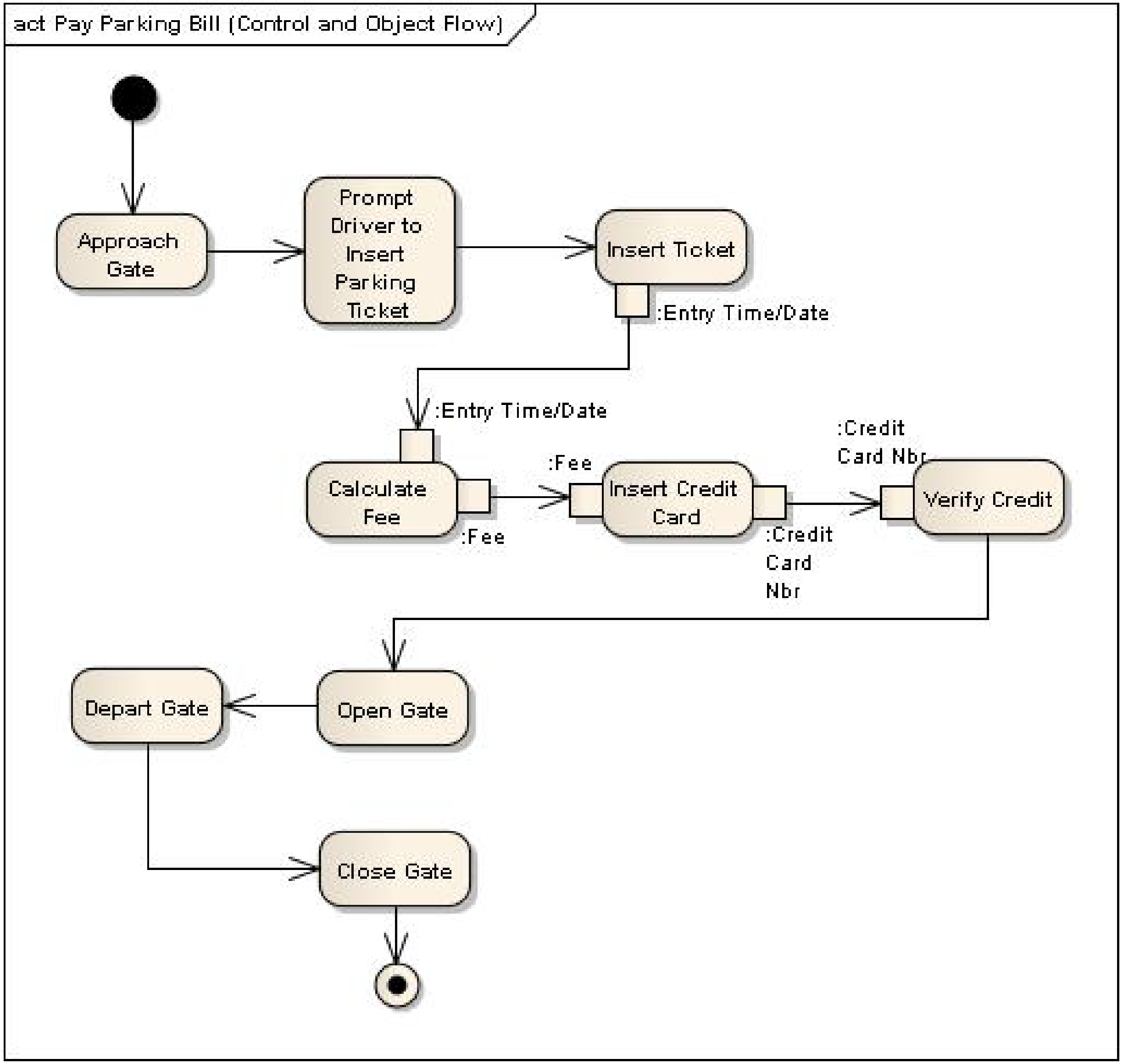
FIGURE 8.20

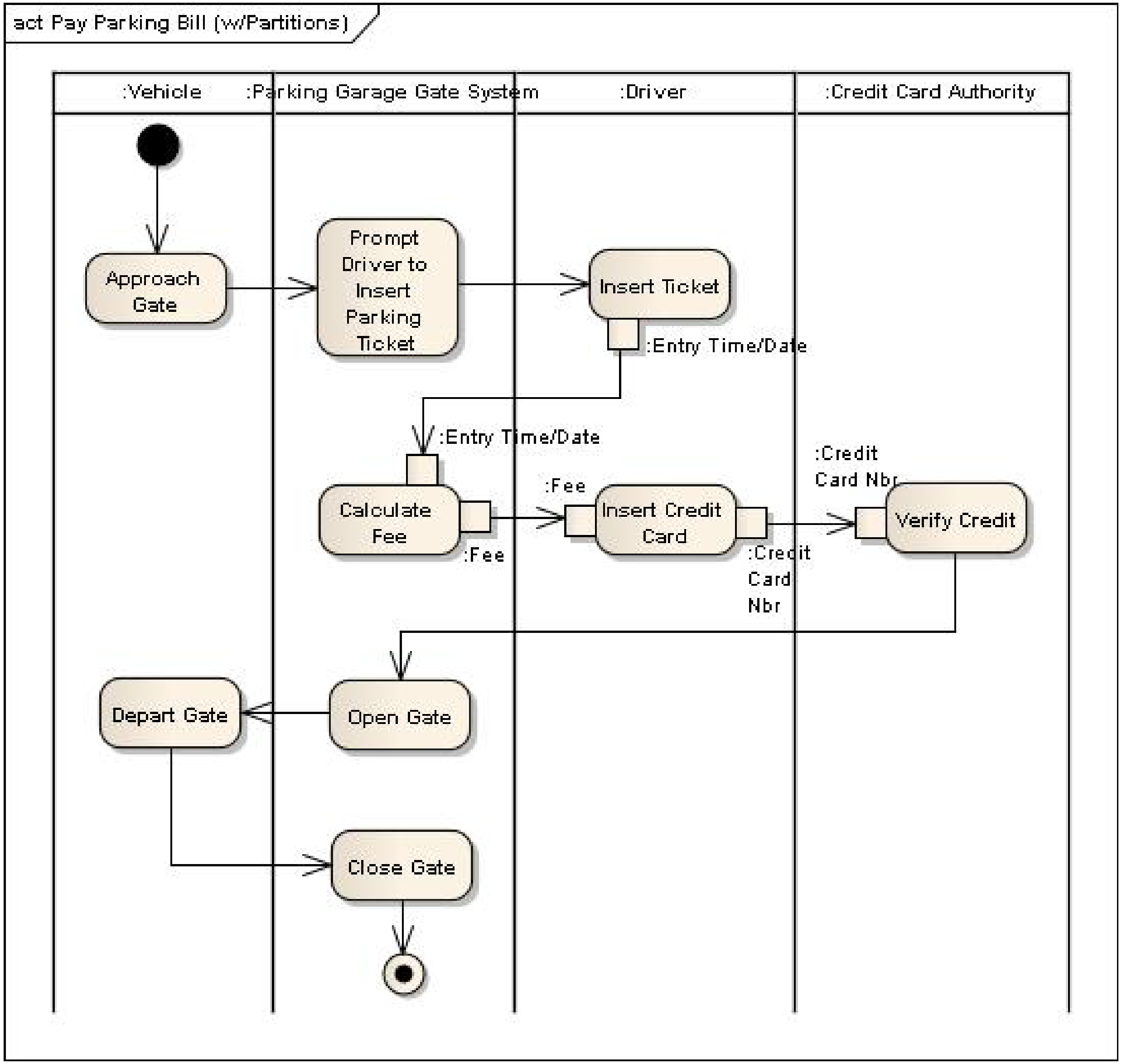
Activity Model (Primary Path)



Activity Model (w/Object Flow)

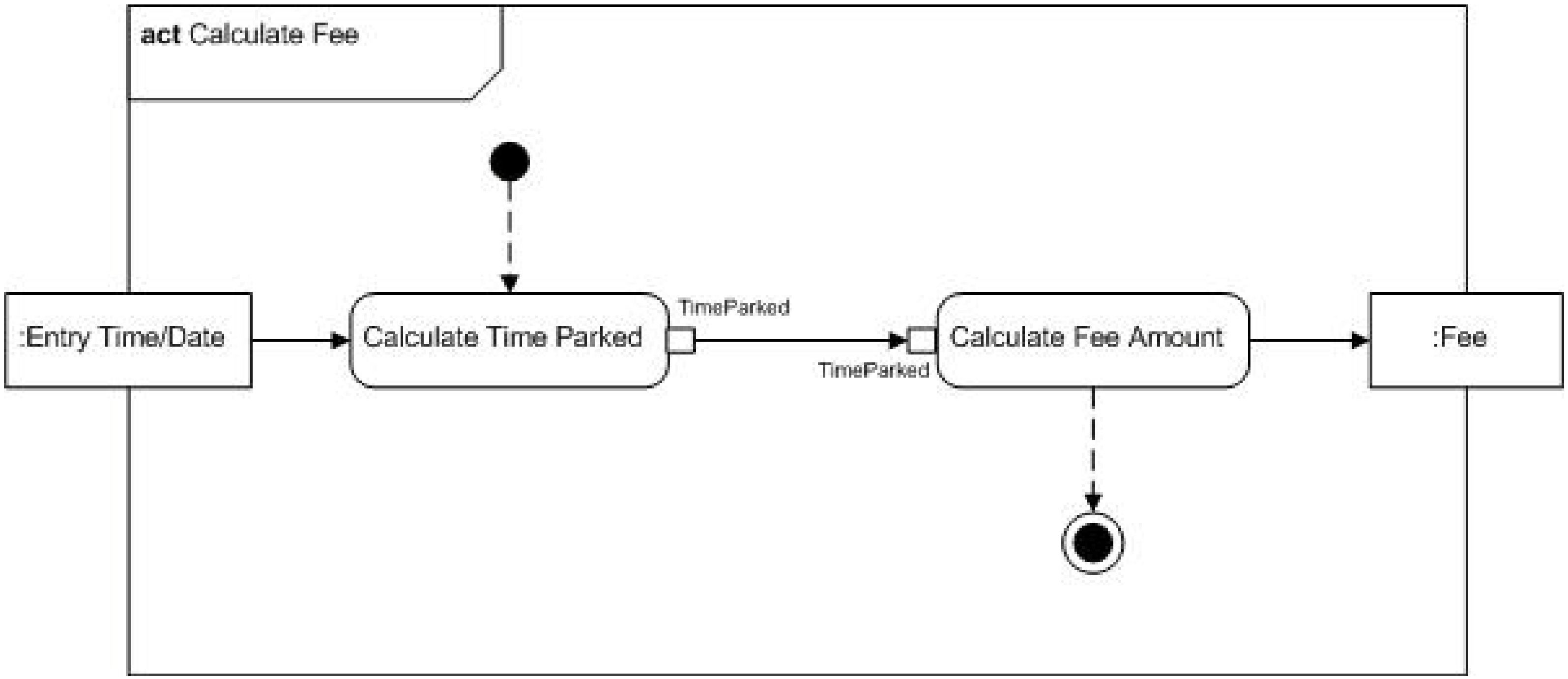


Activity Model (w/Partitions)



Decomposition of Calculate Fee

- Example below shows use of Input and Output Parameters for the Calculate Fee Activity
- Hierarchical relationship of Activities and Actions



Summary

- Activity Diagrams are used to model behavior that specifies the transformation of inputs to outputs through a controlled sequence of Actions
- Activities can have multiple inputs or outputs called parameters
- Activities are made up of actions
- Actions consume input tokens and produce output tokens via pins
- Inputs/outputs can either be streaming or non-streaming
- Object Flows are used to depict the flow of object tokens from one action to other actions
- Control Flows are used to depict the transfer of control from one action to other actions using control tokens
- Call behavior actions can be further decomposed by calling other activities
- Partitions are used to assign responsibility for actions to blocks or parts that the partition represent

MODELING MESSAGE-BASED BEHAVIOR WITH INTERACTIONS

Interactions

- Sequence diagrams provide representations of message based behavior
  - represent flow of control
  - describe interactions between parts
- Sequence diagrams provide mechanisms for representing complex scenarios
  - reference sequences
  - control logic

Start Vehicle Sequence Diagram

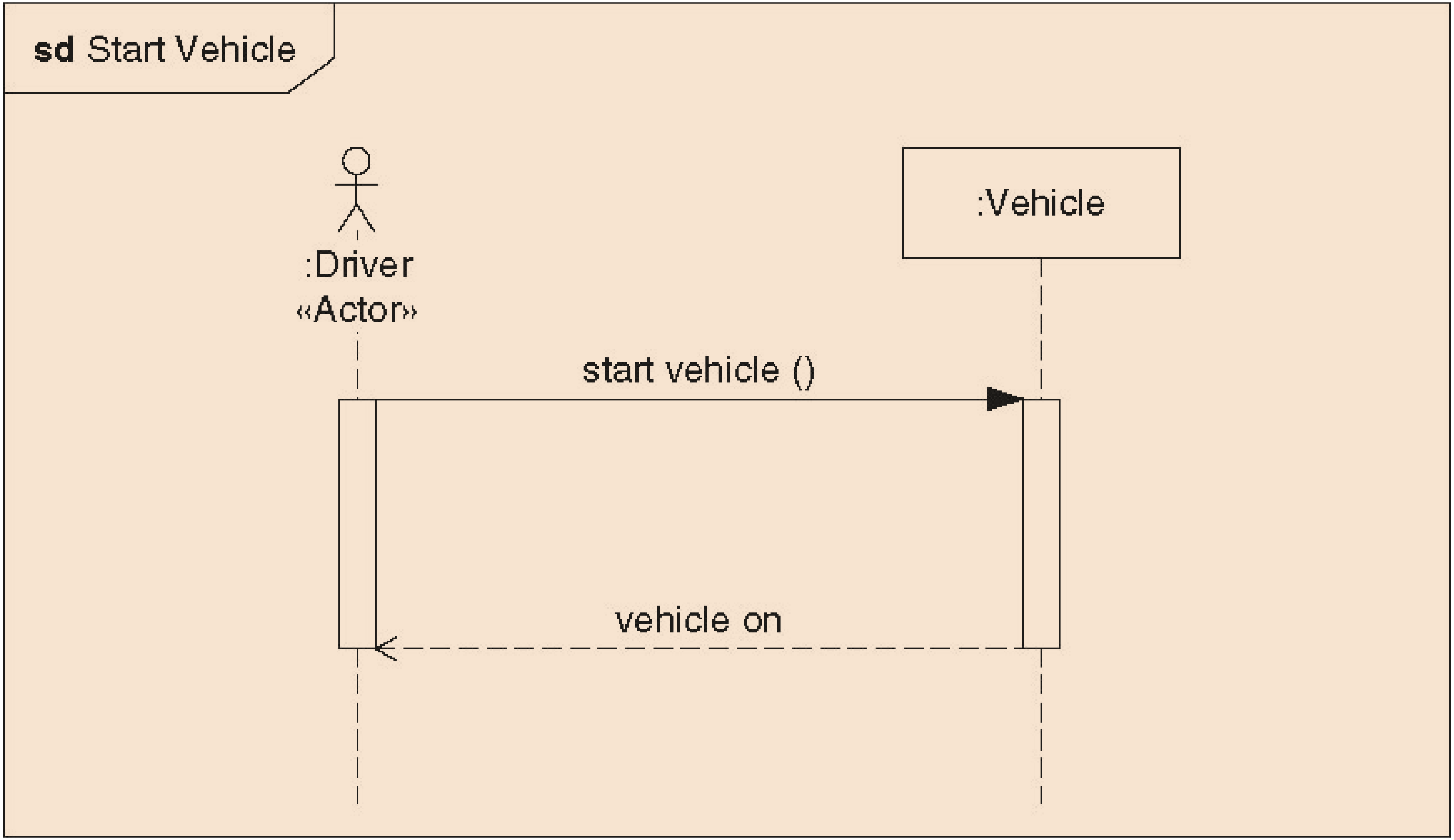


FIGURE 3.6

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Drive Vehicle Sequence Diagram

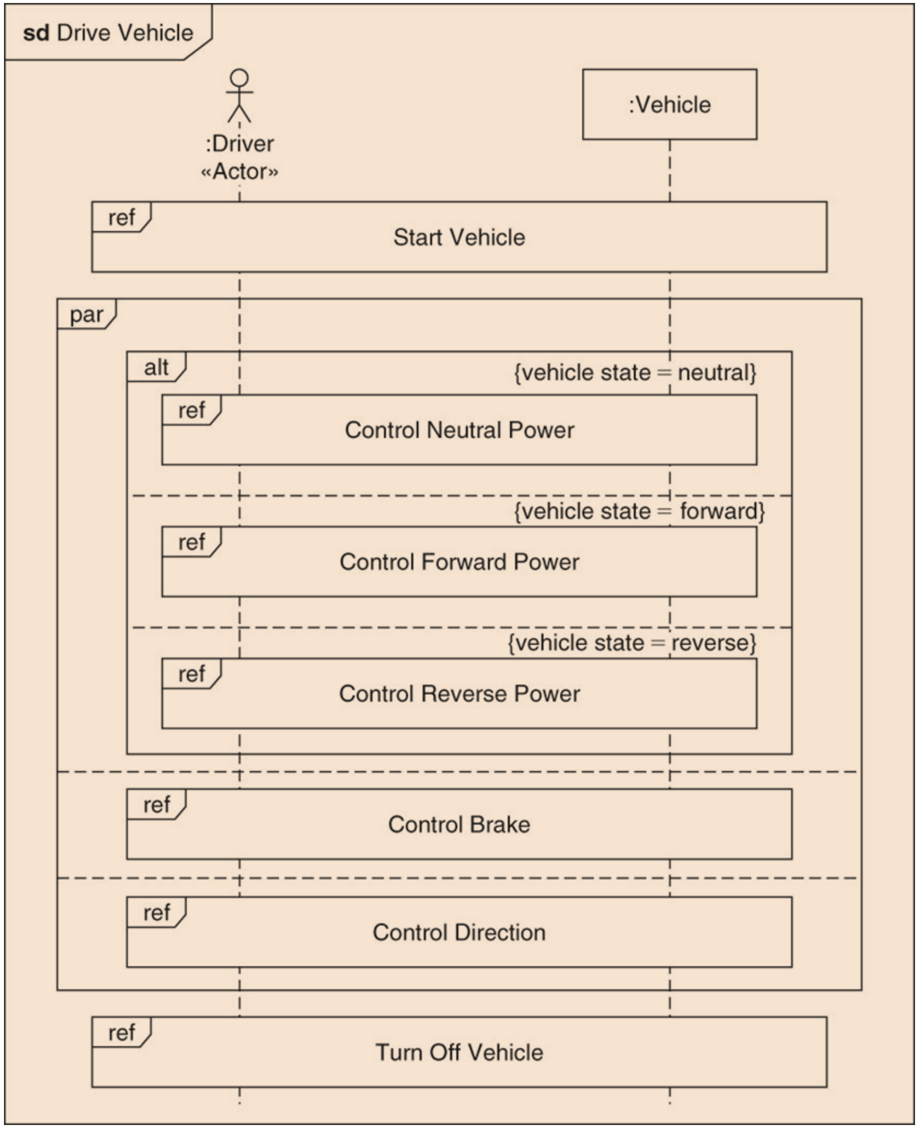

FIGURE 3.5

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Sequence Diagram Components

- Sequence diagrams can be comprised of the following:
  - Lifelines
    - Represents a Structural Element of a system
    - Depicts 'Time'
  - Messages
    - Asynchronous
    - Synchronous
    - Reply

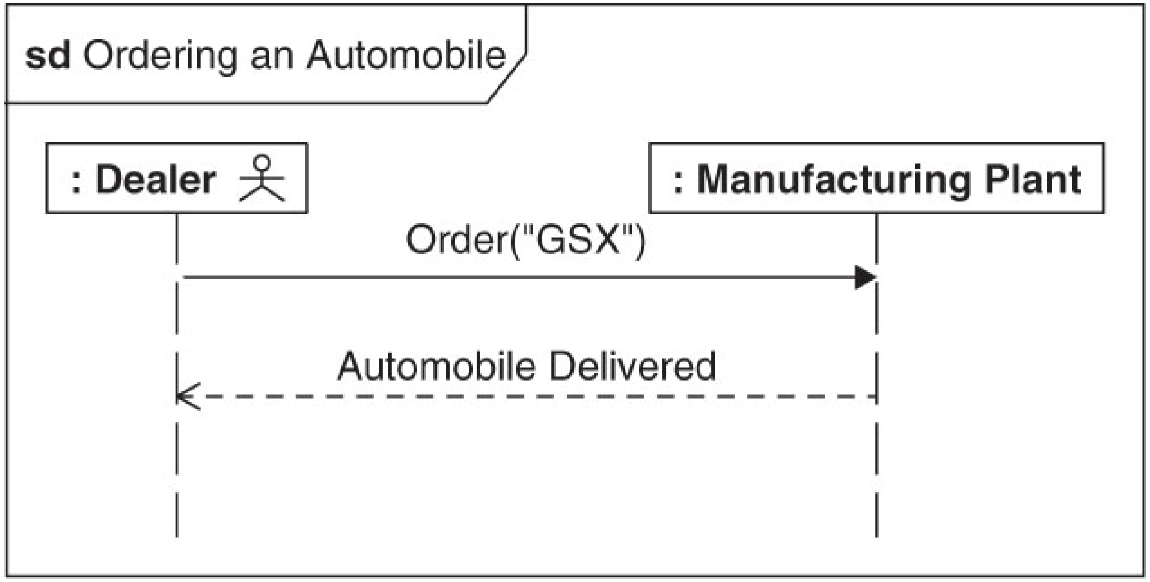

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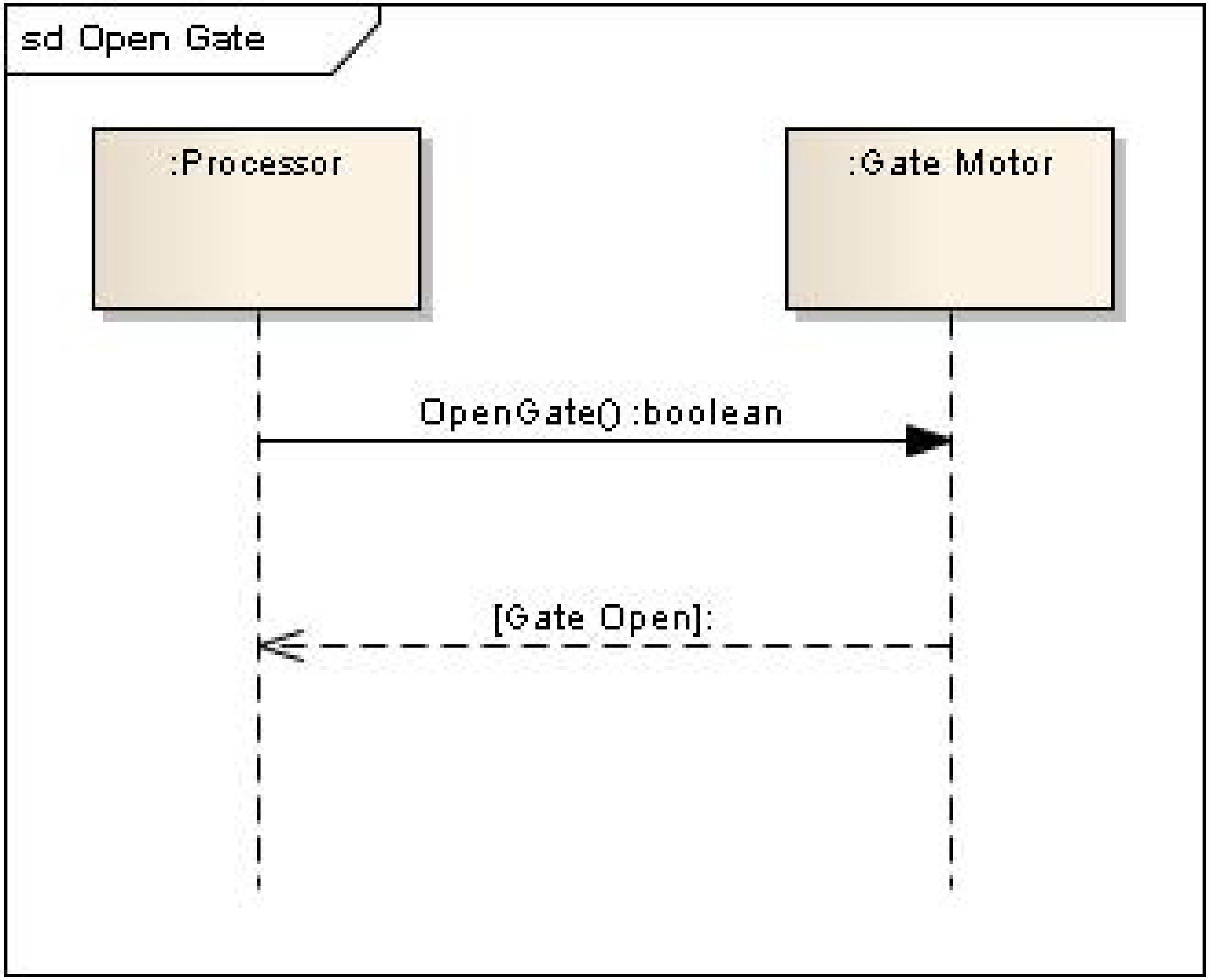
FIGURE 9.4

Sequence Diagram for Opening the Gate



Summary

- Sequence Diagrams are used to depict the interactions between structural elements of a Block
- Sequence Diagrams are comprised of:
  - Lifelines
  - Messages
- Lifelines represent the structural element and depicts Time
- Messages can be either:
  - Asynchronous
  - Synchronous
  - Reply
- Messages represent a call for an operation
- Combined Fragments are used to depict complex interactions and include: alternate paths, parallel paths, optional paths or loops
- Reference Interactions depict re-use of common interactions

MODELING EVENT-BASED BEHAVIOR WITH STATE MACHINES

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.
- Event types
  - Change event
  - Time event
  - Signal event

Drive Vehicle States

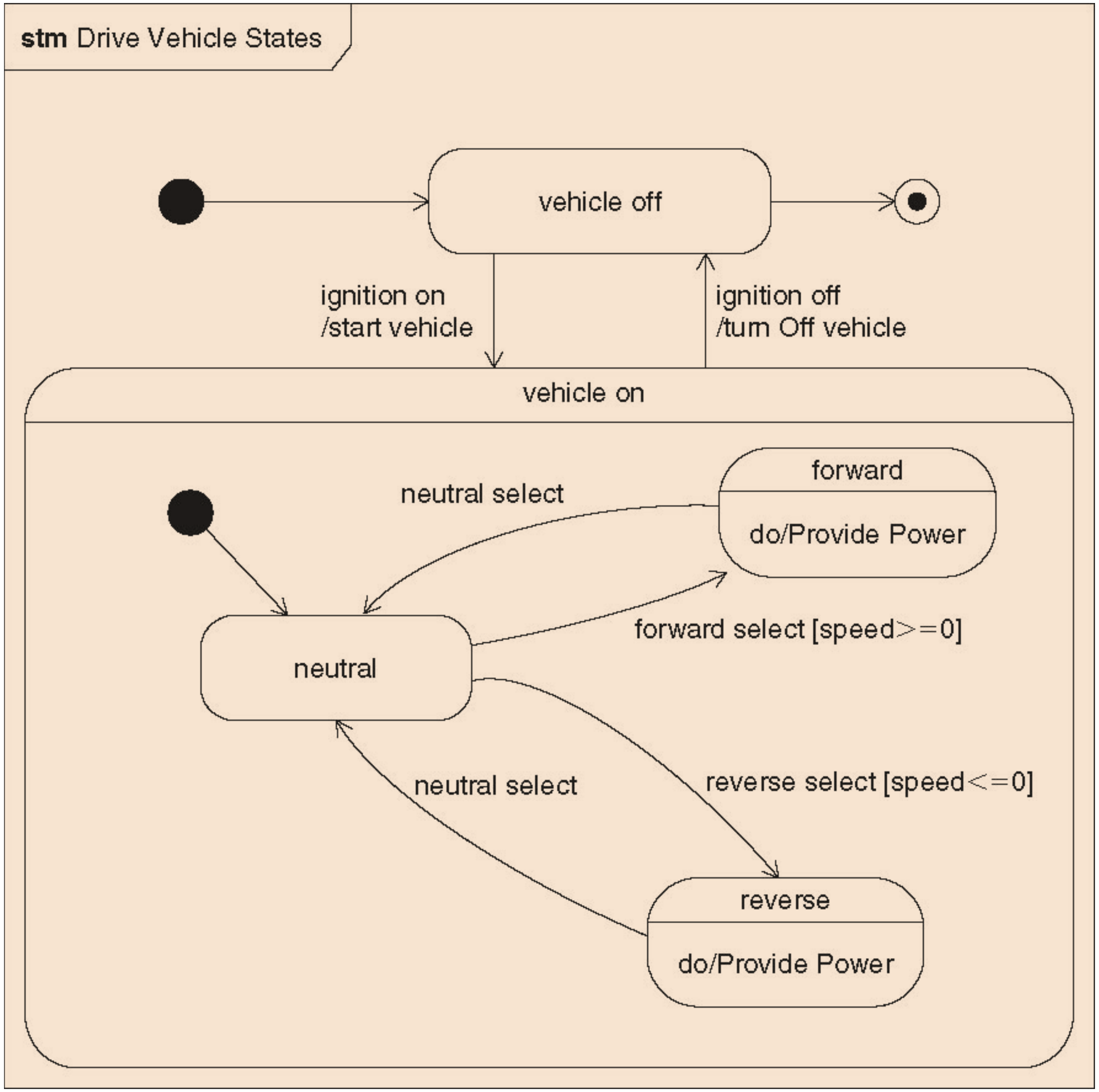


FIGURE 3.8

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States

- States – represents a condition in the life of a block
- Initial State – represented by a black solid dot
- Final State – represented by a bulls-eye

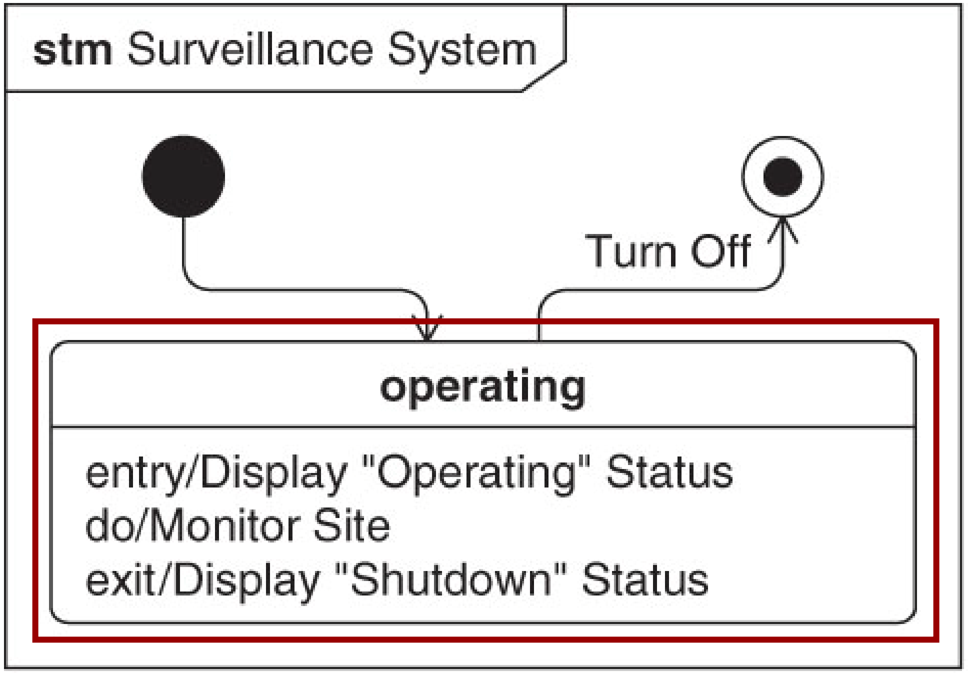
stm Surveillance System
Turn Off
operating
entry/Display "Operating" Status
do/Monitor Site
exit/Display "Shutdown" Status

FIGURE 10.2

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Behaviors

- Actions of a State
  - Types:
    - Entry – what happens when the state is entered
    - Exit – what happens when the state is exited
    - Do – what happens while in a state

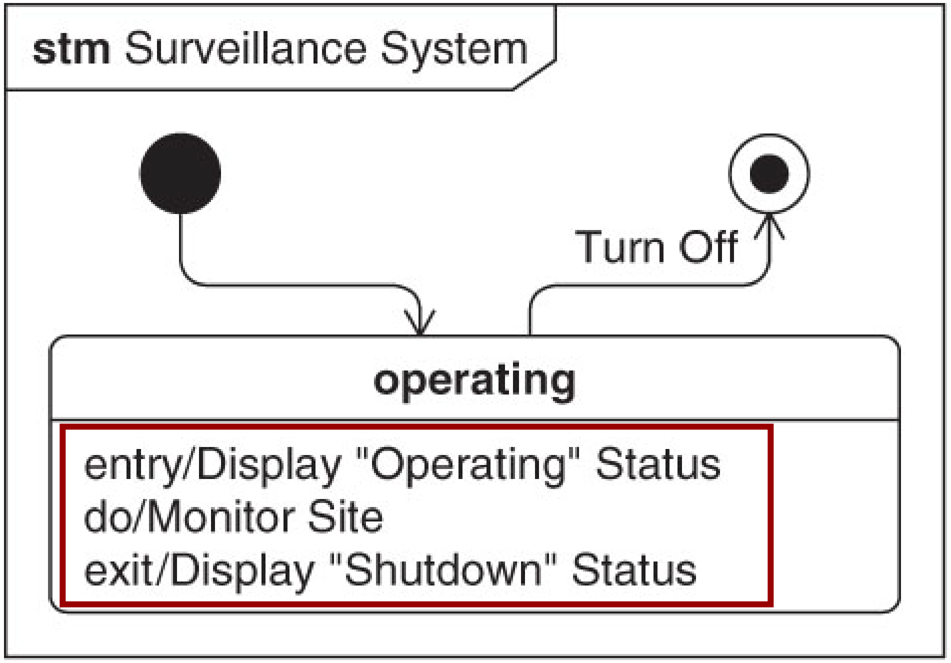
stm Surveillance System
Turn Off
operating
entry/Display "Operating" Status
do/Monitor Site
exit/Display "Shutdown" Status

FIGURE 10.2

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Transitions

- Used to show the flow from one state to another (solid arrow)
- Can consist of triggers, guards, and effects

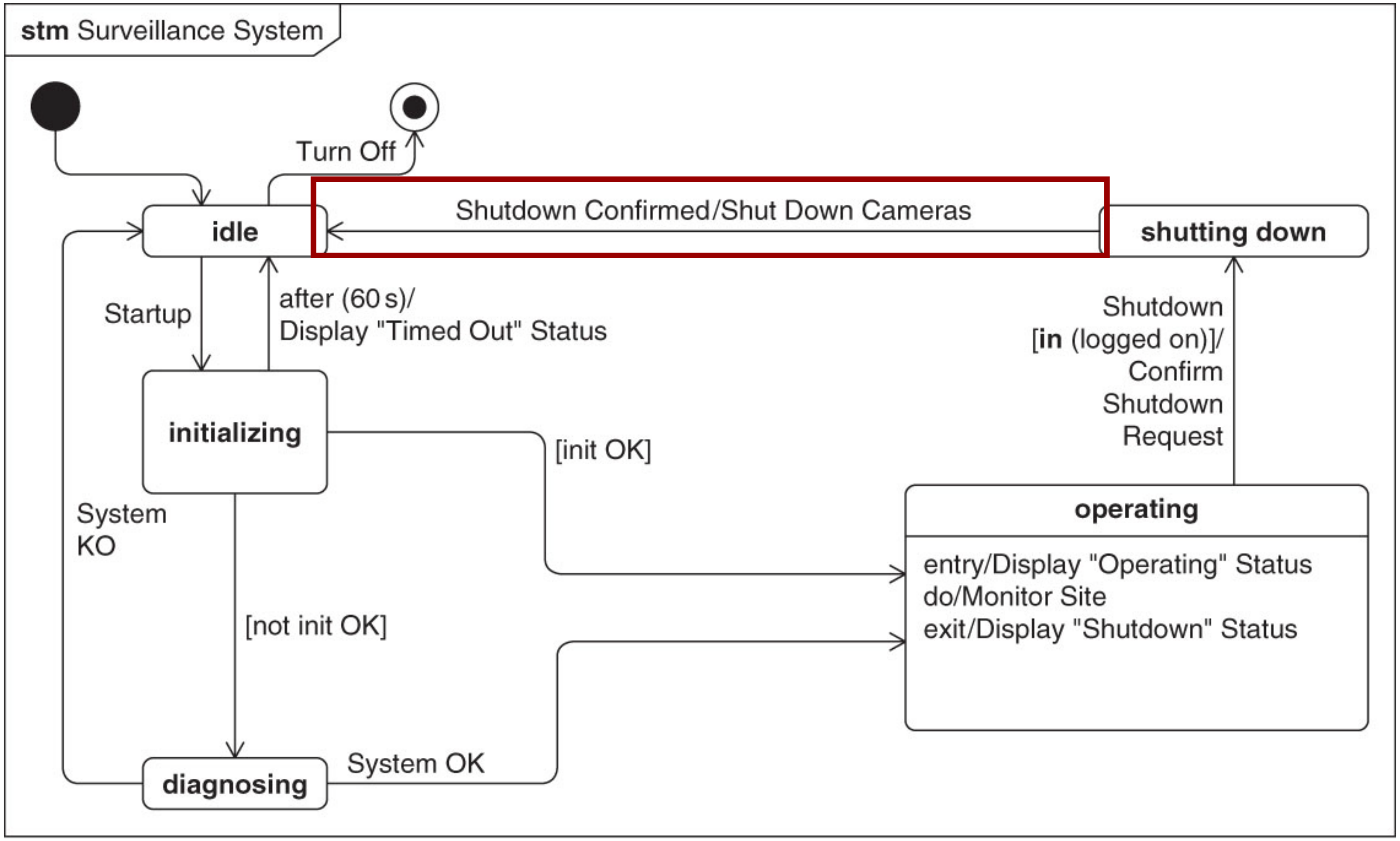

FIGURE 10.3

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Composite States

- Means of depicting the hierarchy of states
- Sub-states – states that are unique to another state of an entity
- Composite States are depicted by enclosing sub-states within a state

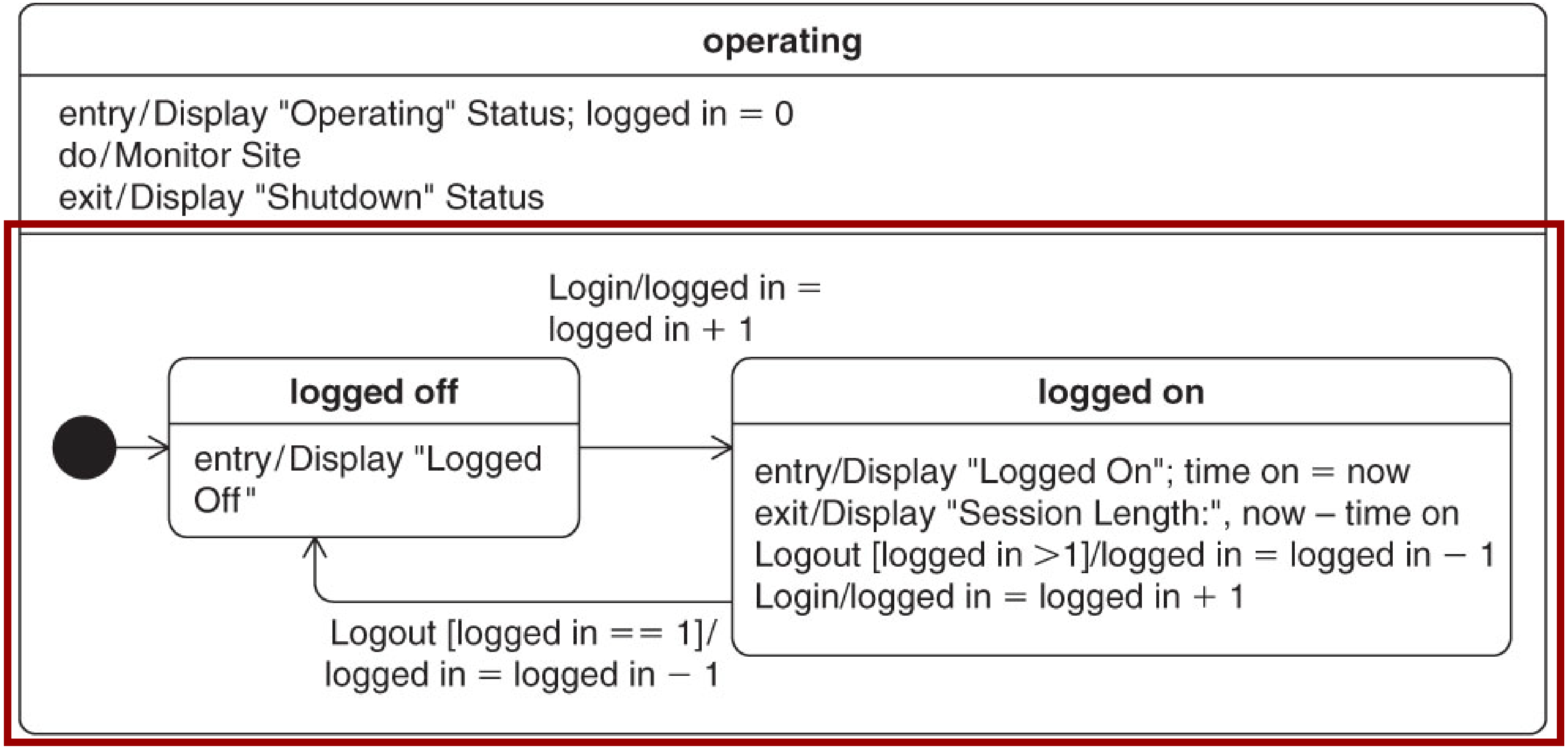
operating
entry/Display "Operating" Status; logged in = 0
do/Monitor Site
exit/Display "Shutdown" Status
Login/logged in = logged in + 1
logged off
entry/Display "Logged Off"
logged on
entry/Display "Logged On"; time on = now
exit/Display "Session Length:", now – time on
Logout [logged in >1]/logged in = logged in – 1
Login/logged in = logged in + 1
Logout [logged in == 1]/ logged in = logged in – 1

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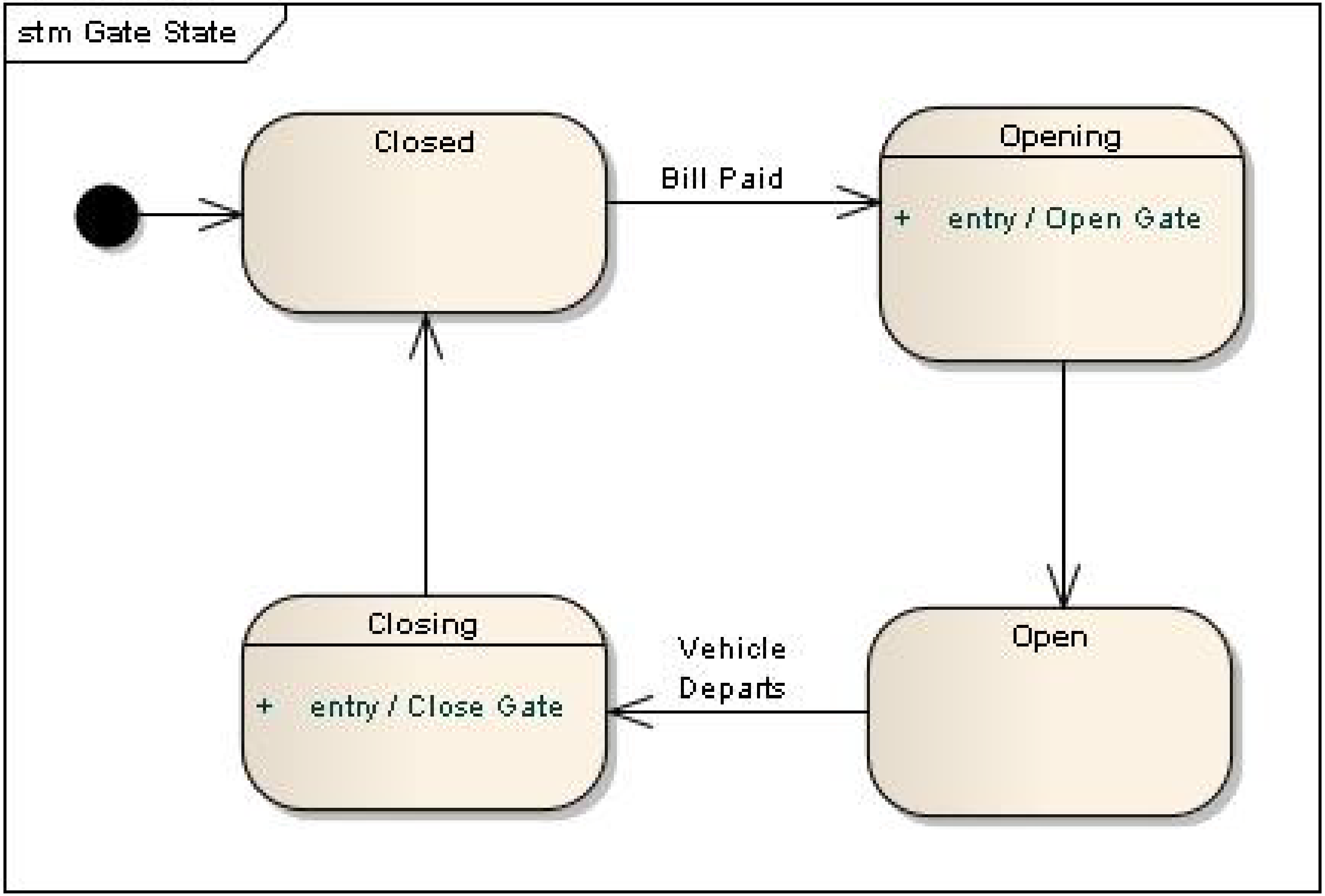
FIGURE 10.9

State Machine for Parking Garage Gate



Summary

- State Machines Diagrams are used to depict how a Block changes State
- State Machines can be comprised of:
  - States
  - Transitions
  - Composite States
- States represent a condition in the life of a Block
- Behaviors are the actions associated with a State
- Transitions are used to show how a Block changes from one State to another
- Transitions can consist of Triggers, Guards, and Effects
- Composite States are used to depict the hierarchy of States

MODELING CONSTRAINTS WITH PARAMETRICS

Parametrics

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

Parametrics Enables Integration of Engineering Analysis with Design Models

Vehicle Acceleration Analysis Parametric Diagram

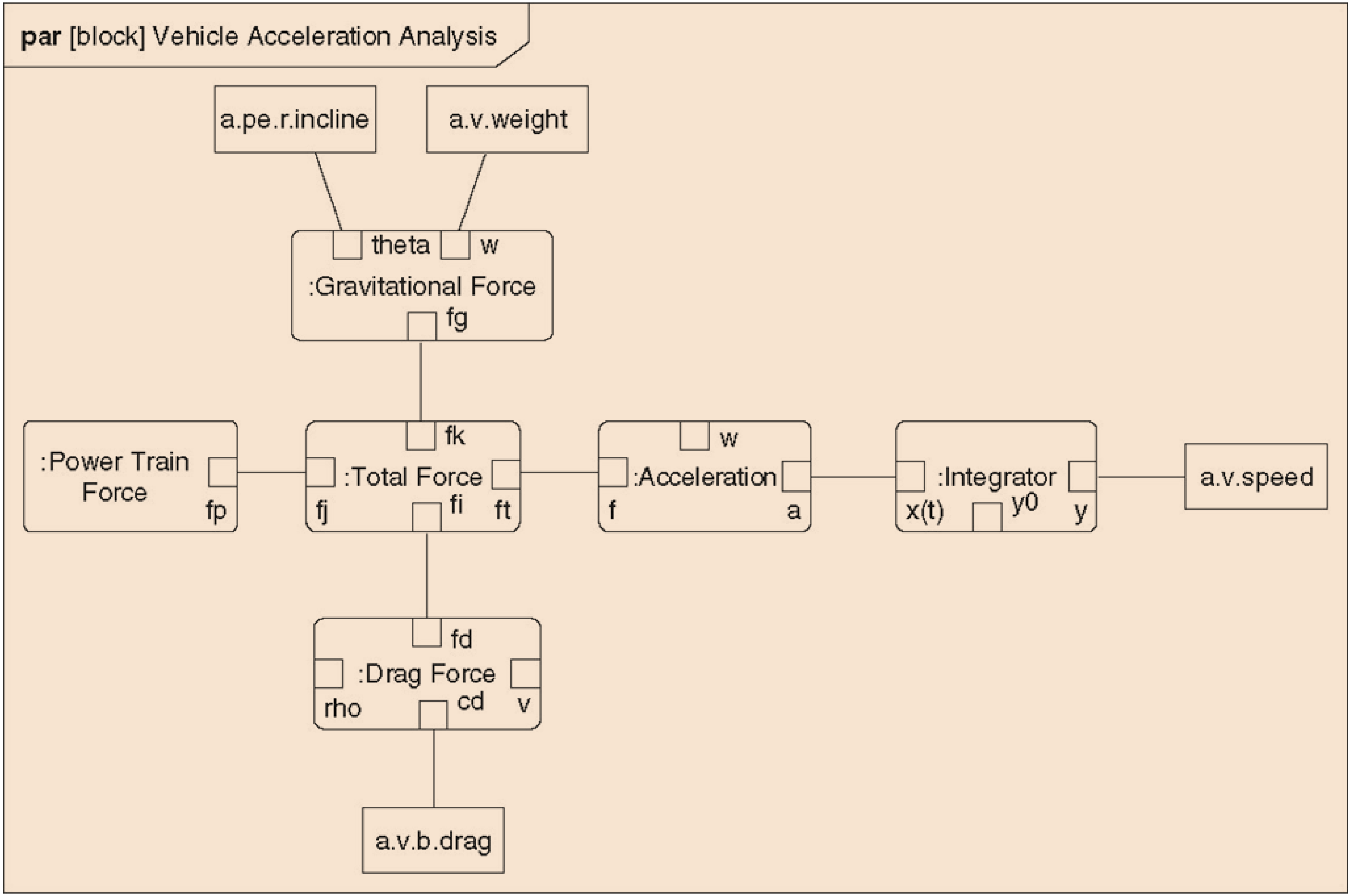
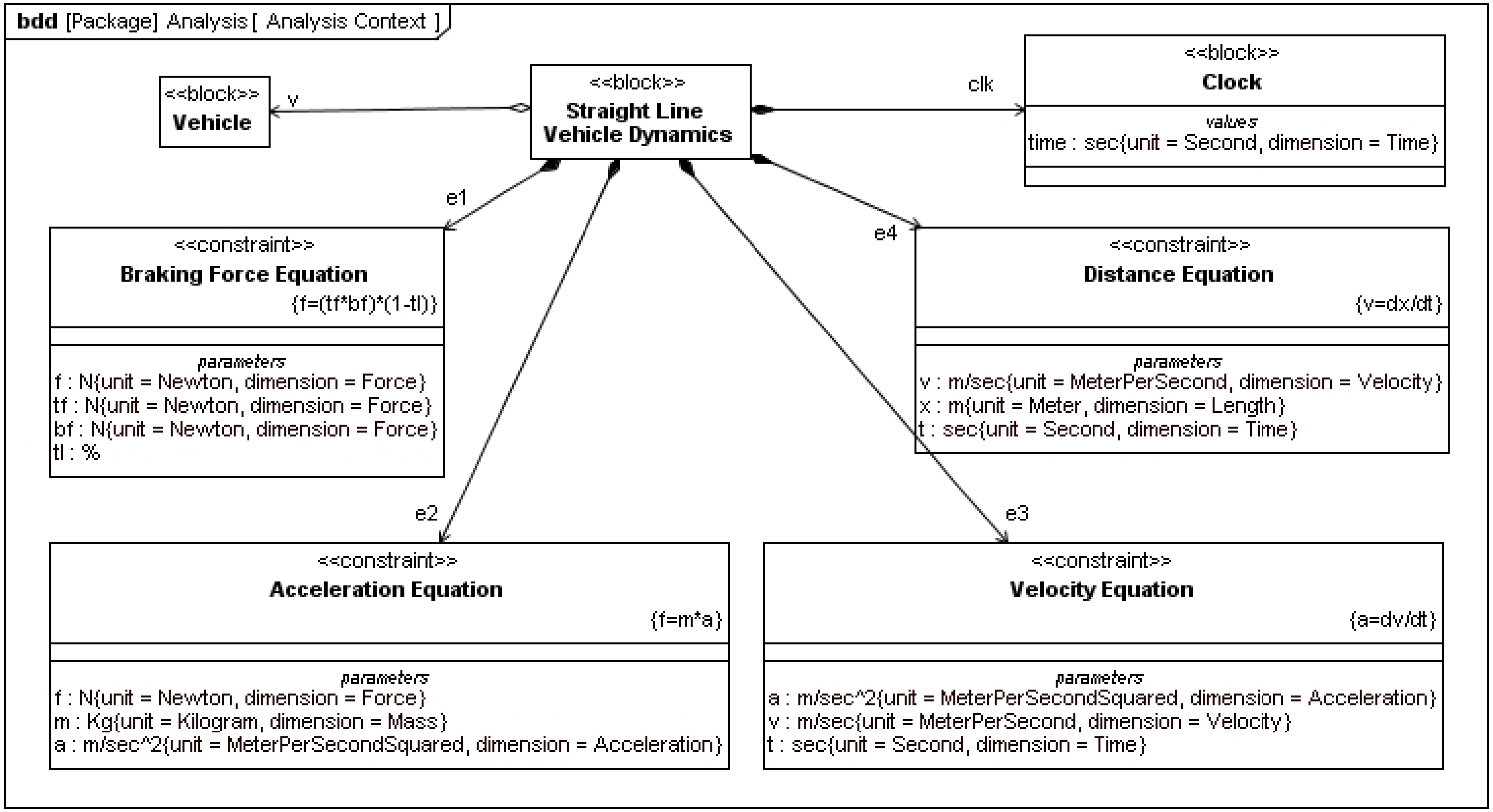


FIGURE 3.14

Defining Constraints in Constraint Blocks

- Constraint Blocks
  - Define equations so that they may be re-used and inter-connected
  - Define a set of parameters
  - Define an expression that constrains the parameters



bdd [Package] Analysis [Analysis Context]

<<block>>
Vehicle

<<block>>
Straight Line Vehicle Dynamics

<<block>>
Clock

values
time : sec{unit = Second, dimension = Time}

<<constraint>>
Braking Force Equation
{f=(tf*bf)*(1-tl)}

parameters
f : N{unit = Newton, dimension = Force}
tf : N{unit = Newton, dimension = Force}
bf : N{unit = Newton, dimension = Force}
tl : %

<<constraint>>
Distance Equation
{v=dx/dt}

parameters
v : m/sec{unit = MeterPerSecond, dimension = Velocity}
x : m{unit = Meter, dimension = Length}
t : sec{unit = Second, dimension = Time}

<<constraint>>
Acceleration Equation
{f=m*a}

parameters
f : N{unit = Newton, dimension = Force}
m : Kg{unit = Kilogram, dimension = Mass}
a : m/sec^2{unit = MeterPerSecondSquared, dimension = Acceleration}

<<constraint>>
Velocity Equation
{a=dv/dt}

parameters
a : m/sec^2{unit = MeterPerSecondSquared, dimension = Acceleration}
v : m/sec{unit = MeterPerSecond, dimension = Velocity}
t : sec{unit = Second, dimension = Time}

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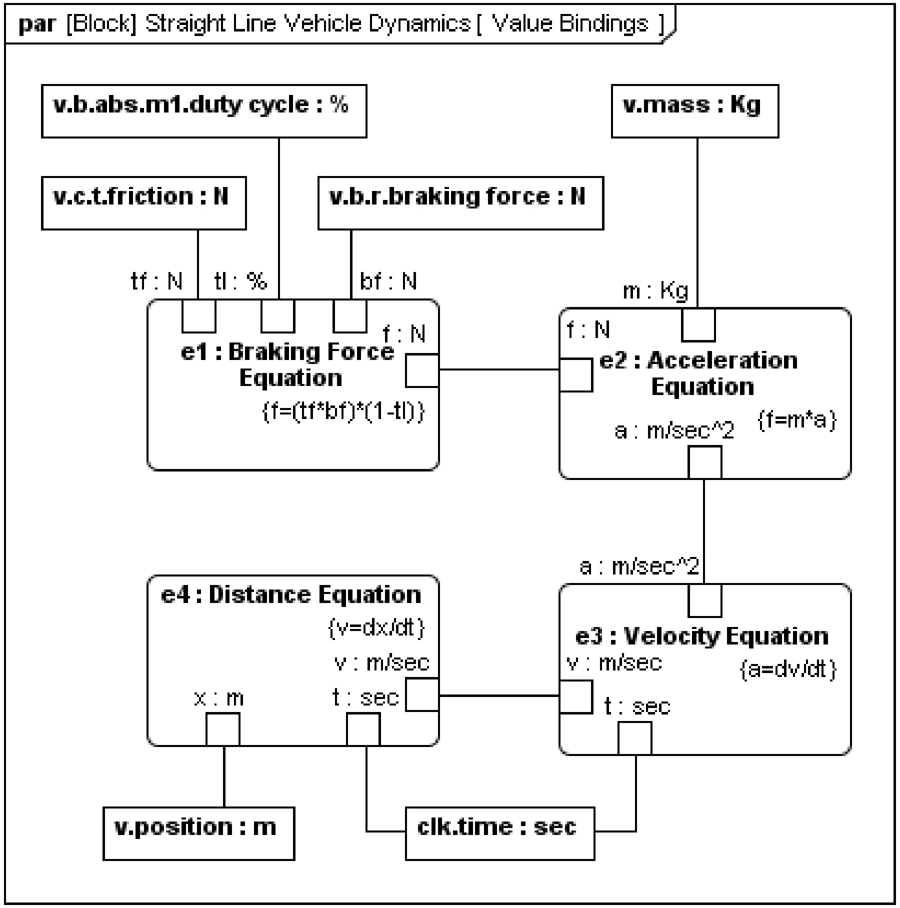
Defining Parametric Models

- Parametric models:
  - Depict a network of equations that constrain the properties of blocks
  - The properties of the system are bound to the parameters of the analysis equations (e.g. vehicle mass is bound to 'm' in F=m x a)
- Example: in the figure, properties of the vehicle are bound to the parameters of the equations used to analyze vehicle stopping distance
- Parametric models thus help identify the properties of the system that are critical to satisfying requirements



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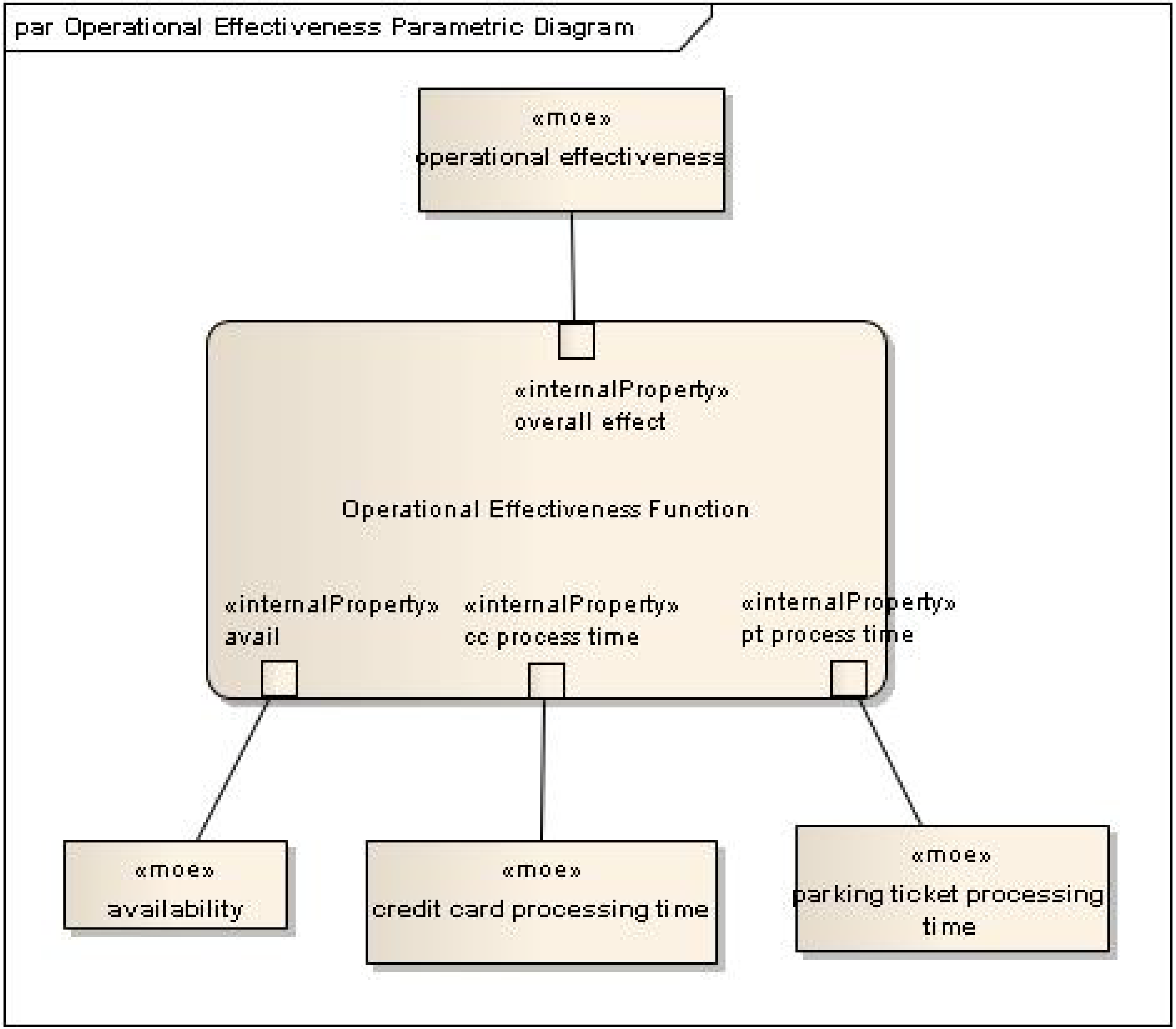
Top-Level Parametric Diagram for Gate System


par Operational Effectiveness Parametric Diagram
«moe»
operational effectiveness
«internalProperty»
overall effect
Operational Effectiveness Function
«internalProperty»
avail
«internalProperty»
cc process time
«internalProperty»
pt process time
«moe»
availability
«moe»
credit card processing time
«moe»
parking ticket processing time

Summary

- Parametric diagrams
    - Capture the analysis as a network of equations
    - Help ensure consistency between the system design model and multiple engineering analysis models
    - Help to manage technical performance measures
- Constraint Blocks
    - Define parameters and constraint expressions
    - Represented on a Block Definition Diagram
- Constraint Property
    - Usage of constraint blocks
    - Represented on a Parametric Diagram

MODELING CROSS CUTTING RELATIONSHIPS WITH ALLOCATIONS

Allocation Relationships

- **Allocation Relationships: Mapping Between Any Two Named Model Elements**
- **A Named Model Element is Allocated to (allocatedTo) or Allocated From (allocatedFrom) Other Model Elements.**
- **Example: System <u>Behavioral Allocation </u>(or Functional Allocation)**
  - **Allocation of System Activities to Blocks**
    - **Each Block Responsible for Executing a Particular Activity**

Allocation Relationships

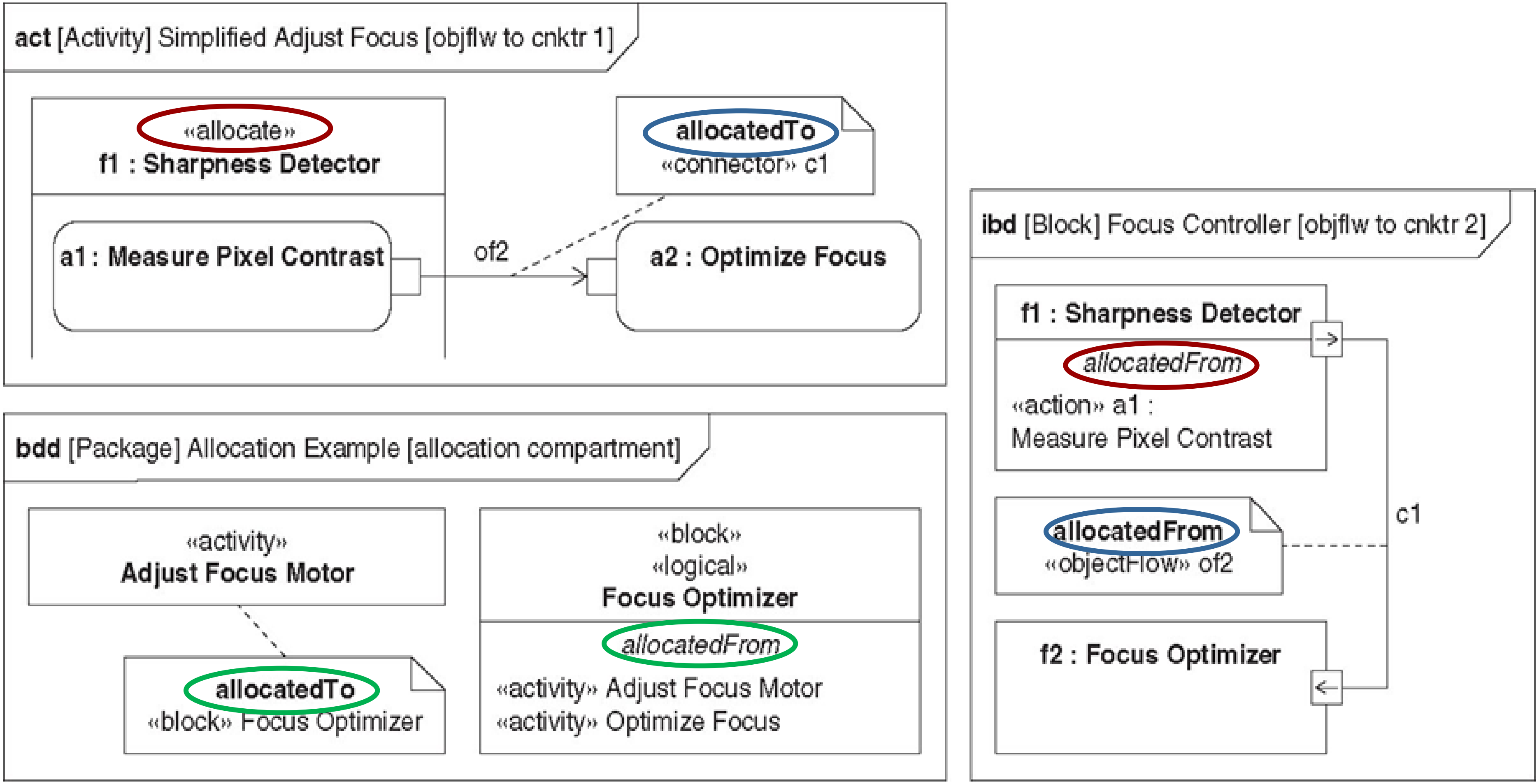
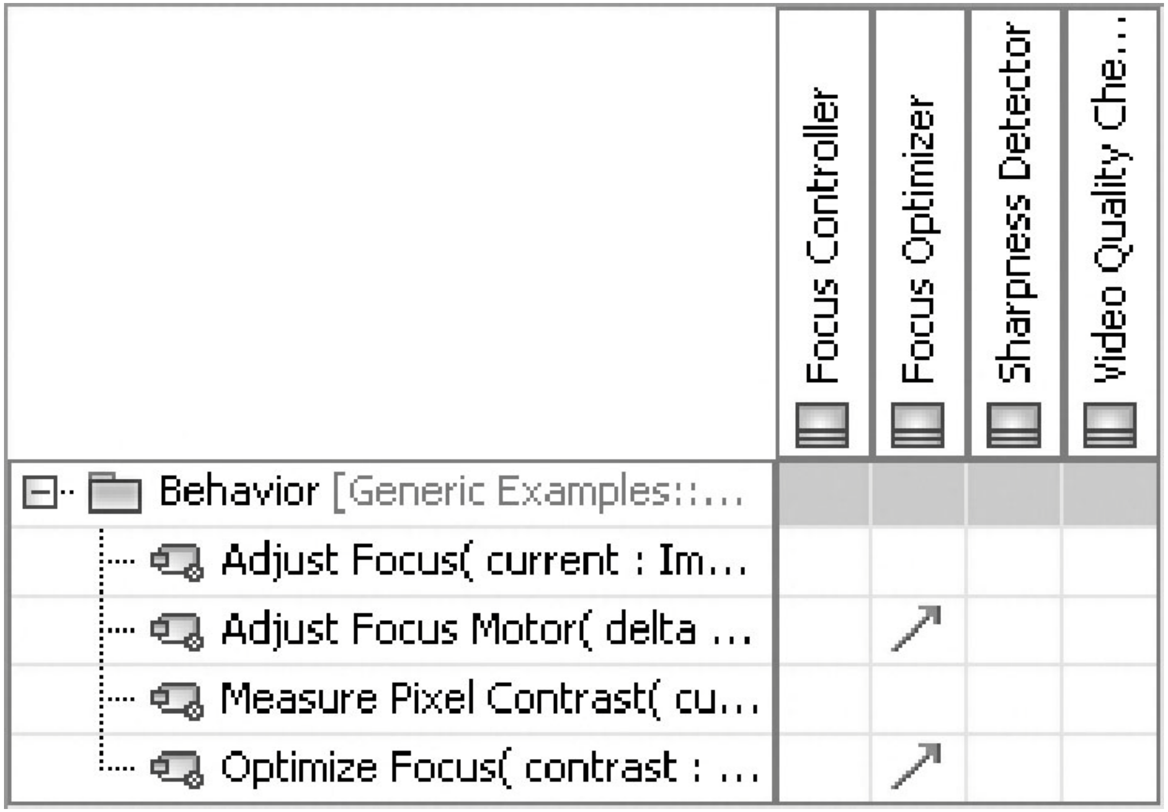


FIGURE 13.1

Allocation Notation

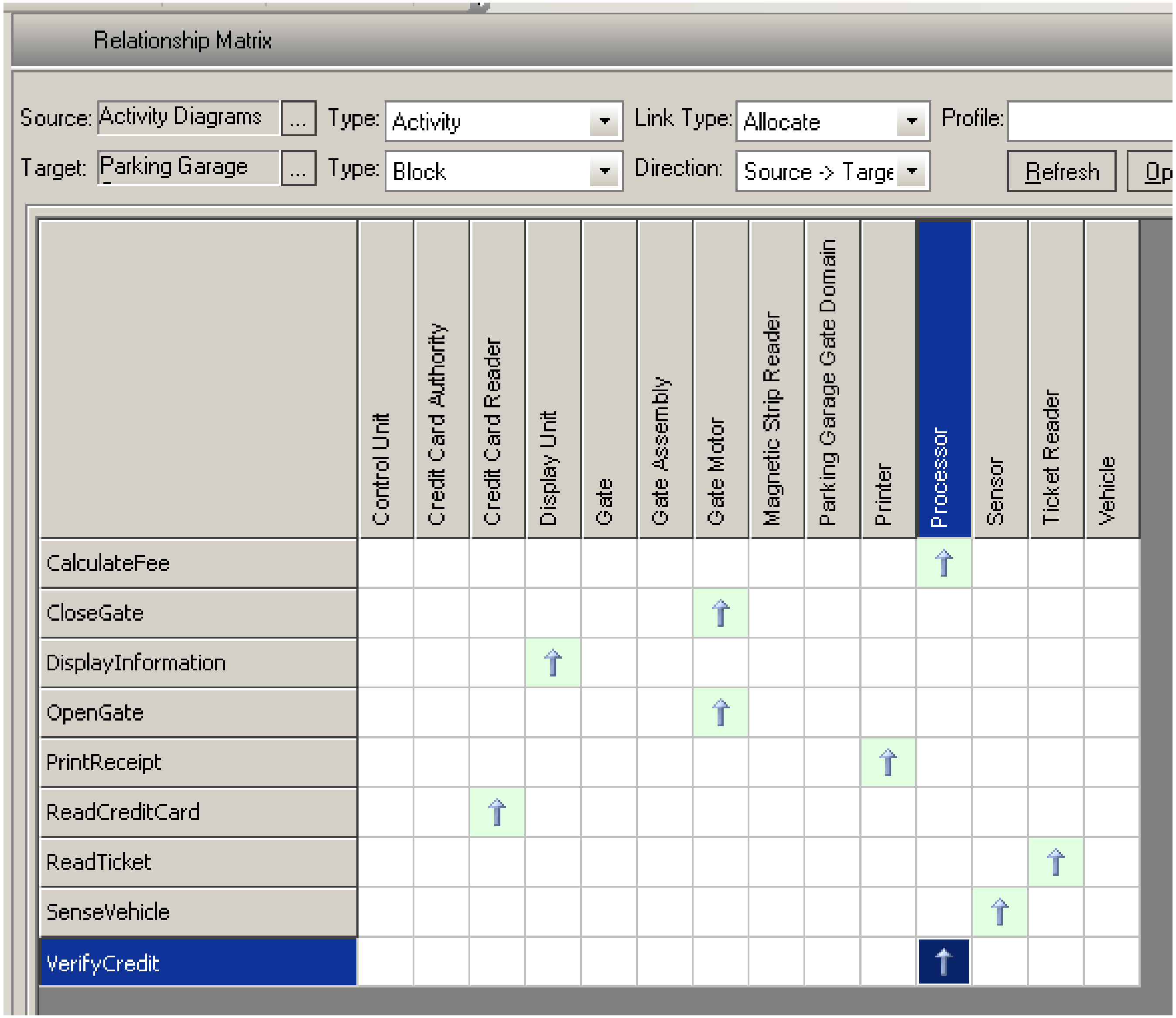
- **<u>Tabular (Table or Matrix) Notation</u>: Multiple Allocation Relationships**
  - **Not specifically prescribed by SysML specification (Tools Vary)**
  - **Useful for concise, compact Allocations Representations**



	Focus Controller	Focus Optimizer	Sharpness Detector	Video Quality Che...
Behavior [Generic Examples::...				
Adjust Focus(current : Im...				
Adjust Focus Motor(delta ...		↗		
Measure Pixel Contrast(cu...				
Optimize Focus(contrast : ...		↗		

FIGURE 13.5

Functional Allocations for Parking Garage Gate



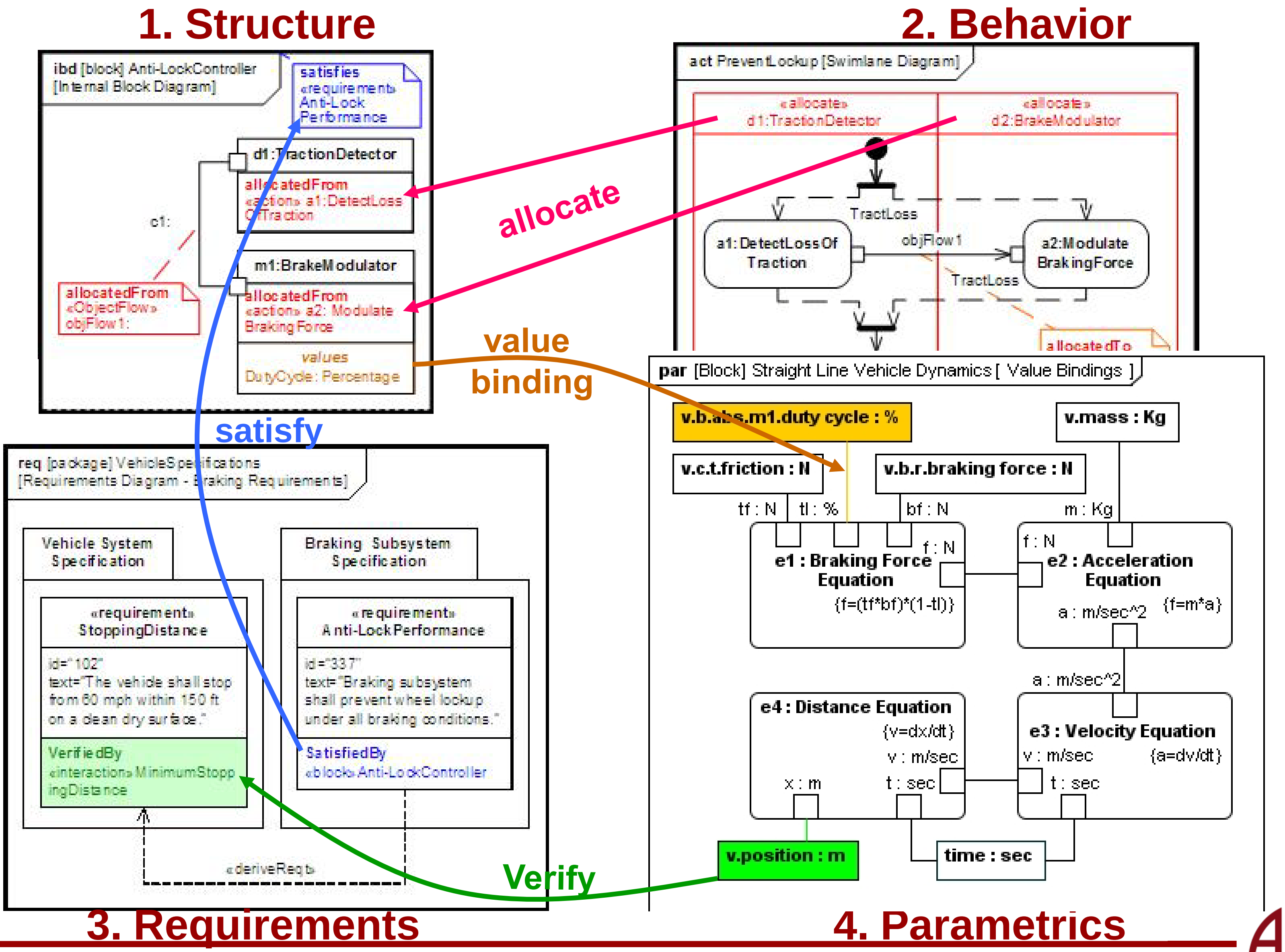
Relationship Matrix

Source: Activity Diagrams ... Type: Activity Link Type: Allocate Profile:

Target: Parking Garage ... Type: Block Direction: Source -> Targe Refresh Op

	Control Unit	Credit Card Authority	Credit Card Reader	Display Unit	Gate	Gate Assembly	Gate Motor	Magnetic Strip Reader	Parking Garage Gate Domain	Printer	Processor	Sensor	Ticket Reader	Vehicle
CalculateFee											↑			
CloseGate							↑							
DisplayInformation				↑										
OpenGate							↑							
PrintReceipt										↑				
ReadCreditCard			↑											
ReadTicket													↑	
SenseVehicle												↑		
VerifyCredit											↑			

Cross Connecting Model Elements



1. Structure

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

satisfies «requirement» Anti-Lock Performance

d1:TractionDetector

allocatedFrom «action» a1:DetectLoss OfTraction

c1:

allocatedFrom «ObjectFlow» objFlow1:

m1:BrakeModulator

allocatedFrom «action» a2: Modulate Braking Force

values DutyCycle: Percentage

2. Behavior

act PreventLockup [Swimlane Diagram]

«allocate» d1:TractionDetector

«allocate» d2:BrakeModulator

TractLoss

a1:DetectLossOf Traction

objFlow1

a2:Modulate BrakingForce

TractLoss

allocatedTo

allocate

value binding

satisfy

3. Requirements

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-Lock Performance

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

SatisfiedBy
«block» Anti-LockController

«deriveReqt»

Verify

4. Parametrics

par [Block] Straight Line Vehicle Dynamics [Value Bindings]

v.b.abs.m1.duty cycle : %

v.mass : Kg

v.c.t.friction : N

v.b.r.braking force : N

tf : N

tl : %

bf : N

m : Kg

f : N

f : N

e1 : Braking Force Equation
{f=(tf*bf)*(1-tl)}

e2 : Acceleration Equation
a : m/sec^2 {f=m*a}

a : m/sec^2

e4 : Distance Equation
{v=dx/dt}
v : m/sec
x : m
t : sec

e3 : Velocity Equation
v : m/sec {a=dv/dt}
t : sec

v.position : m

time : sec

Summary

- Allocations are used to depict mapping of model elements to one another
- There are many types of allocation, including: behavior, structure, and properties
- Allocations allows:
  - Allocating activities to blocks
  - Allocating requirements to blocks
  - Allocating logical elements to physical elements
- Allocation can be represented graphically though the following notations: Direct, Compartment, and Callout
- Tabular representations offer a compact representation of multiple allocation relationships

Class Exercise
Dishwasher Example - Sample Artifacts

Primary

- Requirement diagram – dishwasher spec
- Block definition diagram – top level
- Internal block diagram – dishwasher black box
- Use case diagram
- Activity diagram – black box scenario
- Block definition diagram – input/output definitions
- Block definition diagram – dishwasher hierarchy
- Internal block diagram – dishwasher white box
- Activity diagram – white box scenario
- Requirement diagram - traceability

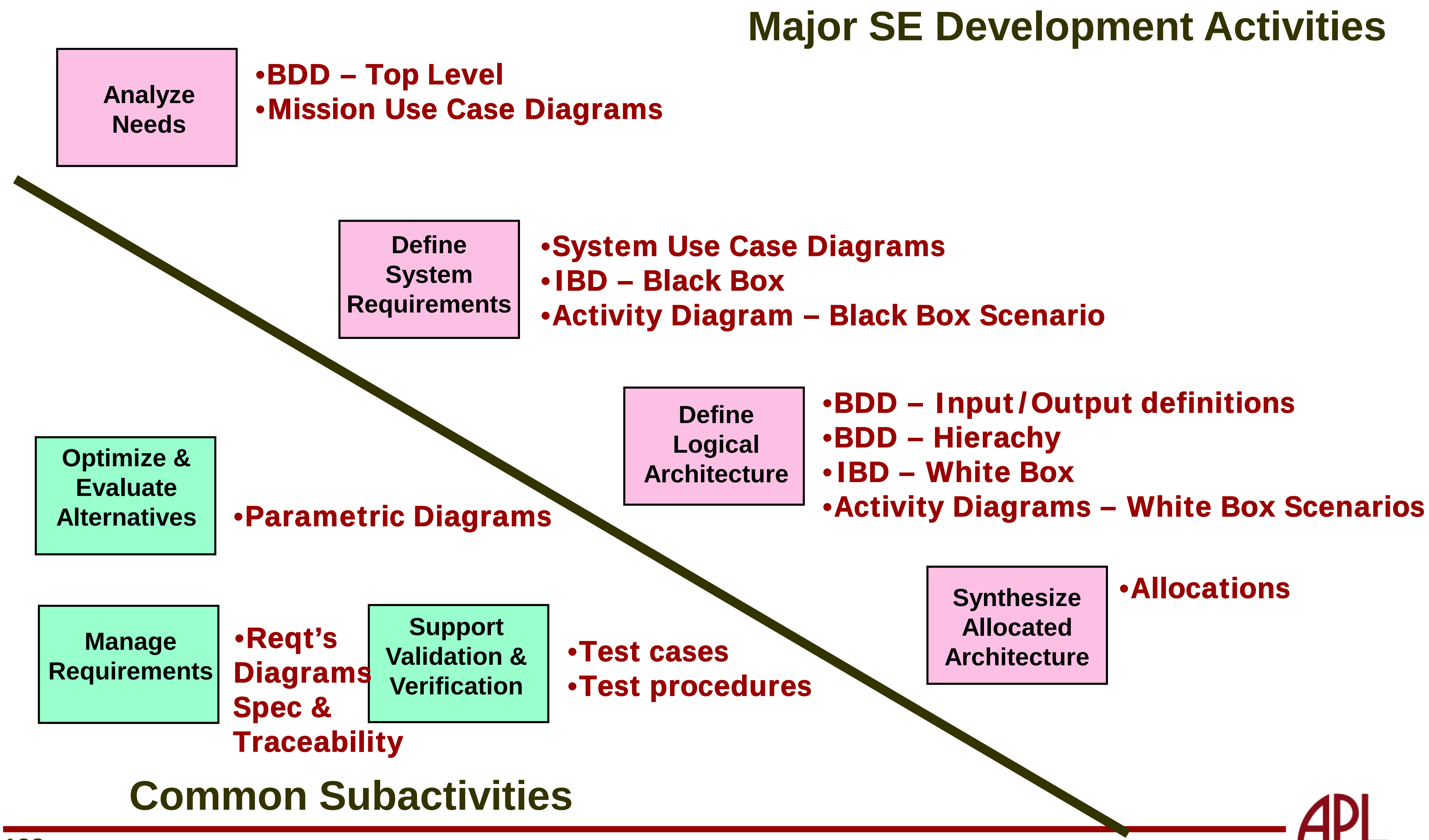
Optional

- Parametric diagram
- State machine diagram
- Sequence diagram

PROCESS SUMMARY

System Modeling Activities – OOSEM

Integrating MBSE into the SE Process



Major SE Development Activities

Analyze Needs

- BDD – Top Level
- Mission Use Case Diagrams

Define System Requirements

- System Use Case Diagrams
- IBD – Black Box
- Activity Diagram – Black Box Scenario

Define Logical Architecture

- BDD – Input/Output definitions
- BDD – Hierachy
- IBD – White Box
- Activity Diagrams – White Box Scenarios

Synthesize Allocated Architecture

- Allocations

Optimize & Evaluate Alternatives

- Parametric Diagrams

Manage Requirements

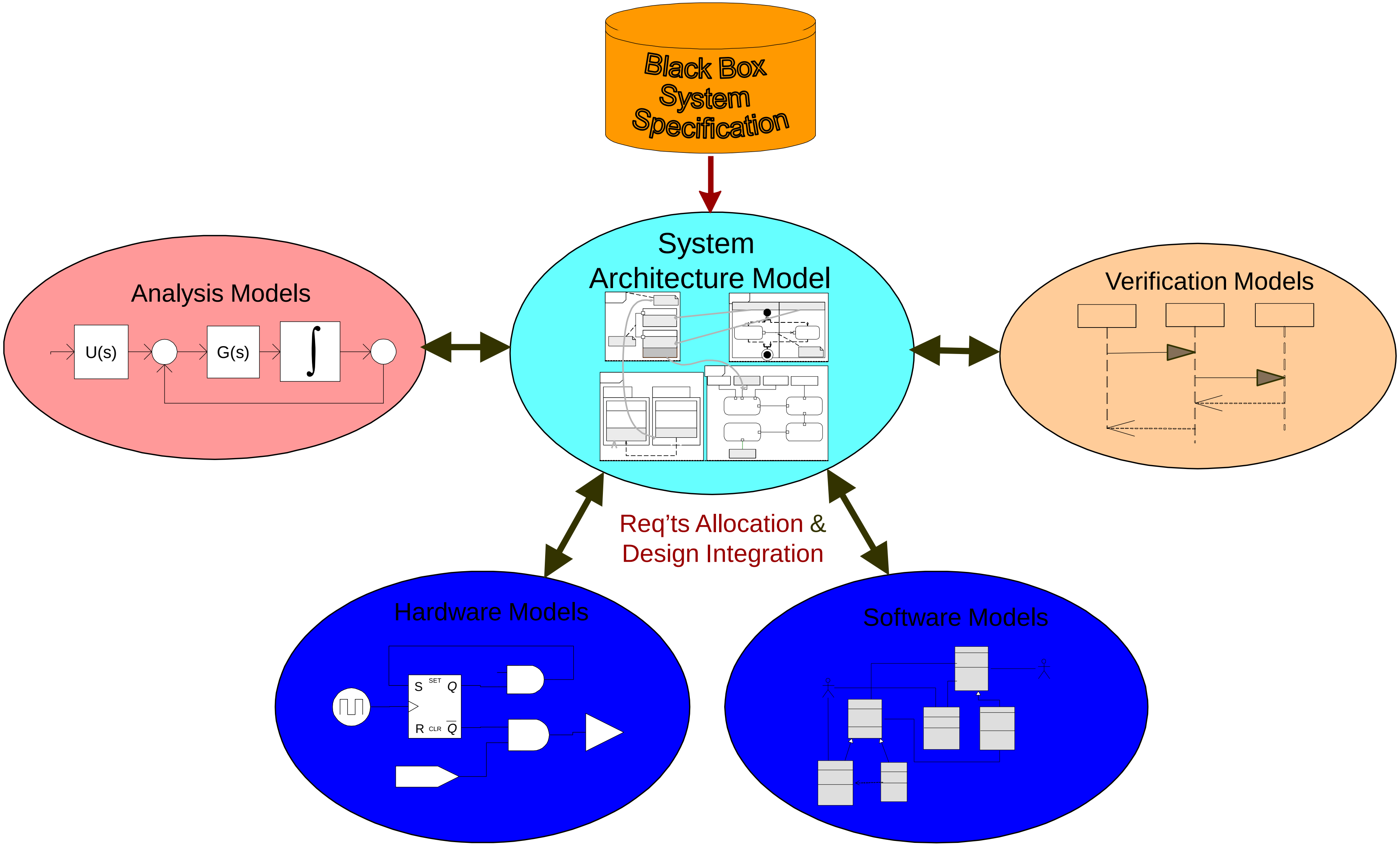
- Reqt's Diagrams Spec & Traceability

Support Validation & Verification

- Test cases
- Test procedures

Common Subactivities

System Architecture Model Provides an Integration Framework



Req'ts Allocation & Design Integration

TOOLS OVERVIEW

Tools Overview

- Tool Integration
- Suggested Tool Selection Criteria
- Partial List of SysML Tools

Tool Integration

- Classes of Tools in a Systems Development Environment
  - Project Management
  - Systems Modeling
  - Performance Simulation
  - Requirements Management
  - Configuration Management and Data Management
  - Verification and Validation
  - Engineering Analysis
  - HW and SW Modeling
  - Document Generation

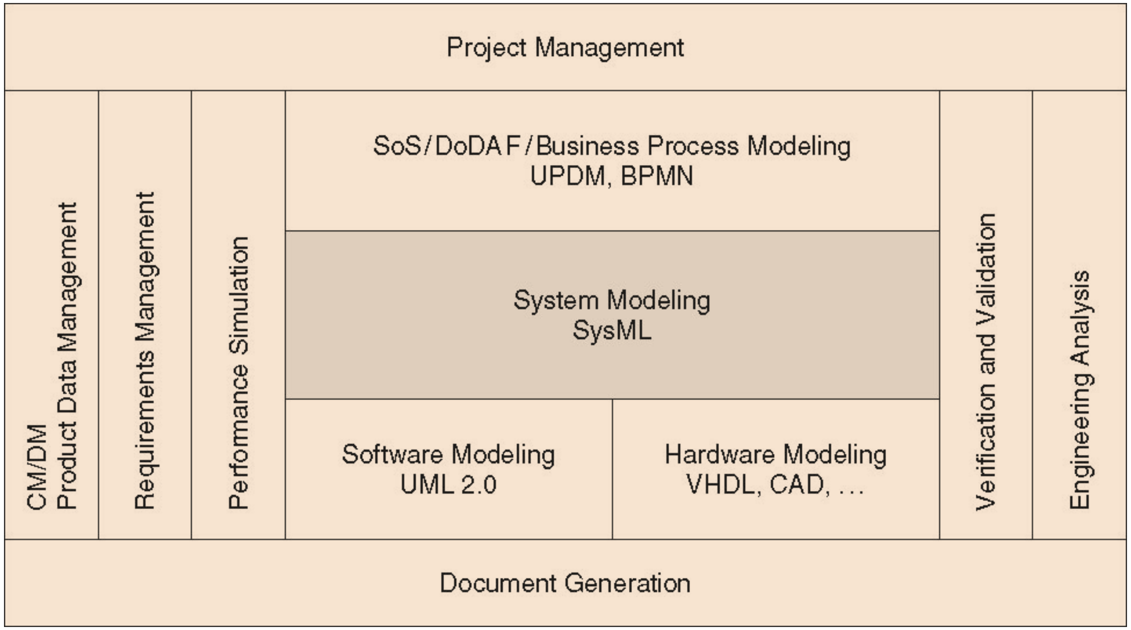


FIGURE 17.2

Tool Integration

- Data Exchange Mechanisms
  - Manual
  - File-based exchange (XMI)
  - Interaction-based exchange (API)
  - Repository-based exchange

- Data Exchange Standards
  - XML Metadata Interchange
  - Application Protocol 233
  - Diagram Interchange Standards
  - Model Transformation

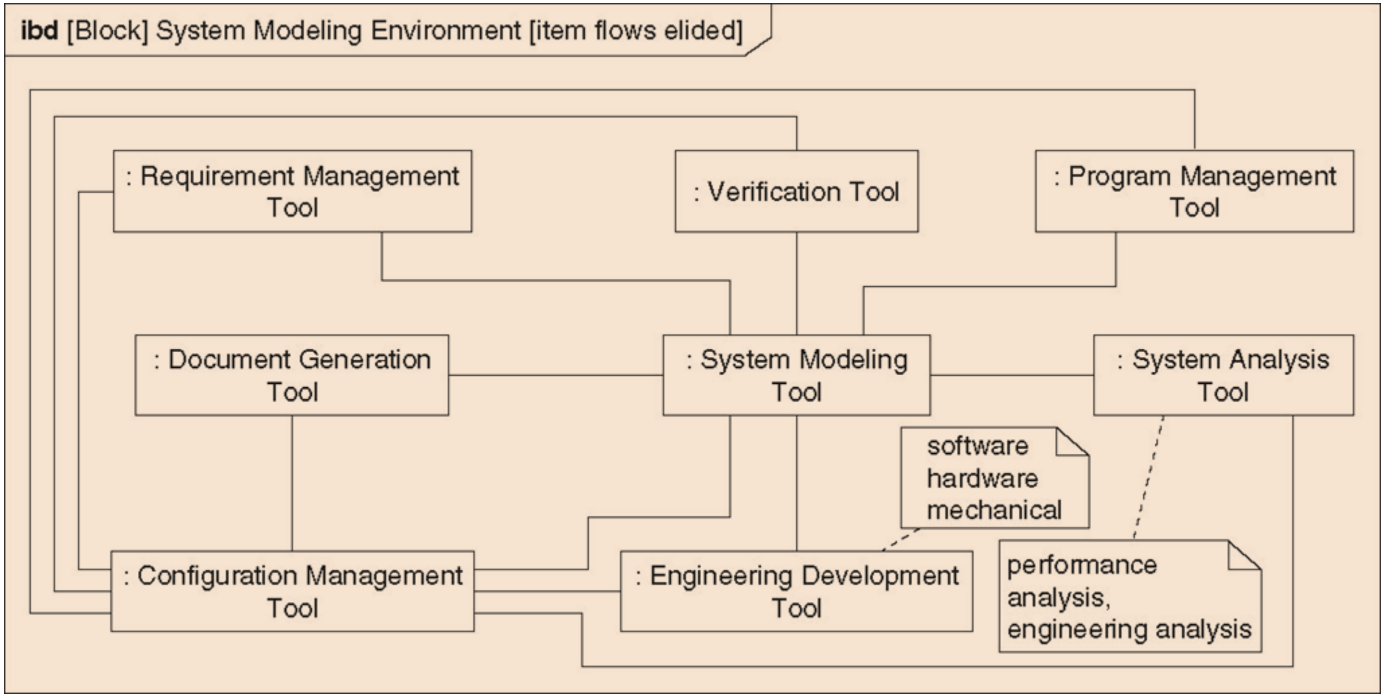

ibd [Block] System Modeling Environment [item flows elided]
: Requirement Management Tool
: Verification Tool
: Program Management Tool
: Document Generation Tool
: System Modeling Tool
: System Analysis Tool
software hardware mechanical
: Configuration Management Tool
: Engineering Development Tool
performance analysis, engineering analysis

FIGURE 17.3

Suggested Tool Selection Criteria

- Conformance to SysML specification
- Usability
- Document Generation capability
- Model execution capability
- Conformance to XMI
- Conformance to AP233
- Integration with other engineering tools
- Performance (maximum number of users, model size)
- Model checking to verify model conformance
- Training, online help, and support
- Availability of model libraries
- Life-cycle cost (acquisition, training, support)
- Vendor viability
- Previous experience with tool
- Support for selected model-based method (e.g. automated scripts, standard reports, etc.)

Partial List of SysML Tools

- IBM - Rhapsody
- No Magic - Magic Draw
- Sparx Systems - Enterprise Architect
- Atego – Artisan Studio
- INTERCax ParaMagic (Magic Draw plug-in)
- Others
  - Microsoft Visio – SysML Template (Pavel Hruby)
  - ….

Note: list taken from SysML RFI 2009 Survey Responses

WRAP-UP

Deploying MBSE

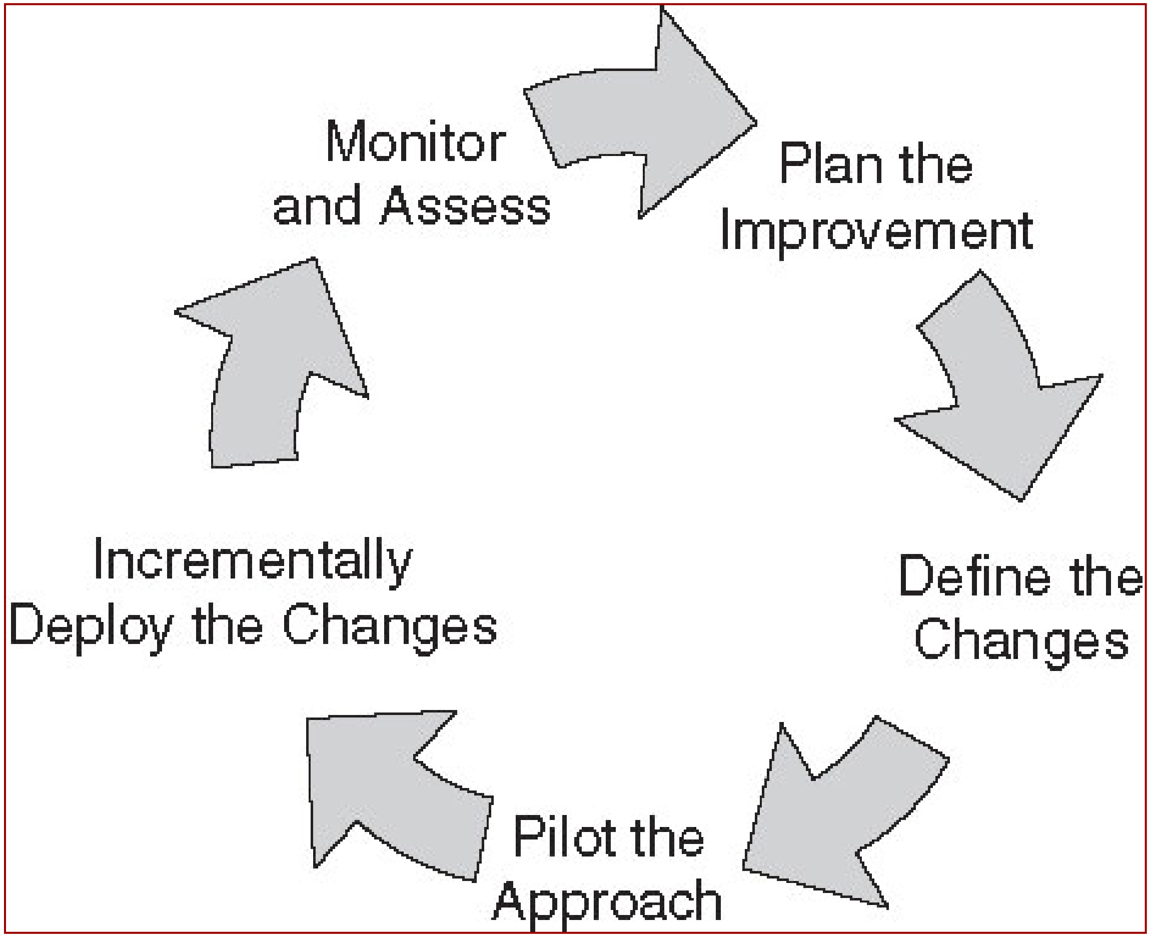


FIGURE 18.1 © 2008 Elsevier, Inc.: A Practical Guide to SysML

Deploy MBSE into your organization as part of your improvement process

Summary

- SysML sponsored by INCOSE/OMG with broad industry and vendor participation and adopted in 2006
- 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
- Multiple vendor implementations available
- Standards based modeling approach for SE expected to improve communications, tool interoperability, and design quality
- Plan SysML transition as part of overall MBSE approach
- Continue to evolve SysML based on user/vendor/researcher feedback and lessons learned