33%

2,498

Where We Started

MBSE Coordinates Development Processes

Our Challenge

MBSE - Transforming Medical Device Design

2017 annual INCOSE international workshop
Los Angeles, CA, USA
January 28 - 31, 2017

Casey Medina & Kristina Fuerst

TERUMOBCT

Models Answer Questions

Structure Implements Function

Making a "Quantum" Leap

Risk Management 2.0

January 28, 2017

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MBSE - Transforming Medical Device Design

Casey Medina & Kristina Fuerst

TERUMOBCT

Unlocking the Potential of Blood

Casey Medina, CSEP

Casey currently practices systems engineering in the medical device industry. He has developed products in the areas of automated stem cell growth, patient monitoring, pulse-oximetry, blood collections and therapeutics. Casey holds multiple patents in the medical device sector. Professionally, he is focused on developing the art of systems engineering in a manner that fosters adoption and acceptance by organizations resistant to change. He currently applies systems engineering practices and principles to enable rapid medical device development and process design and is working to enhance the use of MBSE as an enabler for usability and human factors analyses.

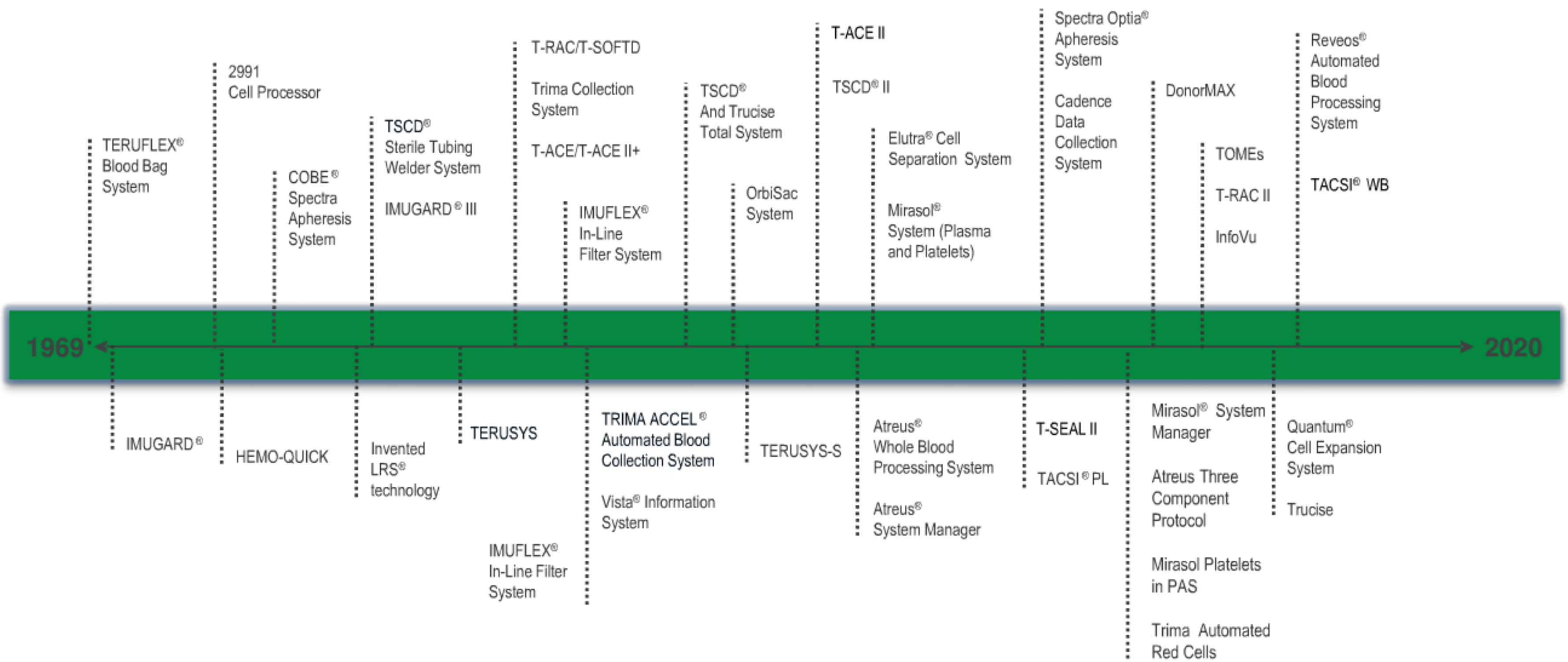
Kristina Fuerst, ASEP

Kristina has been working in the medical device industry as a systems engineer since 2012 and is responsible for the requirements engineering and system architecture development for her team. Kristina developed and implemented an intensive, two-day requirements training course with Casey. Kristina graduated from the University of Colorado at Boulder with a B.S. in Chemical and Biological Engineering and is pursuing her Master's degree in Biomedical Engineering with Rutgers University. She received her ASEP in 2013.

Terumo BCT

Established:	1964 as COBE Laboratories
President and CEO:	David Perez
Number of Associates:	5,300+
Global Headquarters:	Lakewood, Colorado
Regional Headquarters:	Brussels, Buenos Aires, Hong Kong, Tokyo
Manufacturing Facilities:	United States, Belgium, Japan, Northern Ireland, India, Vietnam
Main Business:	A global leader in blood component, therapeutic apheresis and cellular technologies, and the only company with the unique combination of apheresis collections, manual and automated whole blood processing, and pathogen reduction. We believe in the potential of blood to do even more for patients than it does today. This belief inspires our innovation and strengthens our collaboration with customers.
Parent Company:	Terumo Corporation; Tokyo Stock Exchange (4543)

Terumo BCT



1969
2020
TERUFLEX® Blood Bag System
2991 Cell Processor
COBE® Spectra Apheresis System
TSCD® Sterile Tubing Welder System
IMUGARD® III
T-RAC/T-SOFTD
Trima Collection System
T-ACE/T-ACE II+
IMUFLEX® In-Line Filter System
TSCD® And Trucise Total System
OrbiSac System
T-ACE II
TSCD® II
Elutra® Cell Separation System
Mirasol® System (Plasma and Platelets)
Spectra Optia® Apheresis System
Cadence Data Collection System
DonorMAX
TOMEs
T-RAC II
InfoVu
Reveos® Automated Blood Processing System
TACSI® WB
IMUGARD®
HEMO-QUICK
Invented LRS® technology
TERUSYS
IMUFLEX® In-Line Filter System
TRIMA ACCEL® Automated Blood Collection System
Vista® Information System
TERUSYS-S
Atreus® Whole Blood Processing System
Atreus® System Manager
T-SEAL II
TACSI® PL
Mirasol® System Manager
Atreus Three Component Protocol
Mirasol Platelets in PAS
Trima Automated Red Cells
Quantum® Cell Expansion System
Trucise

SysML Elements and Diagrams Created with MagicDraw by No Magic

January 28, 2017

Proceedings of the 25th Annual International Symposium

“From Asking Forgiveness to Saying You're Welcome, Introducing Requirements Engineering to Medical Device Development”

Casey Medina, Kristina Fuerst

“The "V" Model Reloaded”

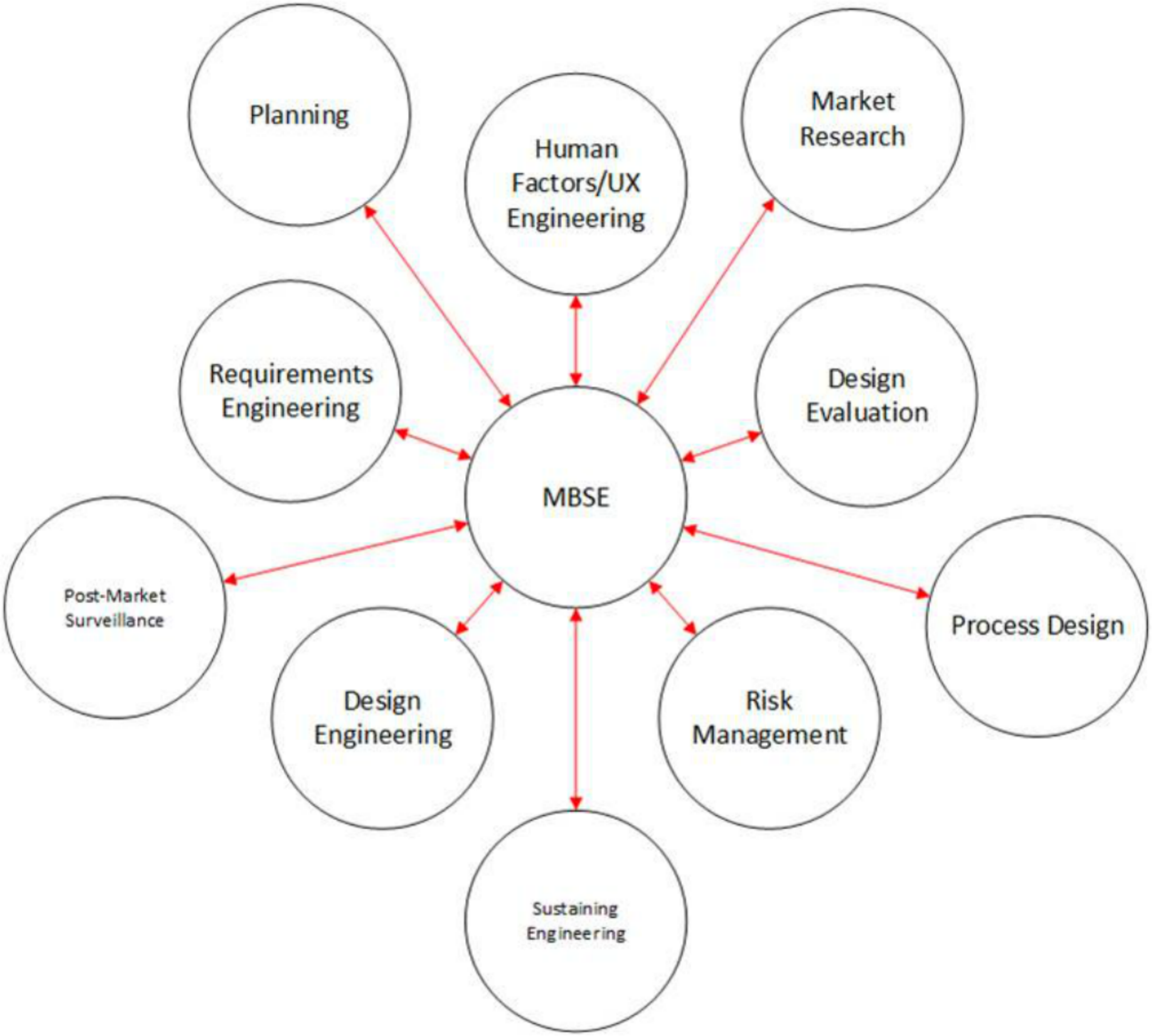
Casey Medina

33%

Where We Started

- No understanding of system architecture outside of limited, localized, software practices
- No process for developing system architecture
- Design information largely captured as "tribal knowledge"

MBSE Coordinates Development Processes



Our Challenge

Controls

- “This is telling me how to do my job!”
- “We know this already.”
- “This isn’t possible to know.”
- “This is too much information.”
- Perception that schedule pressure won’t allow this work to happen

Inputs

- Definition of Intended use (mission statement)
- Process for determining Objectives and Goals
- Process for creating User/Env analysis
    - interactions
    - characteristics
- Descriptions of Situational Behaviors
- Definitions of System Behavior
-TBCT Associate

Teach system modeling to encourage its integration in development processes

Outputs

1 - Demonstrate ability to generate at least 2 levels of hierarchy
2 - Understand what is meant by system behavior and how it is different from system performance
3 - Understand hierarchy and flow of system behaviors
4 - Differentiate black and white box behaviors
5 - Demonstrate ability to create FFBD and context diagrams for system behavior from intended use
6 - Understand how to use the syntax to document the models
7 - Understand these models are the backbone of the project. Dictates Req’s, V&V risk, all parts of design

Enablers

- Examples of various system operational scenarios
- Actual product example
- SAD template
- Example description of system behavior
- Architecture guidance, publications, best practices, etc.

Models Answer Questions

Answers are expensive.
Good answers cost the same.
- Rick Griffith

Teams are more comfortable solving problems than defining them.

Asking the questions right is as important as asking the right questions.

- Ask questions in a personal, engaging manner
- Listen intently – be present
- Create a safe environment
- Help your team capitalize on opportunities to increase their knowledge of their system

How well does this need to perform?
How much should it weigh?
How does the system respond if that happens?
Do I understand all the interfaces?
What do the users think of this design?
Did I capture the requirements accurately?
How much coverage do I have on my V&V activities?

What do I need/hope to learn?
What type of model will best help the team?
How much information do I need to represent?
How many levels of hierarchy are necessary?
How will I verify and validate my model?
How will I share the results of my modeling activities?

Answers are expensive.
Good answers cost the same.
- Rick Griffith

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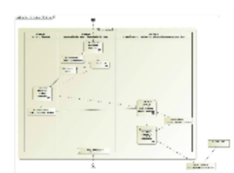
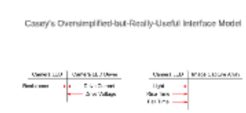
Structure Implements Function





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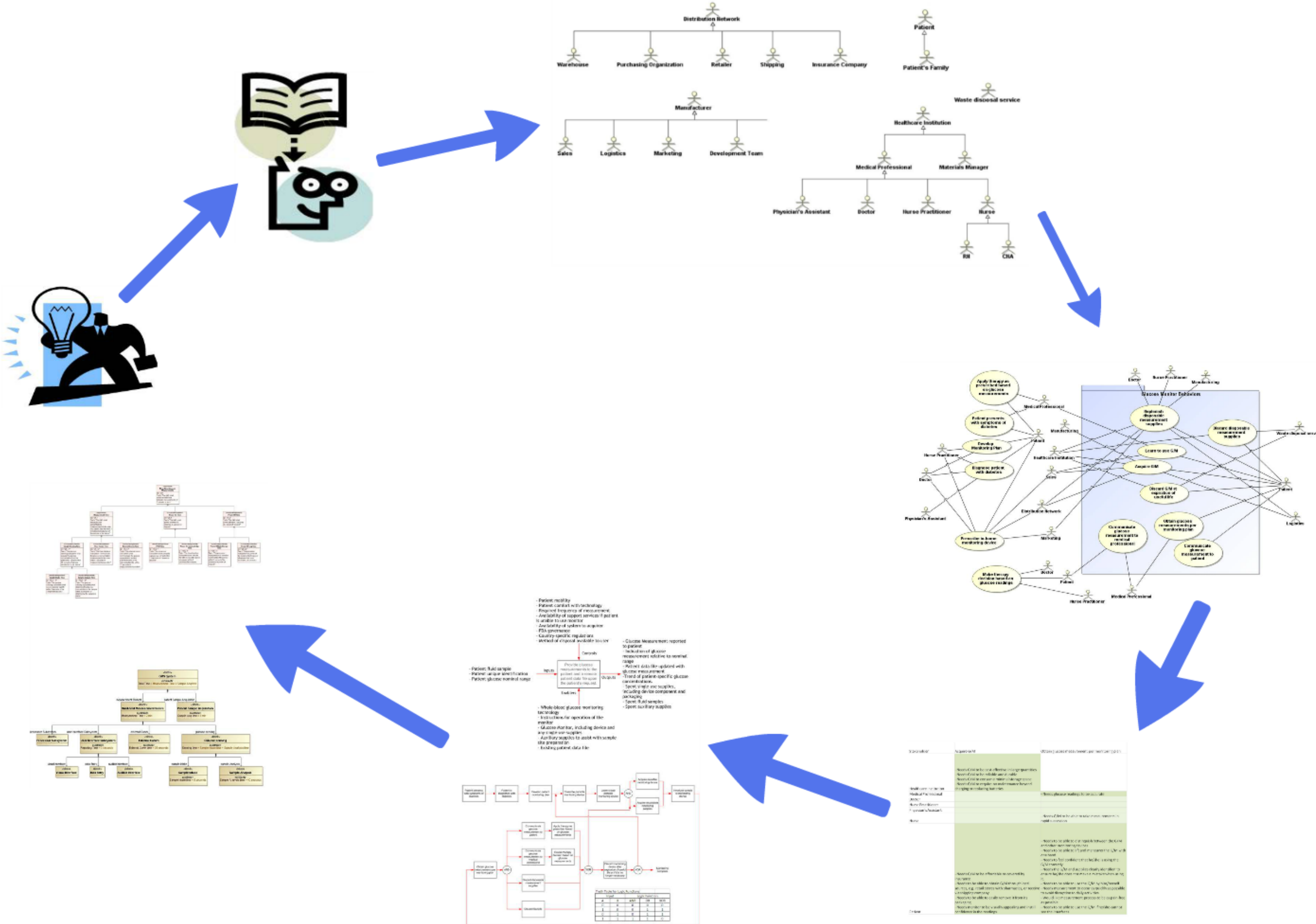

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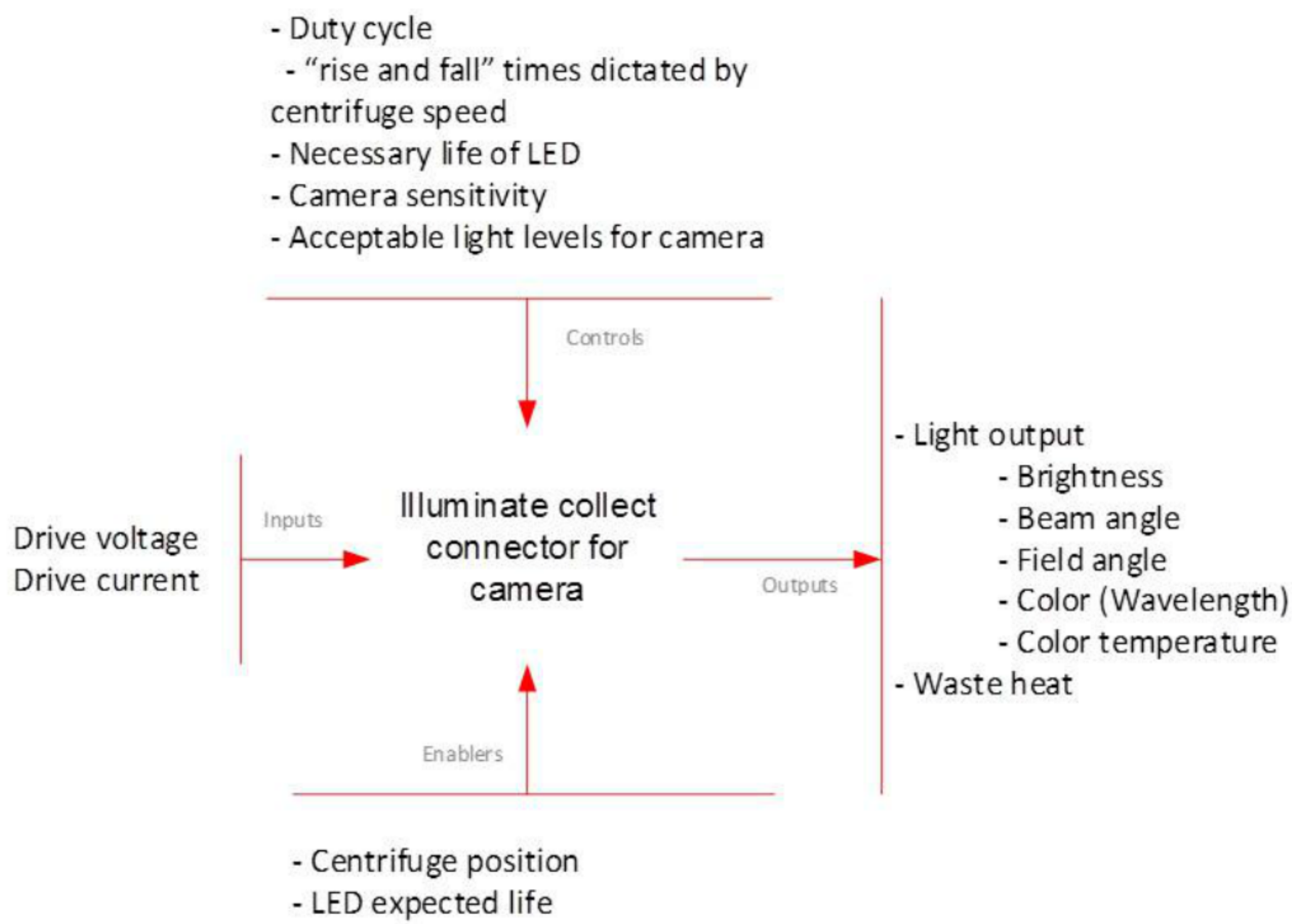
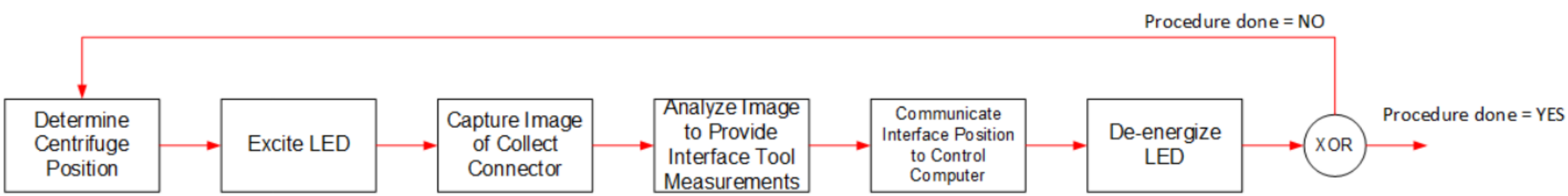
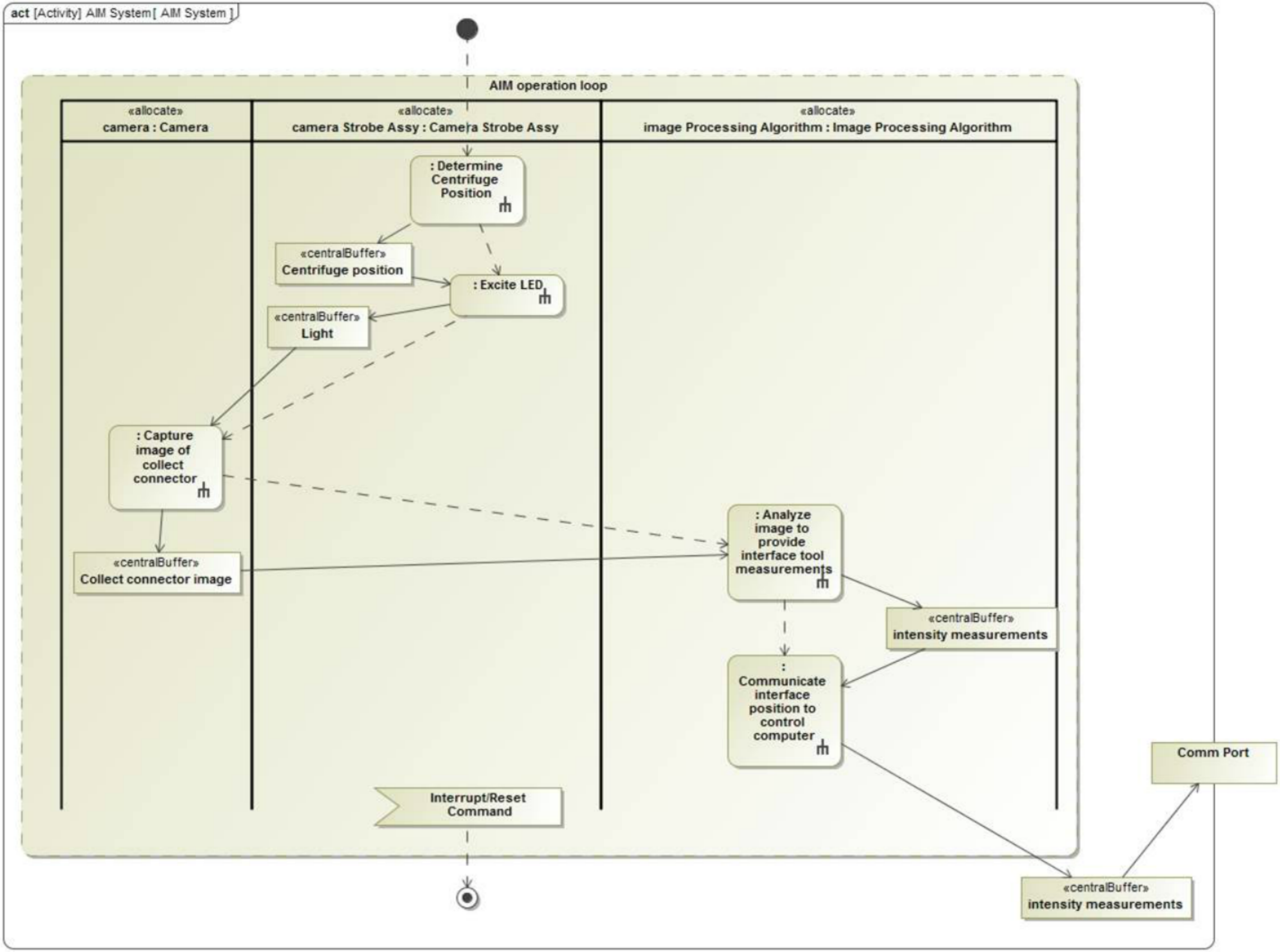
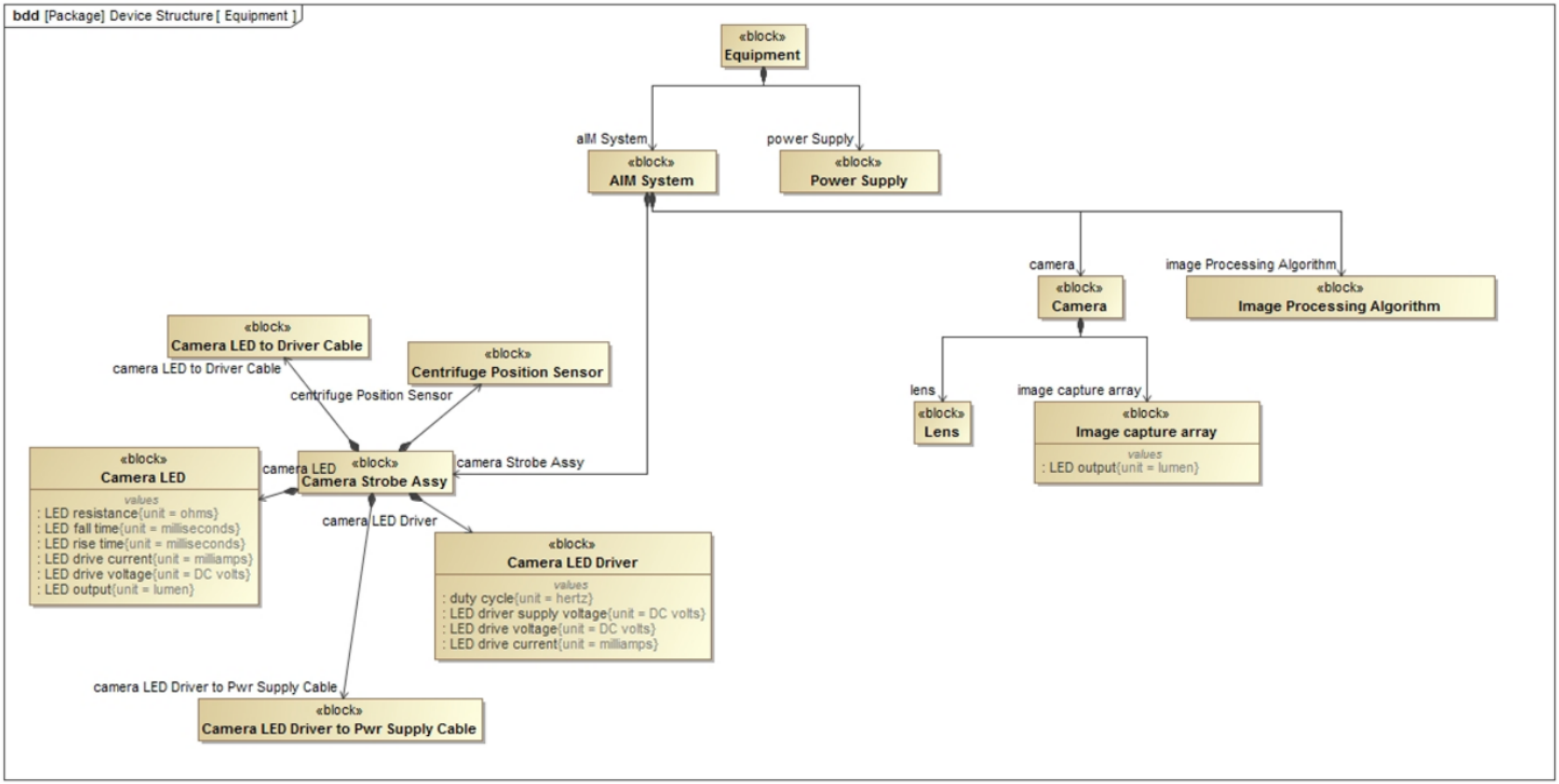
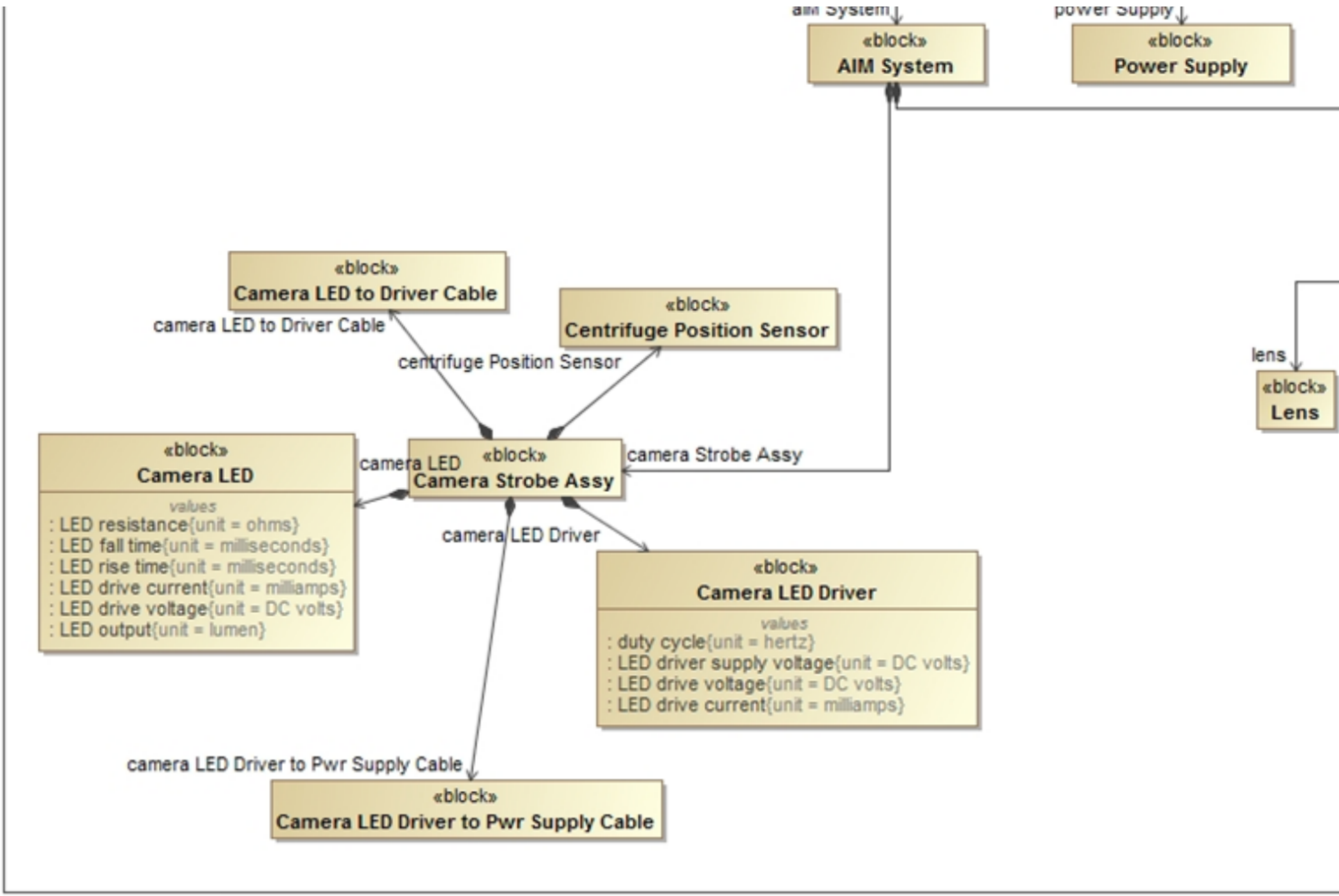

- Duty cycle
- "rise and fall" times dictated by centrifuge speed
- Necessary life of LED
- Camera sensitivity
- Acceptable light levels for camera
Controls
Drive voltage
Drive current
Inputs
Illuminate collect connector for camera
Outputs
- Light output
- Brightness
- Beam angle
- Field angle
- Color (Wavelength)
- Color temperature
- Waste heat
Enablers
- Centrifuge position
- LED expected life


Procedure done = NO
Determine Centrifuge Position
Excite LED
Capture Image of Collect Connector
Analyze Image to Provide Interface Tool Measurements
Communicate Interface Position to Control Computer
De-energize LED
XOR
Procedure done = YES

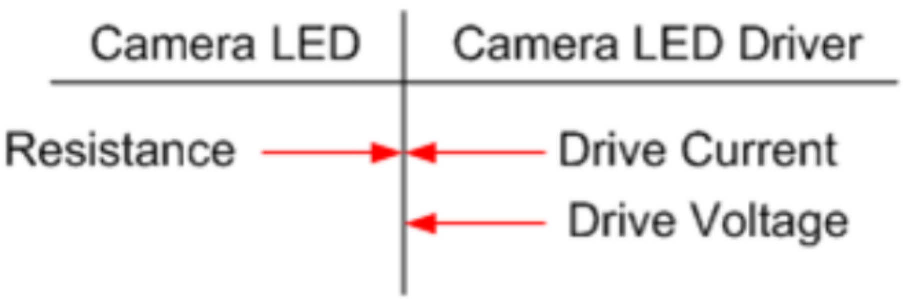

act [Activity] AIM System [AIM System]
AIM operation loop
«allocate»
camera : Camera
«allocate»
camera Strobe Assy : Camera Strobe Assy
«allocate»
image Processing Algorithm : Image Processing Algorithm
: Determine Centrifuge Position
«centralBuffer»
Centrifuge position
: Excite LED
«centralBuffer»
Light
: Capture image of collect connector
«centralBuffer»
Collect connector image
: Analyze image to provide interface tool measurements
«centralBuffer»
intensity measurements
: Communicate interface position to control computer
Interrupt/Reset Command
Comm Port
«centralBuffer»
intensity measurements



January 28, 2017


aIM System
power Supply
«block»
AIM System
«block»
Power Supply
«block»
Camera LED to Driver Cable
camera LED to Driver Cable
«block»
Centrifuge Position Sensor
centrifuge Position Sensor
lens
«block»
Lens
«block»
Camera LED
values
: LED resistance{unit = ohms}
: LED fall time{unit = milliseconds}
: LED rise time{unit = milliseconds}
: LED drive current{unit = milliamps}
: LED drive voltage{unit = DC volts}
: LED output{unit = lumen}
camera LED
«block»
Camera Strobe Assy
camera Strobe Assy
camera LED Driver
«block»
Camera LED Driver
values
: duty cycle{unit = hertz}
: LED driver supply voltage{unit = DC volts}
: LED drive voltage{unit = DC volts}
: LED drive current{unit = milliamps}
camera LED Driver to Pwr Supply Cable
«block»
Camera LED Driver to Pwr Supply Cable

Casey's Oversimplified-but-Really-Useful Interface Model



Before MBSE approach, one product family contained ~30 "requirements" scattered about its documentation

After MBSE approach, that same product family contained ~ 350 requirements, ordered hierarchically.

The team identified V&V gaps and worked hard to fill them.

The team has a great baseline from which to make future enhancements or to deal with obselescence.

Making a "Quantum" Leap

January 28, 2017

Controls

- Regulatory
  - -GMP requirements (closed system, traceability, etc.)
  - -Medical device standards and guidelines
- Hollow fiber technology constraint – adherence of cells
- Society's familiarity with flask culture
- Physiological needs to cells
  - -pH
  - -temperature
- Contamination risks
  - -nonmutagenic (leachables, extractables)
  - -efficacy of cells
- Ability to isolate desired cell types from mixed populations
- Targeted cell types
- Ability of operator to create customized protocols/parameters
- Automation constraints
- Customer locations (APAC, Europe, US, etc.)
  - -Differences in interface types (gas, power, etc.)
  - -Acquisition needs (CE marking, etc.)
- Ability of system to detect anomalous conditions

Inputs

- Initial population of cells in solution (isolated or mixed population)
- Cell growth nutrients/fluids
- Cell growth system
- Unique identification of expansion cycle
- Oxygen supply (gas supply)
- Unique identification for cell expansion
- User interaction data

Activity

Grow adherent and suspension cells in laboratory, clinical, and manufacturing environments

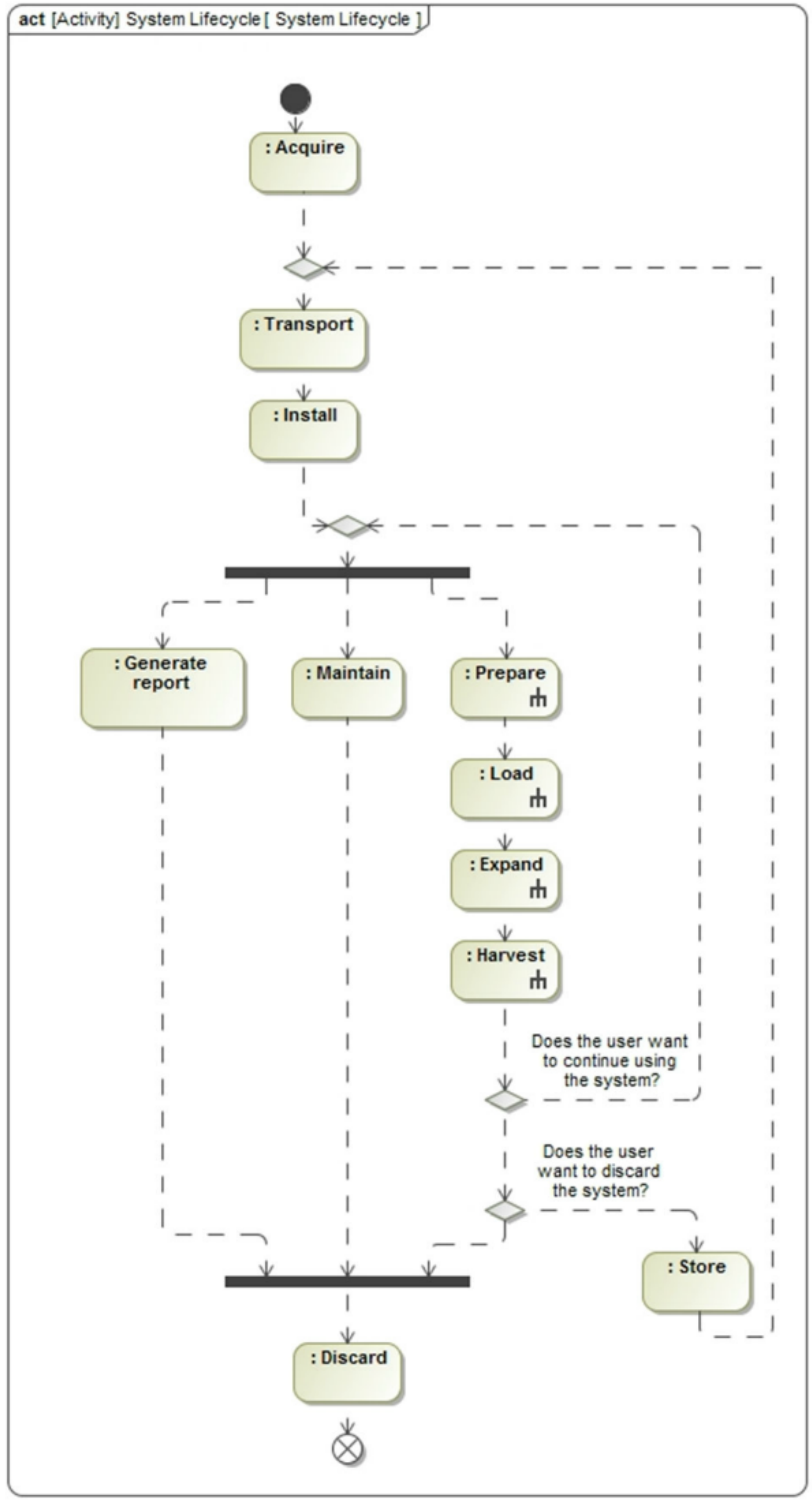
Enablers

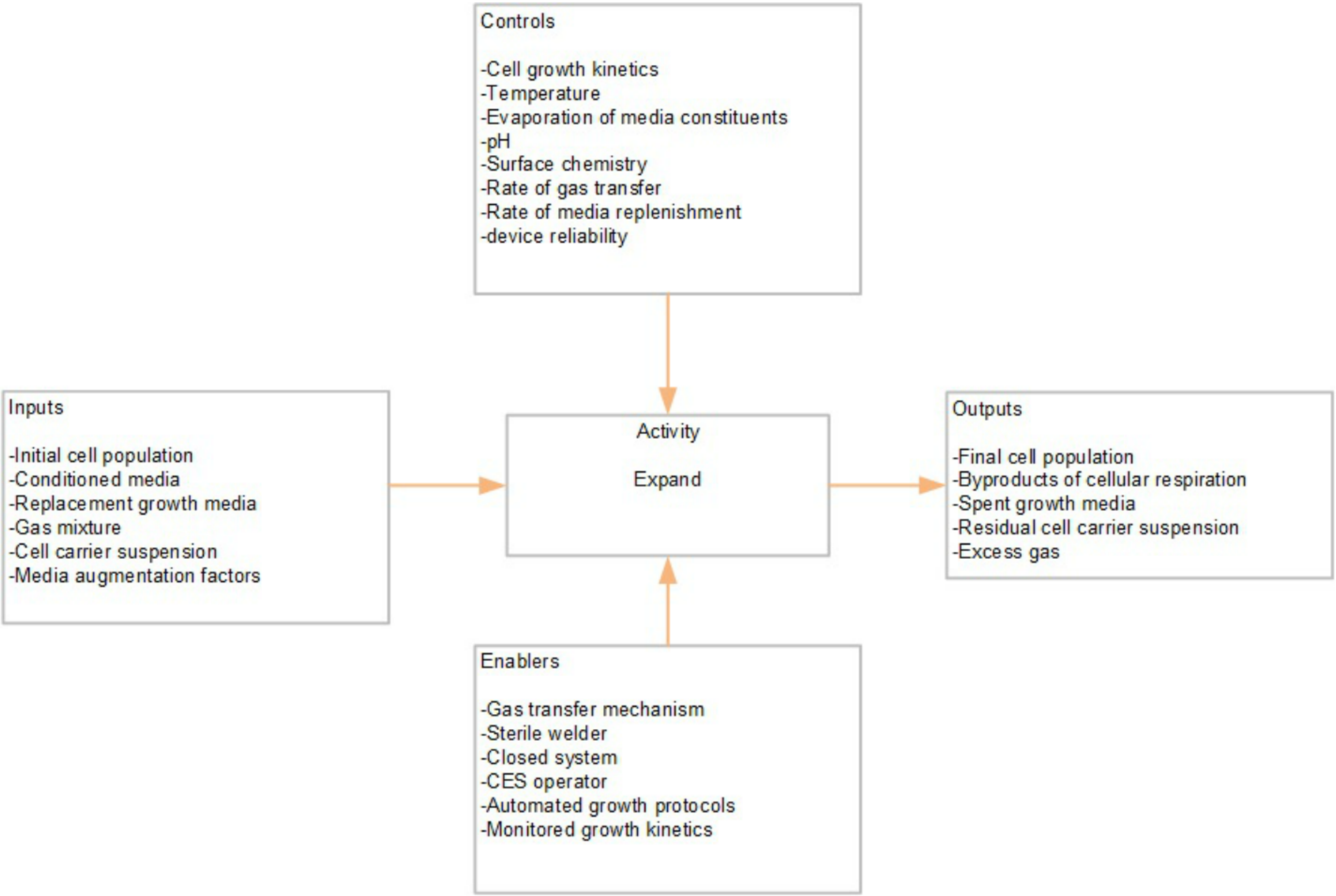
- Skilled personnel (operators, maintainers, trainers)
- System maintenance
- Sterile culture environment (single use set)
- Closed culture environment
- Trained operator
- Cell metabolic rate monitoring method
- Automated protocols
- Data information storage system
- User instructions (service, installation, operation)
- Power supply
- Gas control mechanism
- Cellular respiration byproduct waste management method

Outputs

- Final population of cells
  - Cell number
  - Viability
  - Potency
  - Cellular products (proteins, vectors, etc.)
- Waste materials
  - -Fluid waste
  - -Cell respiratory waste (CO_2, lactate, etc.)
  - -Spent single-use set
  - -Dead/unviable cells
- Exhausted cell growth system
- Reports
  - -User Interaction and system state linked to unique procedure identification
  - -Troubleshooting information (servicing purposes)
- Alerts of anomalous conditions

January 28, 2017


act [Activity] System Lifecycle [System Lifecycle]
: Acquire
: Transport
: Install
: Generate report
: Maintain
: Prepare
: Load
: Expand
: Harvest
Does the user want to continue using the system?
Does the user want to discard the system?
: Store
: Discard



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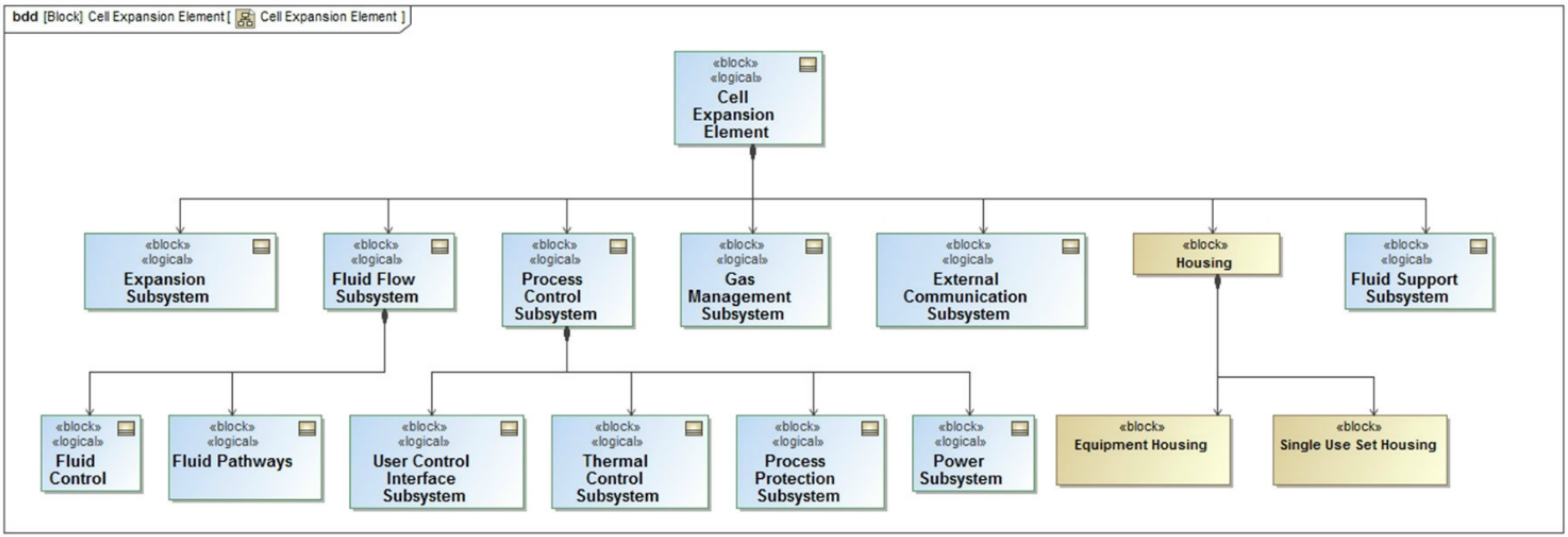
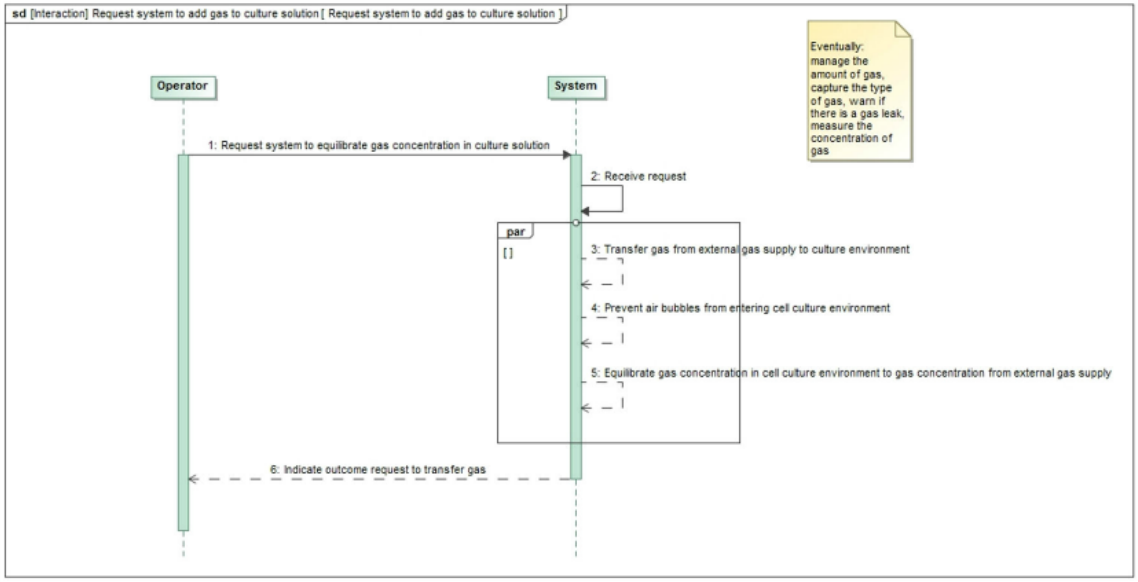
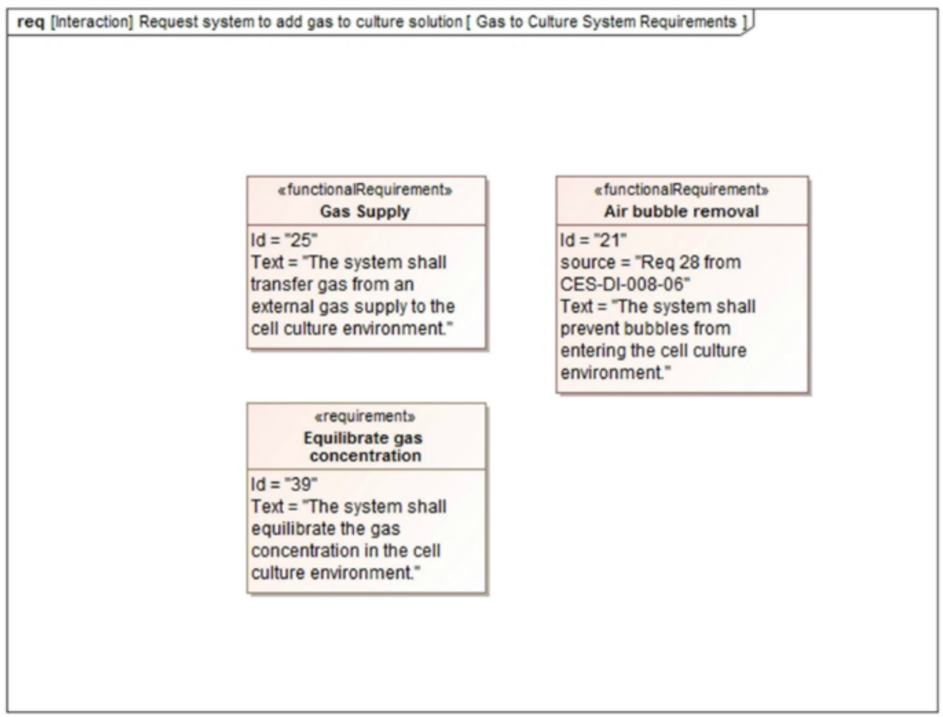
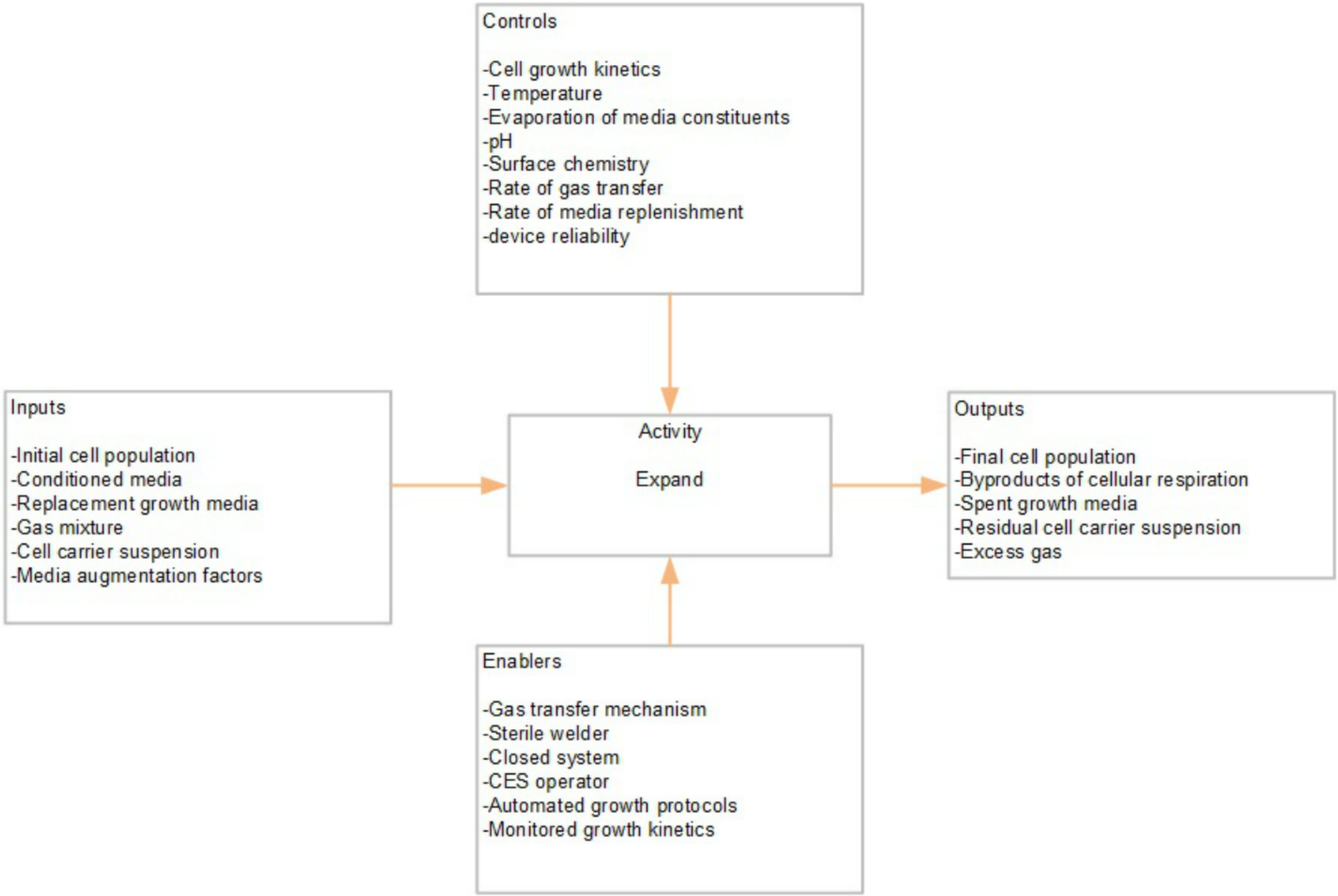
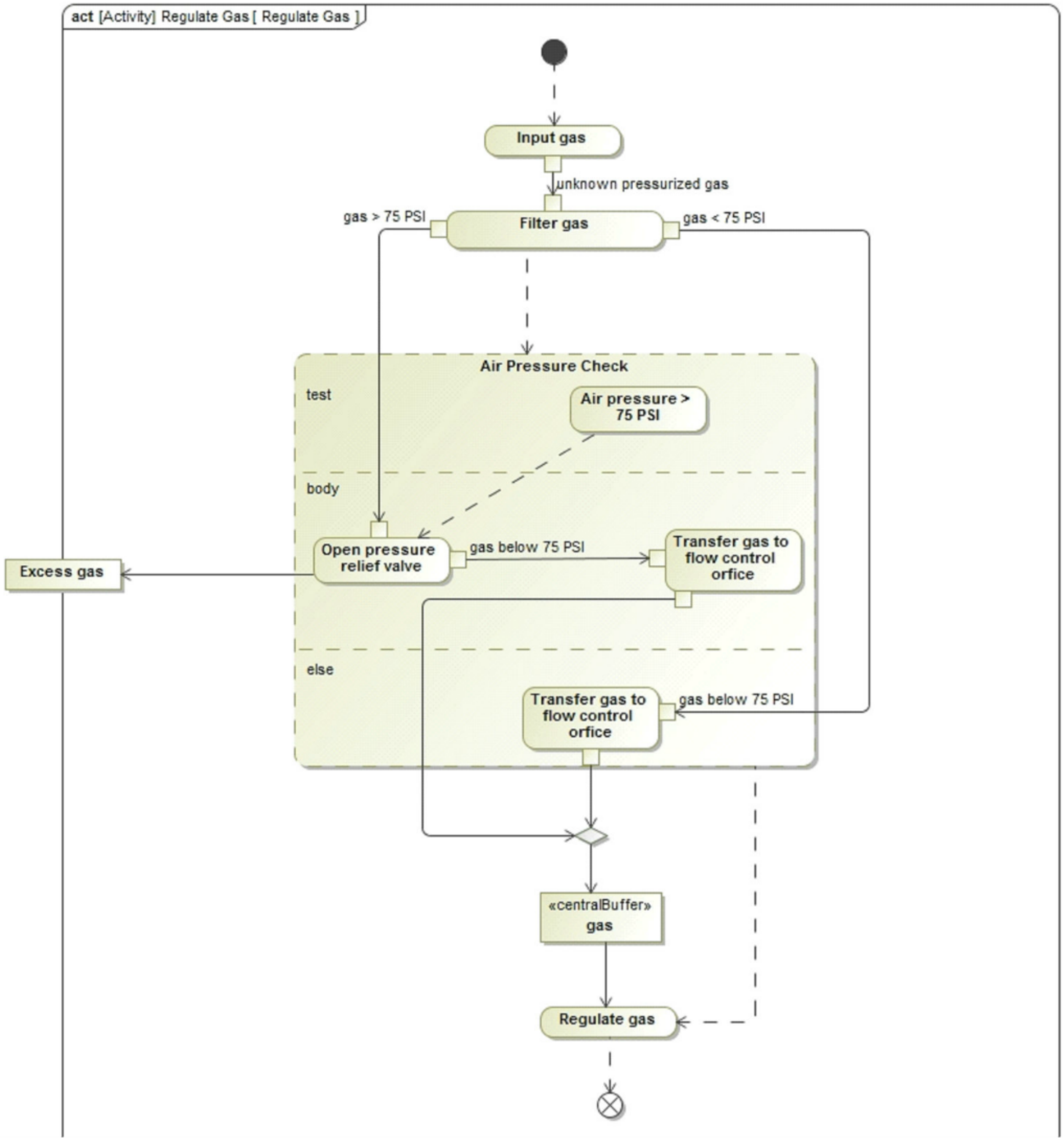

bdd [Block] Cell Expansion Element [Cell Expansion Element]
«block» «logical» Cell Expansion Element
«block» «logical» Expansion Subsystem
«block» «logical» Fluid Flow Subsystem
«block» «logical» Process Control Subsystem
«block» «logical» Gas Management Subsystem
«block» «logical» External Communication Subsystem
«block» Housing
«block» «logical» Fluid Support Subsystem
«block» «logical» Fluid Control
«block» «logical» Fluid Pathways
«block» «logical» User Control Interface Subsystem
«block» «logical» Thermal Control Subsystem
«block» «logical» Process Protection Subsystem
«block» «logical» Power Subsystem
«block» Equipment Housing
«block» Single Use Set Housing

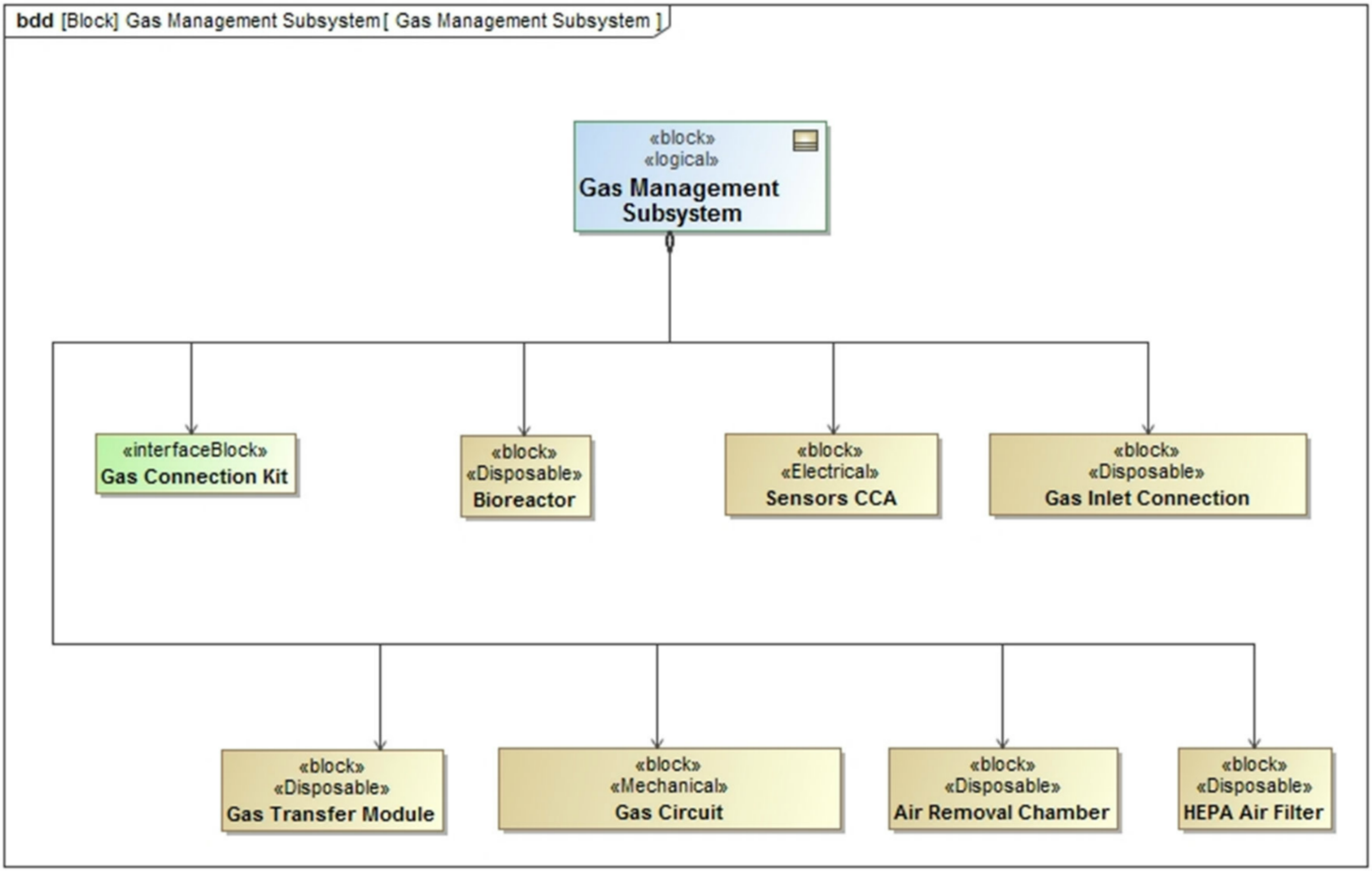

sd [Interaction] Request system to add gas to culture solution [Request system to add gas to culture solution]
Eventually: manage the amount of gas, capture the type of gas, warn if there is a gas leak, measure the concentration of gas
Operator
System
1: Request system to equilibrate gas concentration in culture solution
2: Receive request
par
[ ]
3: Transfer gas from external gas supply to culture environment
4: Prevent air bubbles from entering cell culture environment
5: Equilibrate gas concentration in cell culture environment to gas concentration from external gas supply
6: Indicate outcome request to transfer gas

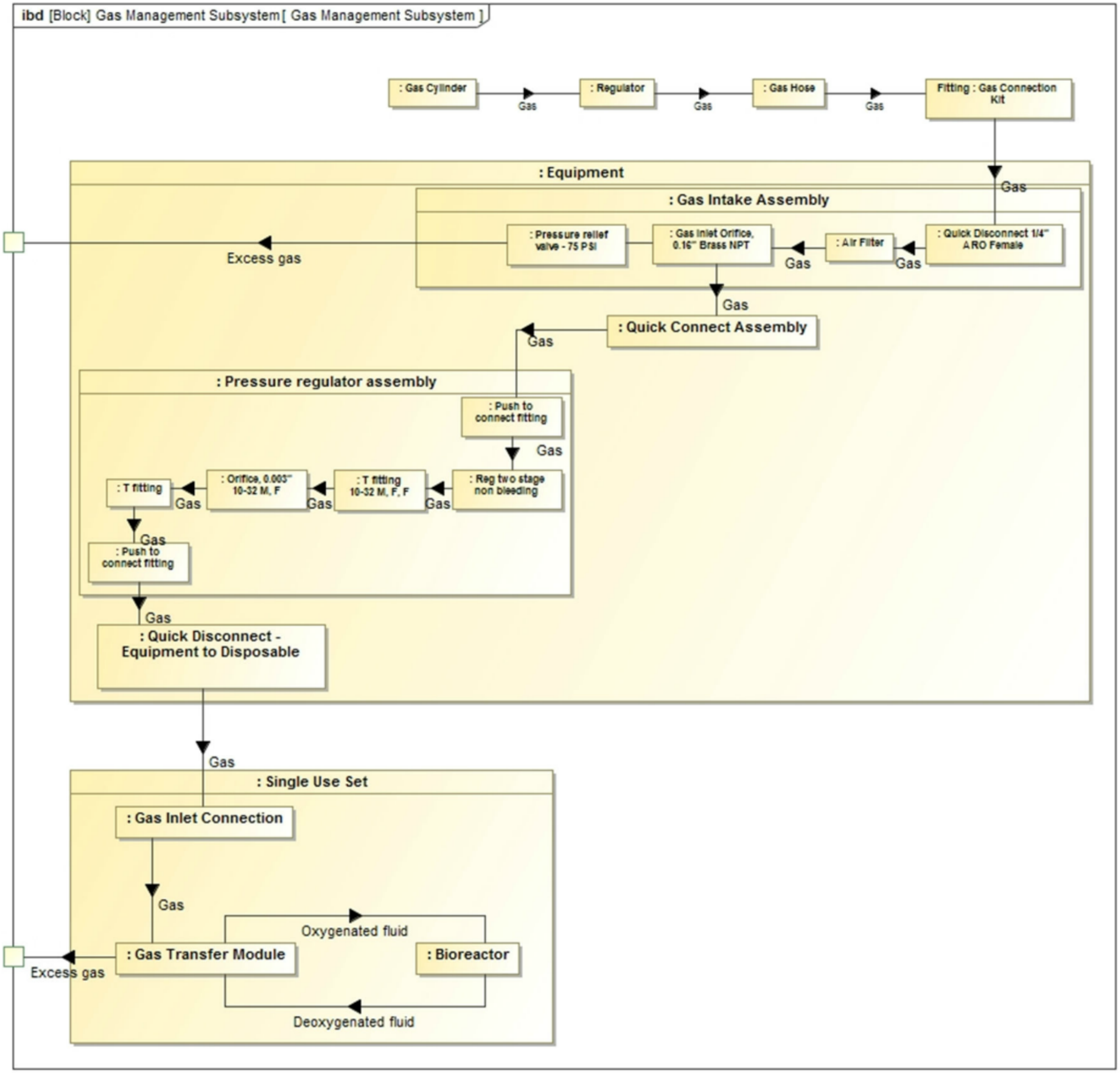

req [Interaction] Request system to add gas to culture solution [Gas to Culture System Requirements]
«functionalRequirement»
Gas Supply
Id = "25"
Text = "The system shall transfer gas from an external gas supply to the cell culture environment."
«functionalRequirement»
Air bubble removal
Id = "21"
source = "Req 28 from CES-DI-008-06"
Text = "The system shall prevent bubbles from entering the cell culture environment."
«requirement»
Equilibrate gas concentration
Id = "39"
Text = "The system shall equilibrate the gas concentration in the cell culture environment."


Controls
-Cell growth kinetics
-Temperature
-Evaporation of media constituents
-pH
-Surface chemistry
-Rate of gas transfer
-Rate of media replenishment
-device reliability
Inputs
-Initial cell population
-Conditioned media
-Replacement growth media
-Gas mixture
-Cell carrier suspension
-Media augmentation factors
Activity
Expand
Outputs
-Final cell population
-Byproducts of cellular respiration
-Spent growth media
-Residual cell carrier suspension
-Excess gas
Enablers
-Gas transfer mechanism
-Sterile welder
-Closed system
-CES operator
-Automated growth protocols
-Monitored growth kinetics



act [Activity] Regulate Gas [Regulate Gas]
Input gas
unknown pressurized gas
gas > 75 PSI
Filter gas
gas < 75 PSI
Air Pressure Check
test
Air pressure > 75 PSI
body
Open pressure relief valve
gas below 75 PSI
Transfer gas to flow control orfice
Excess gas
else
Transfer gas to flow control orfice
gas below 75 PSI
«centralBuffer» gas
Regulate gas


bdd [Block] Gas Management Subsystem[Gas Management Subsystem]
«block»
«logical»
Gas Management Subsystem
«interfaceBlock»
Gas Connection Kit
«block»
«Disposable»
Bioreactor
«block»
«Electrical»
Sensors CCA
«block»
«Disposable»
Gas Inlet Connection
«block»
«Disposable»
Gas Transfer Module
«block»
«Mechanical»
Gas Circuit
«block»
«Disposable»
Air Removal Chamber
«block»
«Disposable»
HEPA Air Filter



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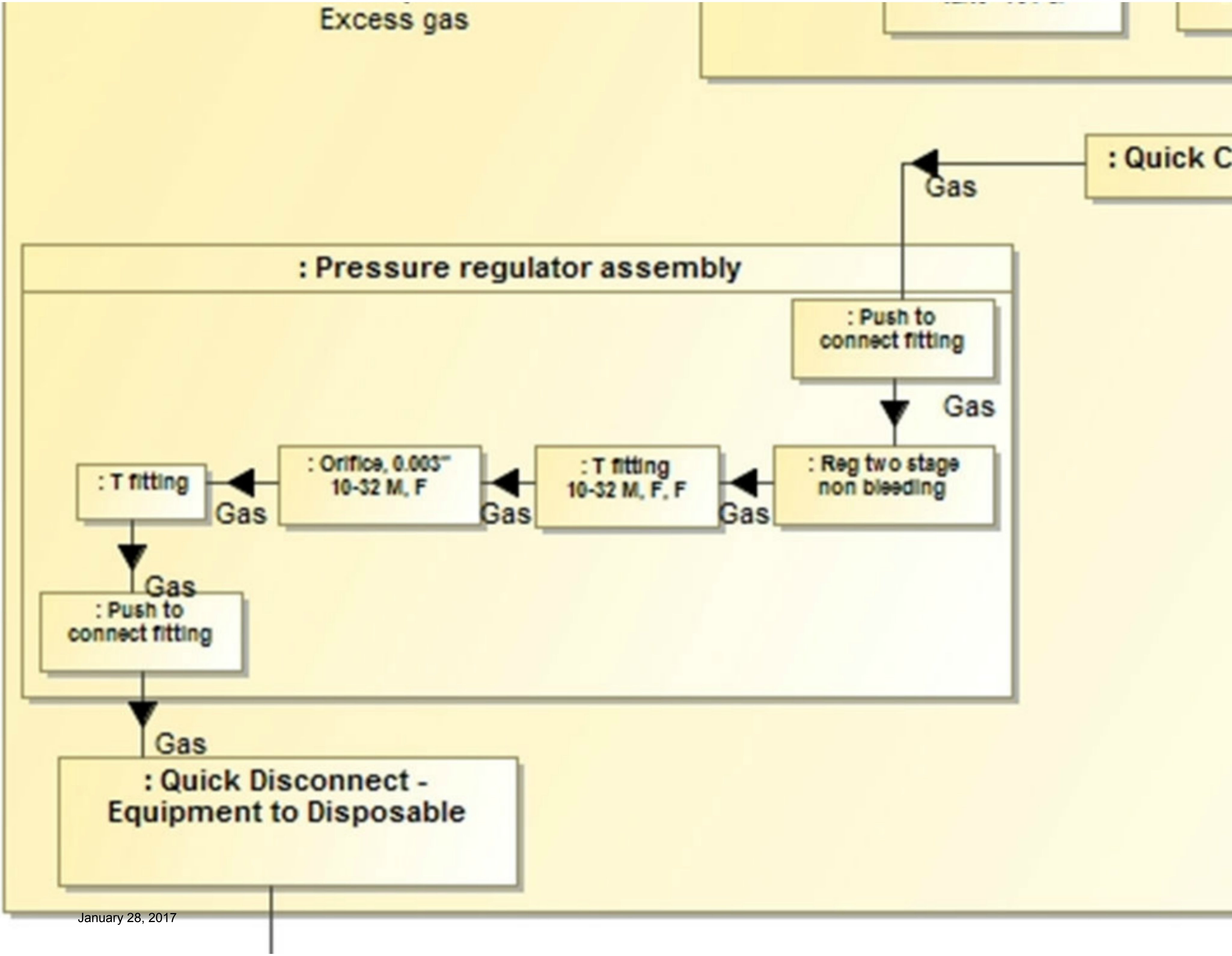
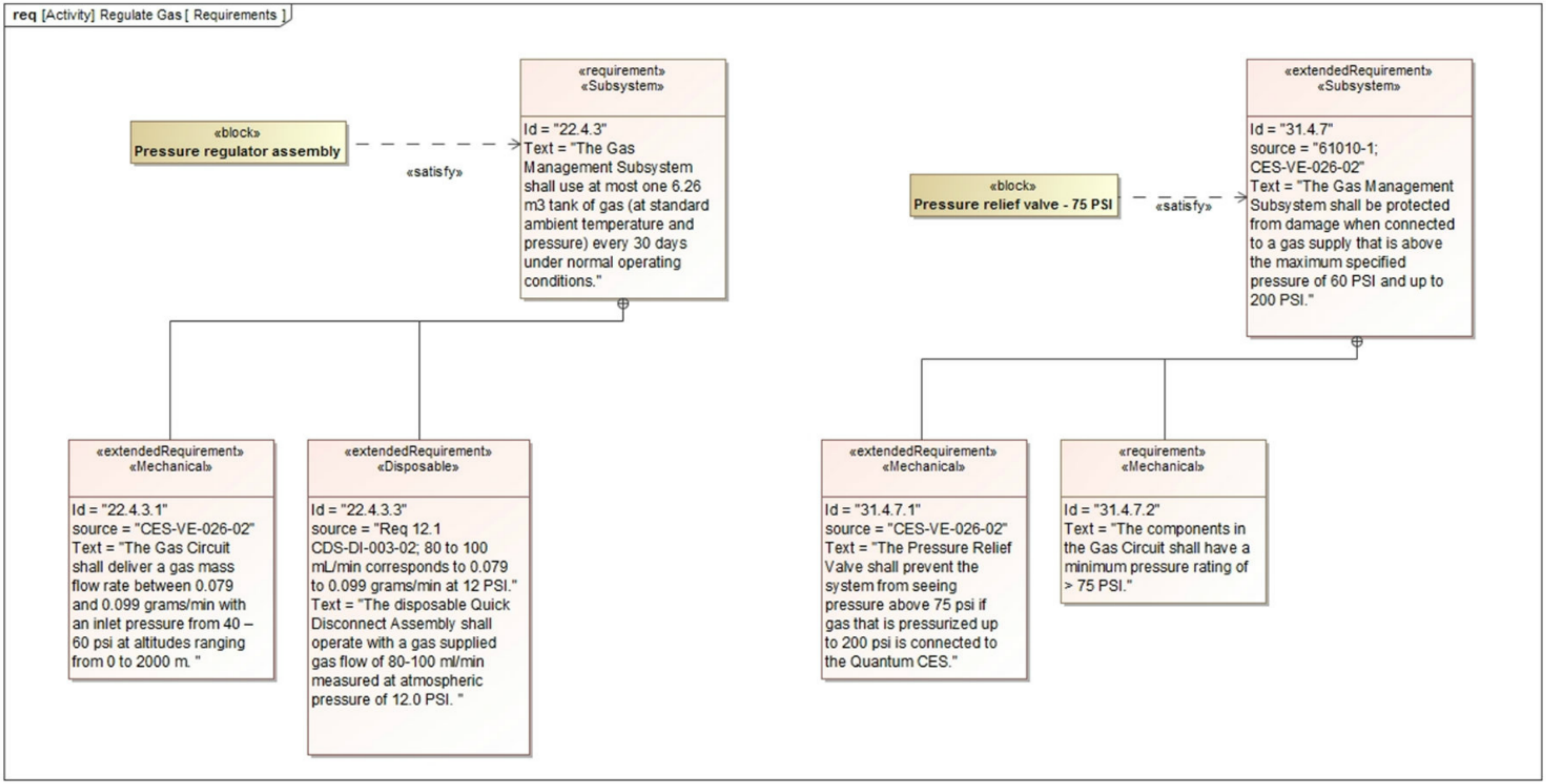
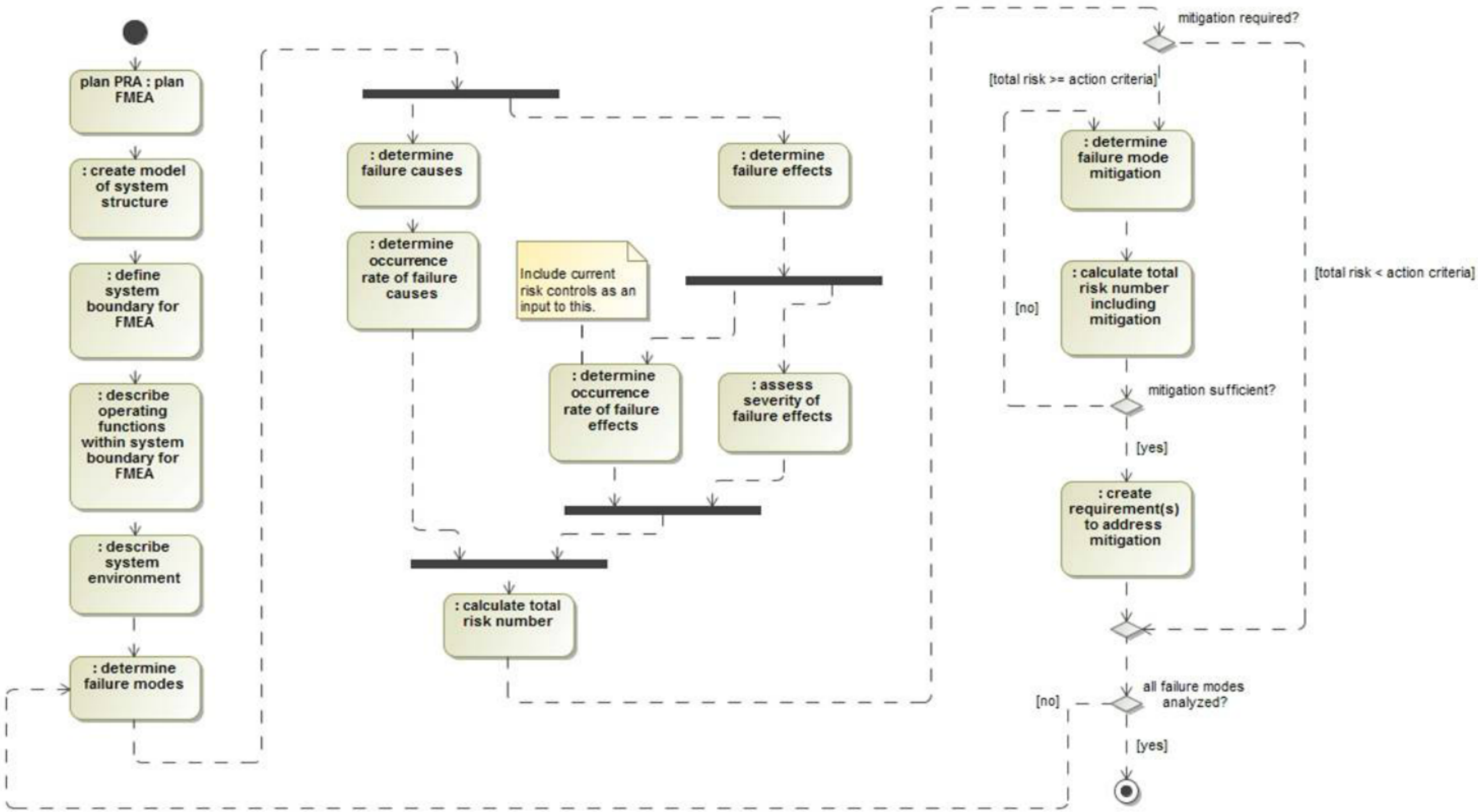

Excess gas
: Quick C
Gas
: Pressure regulator assembly
: Push to connect fitting
Gas
: Reg two stage non bleeding
Gas
: T fitting 10-32 M, F, F
Gas
: Orifice, 0.003" 10-32 M, F
Gas
: T fitting
Gas
: Push to connect fitting
Gas
: Quick Disconnect - Equipment to Disposable


req [Activity] Regulate Gas [Requirements]
«block»
Pressure regulator assembly
«satisfy»
«requirement»
«Subsystem»
Id = "22.4.3"
Text = "The Gas Management Subsystem shall use at most one 6.26 m3 tank of gas (at standard ambient temperature and pressure) every 30 days under normal operating conditions."
«extendedRequirement»
«Mechanical»
Id = "22.4.3.1"
source = "CES-VE-026-02"
Text = "The Gas Circuit shall deliver a gas mass flow rate between 0.079 and 0.099 grams/min with an inlet pressure from 40 – 60 psi at altitudes ranging from 0 to 2000 m. "
«extendedRequirement»
«Disposable»
Id = "22.4.3.3"
source = "Req 12.1 CDS-DI-003-02; 80 to 100 mL/min corresponds to 0.079 to 0.099 grams/min at 12 PSI."
Text = "The disposable Quick Disconnect Assembly shall operate with a gas supplied gas flow of 80-100 ml/min measured at atmospheric pressure of 12.0 PSI. "
«block»
Pressure relief valve - 75 PSI
«satisfy»
«extendedRequirement»
«Subsystem»
Id = "31.4.7"
source = "61010-1; CES-VE-026-02"
Text = "The Gas Management Subsystem shall be protected from damage when connected to a gas supply that is above the maximum specified pressure of 60 PSI and up to 200 PSI."
«extendedRequirement»
«Mechanical»
Id = "31.4.7.1"
source = "CES-VE-026-02"
Text = "The Pressure Relief Valve shall prevent the system from seeing pressure above 75 psi if gas that is pressurized up to 200 psi is connected to the Quantum CES."
«requirement»
«Mechanical»
Id = "31.4.7.2"
Text = "The components in the Gas Circuit shall have a minimum pressure rating of > 75 PSI."

Risk Management 2.0

January 28, 2017



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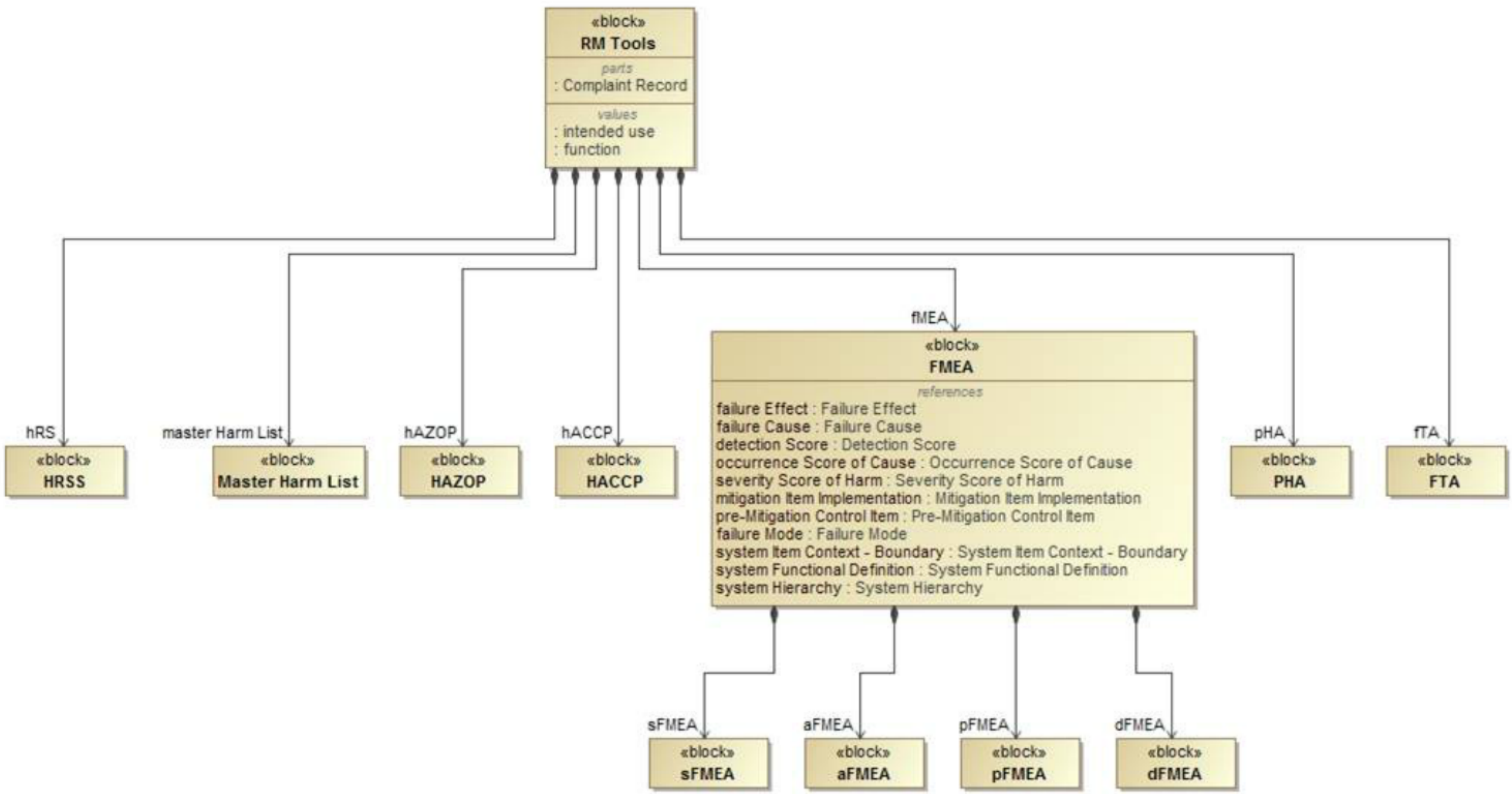
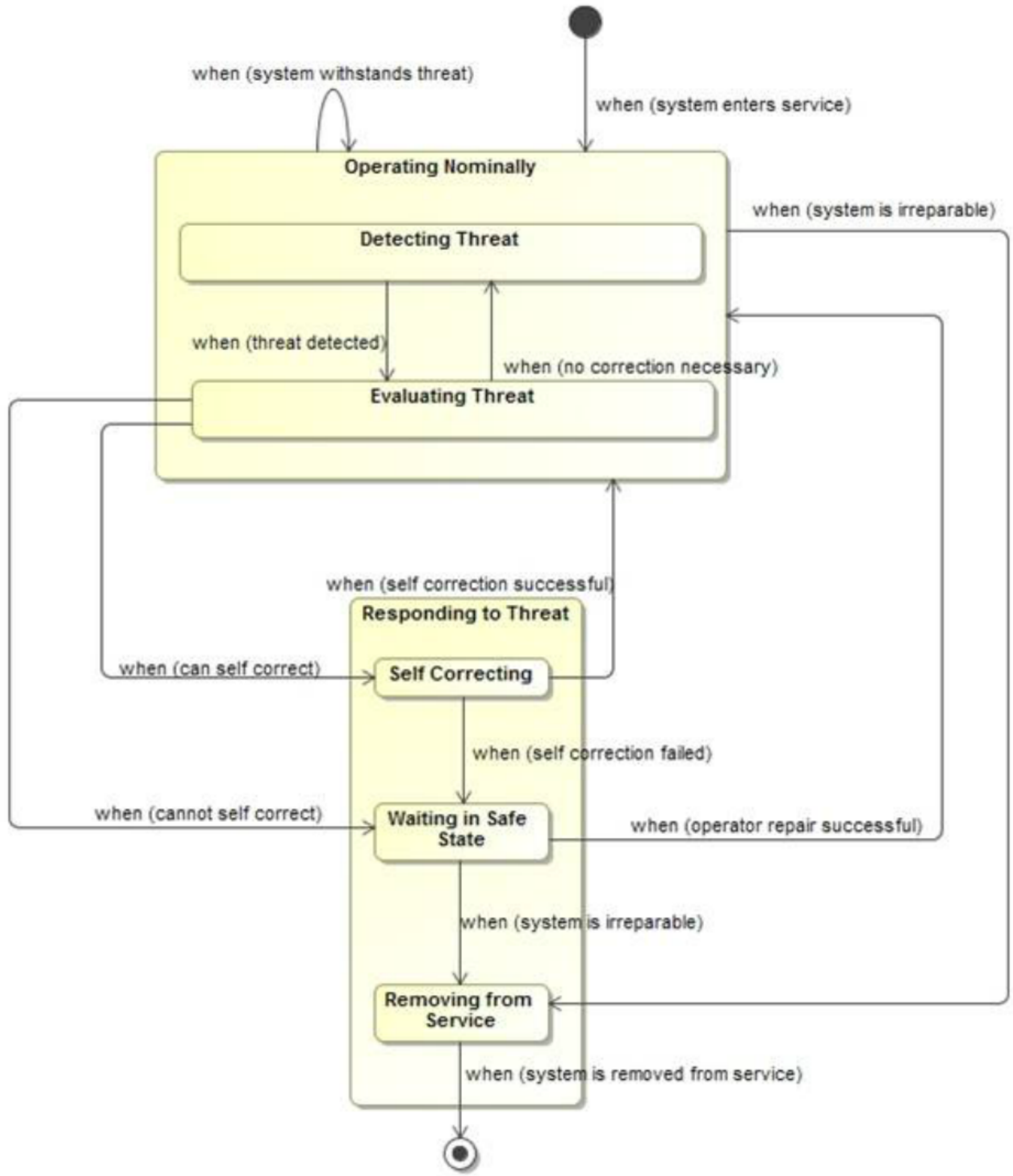
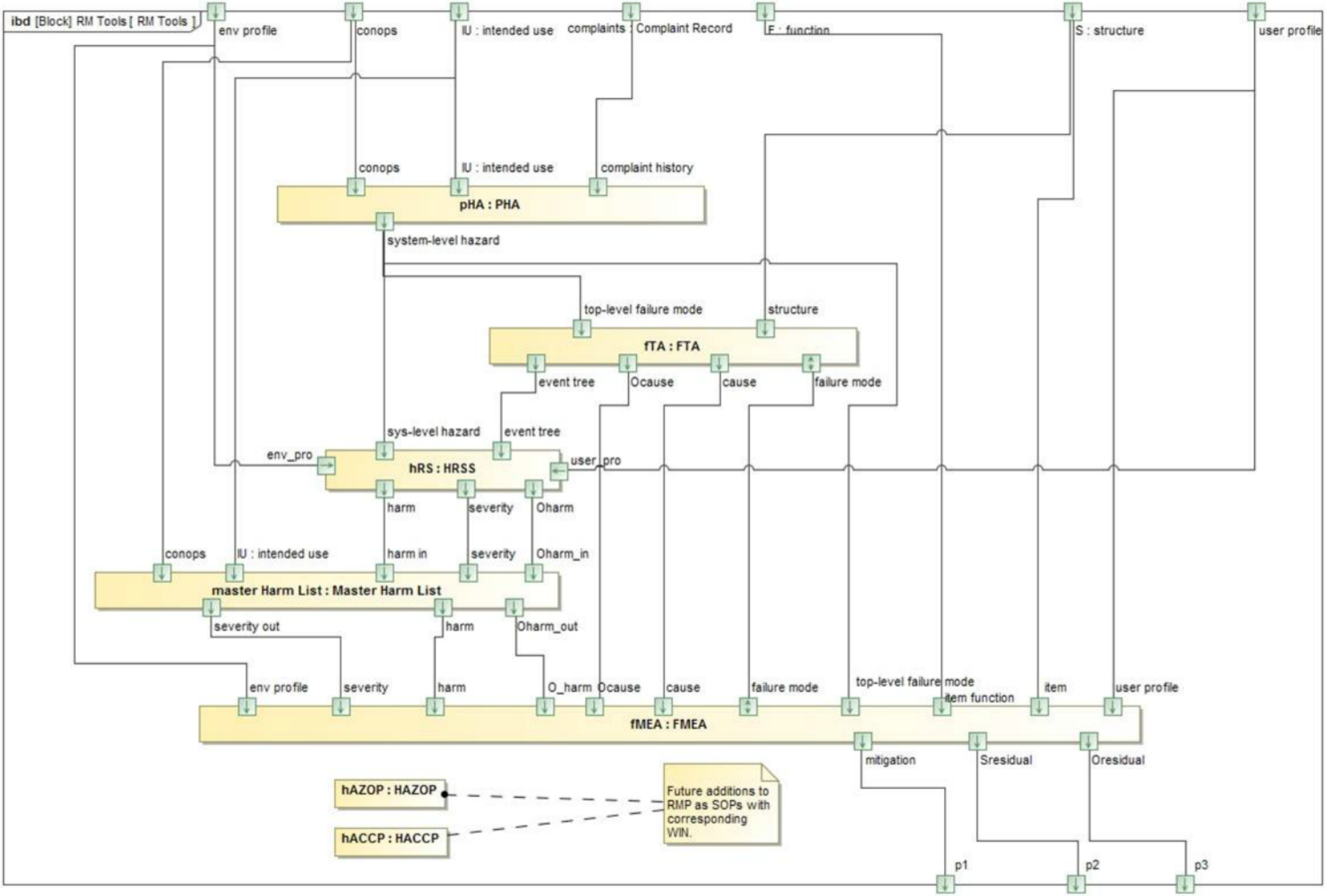
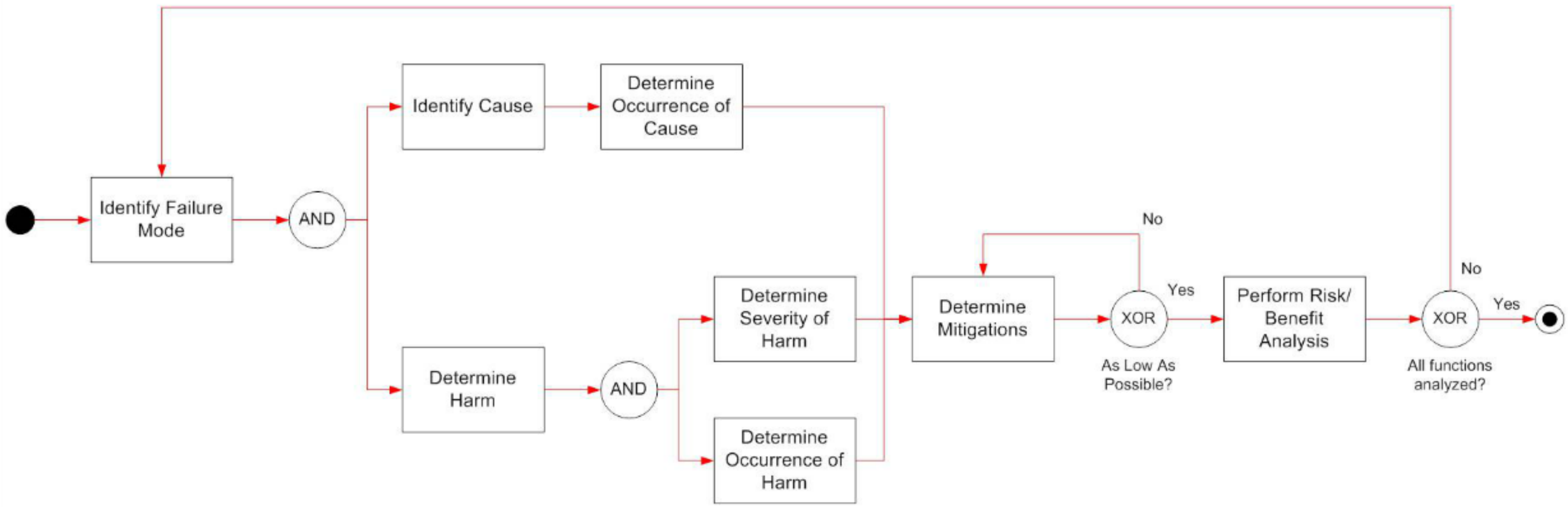

«block»
RM Tools
parts
: Complaint Record
values
: intended use
: function
hRS
«block»
HRSS
master Harm List
«block»
Master Harm List
hAZOP
«block»
HAZOP
hACCP
«block»
HACCP
fMEA
«block»
FMEA
references
failure Effect : Failure Effect
failure Cause : Failure Cause
detection Score : Detection Score
occurrence Score of Cause : Occurrence Score of Cause
severity Score of Harm : Severity Score of Harm
mitigation Item Implementation : Mitigation Item Implementation
pre-Mitigation Control Item : Pre-Mitigation Control Item
failure Mode : Failure Mode
system Item Context - Boundary : System Item Context - Boundary
system Functional Definition : System Functional Definition
system Hierarchy : System Hierarchy
pHA
«block»
PHA
fTA
«block»
FTA
sFMEA
«block»
sFMEA
aFMEA
«block»
aFMEA
pFMEA
«block»
pFMEA
dFMEA
«block»
dFMEA

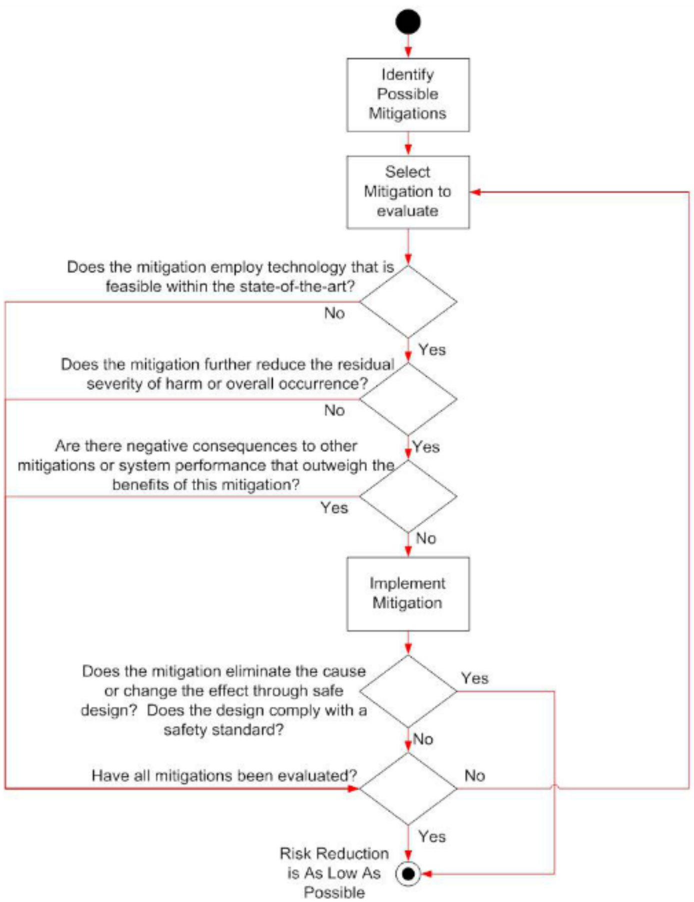


when (system withstands threat)
when (system enters service)
Operating Nominally
when (system is irreparable)
Detecting Threat
when (threat detected)
when (no correction necessary)
Evaluating Threat
when (self correction successful)
Responding to Threat
when (can self correct)
Self Correcting
when (self correction failed)
when (cannot self correct)
Waiting in Safe State
when (operator repair successful)
when (system is irreparable)
Removing from Service
when (system is removed from service)



January 28, 2017


Identify Failure Mode
AND
Identify Cause
Determine Occurrence of Cause
Determine Harm
AND
Determine Severity of Harm
Determine Occurrence of Harm
Determine Mitigations
No
Yes
XOR
As Low As Possible?
Perform Risk/ Benefit Analysis
No
Yes
XOR
All functions analyzed?


Identify Possible Mitigations
Select Mitigation to evaluate
Does the mitigation employ technology that is feasible within the state-of-the-art?
No
Yes
Does the mitigation further reduce the residual severity of harm or overall occurrence?
No
Yes
Are there negative consequences to other mitigations or system performance that outweigh the benefits of this mitigation?
Yes
No
Implement Mitigation
Does the mitigation eliminate the cause or change the effect through safe design? Does the design comply with a safety standard?
Yes
No
Have all mitigations been evaluated?
No
Yes
Risk Reduction is As Low As Possible

Guiding Thoughts

- Keep it simple to give teams confidence and practice in applying fundamentals. Don't overwhelm them!
- Modeling techniques and methodologies may not always be applied "by the book."
- Help teams understand why they're building the model to help them focus and drive for results.
- Teams need to feel that the model helps them get to the finish line more efficiently.
- Keep the end in mind.

Please Remember:

- What is obvious to an SE is not necessarily obvious to others
- Empower your teams to embrace the process
- Allow your teams time to digest and understand the material

We’re only successful if we enable our teams to be successful!