Model Based Systems Engineering (MBSE)

- a Data-Centric Approach -

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Background

- **MBSE methods capture operational and system level functions, structures, and interactions**
  - **Currently useful for initial design and assessment of user requirements and system designs**
    - **For both the actual system and related Modeling and Simulation (M&S) products**
- **MBSE artifacts can become easily disjoint to the product development activities they support**
  - **Require specialized skills to use**
- **Methods to access and use MBSE data for activities not explicitly linked to model artifacts significantly enhances the utility of these products**
  - **At both the technical and enterprise levels**

Goal: Make it easier for System and M&S Engineers and analysts to perform more difficult tasks

Overview

- **Beginning**
  - Object-orientation
  - Model-based design
  - M&S challenges
- **Middle**
  - Generic-to-specific structures and functions
  - Access UML/SysML data
  - Graph theoretic methods
  - Interaction analysis
- **End**
  - Enterprise structures and functions
  - Link to product architecture
  - Information management

Beginning

Atomic Approach

Core Activities

Collect → Capture measurement [signature] data from the environment

Decide → Assess and/or determine course(s) of action

Engage → Operate in a manner which interacts with targets to better understand or alter their [physical or Knowledge] state

Interpret → Derive significant information from data/information with respect to the current body of knowledge

Supporting Activities

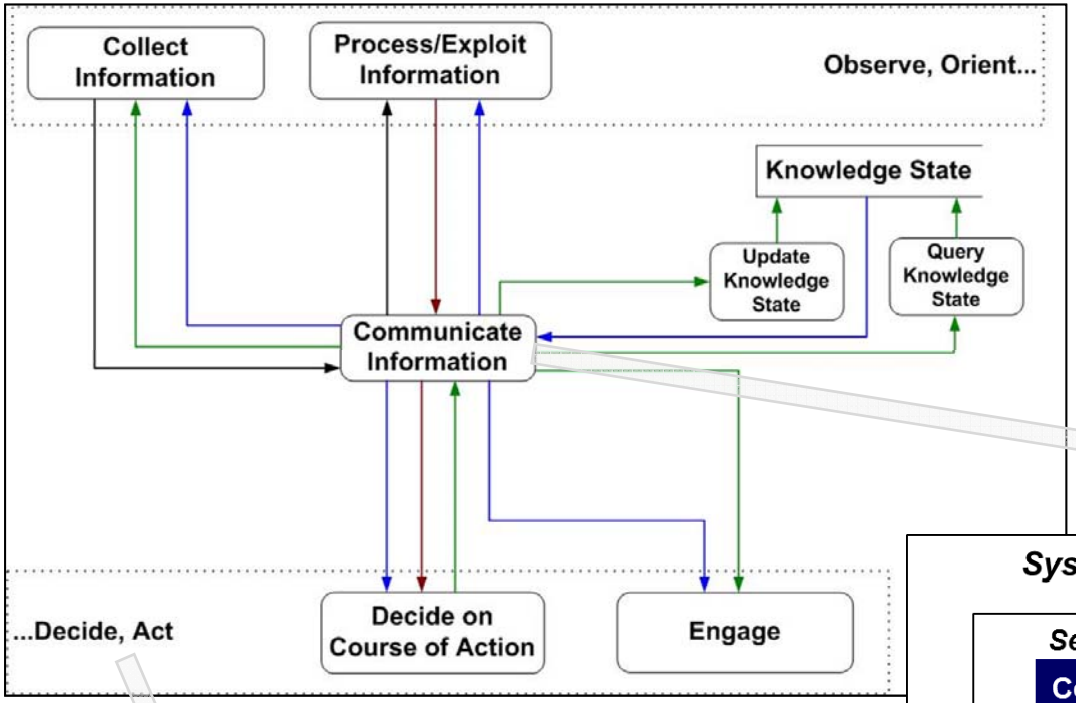
Move → Physically go from one place to another; particularly with the intent to arrive at a position to perform an activity

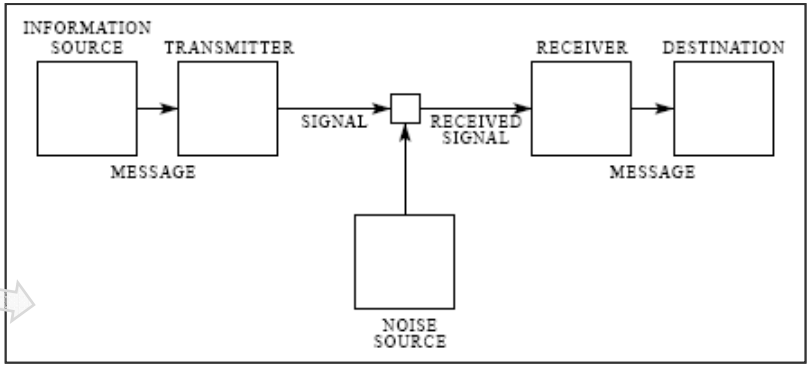
Communicate → Send coherent signals representing data or information from a source with the intent of transferring it to one or more sinks

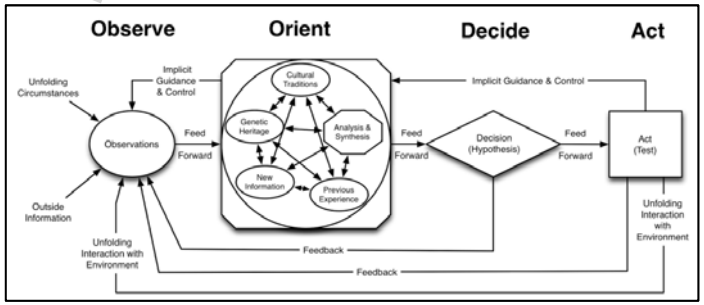
Translate → Convert from one language/protocol to another (some information may be lost)

Alter Knowledge State → Store, retrieve, alter, or remove data, facts, and perceptions possessed by an entity

Fundamentals, Functions and Allocations







System (or Subsystem or configuration item…)

Sensors
Collect

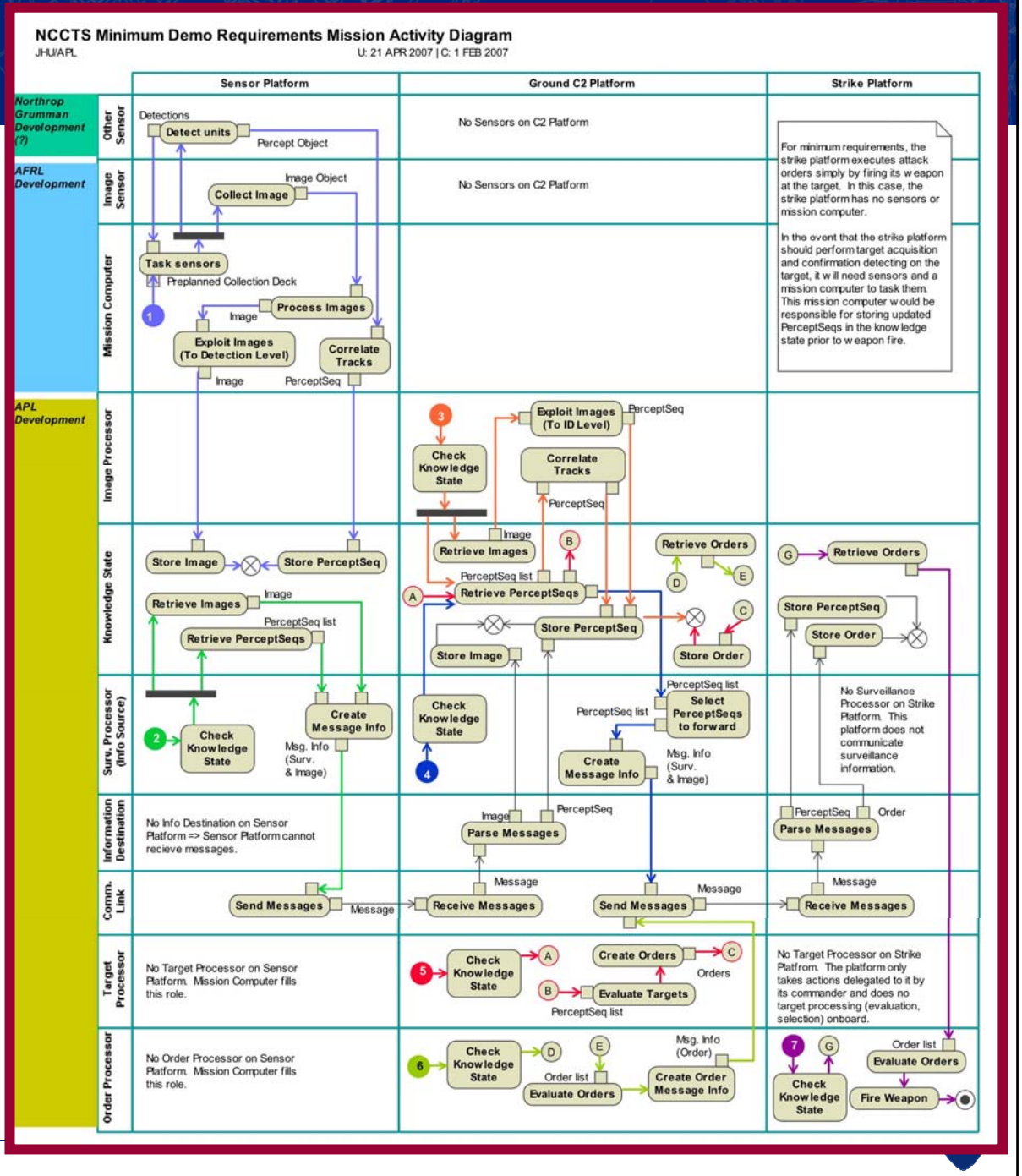
Effectors (Kinetic/non-kinetic systems)
Engage

Information Systems
Interpret
Alter Knowledge State
Decide
Communicate
Translate

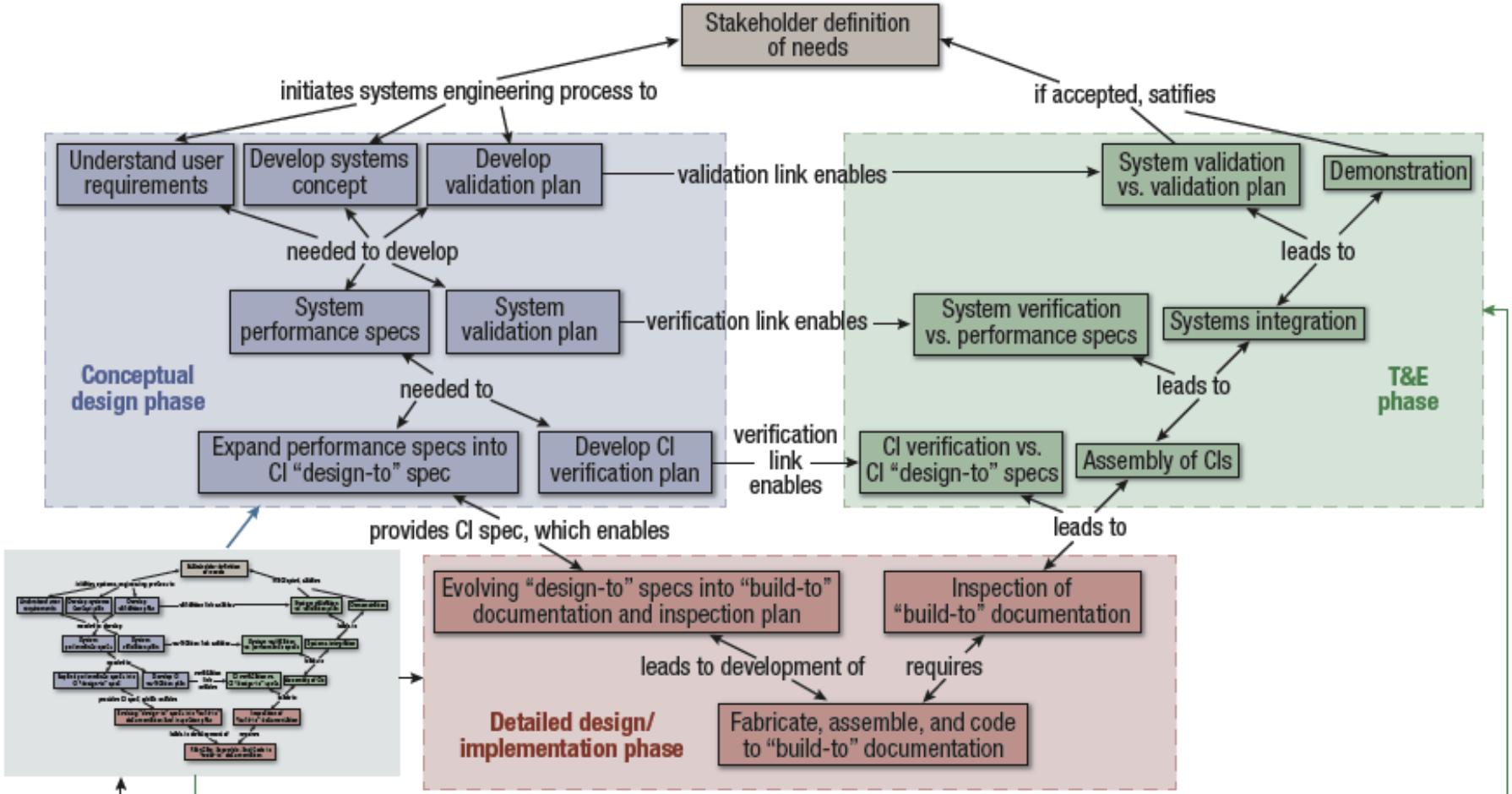
Platforms
(also a container for other systems)
Move

Beginning of Enterprise Links

- Numbered nodes show starting point of a particular model's execution. Execution begins at these points by an external call (e.g., from the FLAMES kernel or from the Knowledge State Monitor model).
- Separate activity threads are colored differently.
- Numbered sequence shows general activity flow, based on proposed configuration of the Knowledge State Monitor.
- Communications model activity is abstracted from this diagram; black arrows are part of communications model activity flows.
- Crossing horizontal boundaries → model-to-model interface, via Knowledge State.
- Crossing vertical boundaries → unit-to-unit interface, via kernel.



M&S Challenges



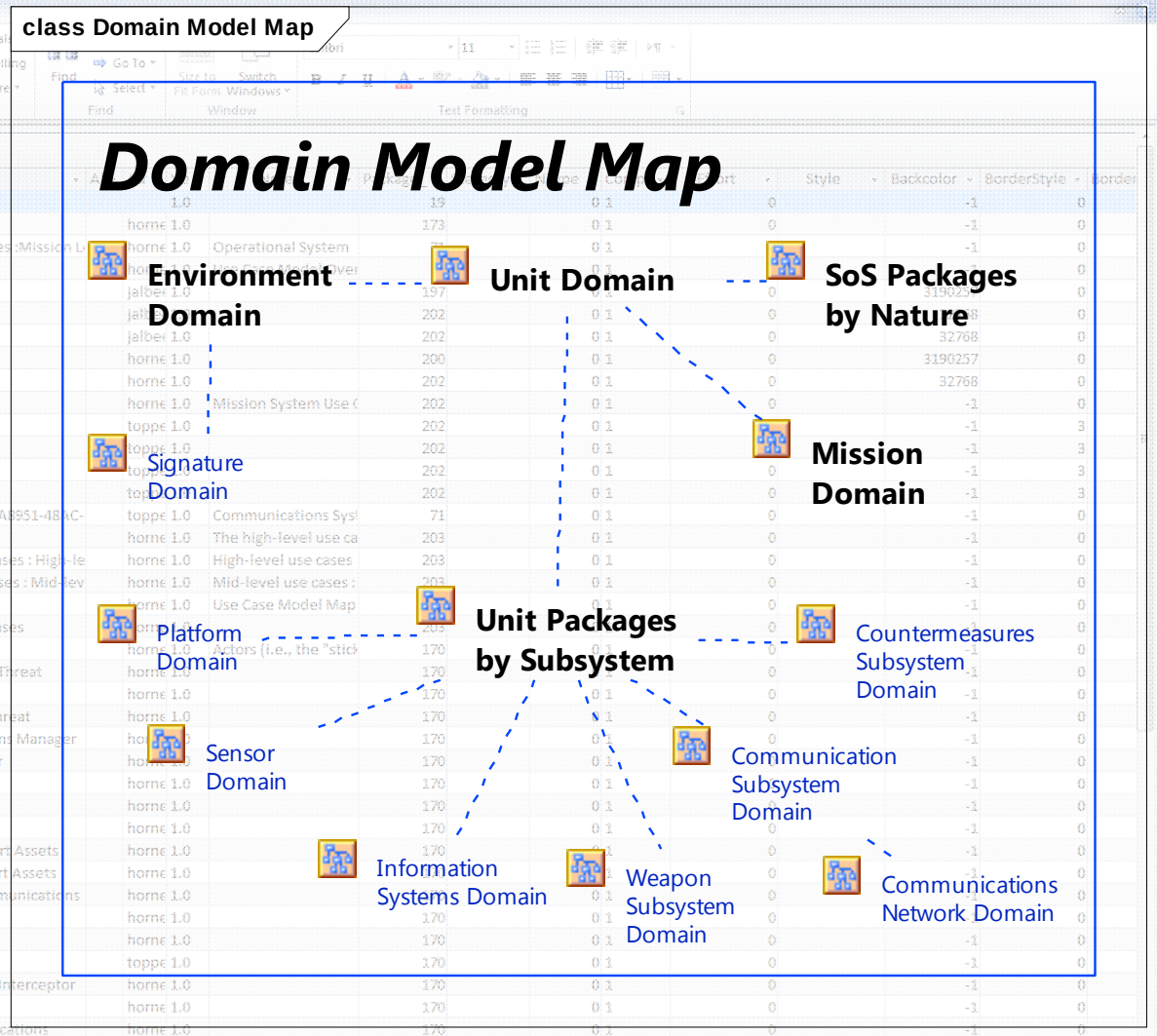
M&S development processes. M&S development mirrors the systems engineering process. M&S development must precede a specific SE phase and create both M&S and systems engineering verification, validation, and accreditation artifacts (e.g., tools and metrics) to support the test phase while maximizing design for reuse.

Source: http://www.jhuapl.edu/techdigest/TD/td3201/32_01-Topper.pdf

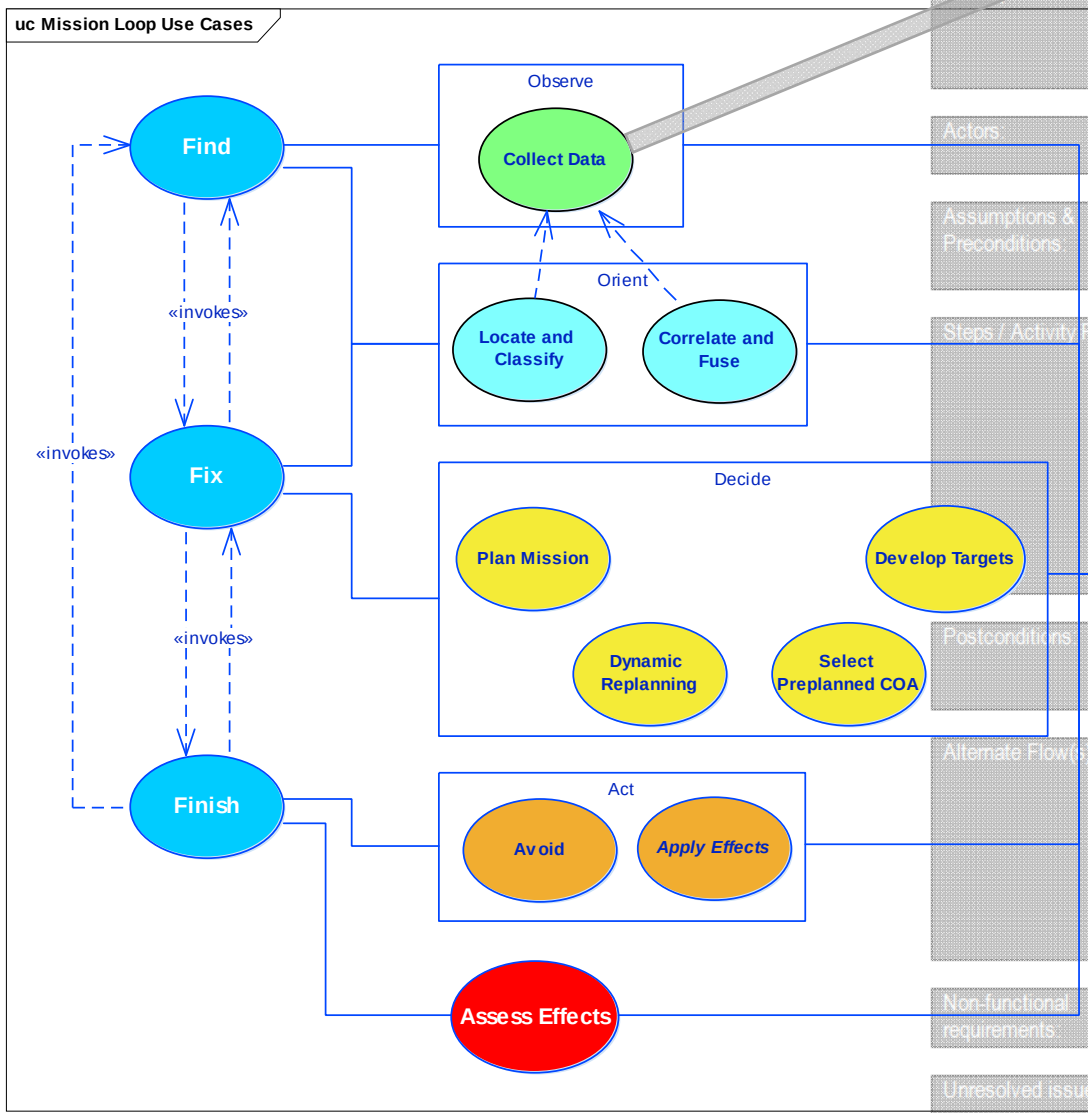
Middle

System Architecting in support of M&S

- Established standard structures represented in a 'Domain Model'
  - Enables reconfiguration and reuse
- Partitions functions and functionality cohesively
- Enables identification of system/subsystem interactions



Functional Modeling



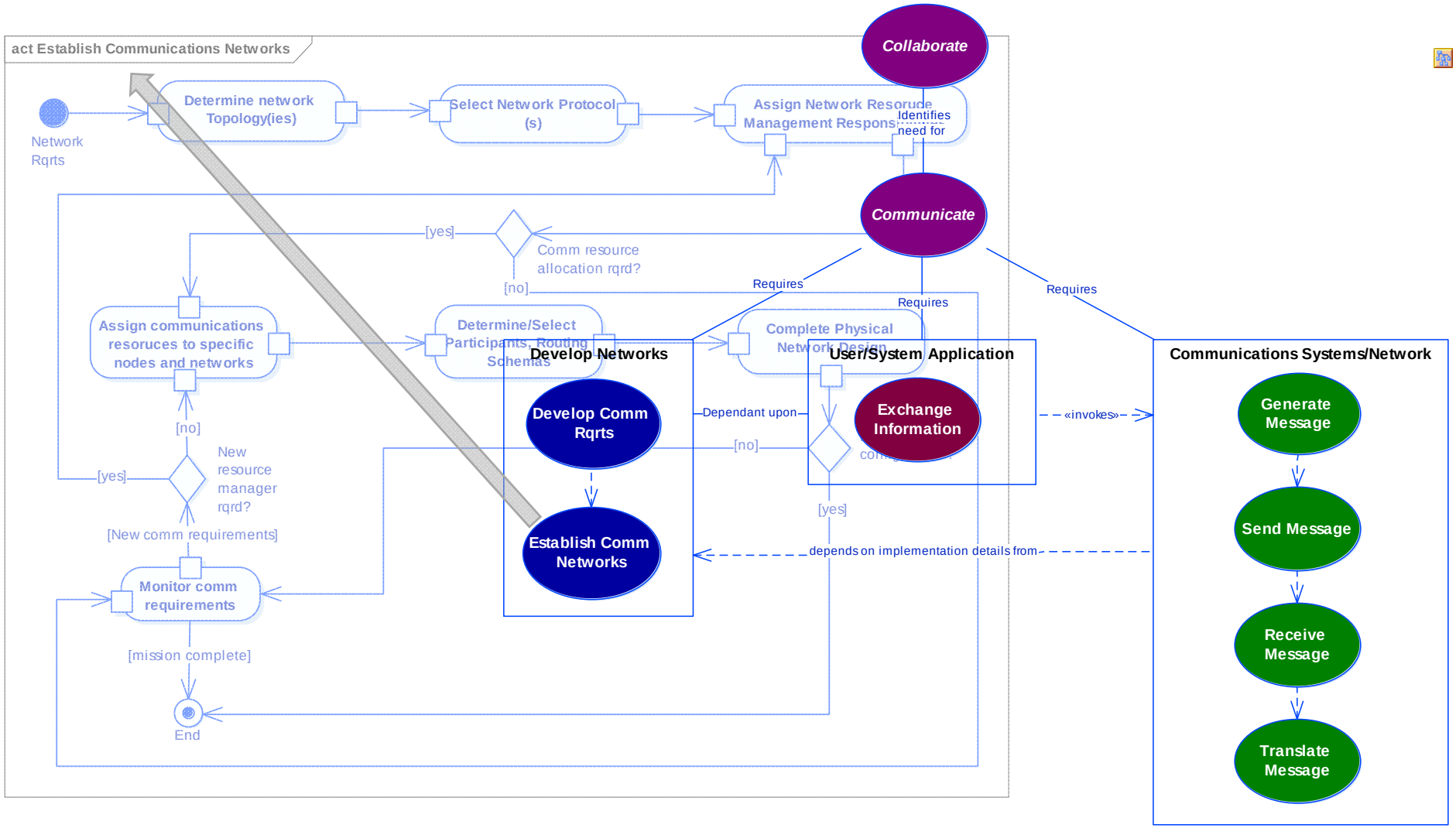
Use Case Description

Example System Program

Name:	Collect Target Information				
Number:		Version:	1.1	Date:	04/06/20xx
Description in context:	The sensor systems available to system X collect information about targets and other entities in the environment (both moving and fixed, emitting and non-emitting) in order to meet tasking directed by the Operator or the Defensive Systems Manager.				
Actors:	Environmental Entities, system X Operator, system X Vehicle, Offensive Systems Manager				
Assumptions & Preconditions:	• Sensor resources are available to system X to support collection of mission information. • Passive sensors are turned on/looking.				
Steps / Activity Flow:	(1st three steps for active, taskable sensors only.) 1. Defensive Systems Manager, Operator, and/or Offensive Systems Manager make sensor tasking requests through the Sensor Manager including sensor modes. 2. Sensor manager prioritizes and commands sensor tasking 3. Sensors, countermeasures, and/or system X are tasked by the DSM to collect information about environment. 4. [illegible] countermeasures, and/or system X search environment for targets. [illegible] termeasures, and/or system X pass sensor report to Sensor				
Postconditions:	• Detection processors have data from which to extract target information and build a combat environment picture. • system X sensors are available for tasking.				
Alternate Flow(s):	1. No system X -owned sensor resources are available: DSM requests other resources to fulfill collection functions. 2. EMCON status precludes sensor operation: a. DSM Determines alternative courses of action or uses existing information. b. EMCON Status override request is generated. 3. System X Operator overrides sensor task: Operator notified of implications to override.				
Non-functional requirements:	• Scalability (?) • Reliability (?)				
Unresolved issues:	• What initiates the periodically checking assessment of continuous sensor/ system X tasks? Is it the sensor manager, or the sensors themselves?				

Decisions and Notes:

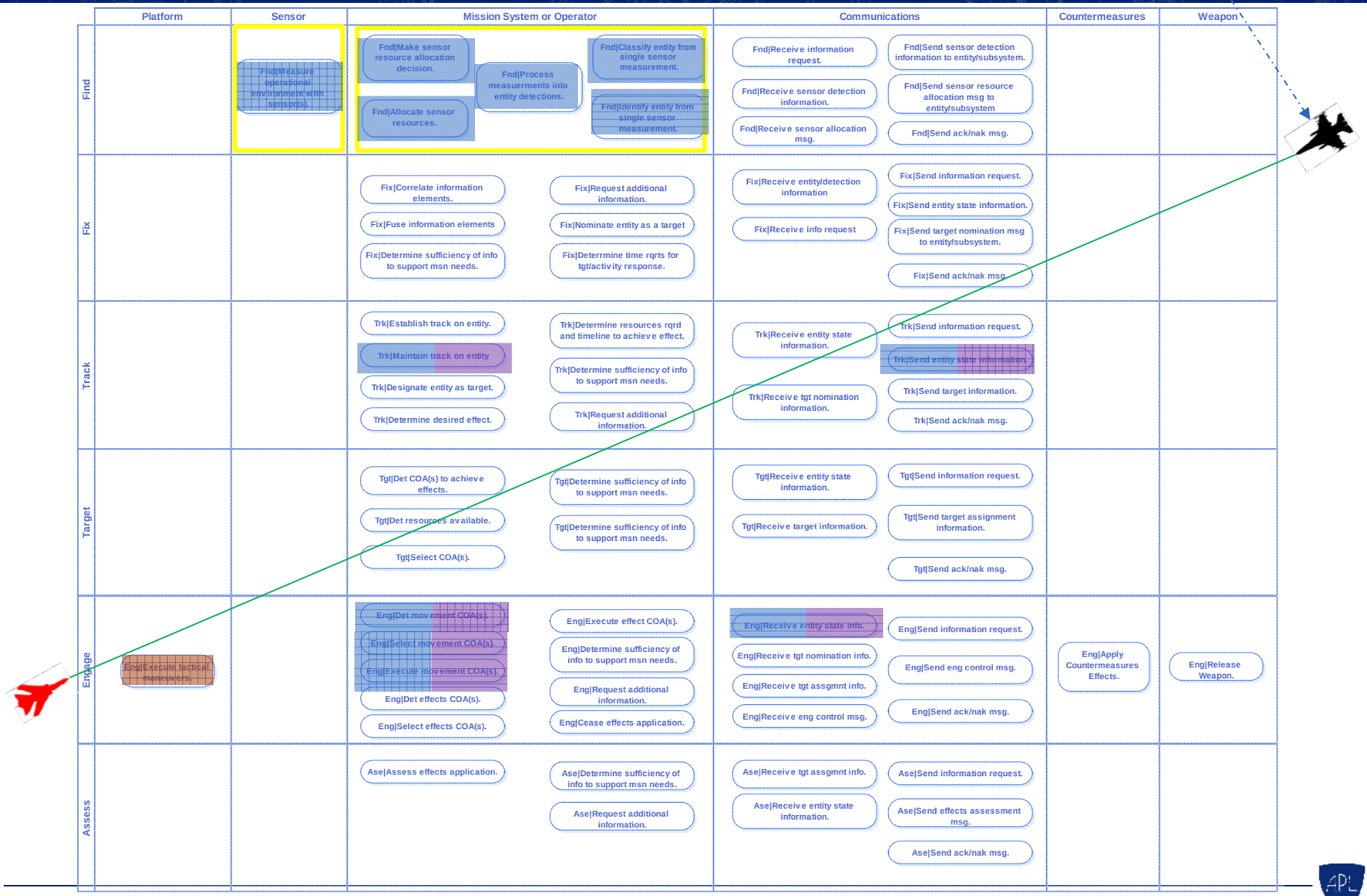
Functional Modeling



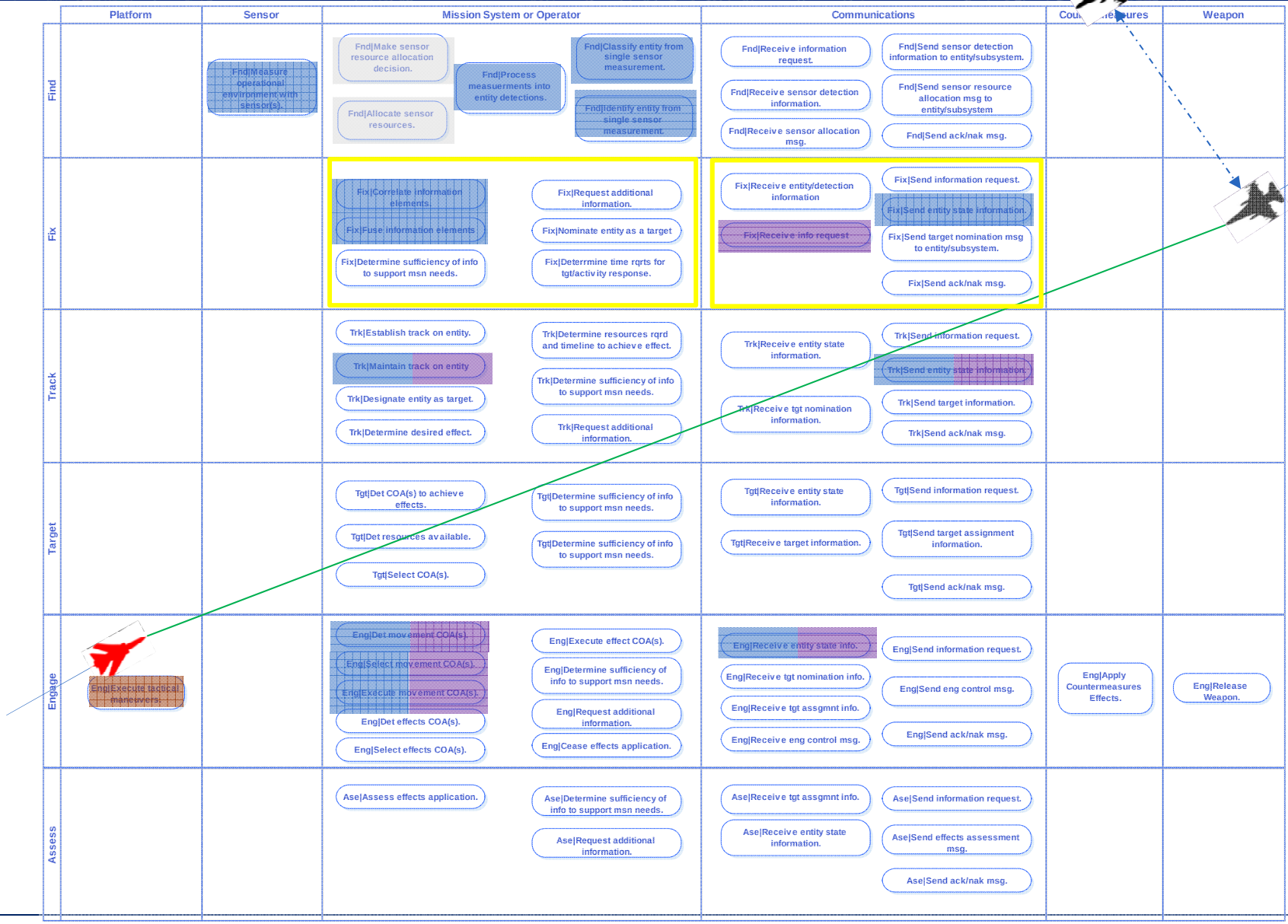
Functional Decomposition

	Platform	Sensor	Mission System or Operator	Communications	Countermeasures	Weapon
Find		Fnd|Measure operational environment with sensor(s).	Fnd|Make sensor resource allocation decision. Fnd|Allocate sensor resources. Fnd|Process measuerments into entity detections. Fnd|Classify entity from single sensor measurement. Fnd|Identify entity from single sensor measurement.	Fnd|Receive information request. Fnd|Receive sensor detection information. Fnd|Receive sensor allocation msg. Fnd|Send sensor detection information to entity/subsystem. Fnd|Send sensor resource allocation msg to entity/subsystem Fnd|Send ack/nak msg.		
Fix			Fix|Correlate information elements. Fix|Fuse information elements Fix|Determine sufficiency of info to support msn needs. Fix|Request additional information. Fix|Nominate entity as a target Fix|Determine time rqrts for tgt/activity response.	Fix|Receive entity/detection information Fix|Receive info request Fix|Send information request. Fix|Send entity state information. Fix|Send target nomination msg to entity/subsystem. Fix|Send ack/nak msg.		
Track			Trk|Establish track on entity. Trk|Maintain track on entity Trk|Designate entity as target. Trk|Determine desired effect. Trk|Determine resources rqrd and timeline to achieve effect. Trk|Determine sufficiency of info to support msn needs. Trk|Request additional information.	Trk|Receive entity state information. Trk|Receive tgt nomination information. Trk|Send information request. Trk|Send entity state information. Trk|Send target information. Trk|Send ack/nak msg.		
Target			Tgt|Det COA(s) to achieve effects. Tgt|Det resources available. Tgt|Select COA(s). Tgt|Determine sufficiency of info to support msn needs. Tgt|Determine sufficiency of info to support msn needs.	Tgt|Receive entity state information. Tgt|Receive target information. Tgt|Send information request. Tgt|Send target assignment information. Tgt|Send ack/nak msg.		
Engage	Eng|Execute tactical maneuvers.		Eng|Det movement COA(s). Eng|Select movement COA(s). Eng|Execute movement COA(s). Eng|Det effects COA(s). Eng|Select effects COA(s). Eng|Execute effect COA(s). Eng|Determine sufficiency of info to support msn needs. Eng|Request additional information. Eng|Cease effects application.	Eng|Receive entity state info. Eng|Receive tgt nomination info. Eng|Receive tgt assgmnt info. Eng|Receive eng control msg. Eng|Send information request. Eng|Send eng control msg. Eng|Send ack/nak msg.	Eng|Apply Countermeasures Effects.	Eng|Release Weapon.
Assess			Ase|Assess effects application. Ase|Determine sufficiency of info to support msn needs. Ase|Request additional information.	Ase|Receive tgt assgmnt info. Ase|Receive entity state information. Ase|Send information request. Ase|Send effects assessment msg. Ase|Send ack/nak msg.		

Example - Find



Example - Fix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Fnd|Receive information request.
Fnd|Receive sensor detection information.
Fnd|Receive sensor allocation msg.
Fnd|Send sensor detection information to entity/subsystem.
Fnd|Send sensor resource allocation msg to entity/subsystem
Fnd|Send ack/nak msg.
Fix|Correlate information elements.
Fix|Fuse information elements
Fix|Determine sufficiency of info to support msn needs.
Fix|Request additional information.
Fix|Nominate entity as a target
Fix|Determine time rqrts for tgt/activity response.
Fix|Receive entity/detection information
Fix|Receive info request
Fix|Send information request.
Fix|Send entity state information.
Fix|Send target nomination msg to entity/subsystem.
Fix|Send ack/nak msg.
Trk|Establish track on entity.
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Trk|Send target information.
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Tgt|Det COA(s) to achieve effects.
Tgt|Det resources available.
Tgt|Select COA(s).
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Eng|Send information request.
Eng|Send eng control msg.
Eng|Send ack/nak msg.
Eng|Apply Countermeasures Effects.
Eng|Release Weapon.
Ase|Assess effects application.
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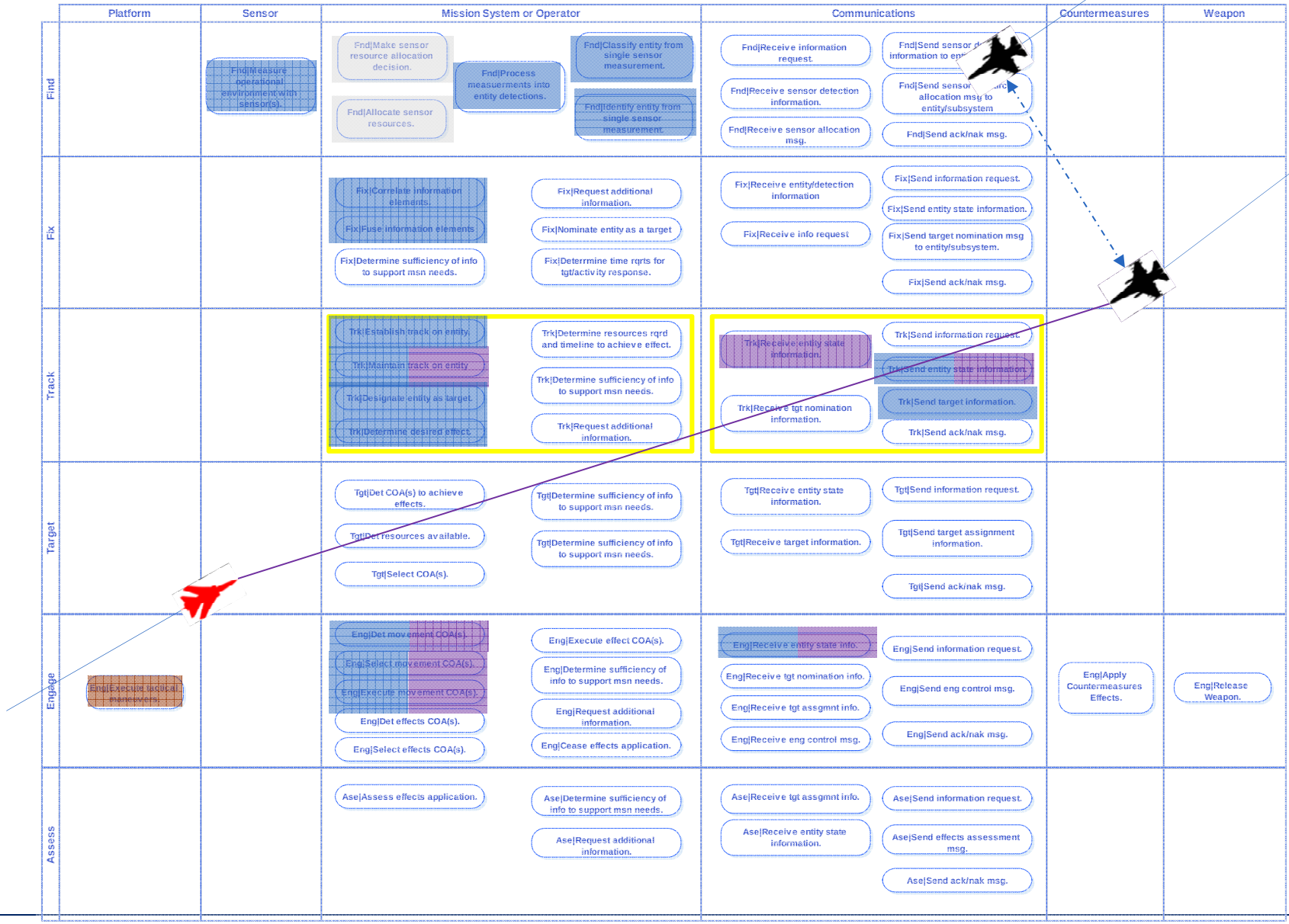
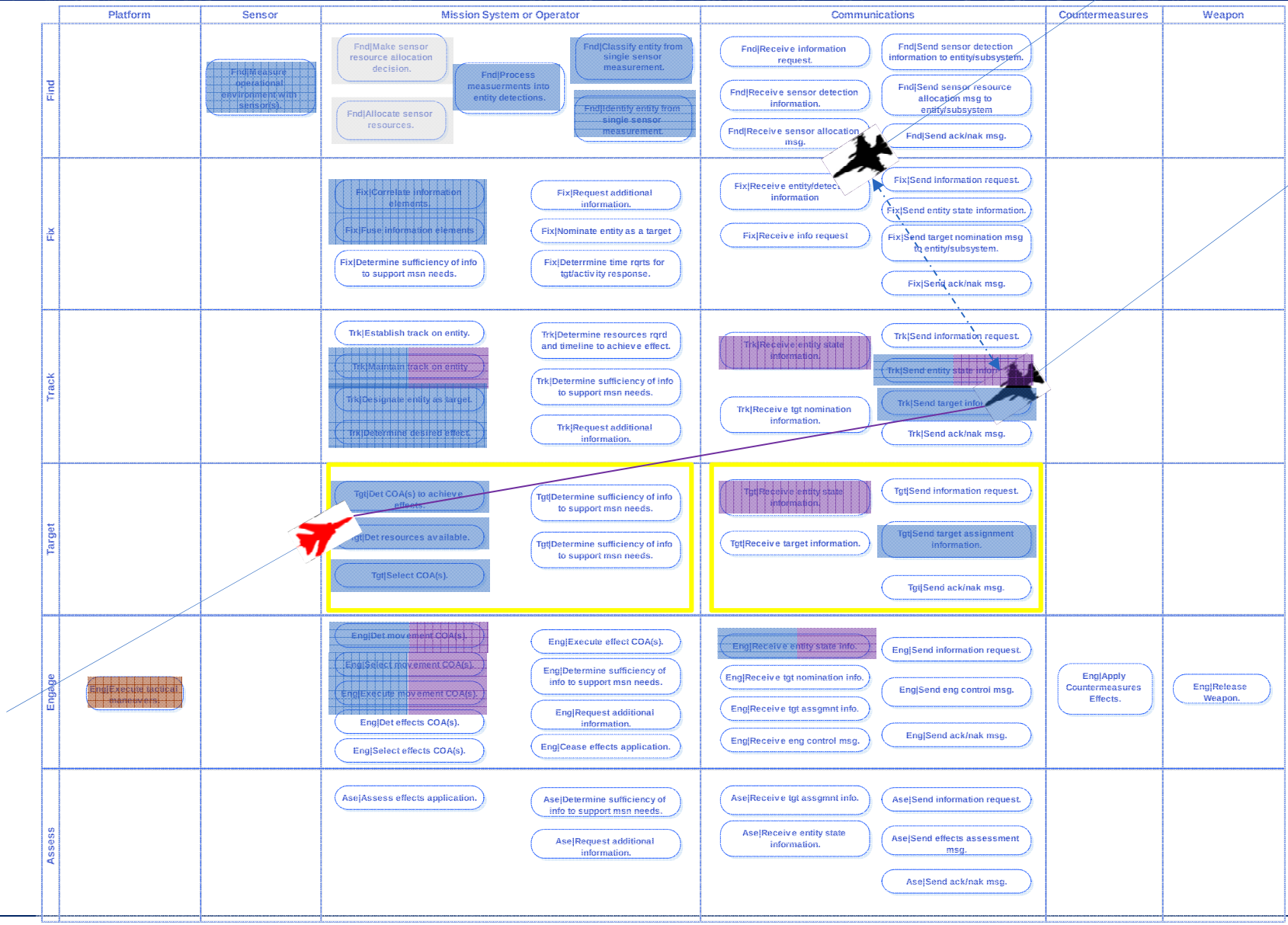
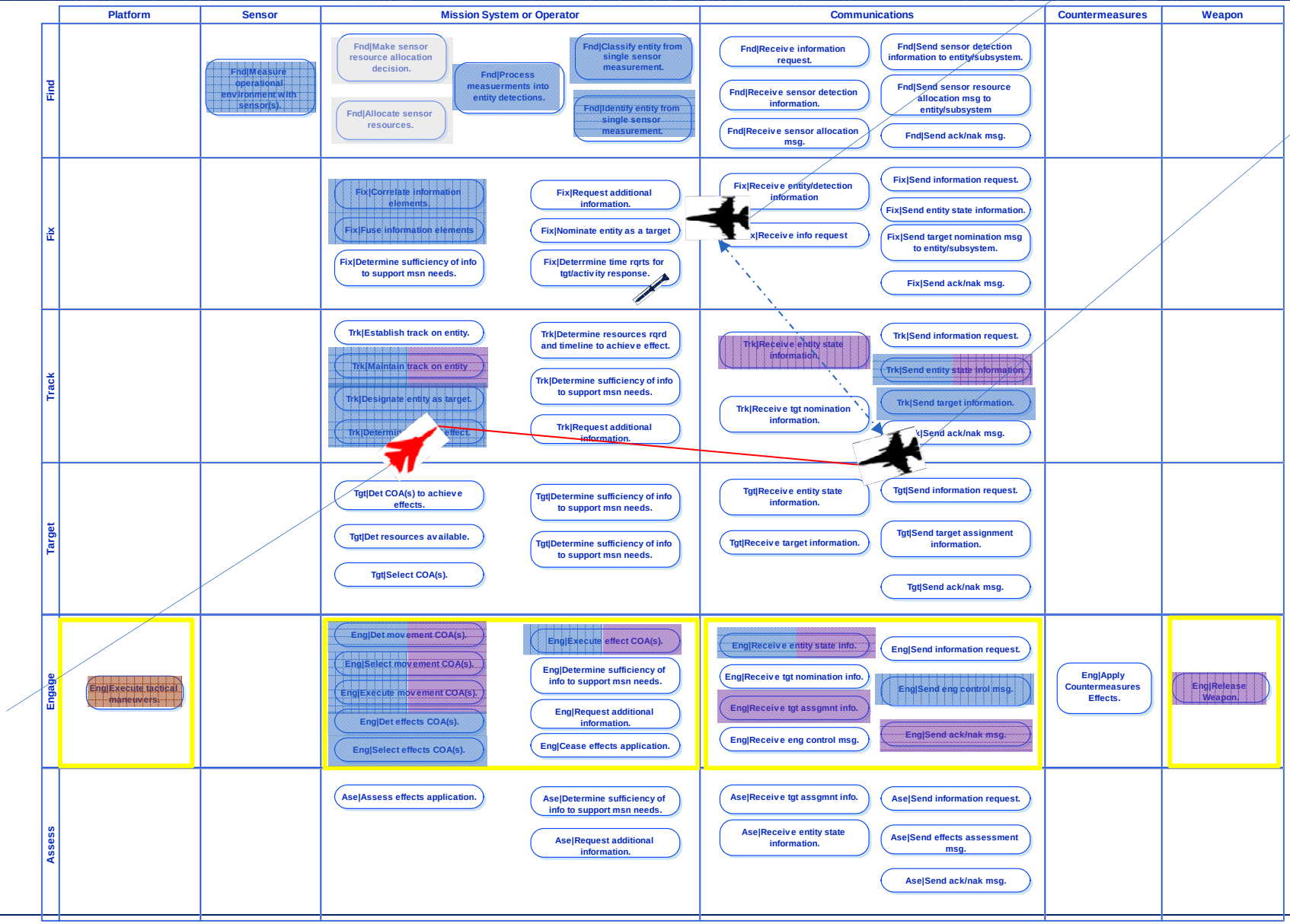
Example - Track



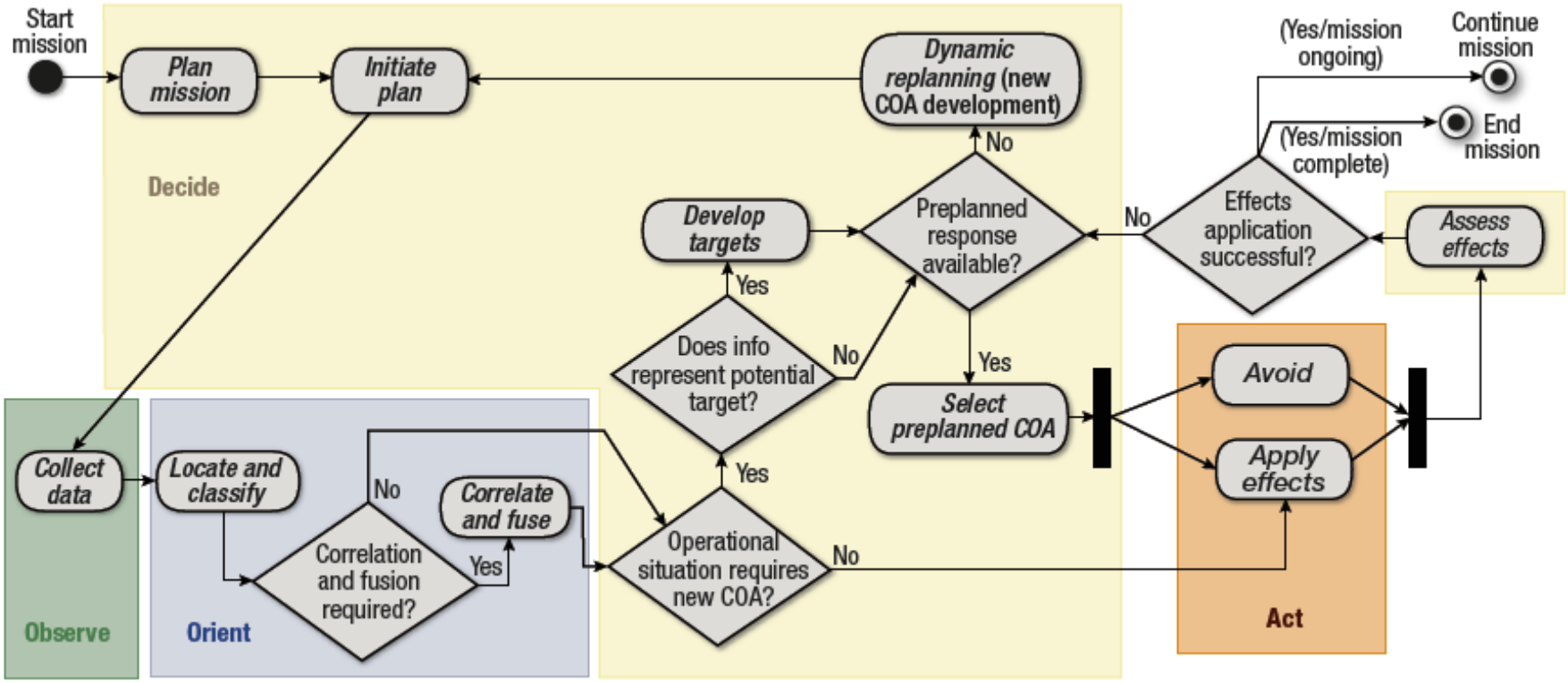
Example - Target



Example - Engage



Edges and Vertices – using model data



Source: http://www.jhuapl.edu/techdigest/TD/td3201/32_01-Topper.pdf

Functional Decomposition

- Data queried from UML/SysML relational database
  - O-O to RDBMS data integrity
- Assessment of functional threads
- Trace to requirements
- Executable models

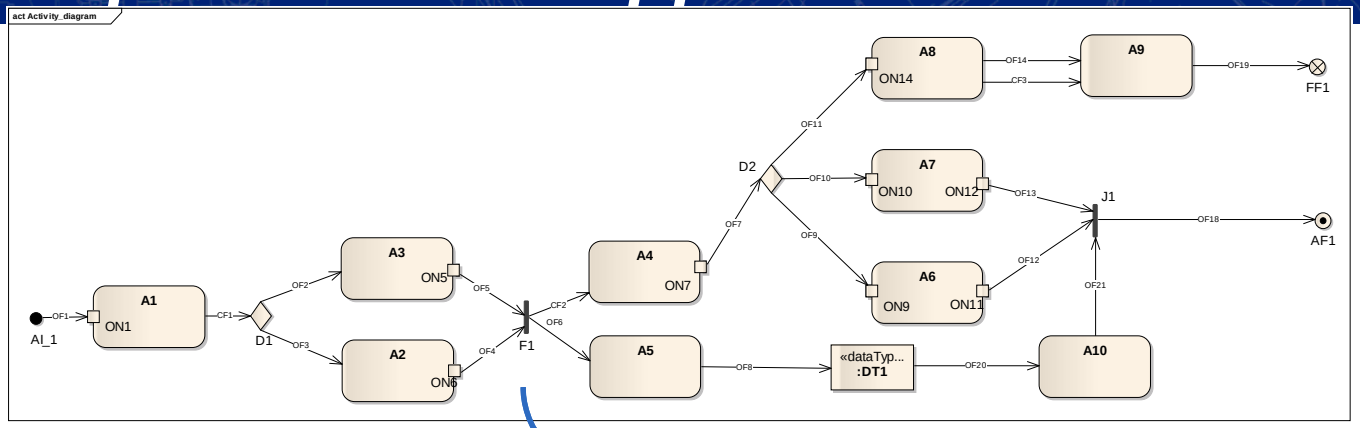
StartObjectName	StartObjectType	EndObjectName	EndObjectType
Start mission (394)	StateNode	*Plan mission* (362)	Activity
Plan mission (362)	Activity	*Initiate plan* (356)	Activity
Initiate plan (356)	Activity	*Collect data* (327)	Activity
Collect data (327)	Activity	*Locate and classify* (357)	Activity
Locate and classify (357)	Activity	Correlation and fusion required? (381)	Decision
Correlation and fusion required? (381)	Decision	*Correlate and fuse* (337)	Activity
Correlate and fuse (337)	Activity	Operational situation requires new COA? (390)	Decision
Operational situation requires new COA? (390)	Decision	Does info represent potential target? (382)	Decision
Does info represent potential target? (382)	Decision	*Develop targets* (343)	Activity
Develop targets (343)	Activity	Preplanned response available? (391)	Decision
Preplanned response available? (391)	Decision	*Select preplanned* COA (365)	Activity
Select preplanned COA (365)	Activity	Fork from *Select preplanned* COA (412)	Synchronization
Fork from *Select preplanned* COA (412)	Synchronization	*Avoid* (323)	Activity
Avoid (323)	Activity	Join to *Assess effects* (411)	Synchronization
Join to *Assess effects* (411)	Synchronization	*Assess effects* (316)	Activity
Assess effects (316)	Activity	Effects application successful? (383)	Decision
Effects application successful? (383)	Decision	Preplanned response available? (391)	Decision
Preplanned response available? (391)	Decision	*Select preplanned* COA (365)	Activity
Select preplanned COA (365)	Activity	Fork from *Select preplanned* COA (412)	Synchronization
Fork from *Select preplanned* COA (412)	Synchronization	*Apply effects* (311)	Activity
Apply effects (311)	Activity	Join to *Assess effects* (411)	Synchronization
Join to *Assess effects* (411)	Synchronization	*Assess effects* (316)	Activity
Assess effects (316)	Activity	Effects application successful? (383)	Decision
Effects application successful? (383)	Decision	End mission (380)	StateNode

Color coding associates each activity with a phase in the observe (green)–orient (blue)–decide (yellow)–act (orange) process. Numbers in parentheses in the table and in Fig. 9 are internal node indices in the thread data.

Source: http://www.jhuapl.edu/techdigest/TD/td3201/32_01-Topper.pdf

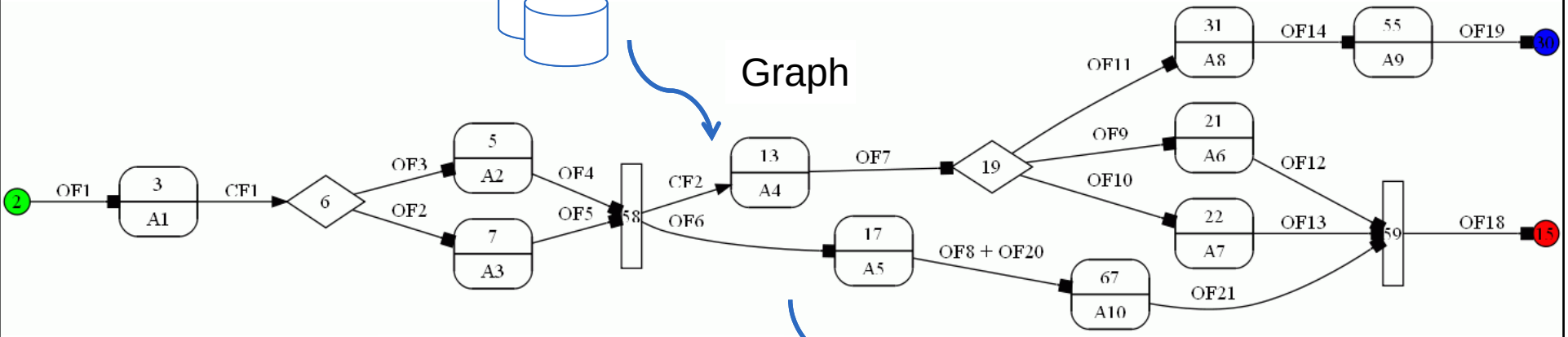
Graph Theoretic Approach

Example

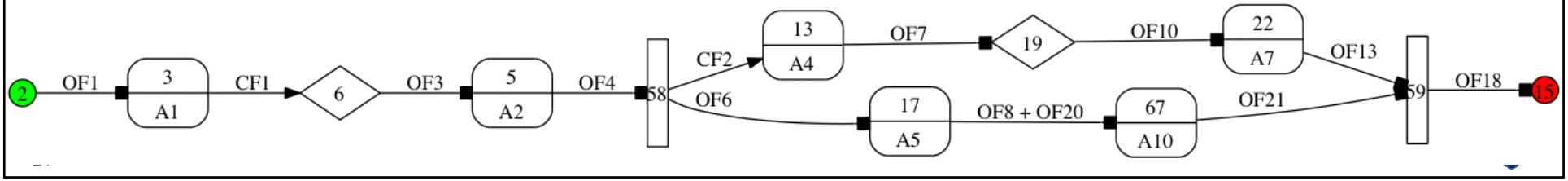


Database

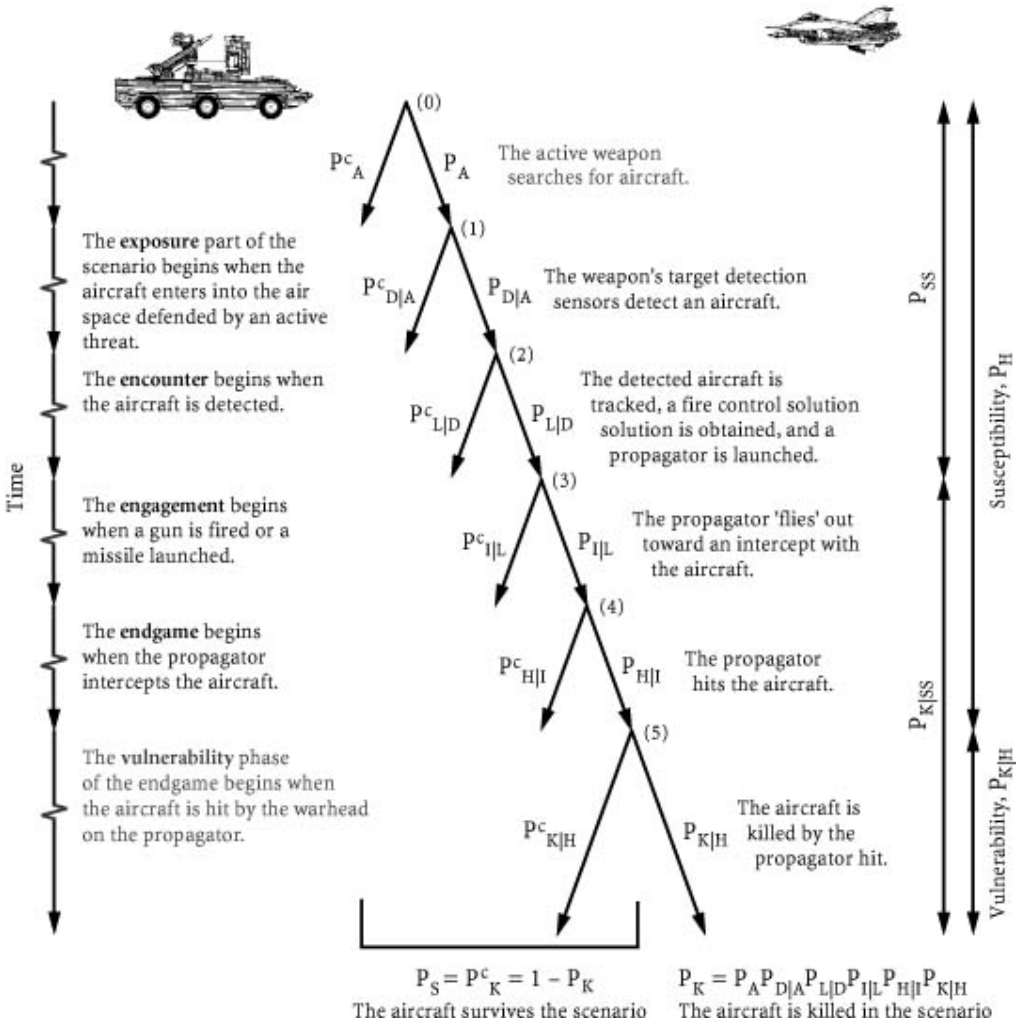
Graph



Mission thread (1 of 6)



Stochastic Methods



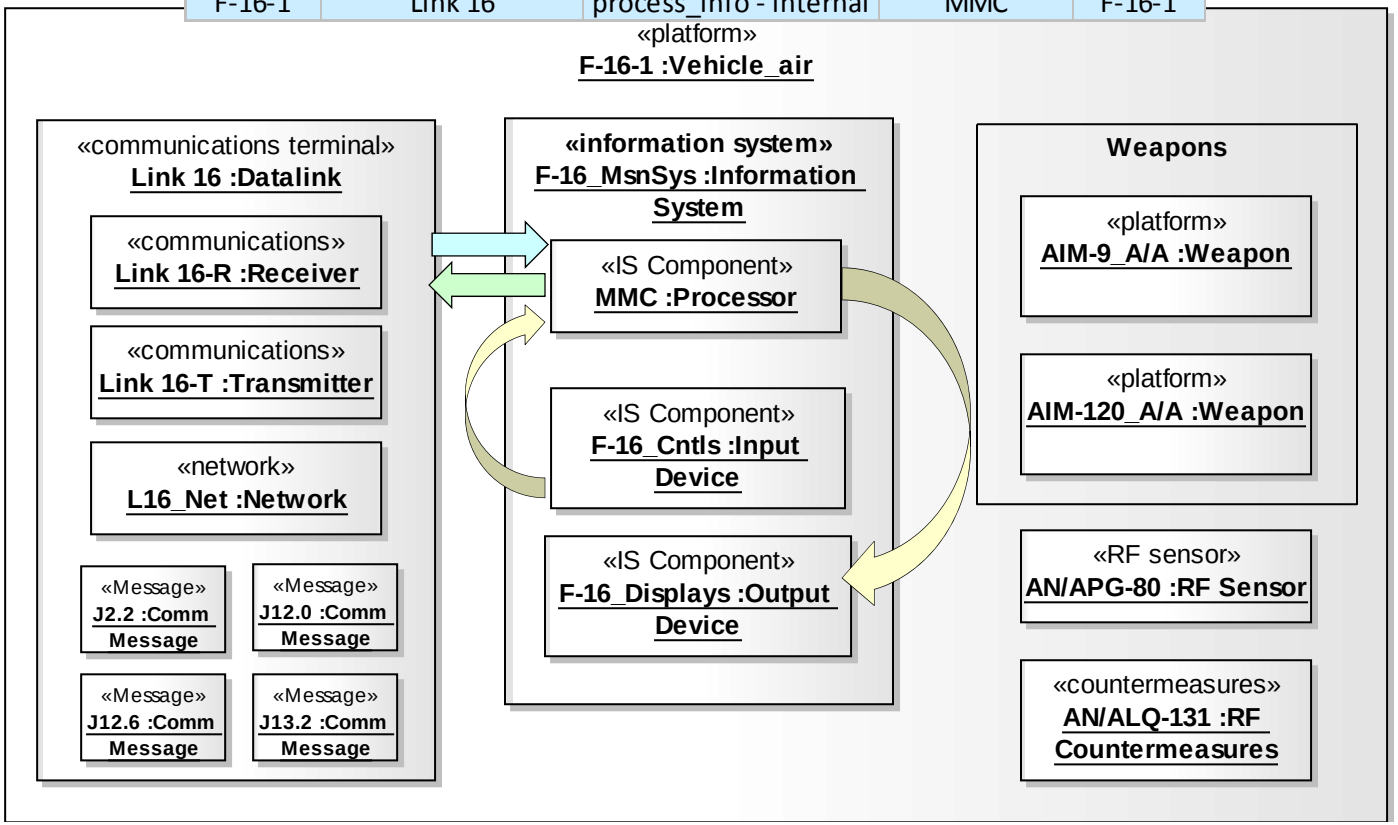
Source: The Fundamentals of Aircraft Combat Survivability Analysis and Design, Ball, 1985

Equation	Description of probability
Aircraft survival in a single-shot scenario	
$P_H = P_A P_{D\|A} P_{L\|D} P_{I\|L} P_{H\|I}$ [a−e]	Prob. the aircraft is hit in the scenario
$P_K = P_H P_{K\|H}$ [f]	Prob. the aircraft is killed in the scenario (by a hit)
$P_F = P_A P_{D\|A} P_{L\|D} P_{I\|L} P_{F\|I}$ [g]	Prob. the HE warhead on the propagator fuzes in the scenario
$P_K = P_F P_{K\|F}$ [h]	Prob. the aircraft is killed in the scenario (by a proximity-fuzed detonation)
$P_{E\|A} = P_{D\|A} P_{L\|D}$	Prob. the aircraft is engaged by an active weapon
$P_E = P_A P_{E\|A}$	Prob. the aircraft is engaged in the scenario
$P_{E(\text{single shot})} = P_{SS} = P_A P_{E\|A}$	Prob. a single shot is fired at the aircraft in the scenario
$P_{H\|SS} = P_{I\|L} P_{H\|I}$	Prob. the aircraft is hit, given a single shot
$P_{F\|SS} = P_{I\|L} P_{F\|I}$	Prob. of fuzing, given a single shot
$P_{K\|SS} = P_{SSK} = P_{H\|SS} P_{K\|H}$	Prob. the aircraft is killed (by a hit), given a single shot
$P_{K\|SS} = P_{SSK} = P_{F\|SS} P_{K\|F}$	Prob. the aircraft is killed (by a prox-fuzed det.), given a single shot
$P_K = P_{SS} P_{K\|SS}$	Prob. the aircraft is killed in a single-shot scenario
$P_S = 1 - P_K$	Prob. the aircraft survives the single-shot scenario
Aircraft survival in a multiple, independent-shot scenario	
P_E	Prob. the aircraft is engaged in the scenario with one or more shots
P_{Ki}	Prob. the *i*th shot kills the aircraft, given a shot at a live aircraft
P_{Si}	Prob. the *i*th shot does not kill the aircraft, given a shot at a live aircraft
$P_K^{(i)} = P_{S1} P_{S2} \ldots P_{Si-1} P_{Ki}$	Prob. the aircraft is killed by the *i*th shot in the scenario
$P_{K\|E} = P_K^{(1)} + P_K^{(2)} \ldots + P_K^{(n)}$	Prob. the aircraft is killed in the engagement consisting of *N* shots
$P_{S\|E} = P_{S1} P_{S2} \ldots P_{SN} = (1 - P_{K1}) \times (1 - P_{K2}) \ldots (1 - P_{KN})$	Prob. the aircraft survives the *N* (different) shot engagements
$P_{S\|E} = (1 - P_{K\|SS})^N = 1 - P_{K\|E}$	Prob. the aircraft survives the *N* (identical) shot engagements

Interaction Generation (Internal - between subsystems)

SrcName	SrcSubsystem	Interaction	SnkSubsystem	SnkName	Operation
F-16-1	MMC	Send_msg_info	Link 16	F-16-1	process_msg
F-16-1	MMC	Send_cmd_info	Link 16	F-16-1	process_cmd

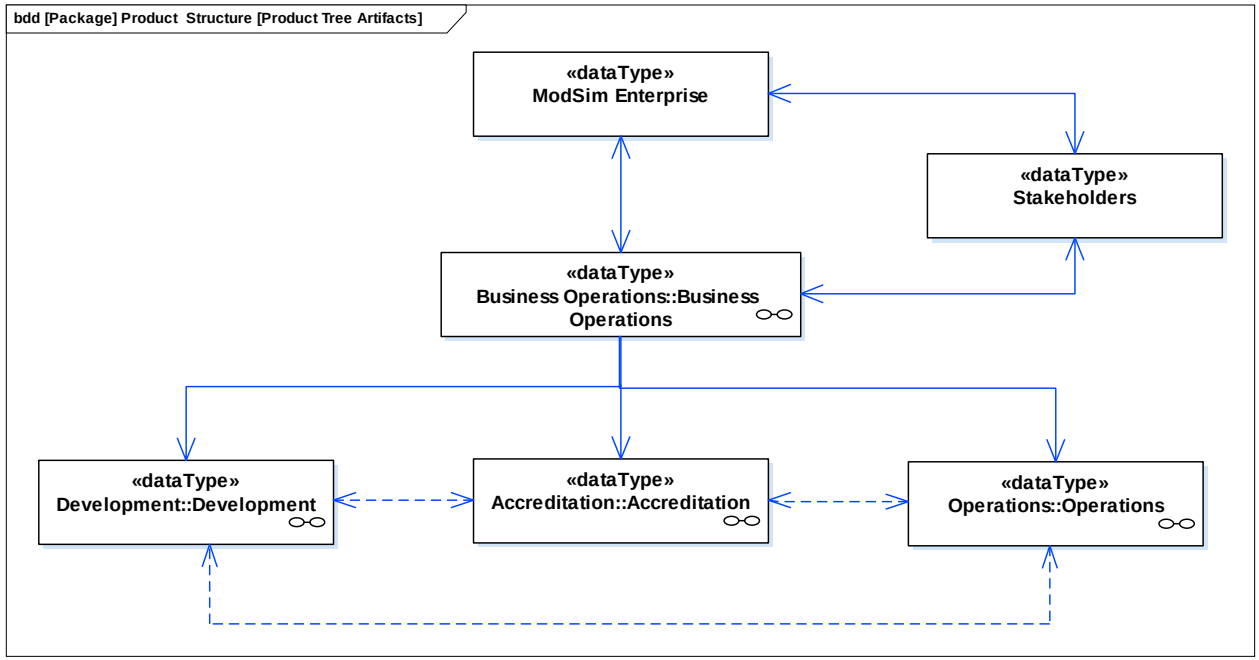
SrcName	SrcSubsystemName	Interaction	SnkSubsystem	SnkName
F-16-1	Link 16	process_info - internal	MMC	F-16-1

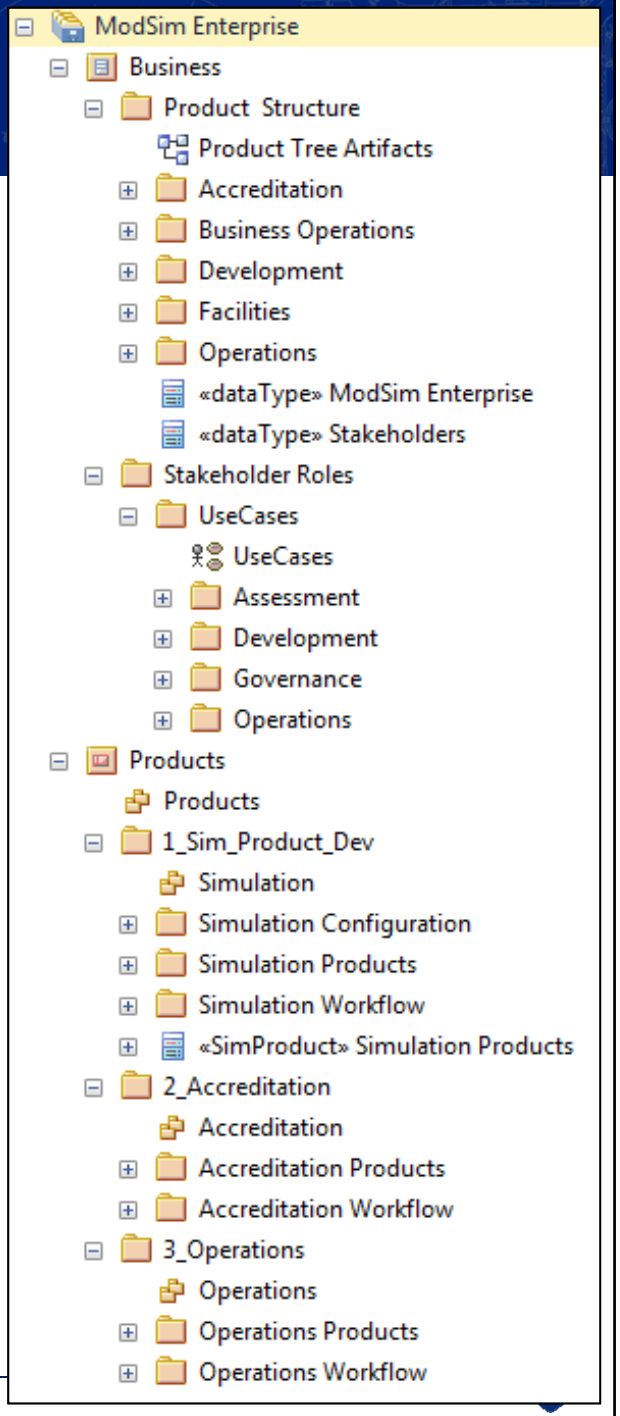


SrcName	SrcSubsystem	Interaction	SnkName	SnkSubsystem
F-16-1	F-16_Cntls	send_info	F-16-1	MMC
F-16-1	F-16_Cntls	send_cmd	F-16-1	MMC
F-16-1	MMC	display_info	F-16-1	F-16_Displays

End (?)

Enterprise Architecting

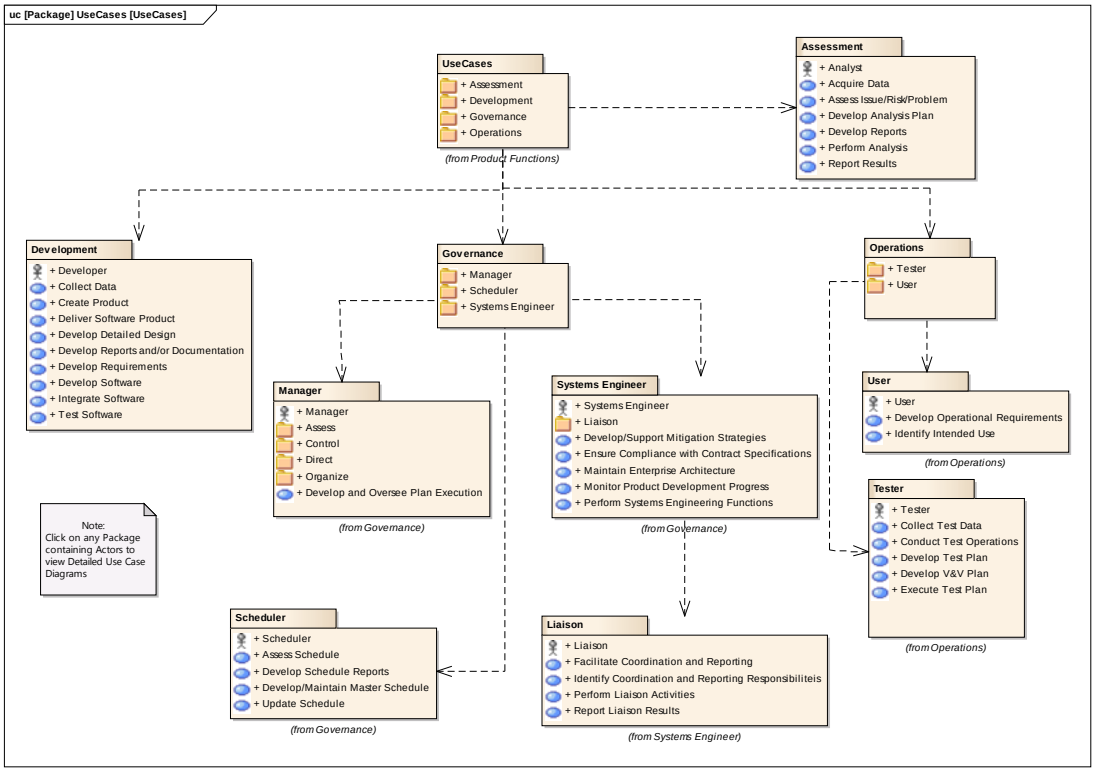




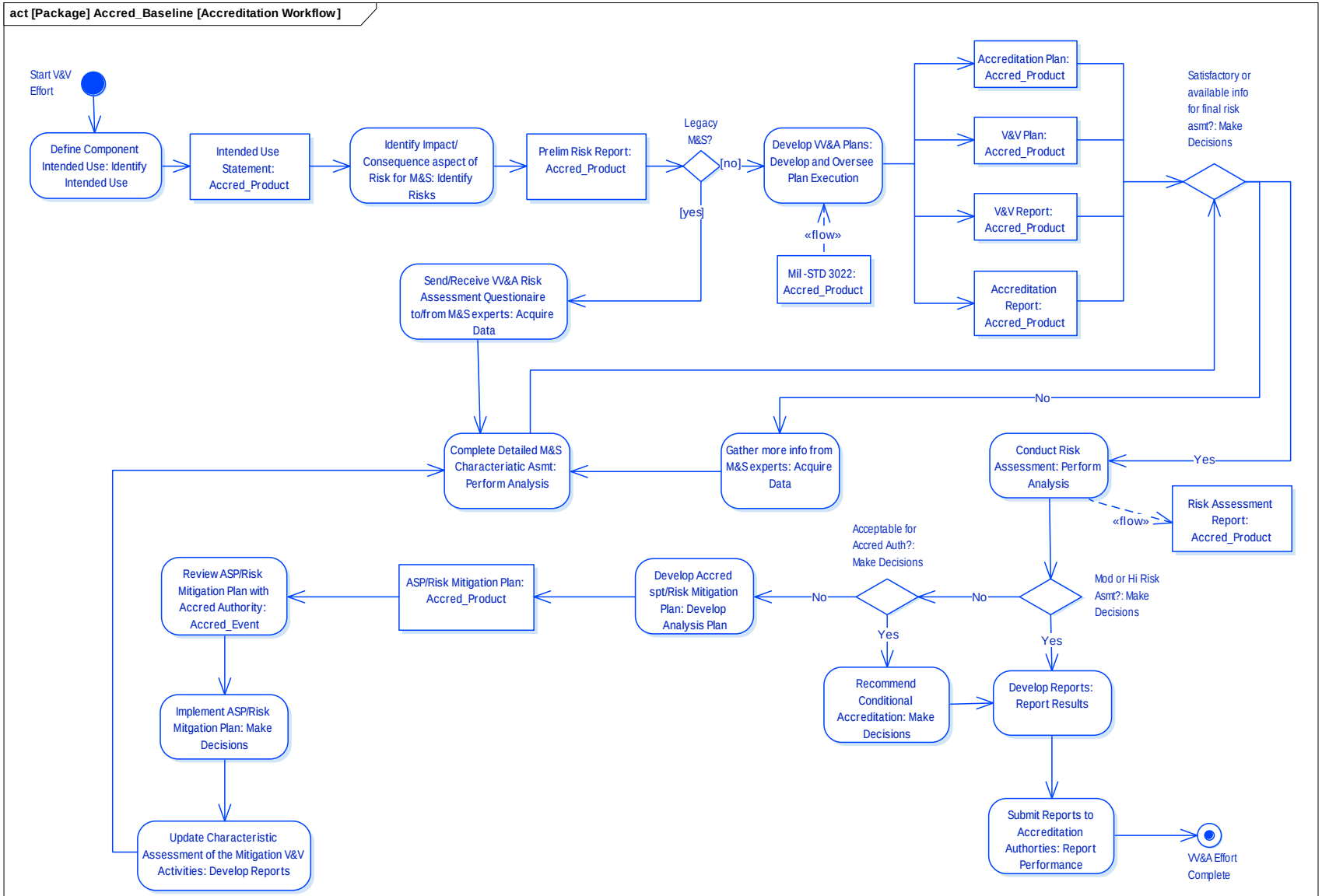
- **Domain structure for M&S**
  - **Products**
  - **Functions**
- **Transferable to file system (Windows, Unix, etc.)**
- **Links mode/model database and file systems**

Enterprise Architecting

- **Developed comprehensive reference set of use cases which define tasks required to complete simulation development, accreditation, and execution activities**
- **Enable specific workflow generation**
  - **Identify required skills and product outputs**
  - **Database/graph techniques combined with simulation product tree data enables generation of detailed work breakdown structures (WBS)**
- **WBS models can be tagged with cost/schedule information and linked to MS Project files**



Business Process Example – VV&A Workflow



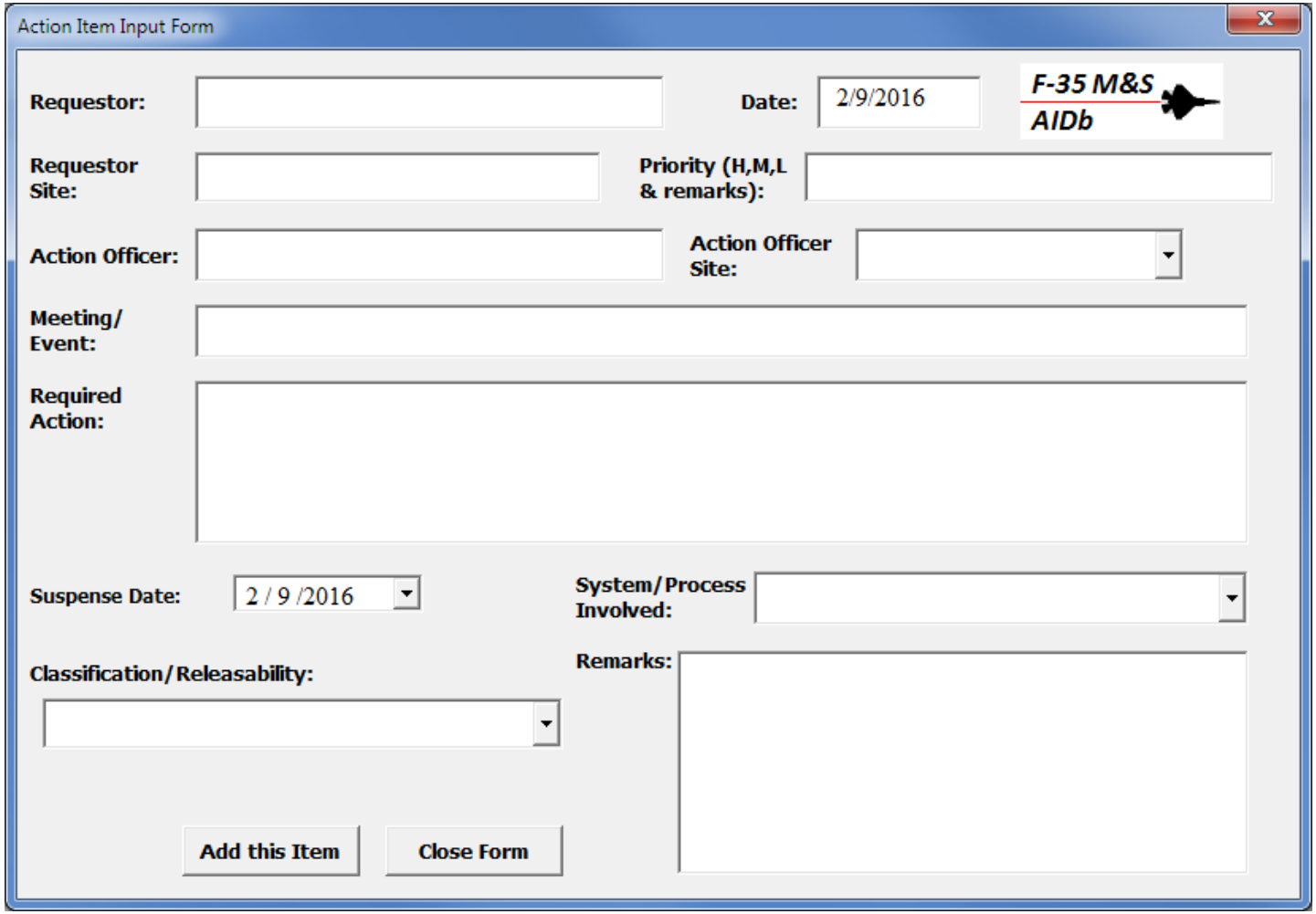
Source: http://sites.nationalacademies.org/cs/groups/depssite/documents/webpage/deps_068593.pdf

Workflow Data

Model Name	StartObjName	StartObjType	EndObjName	EndObjType	Product
Accreditation Workflow	Define Component Intended Use	Activity	Intended Use Statement	Object	Accred_Product
	Intended Use Statement	Object	Identify Impact/ Consequence aspect of Risk for M&S	Activity	
	Identify Impact/ Consequence aspect of Risk for M&S	Activity	Prelim Risk Report	Object	Accred_Product
	Prelim Risk Report	Object	Legacy M&S?	Decision	
	Develop VV&A Plans	Activity	Accreditation Plan	Object	Accred_Product
	Develop VV&A Plans	Activity	V&V Plan	Object	Accred_Product
	Develop VV&A Plans	Activity	V&V Report	Object	Accred_Product
	Develop VV&A Plans	Activity	Accreditation Report	Object	Accred_Product
	Accreditation Plan	Object	Satisfactory or available info for final risk asmt?	Decision	
	V&V Plan	Object	Satisfactory or available info for final risk asmt?	Decision	
	V&V Report	Object	Satisfactory or available info for final risk asmt?	Decision	
	Accreditation Report	Object	Satisfactory or available info for final risk asmt?	Decision	
	Conduct Risk Assessment	Activity	Mod or Hi Risk Asmt?	Decision	
	Mod or Hi Risk Asmt?	Decision	Acceptable for Accred Auth?	Decision	
	Satisfactory or available info for final risk asmt?	Decision	Gather more info from M&S experts	Activity	
	Satisfactory or available info for final risk asmt?	Decision	Conduct Risk Assessment	Activity	
	Mil -STD 3022	Object	Develop VV&A Plans	Activity	
	Gather more info from M&S experts	Activity	Complete Detailed M&S Characteriatic Asmt	Activity	
	Complete Detailed M&S Characteriatic Asmt	Activity	Satisfactory or available info for final risk asmt?	Decision	
	Acceptable for Accred Auth?	Decision	Develop Accred spt/Risk Mitigation Plan	Activity	
	ASP/Risk Mitigation Plan	Object	Review ASP/Risk Mitigation Plan with Accred Authority	Activity	
	Develop Accred spt/Risk Mitigation Plan	Activity	ASP/Risk Mitigation Plan	Object	Accred_Product
	Review ASP/Risk Mitigation Plan with Accred Authority	Activity	Implement ASP/Risk Mitgation Plan	Activity	
	Start V&V Effort	StateNode	Define Component Intended Use	Activity	
	Acceptable for Accred Auth?	Decision	Recommend Conditional Accreditation	Activity	
	Mod or Hi Risk Asmt?	Decision	Develop Reports	Activity	
	Recommend Conditional Accreditation	Activity	Develop Reports	Activity	
	Develop Reports	Activity	Submit Reports to Accreditation Authorties	Activity	
	Submit Reports to Accreditation Authorties	Activity	VV&A Effort Complete	StateNode	
	Legacy M&S?	Decision	Develop VV&A Plans	Activity	
	Legacy M&S?	Decision	Send/Receive VV&A Risk Assessment Questionaire to/from M&S experts	Activity	
	Send/Receive VV&A Risk Assessment Questionaire to/from M&S experts	Activity	Complete Detailed M&S Characteriatic Asmt	Activity	
	Conduct Risk Assessment	Activity	Risk Assessment Report	Object	Accred_Product
	Implement ASP/Risk Mitgation Plan	Activity	Update Characteristic Assessment of the Mitigation V&V Activities	Activity	
	Update Characteristic Assessment of the Mitigation V&V Activities	Activity	Complete Detailed M&S Characteriatic Asmt	Activity	

```
SELECT t_diagram.Name, t_object.Name AS StartObjName, t_object.Object_Type AS StartObjType, t_object_1.Name AS EndObjName,
t_object_1.Object_Type AS EndObjType, t_object_1.Classifier AS EndObjClass, t_object_2.Name
FROM ((t_object RIGHT JOIN ((t_diagram LEFT JOIN t_diagramlinks ON t_diagram.Diagram_ID = t_diagramlinks.DiagramID) LEFT JOIN t_connector ON
t_diagramlinks.ConnectorID = t_connector.Connector_ID) ON t_object.Object_ID = t_connector.Start_Object_ID) LEFT JOIN t_object AS t_object_1 ON
t_connector.End_Object_ID = t_object_1.Object_ID) LEFT JOIN t_object AS t_object_2 ON t_object_1.Classifier = t_object_2.Object_ID
WHERE (((t_diagram.Diagram_ID)=138));
```

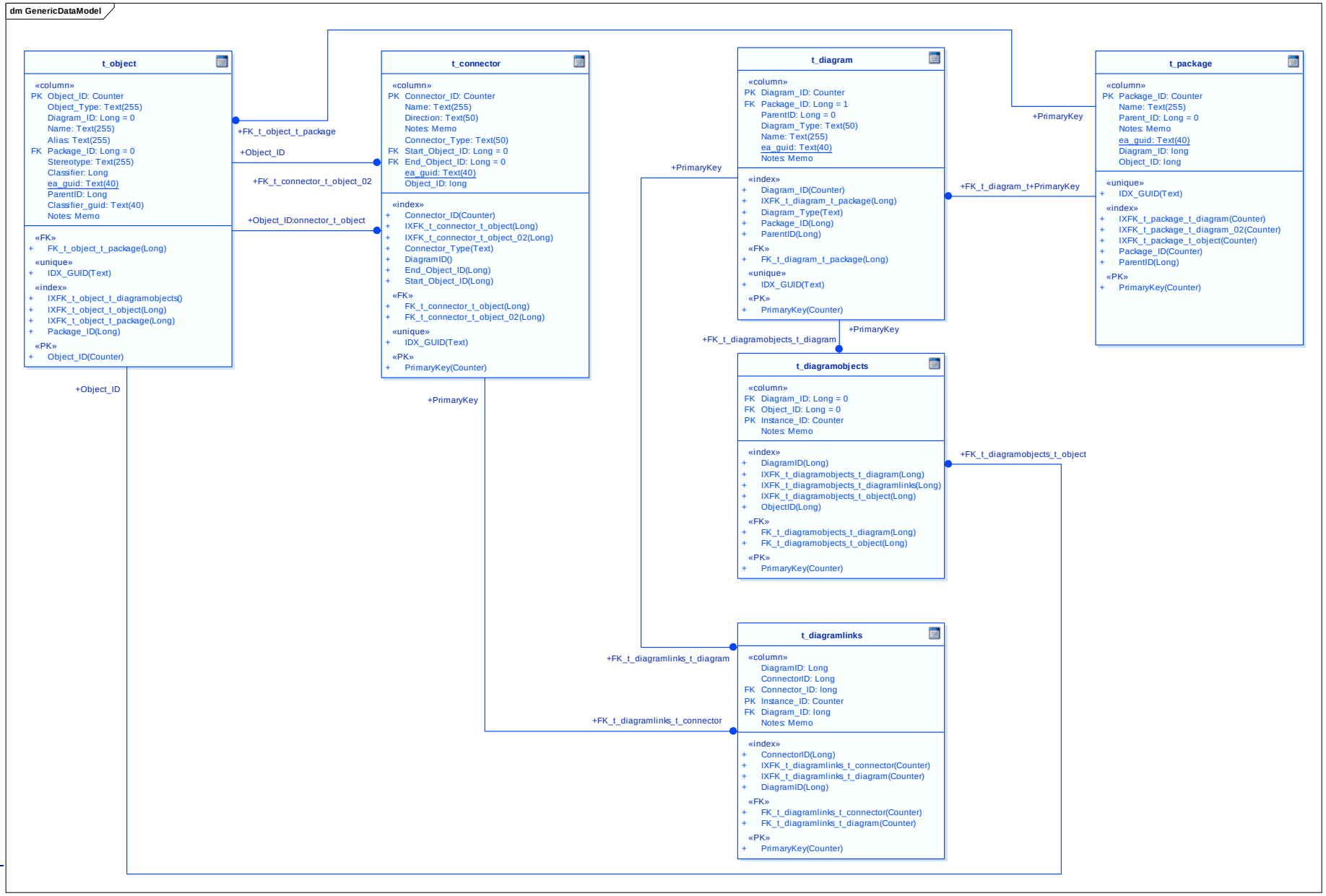
Example Data Entry Form



Standardized forms are easily developed to interact with MBSE/database and other program artifacts

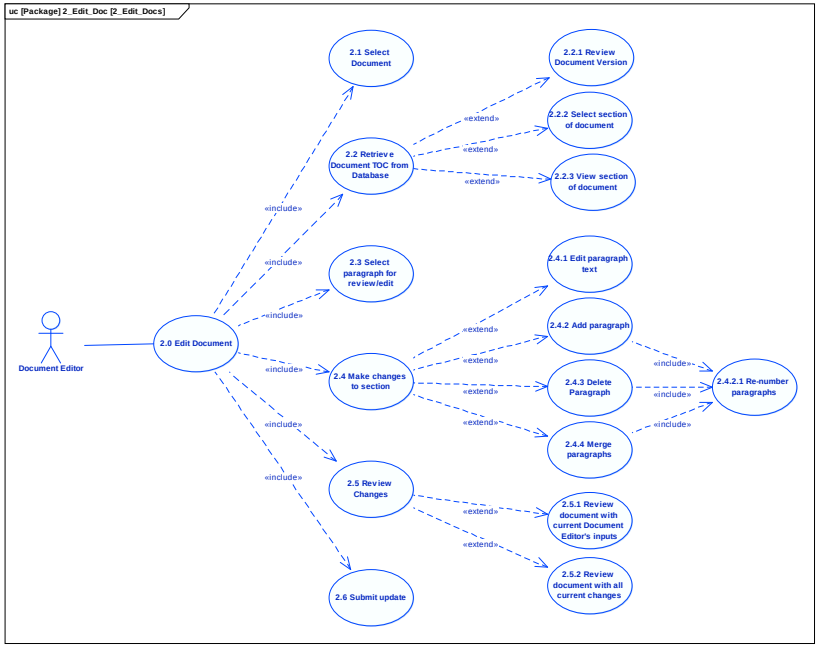
Architecture Data Model

Used to describe all products, activities, and data



Documentation Development and Configuration Control

- **Developed methods to create representations of documents using SysML**
  - **Use both product and, where needed, document-specific SysML models**
- **Developed relational database methods to input/output document data and produce formal documents (e.g. statement of work (SOW), System Software Specification (SSS), etc)**
- **Extraction of all or a portion of a given document for review and editing is possible**
  - **Imposes configuration control**
  - **Captures change rationale and history**
  - **Facilitates rapid impact assessment of changes on the architecture**



Data-Centric MBSE

- **Standardized Domain Model enable specification of system configuration and their functions cohesively**
  - **Facilitates link between real and M&S architecture**
  - **Trace functions/requirements**
  - **Done right it works across many programs and systems**
- **Accessing UML/SysML data enables analysis**
  - **Functions/functionality**
  - **Fidelity requirements**
  - **Interactions**
- **Domain/Graph techniques also apply to the Enterprise/Business architecture**
  - **Links business processes to the product architecture**
  - **Enables cost/schedule assessments**
  - **Standard data structure enables link between business and technical architectures**
    - **Reduces tool dependencies, enables simple app development, increases ROI**