NDIA 10th Annual Systems Engineering Conference

"Discussion of the US Army RDECOM APS Objective Trade Study"

October, 2007

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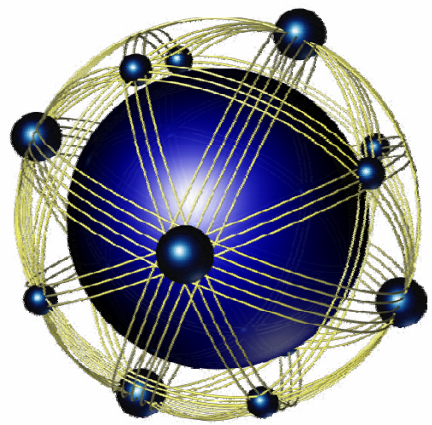


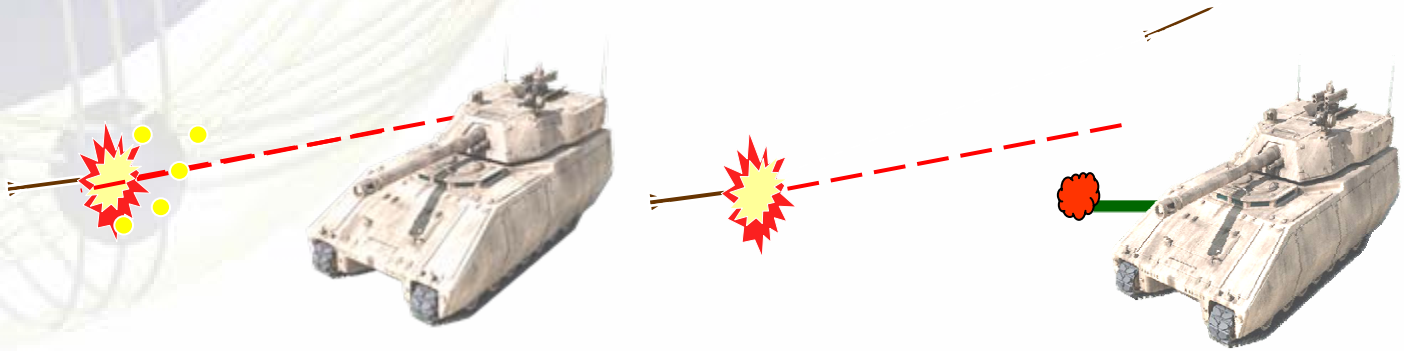
Outline

- Study Description
- Trade Study Process
  - IPT
  - Tools Developed
  - APS Architectures
  - Trade Study Tool Architecture
- Summary

APS Trade Study Description

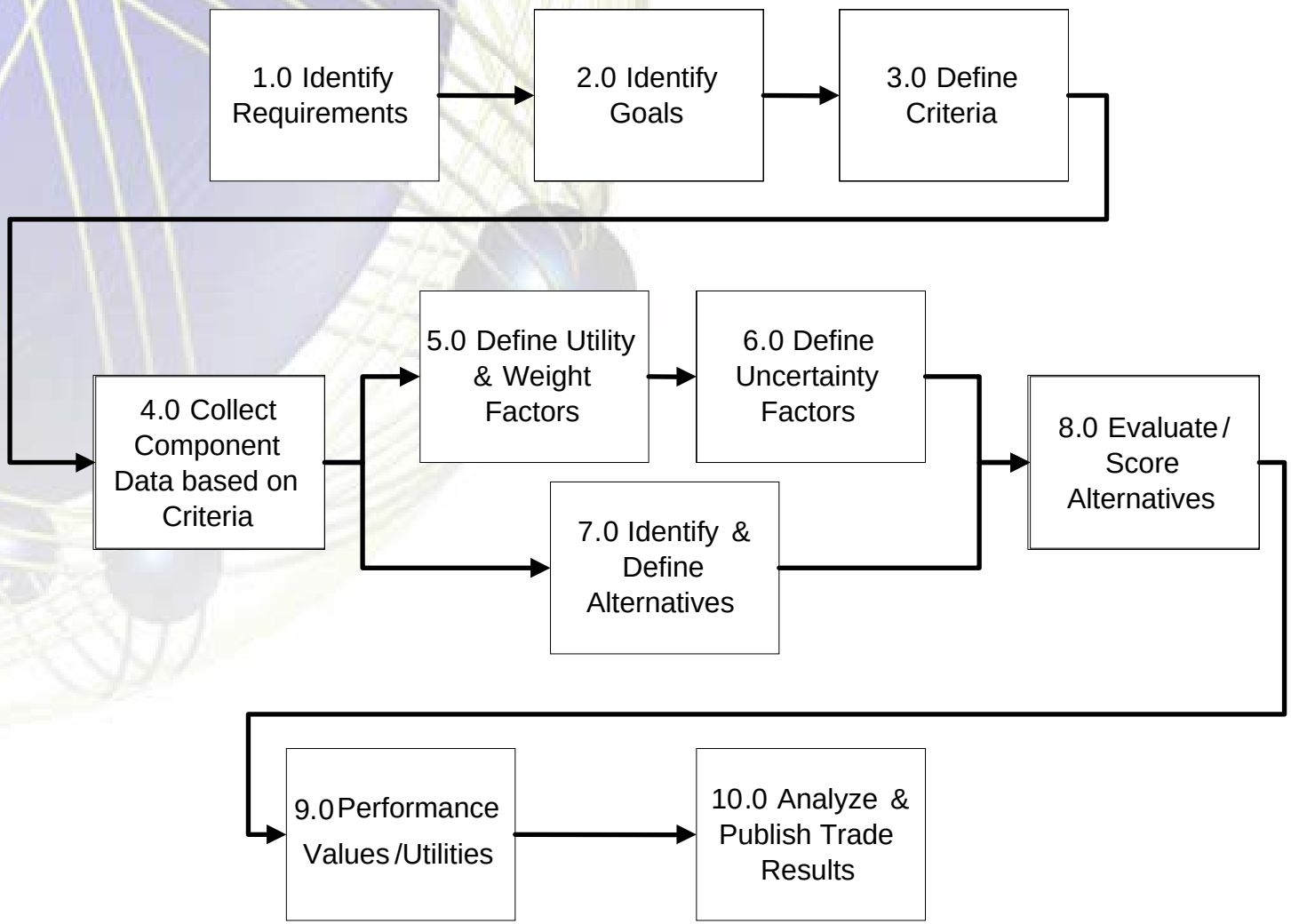
RDECOM effort led by the ARDEC System Engineering Directorate

Identify, define, and evaluate potential Universal (Objective) Active Protection System (APS) approaches for the Future Combat System (FCS).



Provide decision makers the tools/data to help identify RDECOM's Science and Technology investments needed to get to an objective APS system.

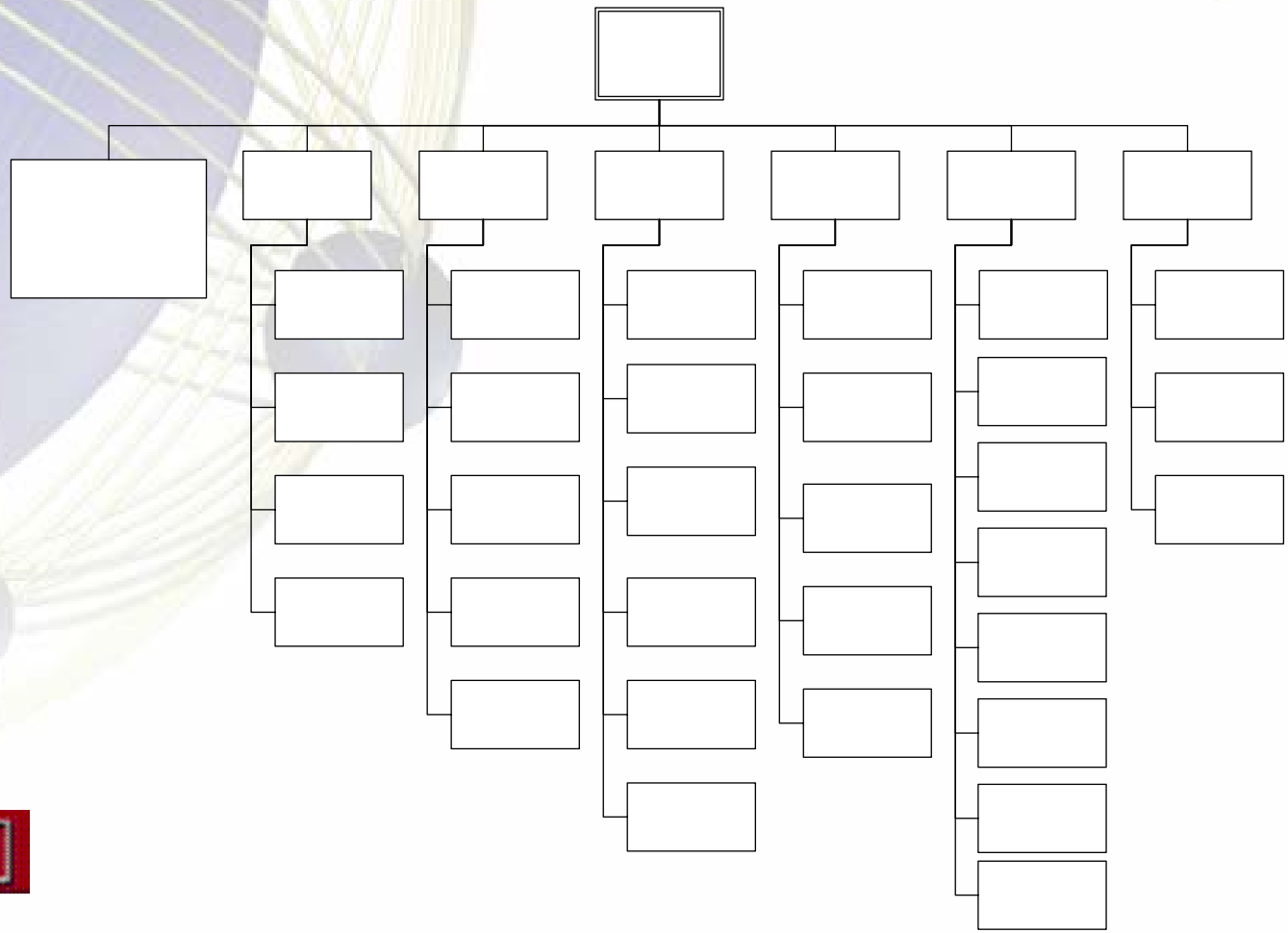
Trade Study Process



Trade Study Based on Disciplined & Structured Process

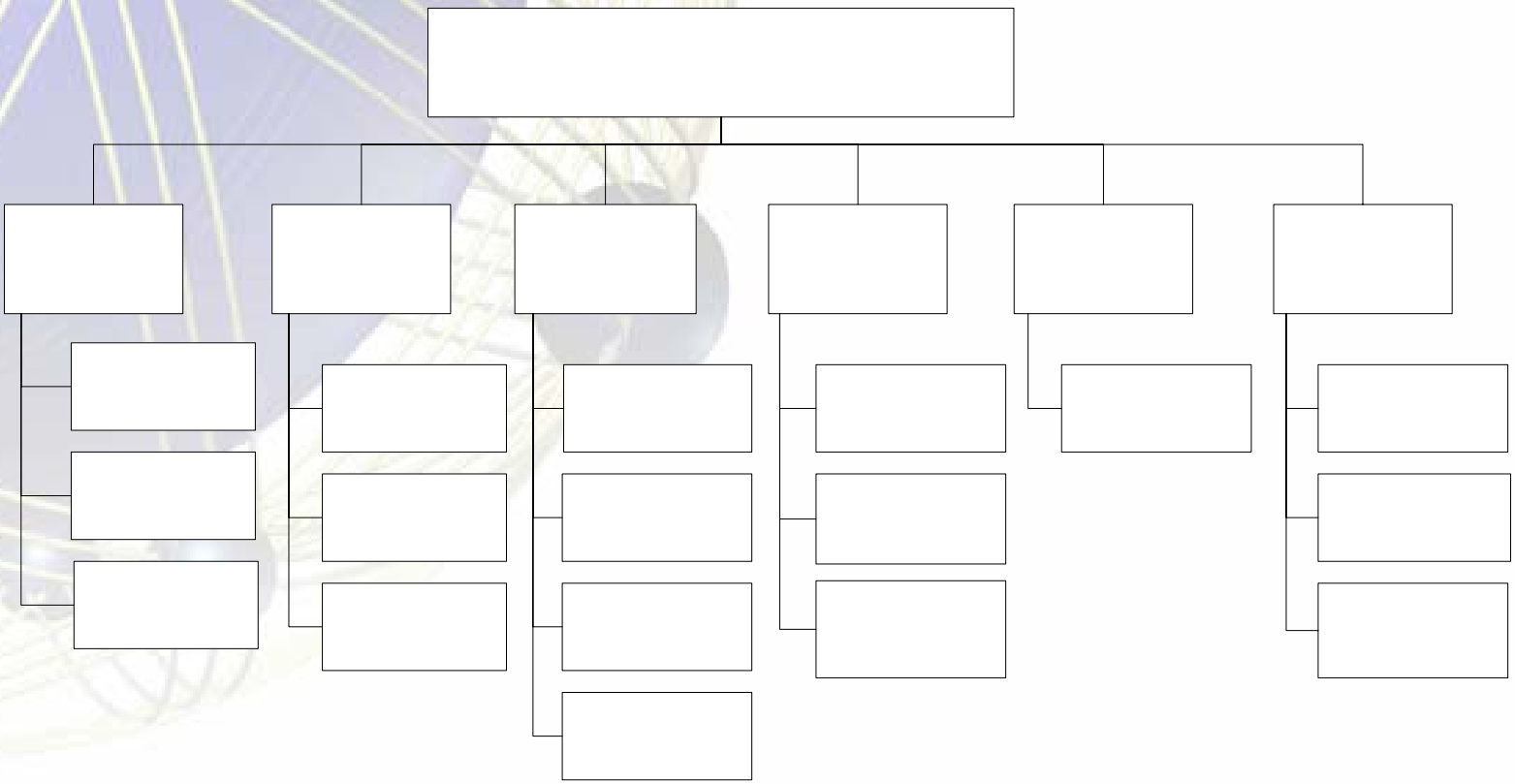
Used an IPT approach

ARDEC



The Trade Study was a Team Effort

1.0-2.0-3.0 -5.0 Requirements – Goals – Criteria - Weights & Utility



Requirements and Stakeholders Drive Decision Criteria

4.0 Collect Component Database on Criteria

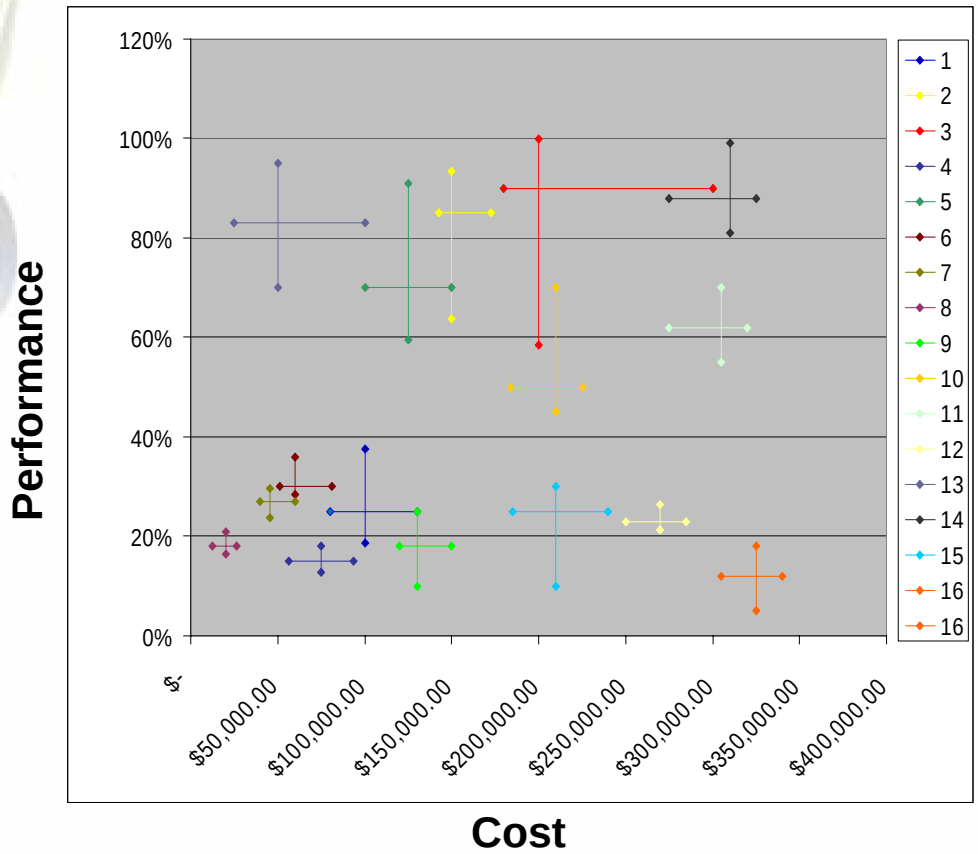
- **Technologies list build based on surveying R&D community thru several technical interchange meetings.**
  - ✓ **Technology specific performance characteristics established**
  - ✓ **Data call to Industry and Government**

- **Series of Data Validation meetings to confirm data used in study was accepted by community.**
  - ✓ **Performance Values**
  - ✓ **TRL**

This took a lot of coordination and cooperation between Government and Industry to get right!!!!

6.0 Define Uncertainty Factors

- Data Uncertainty assessed by determining:
  - ✓ **Component TRL**
  - ✓ **Data Confidence**
- Data Uncertainty applied to criteria scores to determine plus and minus range



Data uncertainty helped visualize Results and risk!!!

7.0 Identify & Define Alternatives

- List Systems/Components
- Previous Trades
- Component Data
- Requirements

- Existing Systems
- Analysis Method,Tools
- System Assumptions

- System Alternatives
- System ID

4 → **Candidate Systems 7.1** → **Evaluate Candidates 7.2** → **Define Alternatives 7.3** → 8

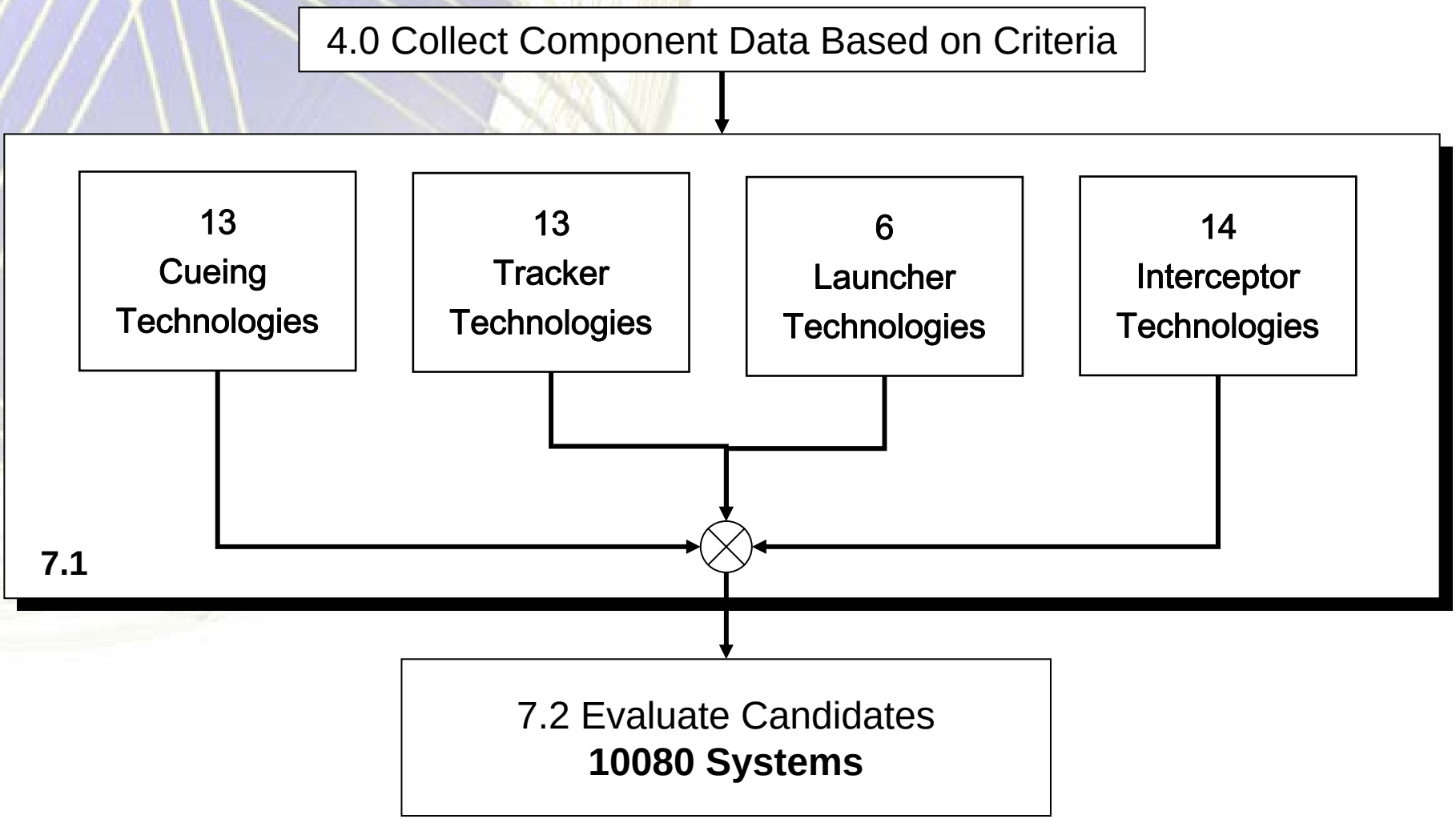
- Integrate System Candidates
- Organize Component Data
- ID Functional Architectures

- Analyze System Candidate Potential
  - Timeline
  - Accuracy
  - Component Compatibility

Reach Consensus

System and Technology Architectures Required!!!!!

7.1 Candidate Systems



All Technology Combinations Were Evaluated

Function Definitions (1 of 2)

Function	Definition
Detect, Acquire	Measure and report an event not due to ambient noise
Declare	Measure and report an persistent object that should be tracked
Classify	Measure and report what the persistent object is either by class or specific type/item.
Coarse Track	Measure and report an object and determine that it's trajectory point of closest approach to our platform is threatening. Classify and coarse track may be based on the same measured data set and completed at the same time
Initial Slew	Initial slew of launcher to launch position using fire control solution based on coarse track
Initial Tube Selection	Initial designation of launch tube or tubes in fixed system that need to be "warmed up" using fire control solution based on coarse track
Fine Track	Measure and report a target to enable calculation of a fire control solution
Fine Slew & Fire Control	Slew launcher to final position and launch an interceptor loaded with any required flight path, terminal guidance, and fuzing information
Final Tube Selection & Fire Control	Final designation of launch tube in fixed system and launch an interceptor loaded with any required flight path, terminal guidance, and fuzing information

APS system functions defined from all technology components and systems studied.

Function Definitions (2 of 2)

Function	Definition
In-Flight Track	Measure and report a target trajectory to provide in-flight guidance to an interceptor
No-Op	“No operation” - used to designate function not performed
In-Flight Guidance	Propulsion to change flight path of interceptor
Terminal Track	Measure and report a target trajectory to provide terminal guidance & fuzing updates to an interceptor
Terminal Guidance & Fuze	Orient (focus) the warhead to produce the desired effect & initiate the effect at the prescribed time and / or the prescribed distance from target
Warhead Effect	Target negation

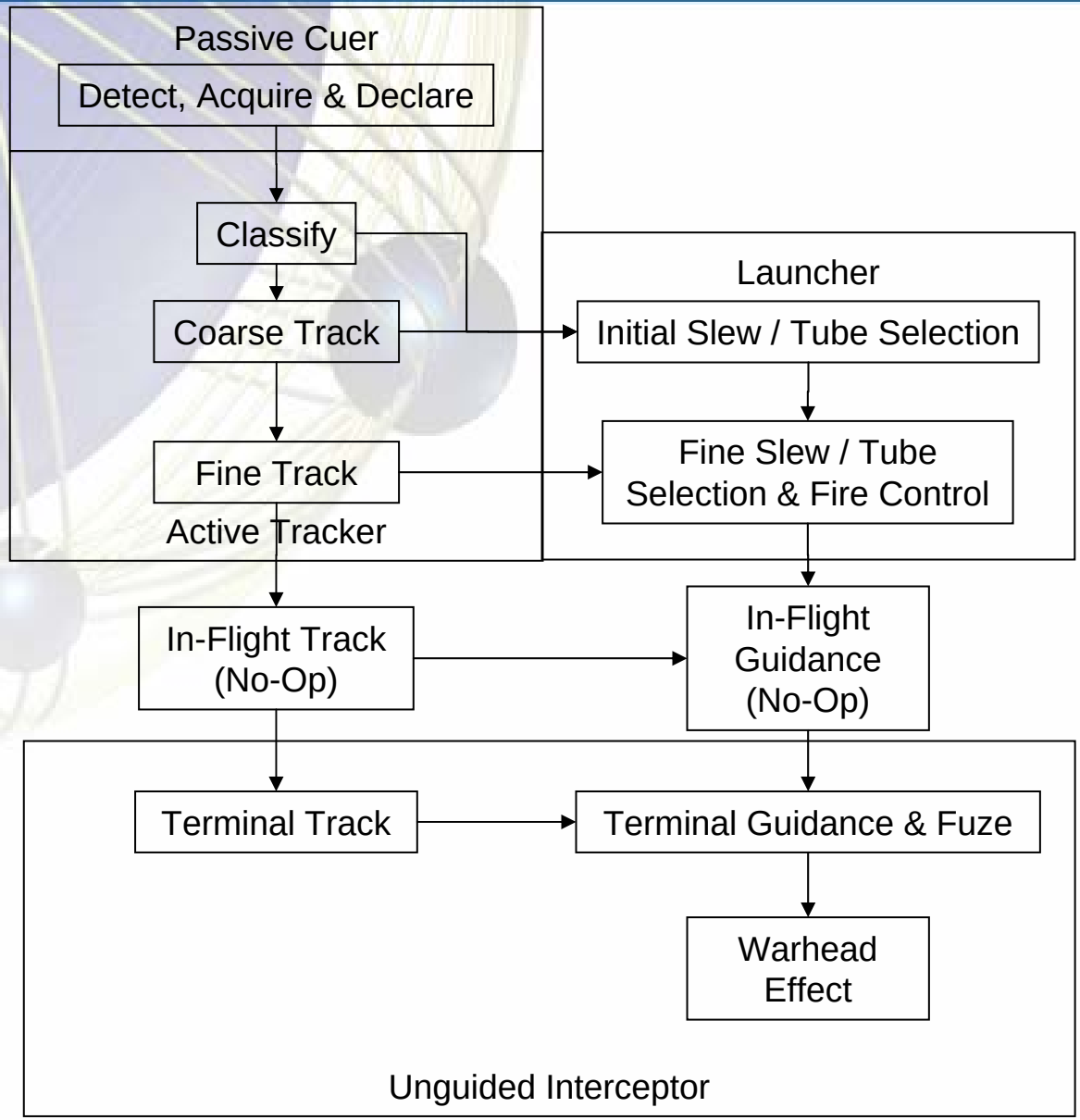
APS system functions defined from all technology components and systems studied.

Generic APS Architectures

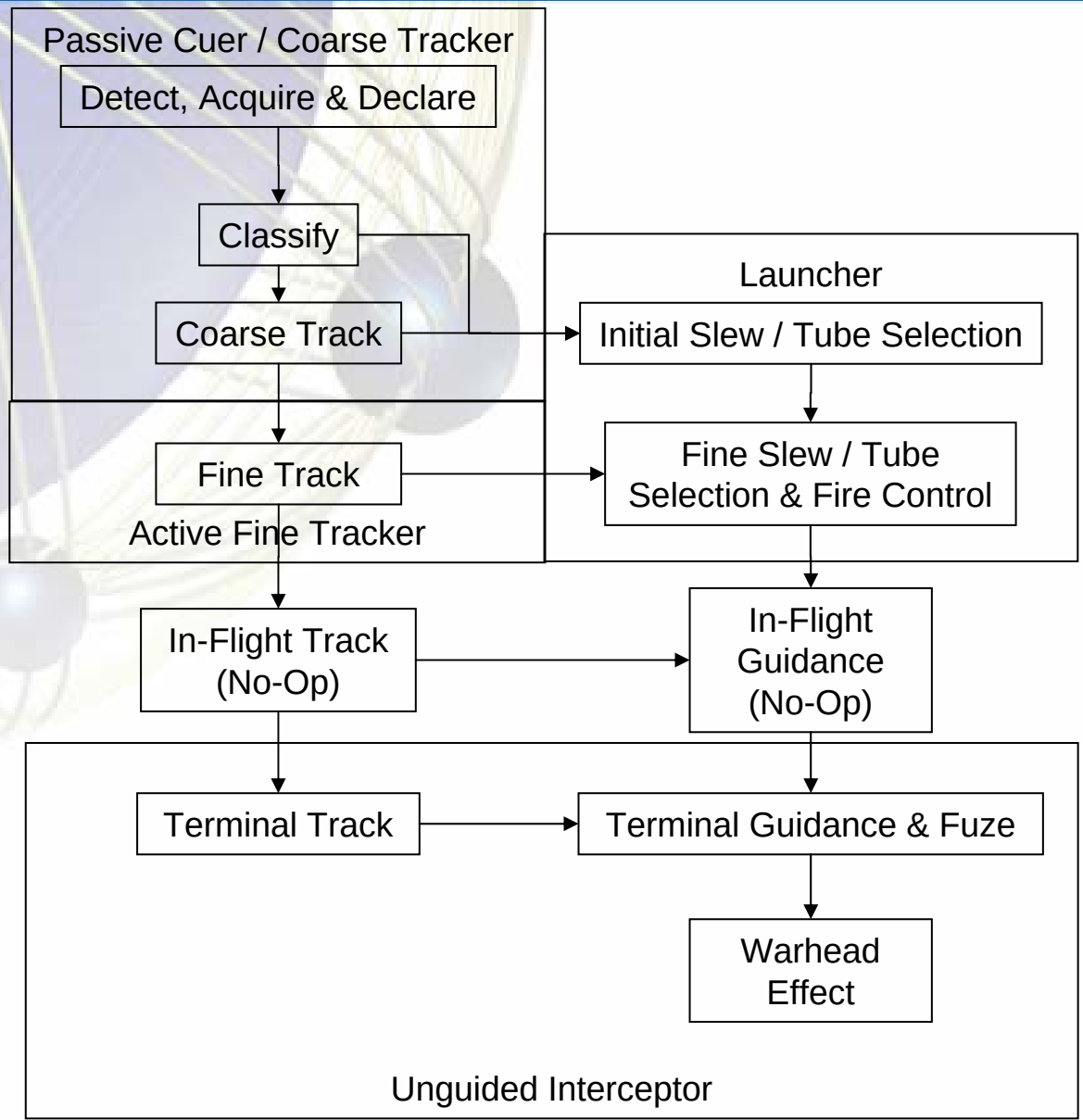
		Architectures for Unguided Interceptors				Architectures for Guided Interceptors			
		U1	U2	U3	U4	G1	G2	G3	G4
System Functions	Detect, Acquire & Declare	Passive Cuer	Passive Cuer / Coarse Tracker	Passive Cuer	Active Cuer / Tracker	Passive Cuer	Passive Cuer / Coarse Tracker	Passive Cuer	Active Cuer / Tracker
	Classify	Active Tracker		Passive or Active Coarse Tracker		Active Tracker		Passive or Active Coarse Tracker	
	Coarse Track								
	Initial Slew / Tube Selection	Launcher	Launcher	Launcher	Launcher	Launcher	Launcher	Launcher	Launcher
	Fine Track	Active Tracker	Active Fine Tracker	Active Fine Tracker	Active Cuer / Tracker	Active Tracker	Active Fine Tracker	Active Fine Tracker	Active Cuer / Tracker
	Final Slew / Tube Selection & Fire Control	Launcher	Launcher	Launcher	Launcher	Launcher	Launcher	Launcher	Launcher
	In-Flight Track	None	None	None	None	Active Tracker	Active Fine Tracker	Active Fine Tracker	Active Cuer / Tracker
	In-Flight Guidance					Guided Interceptor	Guided Interceptor	Guided Interceptor	Guided Interceptor
	Terminal Track	Unguided Interceptor	Unguided Interceptor	Unguided Interceptor	Unguided Interceptor	Active Tracker	Active Fine Tracker	Active Fine Tracker	Active Cuer / Tracker
	Terminal Guidance & Fuze					Guided Interceptor	Guided Interceptor	Guided Interceptor	Guided Interceptor
	Warhead Effect								

Functional allocation to components provided context for data provided on specific components and was critical in both the Timeline and Accuracy Analysis.

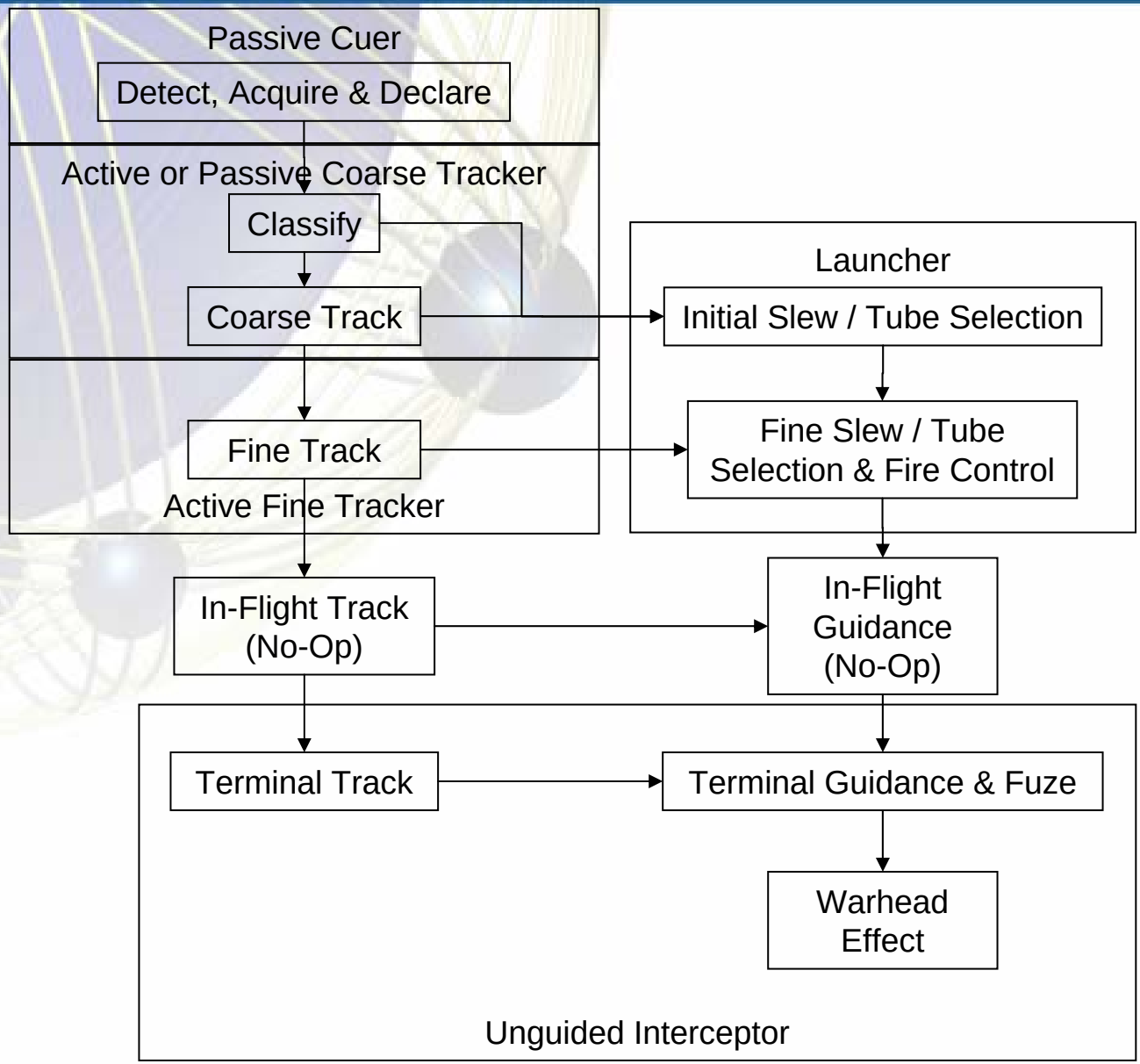
Architecture U1



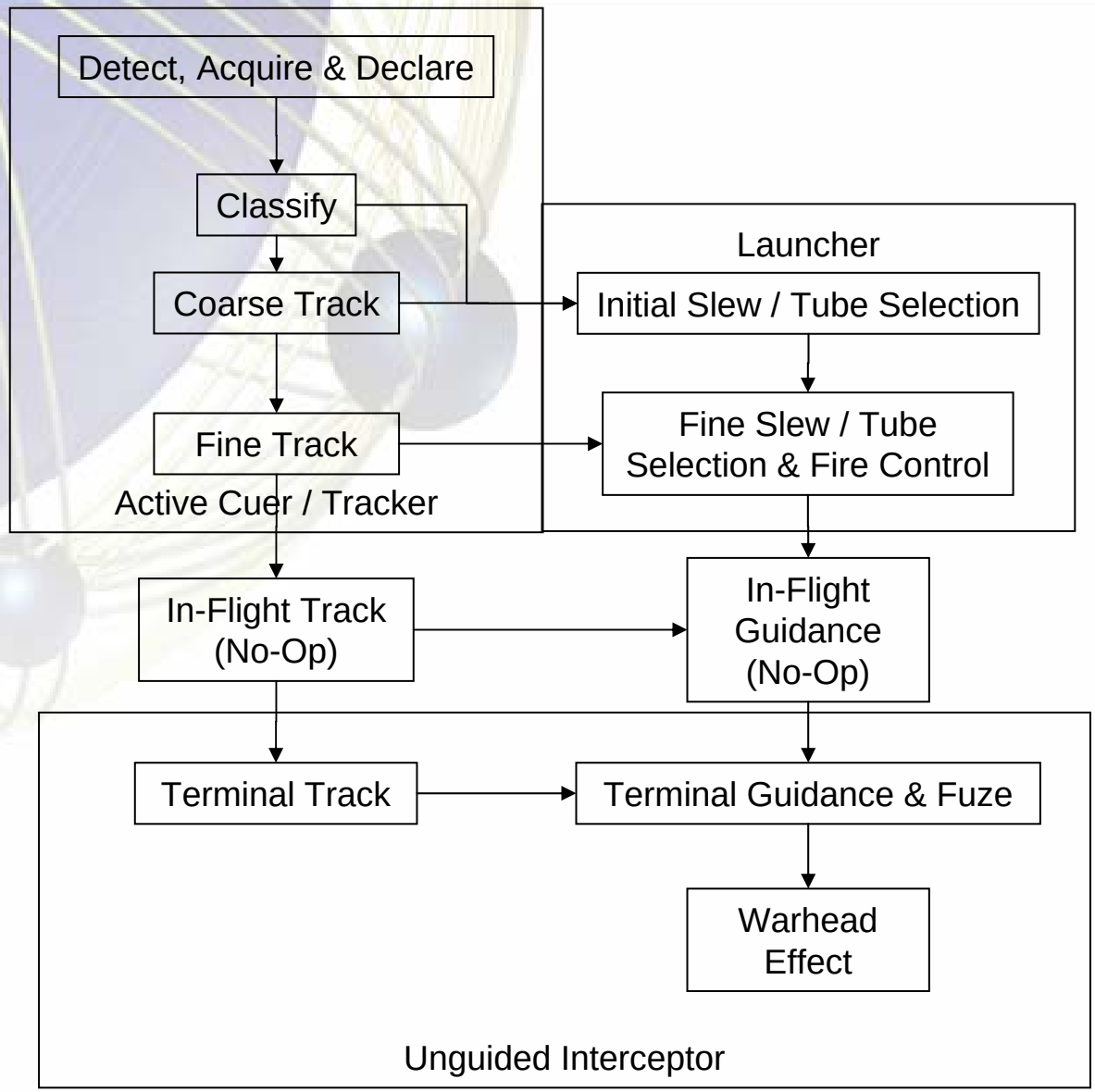
Architecture U2



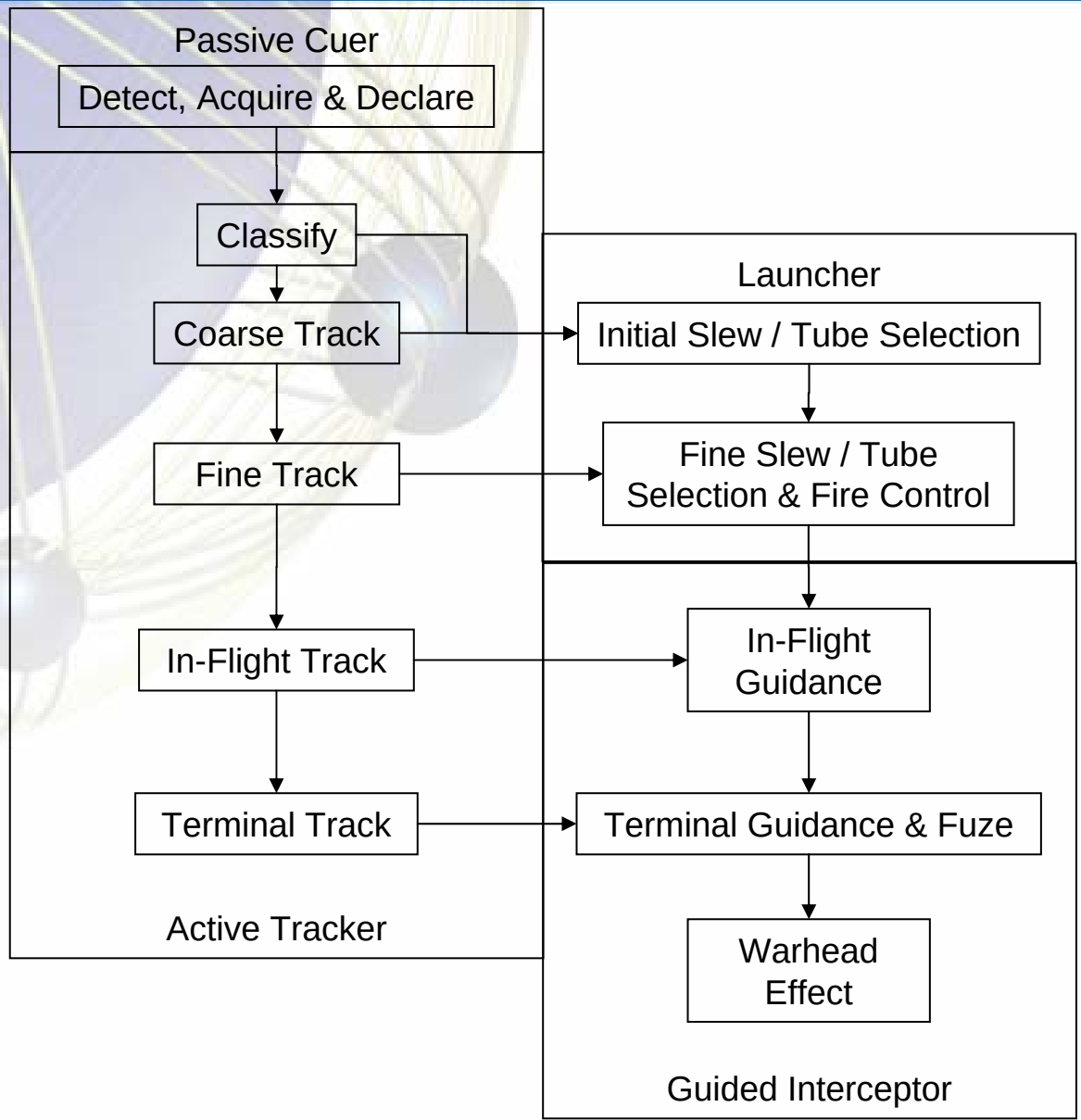
Architecture U3



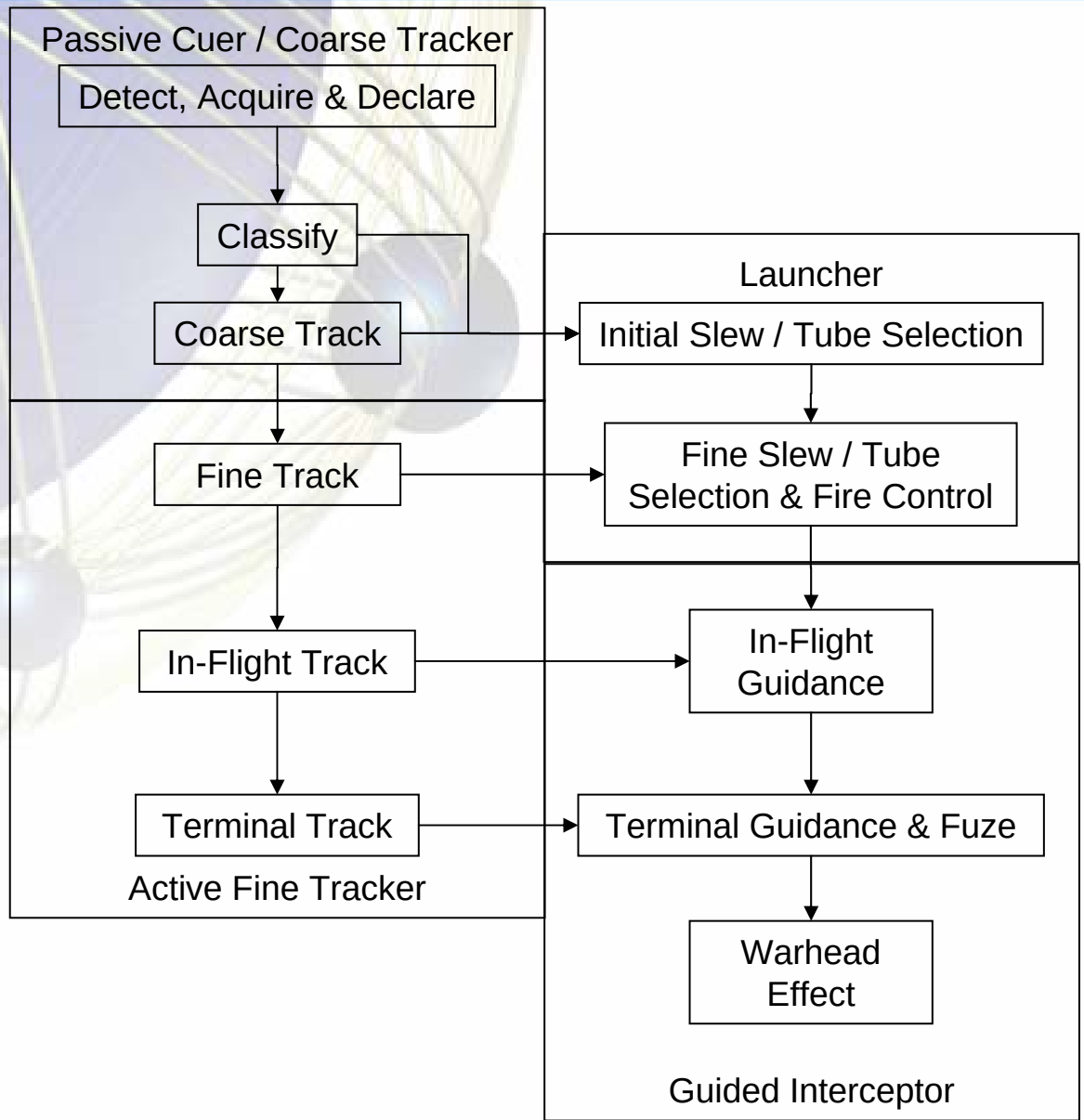
Architecture U4



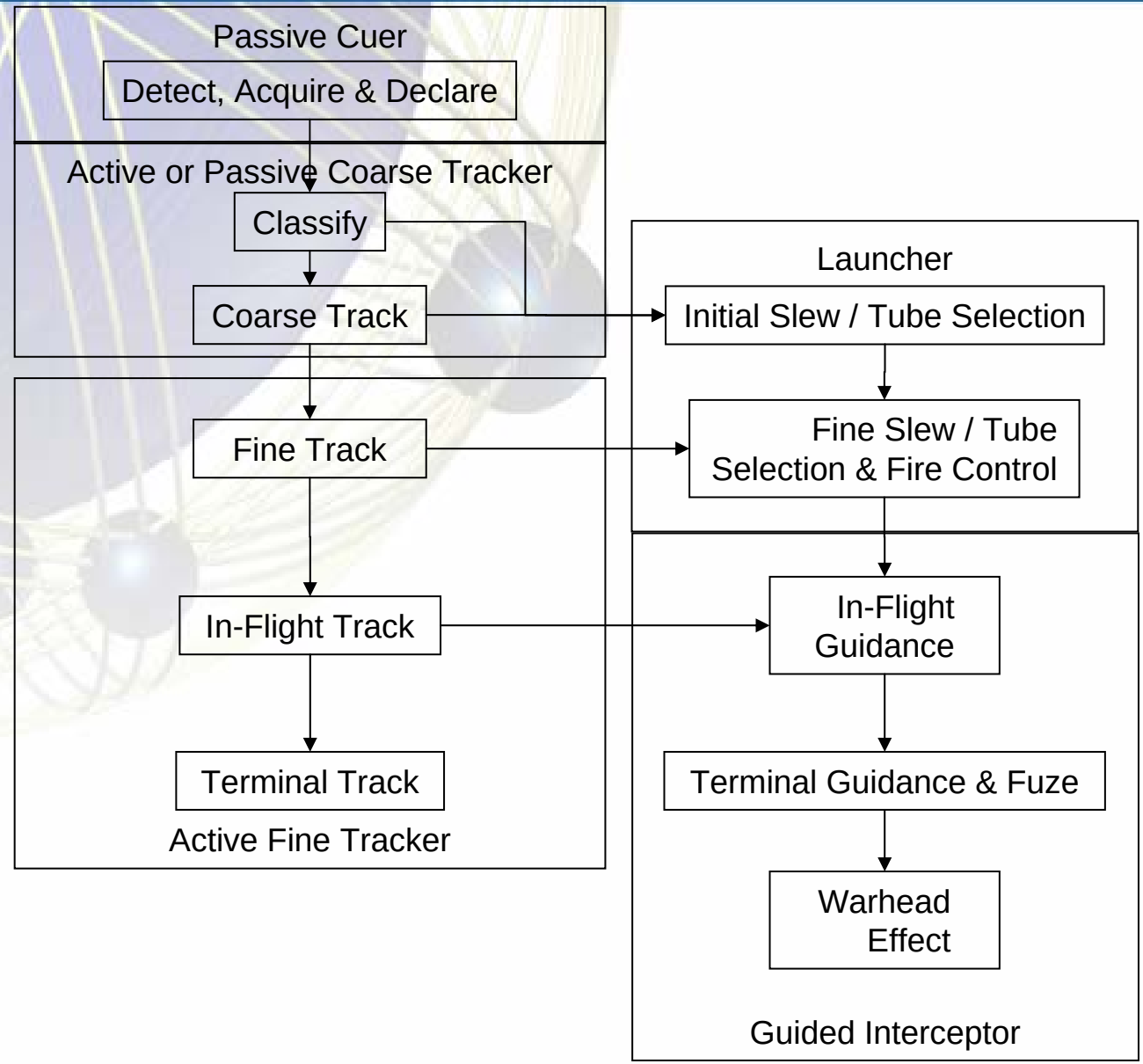
Architecture G1



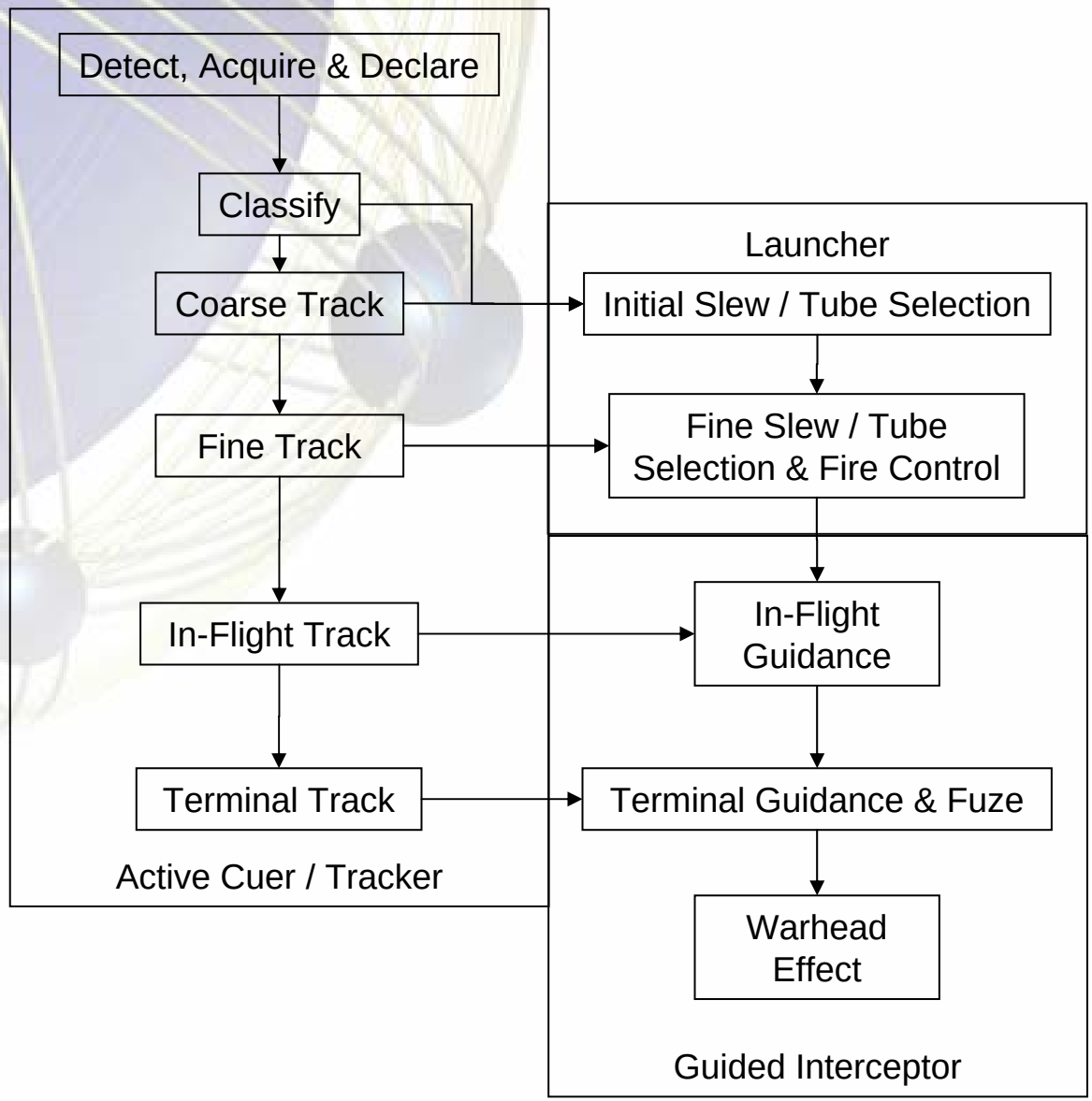
Architecture G2



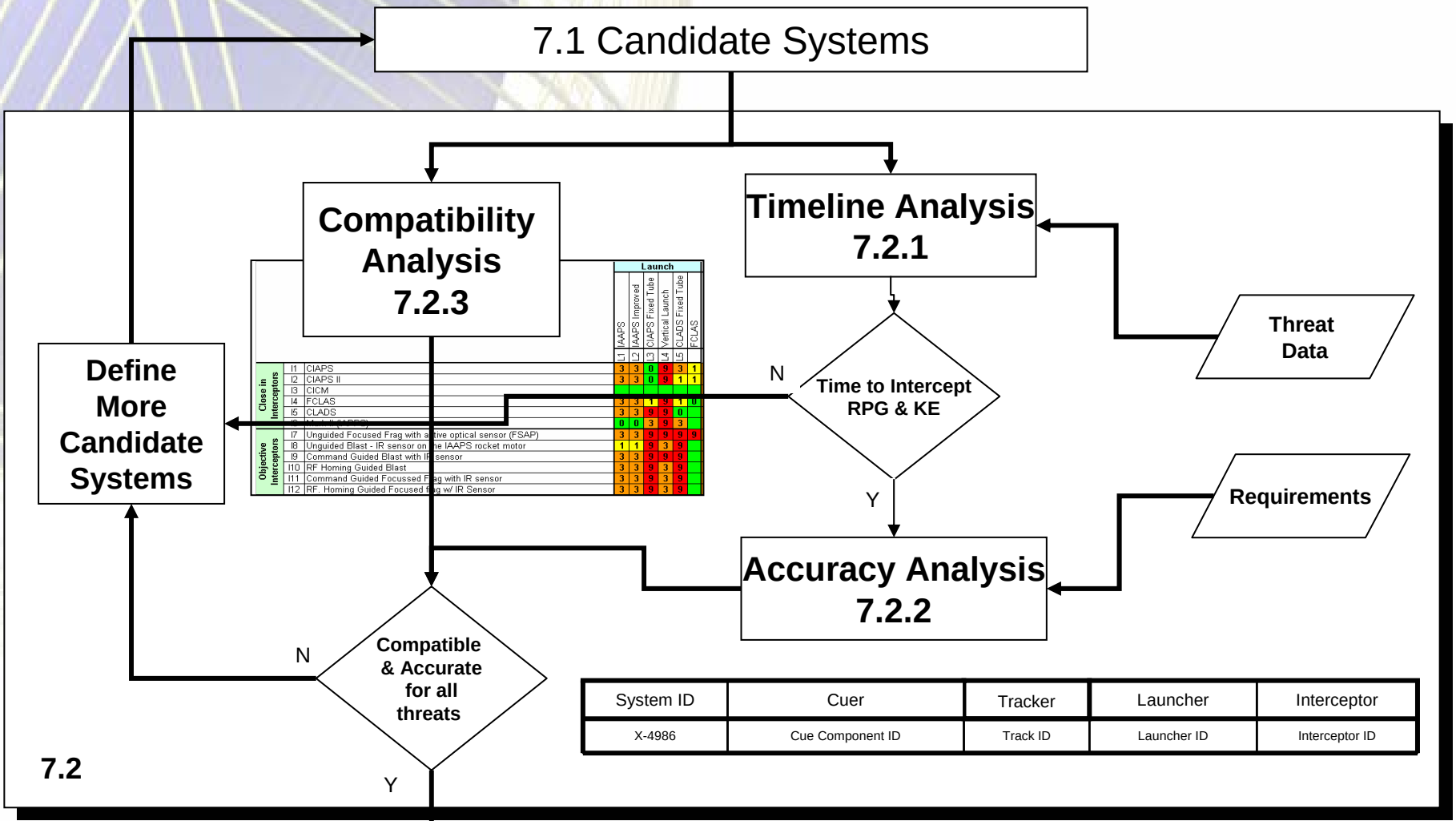
Architecture G3



Architecture G4



7.2 Evaluate Candidates

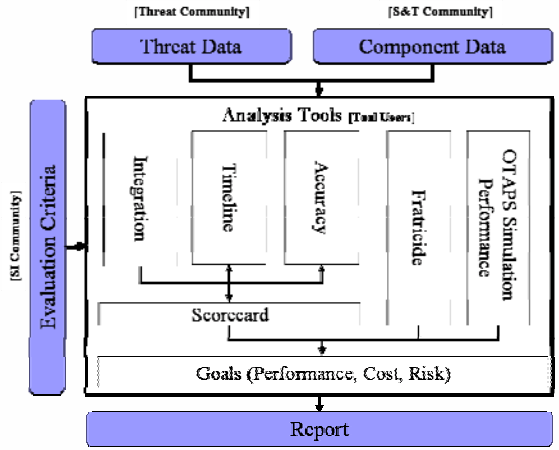


System ID was key to configuration control and essential to manage resulting data.

APS Trade Study Tool Architecture

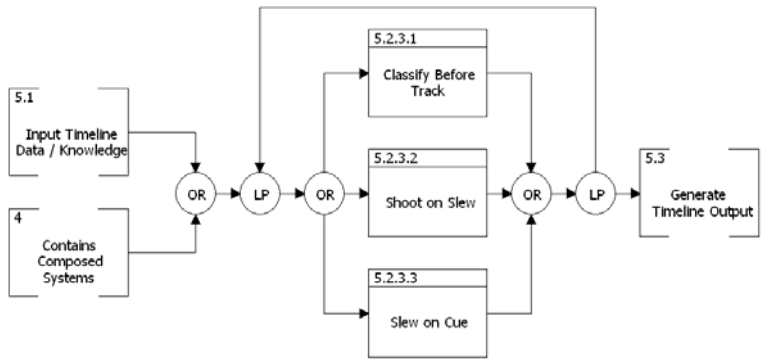
Abstract Architecture

- ❑ Schematic Block Diagrams
  - ✓ Physical Architecture
  - ✓ Interfaces

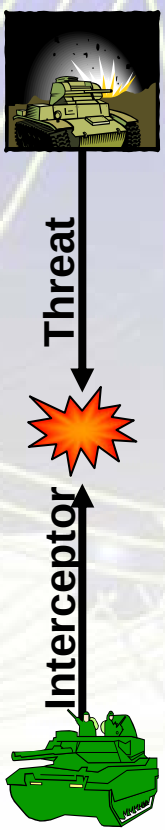


Formal Architecture

- ❑ IDEF0, FFBD, EFFBD, Hierarchy
  - ✓ Physical Architecture
  - ✓ Functional Architecture
  - ✓ Interfaces
  - ✓ Data Flow

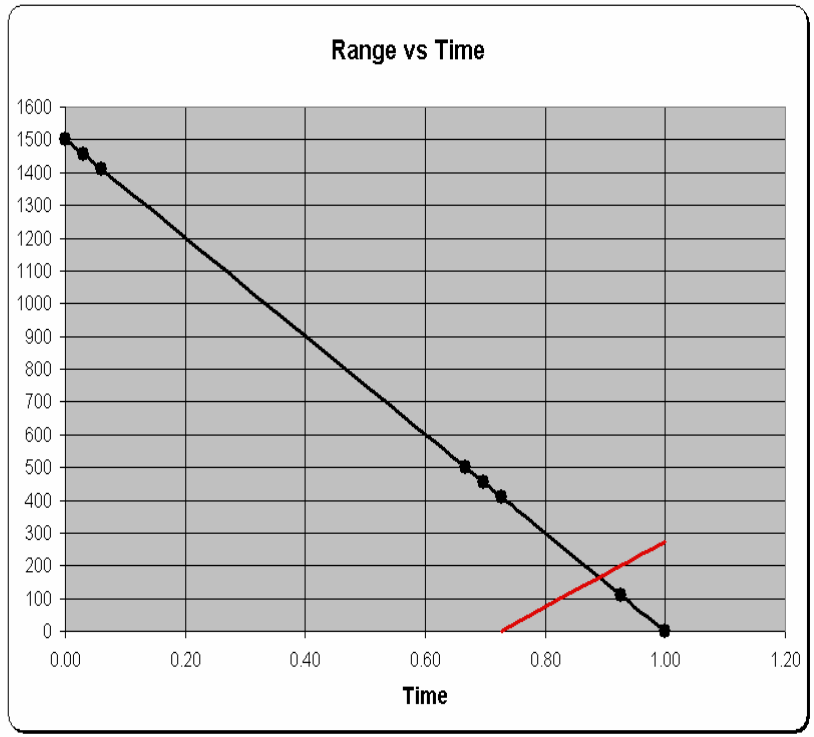


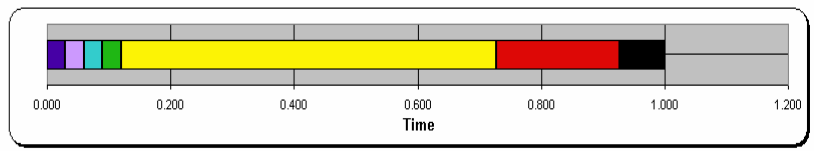
7.2.1 Timeline Analysis



Threat	Threat Launch Range	1500.00	Meters
	Threat Average Velocity	1500.00	Meters/Second
	Time to impact Platform	1.00	Seconds
	Threat Time to Intercept Point	0.87	Seconds
Interceptor	Min Range to Defeat Threat	200.00	Meters
	Time to Min Range	0.20	Seconds
	Interceptor Average Velocity	1000.00	Meters/Second

System Functions		Function Time	Timeline	Threat Range to Platform	Interceptor Range to Threat
	Threat Launch	0.000	0.00	1500	
Cue	Cue	0.030	0.03	1455	
	Track Handoff	0.000	0.03	1455	
Track	Track Established	0.030	0.06	1410	
	Min Fire Control Time	0.000	0.06	1410	
Margin		0.607	0.67	501	
Launch	Slew	0.030	0.70	456	
	Stabilize	0.030	0.73	411	
Intercept	Initiate Interceptor	0.000	0.73	411	0
	Launch & Fly Out	0.200	0.93	111	200
	Platform Defeat	0.073	1.00	9.48E-13	273.33





Pass Screen

Timeline Analysis was a first order filter used to Identify Technology Combinations that do not have potential to achieve FCS Objective APS requirements.

7.2.3 Compatibility Analysis

SCORING INSTRUCTIONS

Level	Component Compatibility Description
9	- Significant software integration with concurrently developed hardware.
3	- Hardware and/or software interfaces defined and analyzed so complexity is
1	- Software and/or hardware interfaces known but need to be revised with as
0	- Interfaces exist and no changes are required.

Hardware interface c

- Mechanical – envelope, attachment, obscuration, alignment
- Hydraulic and pneumatic - flow rates, pressures
- Mass – weight, moments of inertia, centers of gravity
- Environment – mechanical shock and vibration, particulate, el
- Thermal - temperature limits, temperature control
- Electrical – signals, voltage, power

Software interface considerations include added requirements for

- Data encryption and encoding
- Data structures
- Data storage
- Data transfer rates
- Data communication protocols
- Data processing and algorithms

Experties

0	No experties, Don't fill out scores for anything you have no exp
1	If you have seen a briefing on the technology or have only rece
3	If you have a working knowledge (understand underlying physic
9	If you are intimately involved in designing, developing, and or in

Cue - Track Results

Launch - Intercept Results

Launch - Intercept Compatibility Results

Interceptors	Launchers						
	Launcher 1	Launcher 2	Launcher 3	Launcher 4	Launcher 5	Launcher 6	Launcher 7
Interceptor 1	1	1	1	1		9	0
Interceptor 2	1	0	0	3		9	1
Interceptor 3	0	2	0	9	1	9	2
Interceptor 4	1	1	1		1		1
Interceptor 5	0	4	3	1		1	4
Interceptor 6	0	4	3	1		1	4
Interceptor 7		3	9	3	3	0	3
Interceptor 8		3	9		3		3
Interceptor 9		1	9	3	1	0	1
Interceptor 10		3	9	3	3	0	3
Interceptor 11		1	9	1	1	1	1
Interceptor 12		1	9	1	1	1	1
Interceptor 13	0	9	9		0		3

Compatibility Analysis was used to determine if the Technology Combinations interfaces were compatible and could realistically be combined to form a system.

7.3 Define Alternatives

7.2 Evaluate Candidates

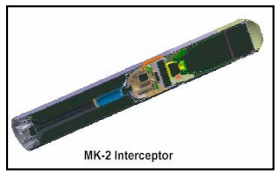
Define System Configuration 7.3.1

Define Alternative Architecture 7.3.2

Define Principle of Operation 7.3.3

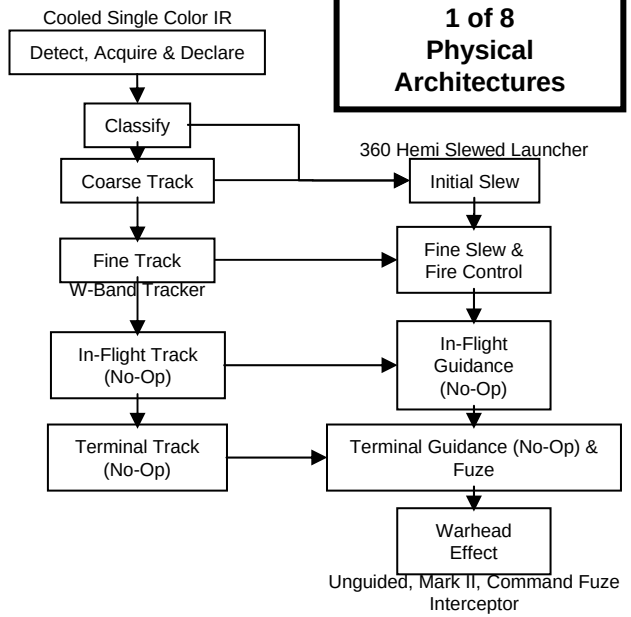
5.3

System ID	Cuer	Tracker	Launcher	Interceptor
A-**4986**	**Cuer 04**	**Tracker 09**	**Launcher 08**	**Interceptor 06**



Principle of Operations

1 of 8 Physical Architectures



8.0 Evaluate / Score Alternatives

Capture Design Details of each system that passes the timeline and accuracy analysis.

7.0 Identify & Define Alternatives

- List Systems/Components
- Previous Trades
- Component Data
- Requirements

- Existing Systems
- Analysis Method,Tools
- System Assumptions

- System Alternatives
- System ID

4 → **Candidate Systems 7.1** → **Evaluate Candidates 7.2** → **Define Alternatives 7.3** → 8

- Integrate System Candidates
- Organize Component Data
- ID Functional Architectures

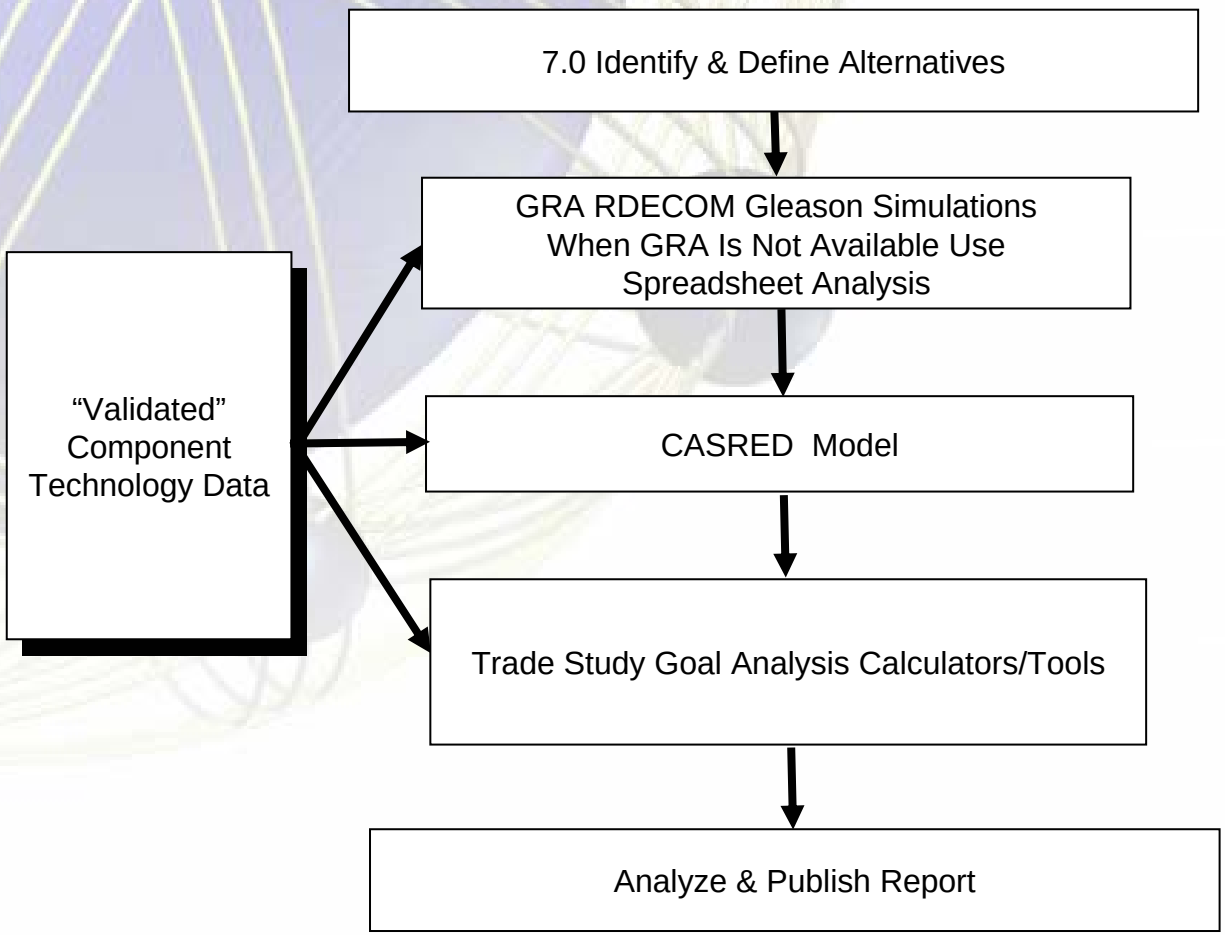
- Analyze System Candidate Potential
  - Timeline
  - Accuracy
  - Component Compatibility

Reach Consensus

System and Technology Architectures Required!!!!!

8.0 Score APS(s) Alternatives

Measure how well each of the systems meets the Goals!



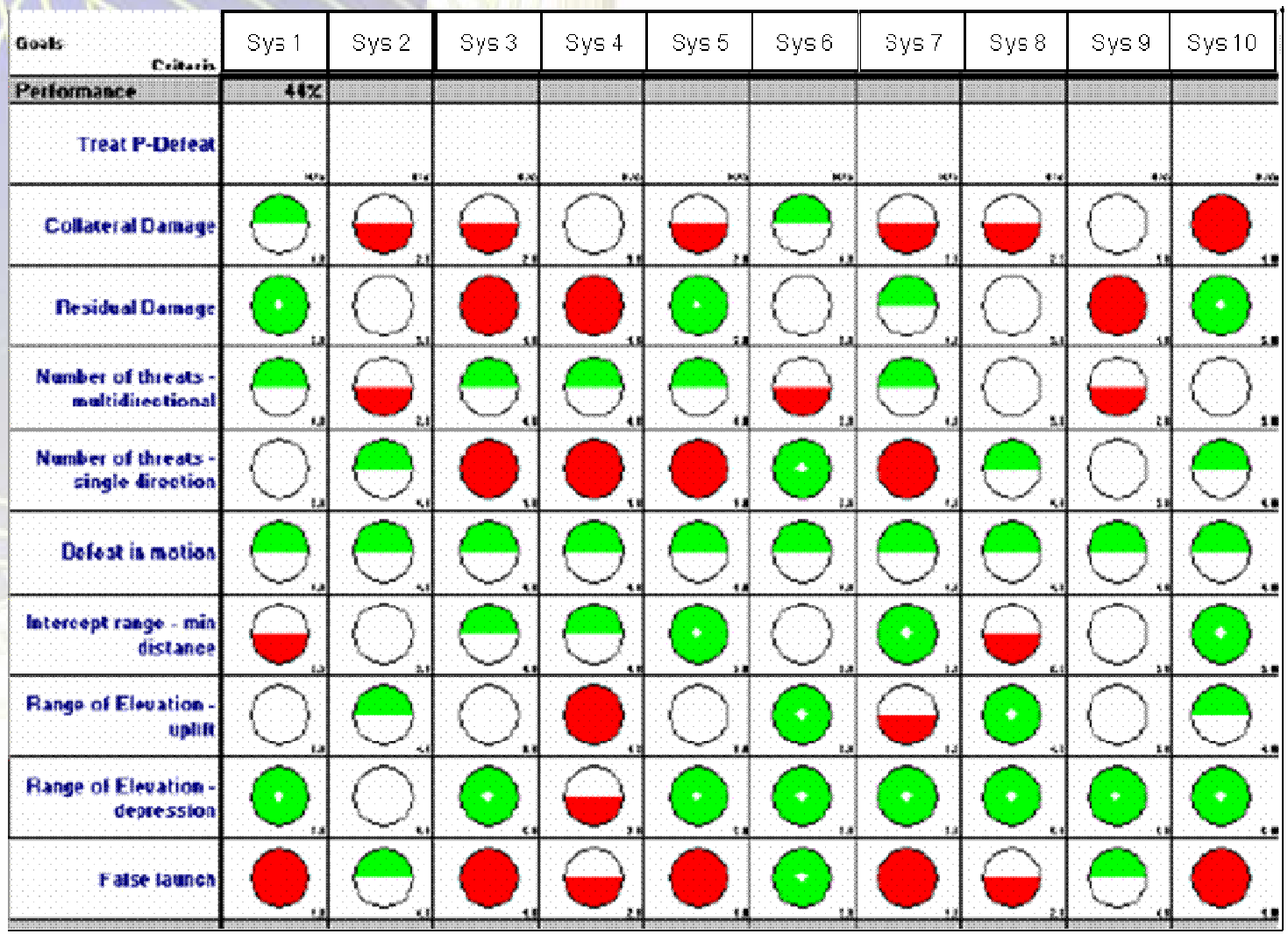
Goal 1*
Pp (Threat 1)
Pp (Threat 2)
Pp (Threat 3)

Goal 2
Max. Fratricide & Collateral Damage Control

Goal 3 - 6
Max Operability
Min Interface Needs
Min Schedule Risk
Minimize Cost

Trade Study Leverages Models/Simulations

9.0 Performance Values/Utility



Summary

- Using the program requirements to derive the evaluation criteria made the trade study results traceable to user needs.
- Involving all stakeholders early and often allowed for acceptable end results.
- Establishing a System ID scheme was key to configuration control and essential to manage resulting data.
- Capturing System Architectures was essential to understand how to model system time function and communicate it to the community.
- Tool Architecture helped to communicate how each tool was used in the trade study process.
- As a result of capturing the tool architecture
  - ✓ many tool interface gaps were identified and fixed.
  - ✓ The Schematic Block diagram was updated to be more correct.
- Tool Architecture was valuable to communicate with each tool developer interfaces
- Modeling and Simulation was a key player in conducting the APS Trade Study and helped to drive decisions. This study could not be don't without using models.
- Using a defined process were all stakeholders were involved and had a voice yielded results the community could accept.

The Systems Engineering Process was instrumental to the success of the APS Trade Study.

BACKUP SLIDES

APS Trade Study Tool Architecture

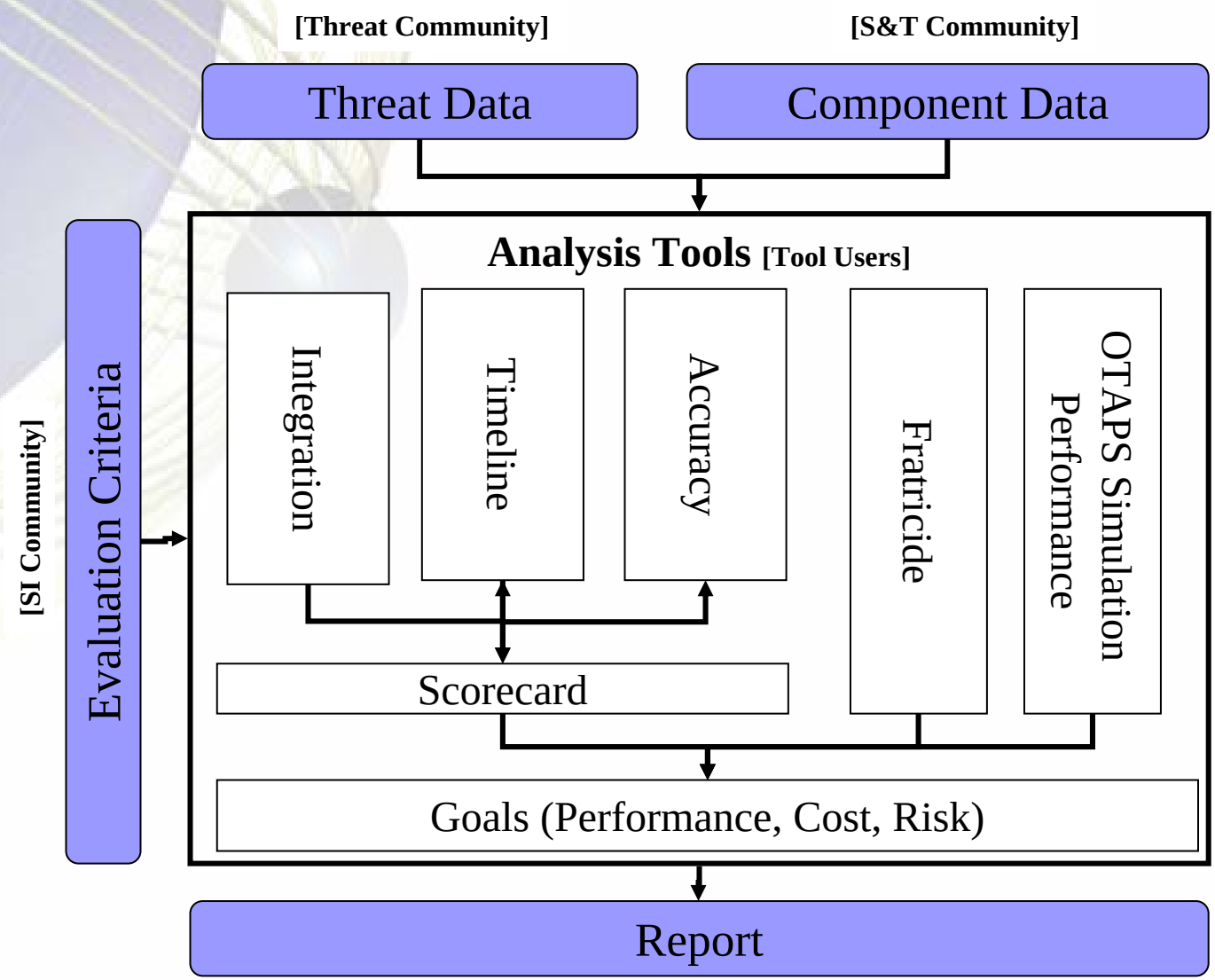
Abstract Architecture

- Schematic Block Diagrams
  - ✓ Physical Architecture
  - ✓ Interfaces

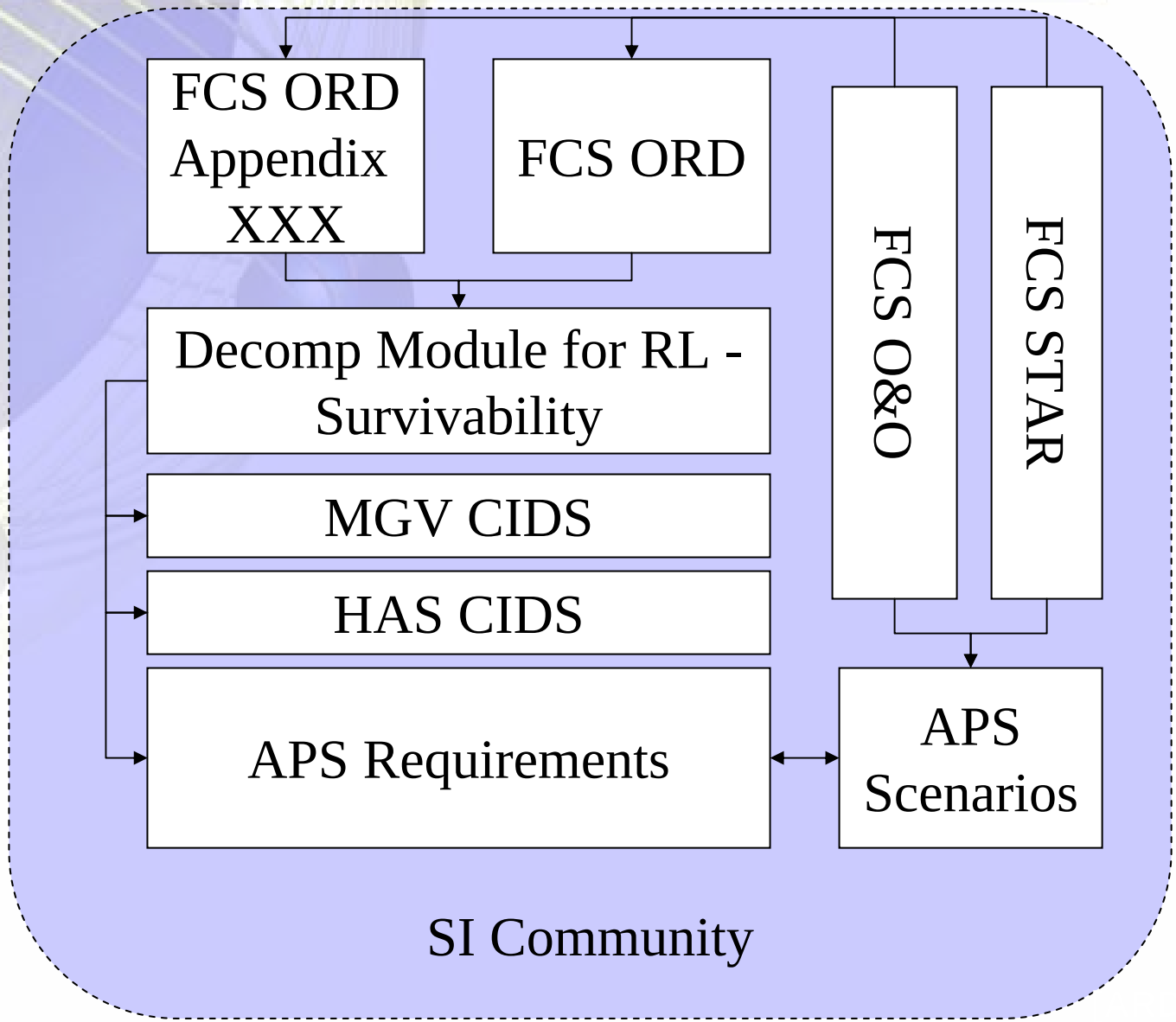
Formal Architecture

- IDEF0, FFBD, EFFBD, Hierarchy

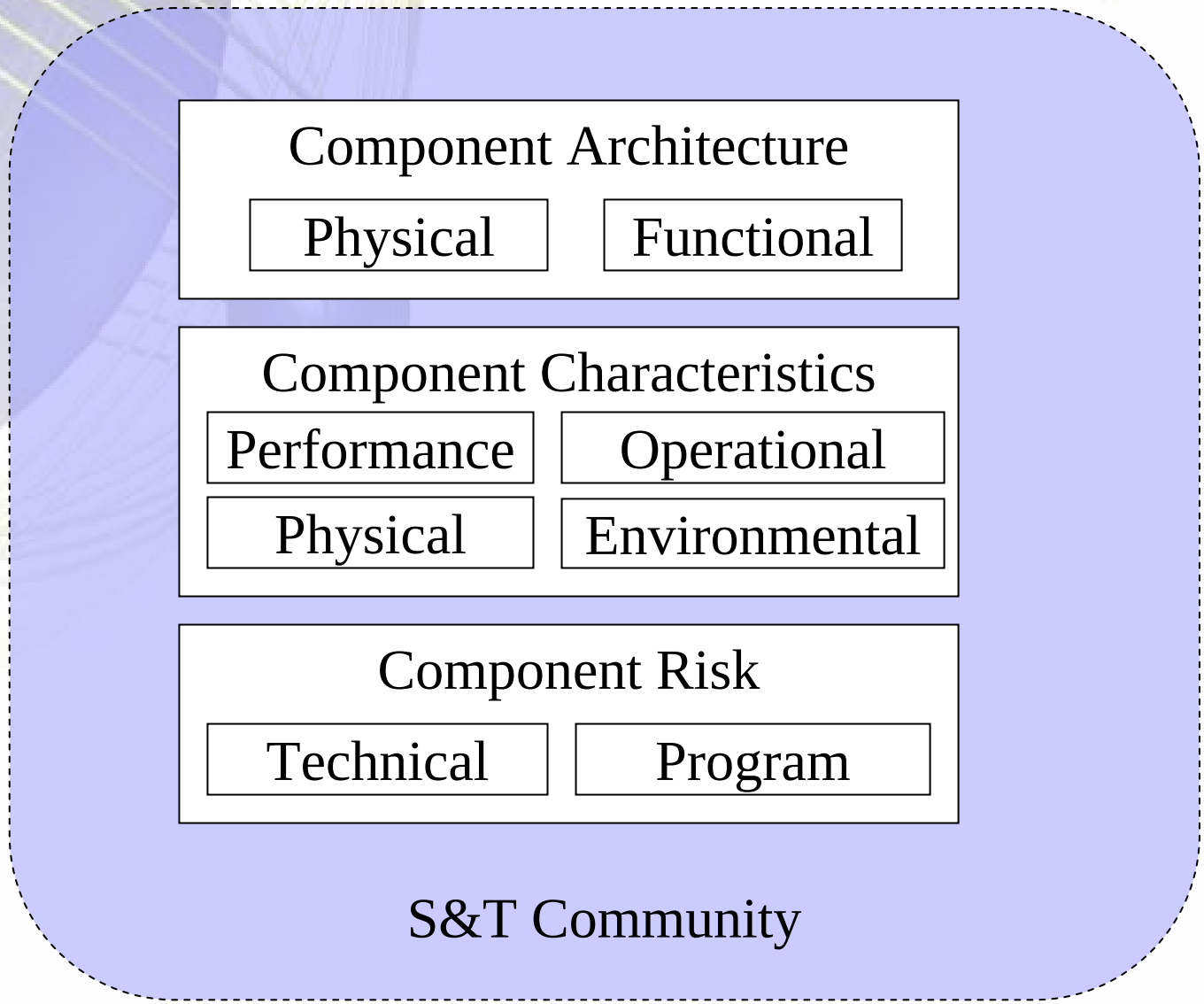
Schematic Block Diagram



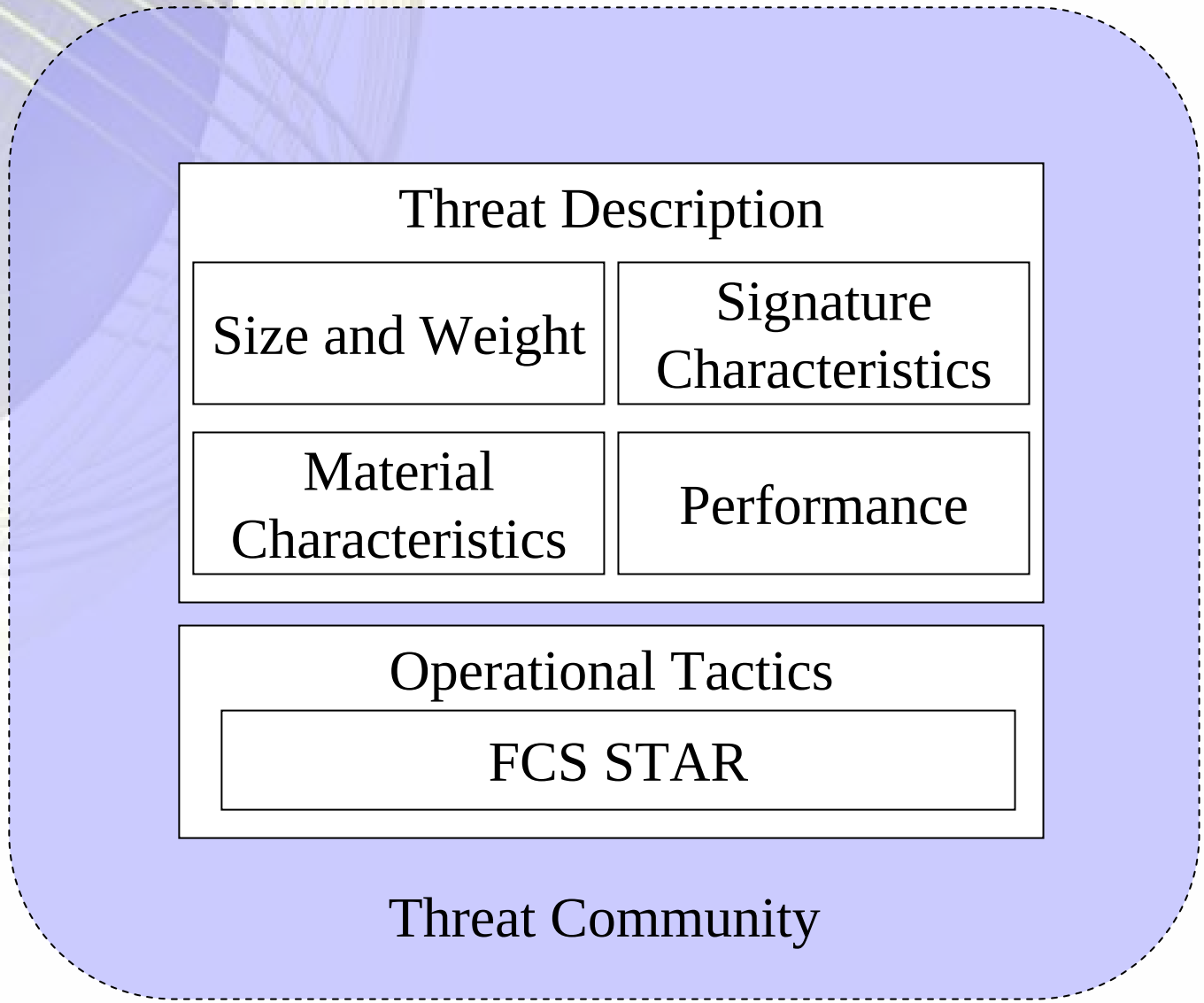
Evaluation Criteria



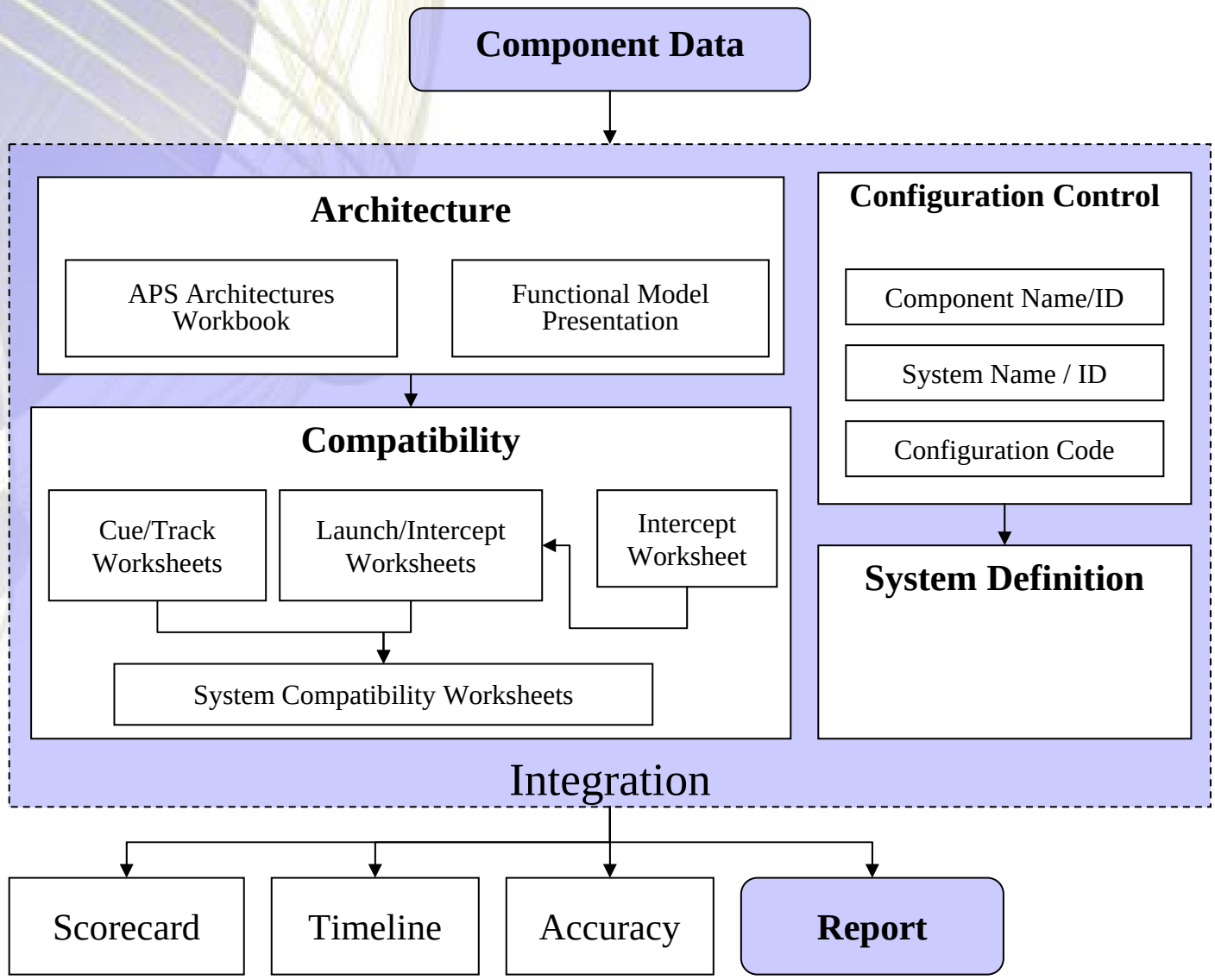
Component Data



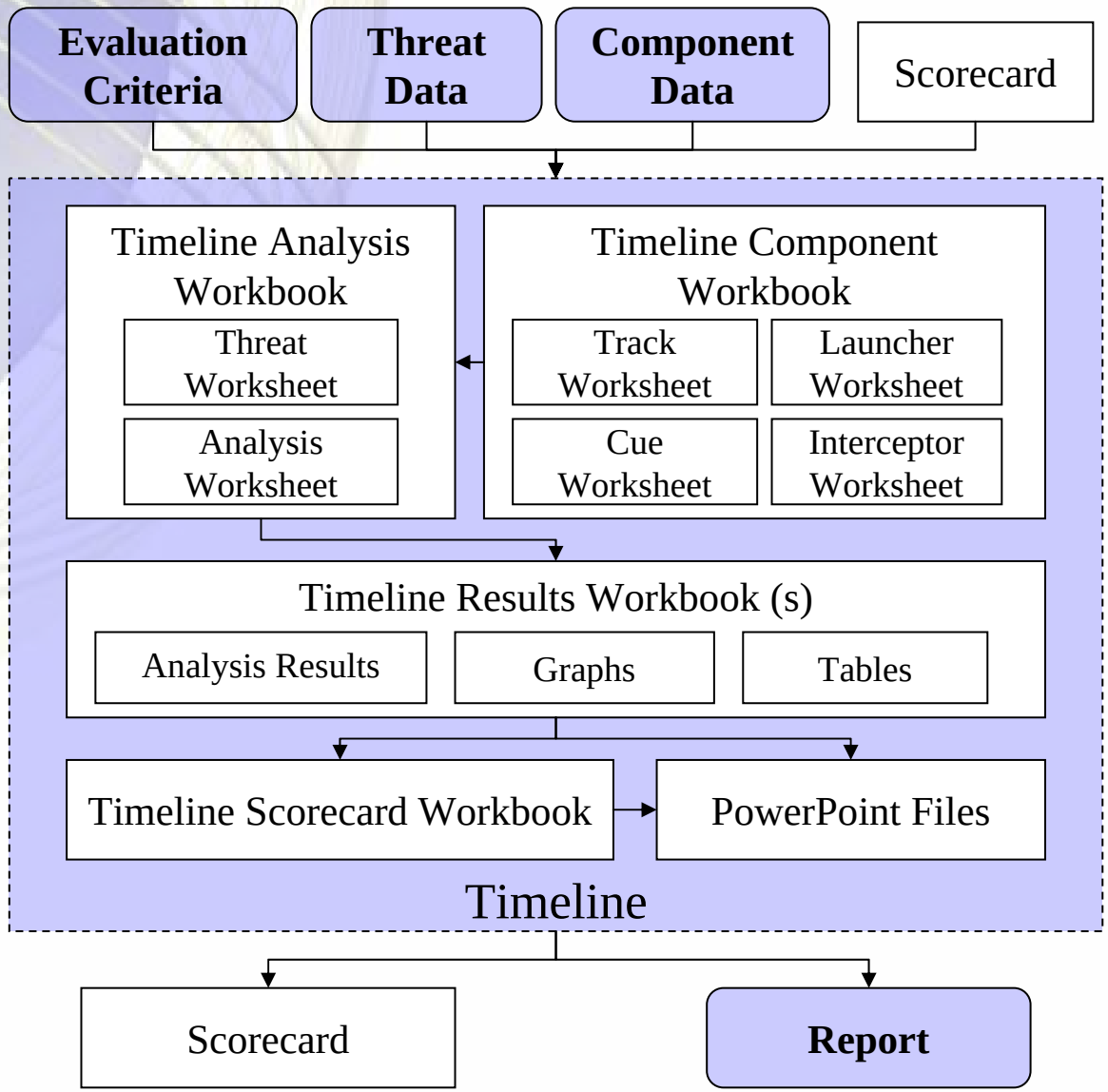
Threat Data


Threat Description
Size and Weight
Signature Characteristics
Material Characteristics
Performance
Operational Tactics
FCS STAR
Threat Community

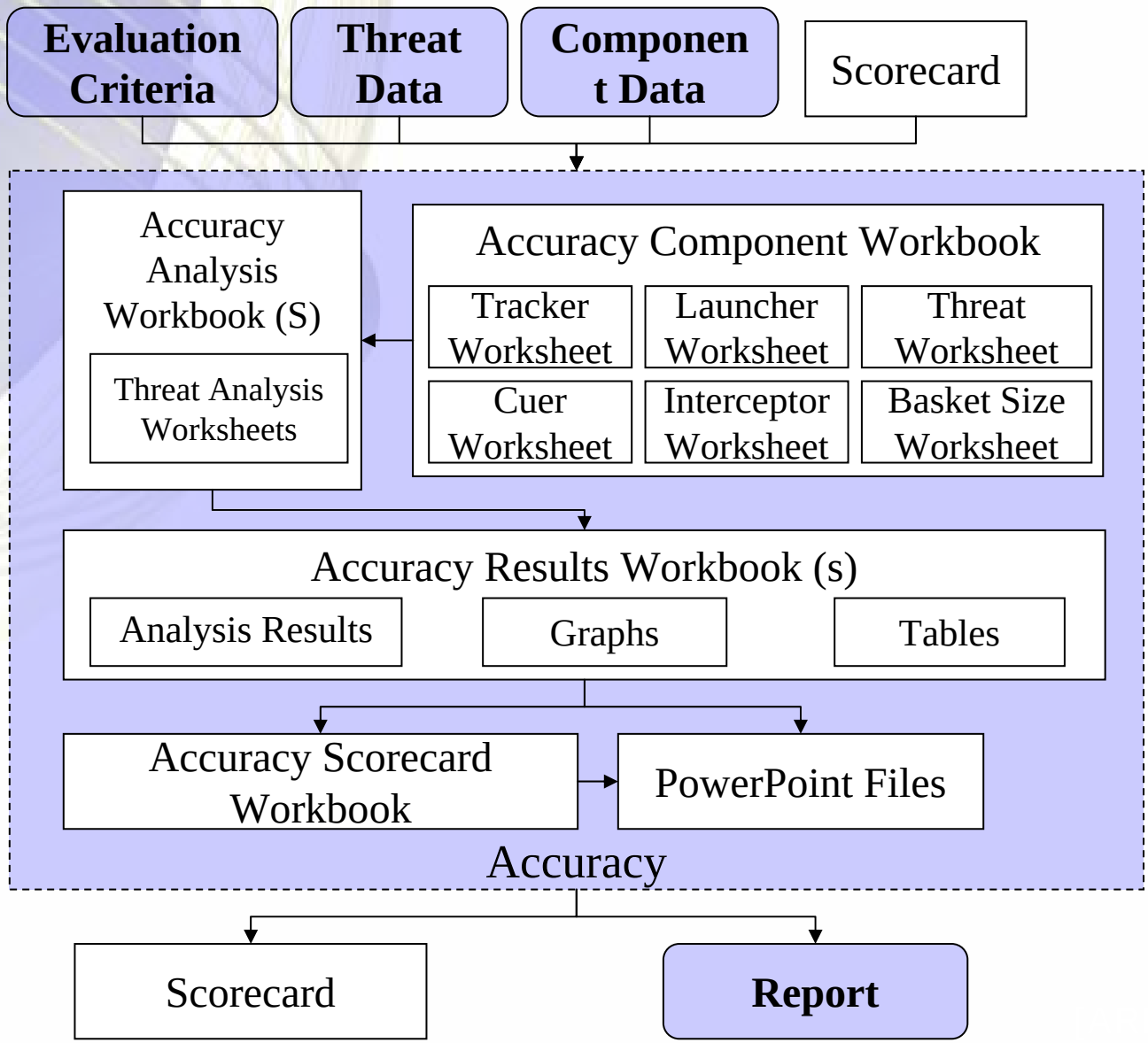
Integration



Timeline


Evaluation Criteria
Threat Data
Component Data
Scorecard
Timeline Analysis Workbook
Threat Worksheet
Analysis Worksheet
Timeline Component Workbook
Track Worksheet
Launcher Worksheet
Cue Worksheet
Interceptor Worksheet
Timeline Results Workbook (s)
Analysis Results
Graphs
Tables
Timeline Scorecard Workbook
PowerPoint Files
Timeline
Scorecard
Report

Accuracy


Evaluation Criteria
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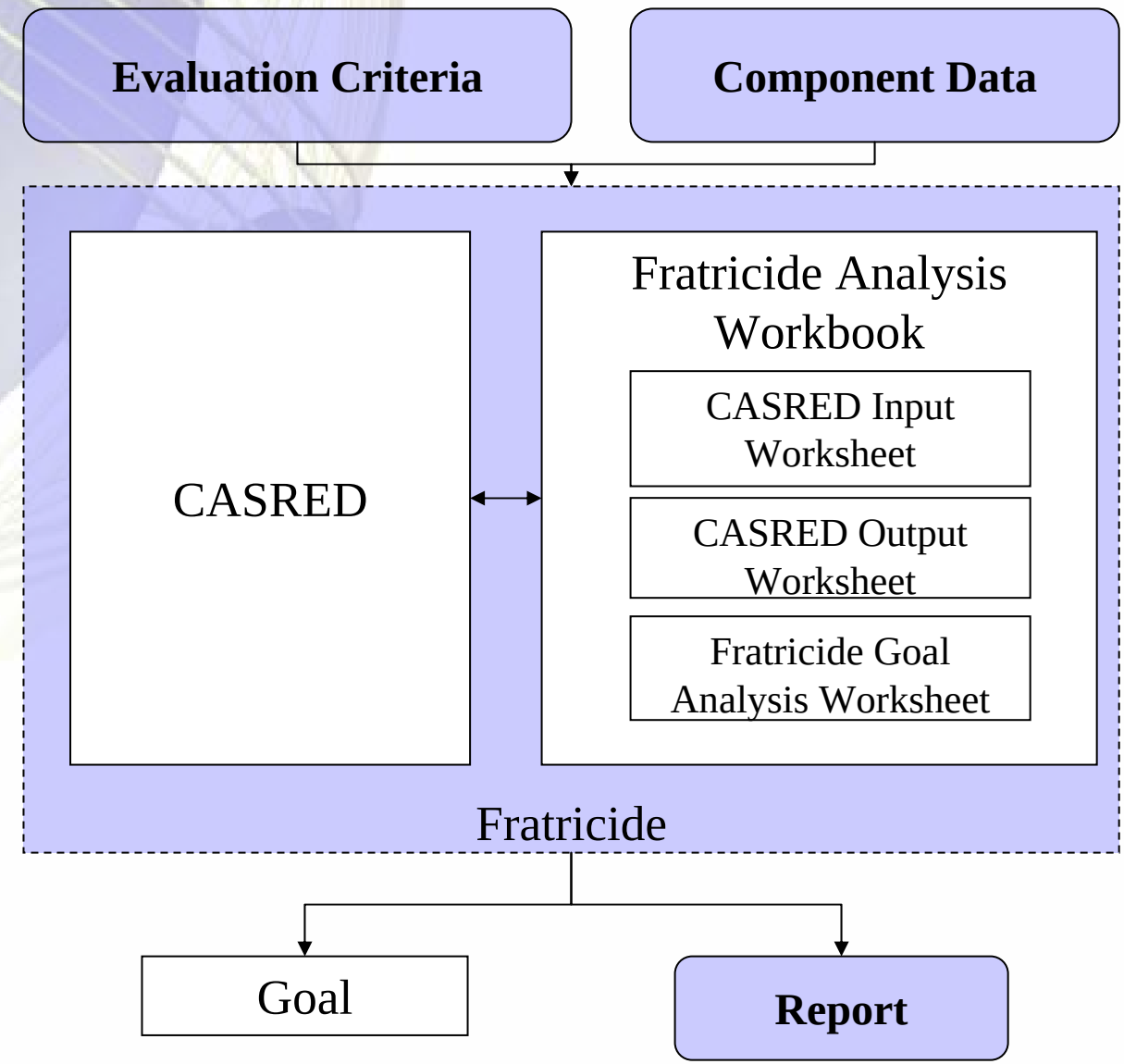
Threat Analysis Worksheets
Accuracy Component Workbook
Tracker Worksheet
Launcher Worksheet
Threat Worksheet
Cuer Worksheet
Interceptor Worksheet
Basket Size Worksheet
Accuracy Results Workbook (s)
Analysis Results
Graphs
Tables
Accuracy Scorecard Workbook
PowerPoint Files
Accuracy
Scorecard
Report

Fratricide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CASRED Input Worksheet
CASRED Output Worksheet
Fratricide Goal Analysis Worksheet
Fratricide
Goal
Report

Home
Threat Data
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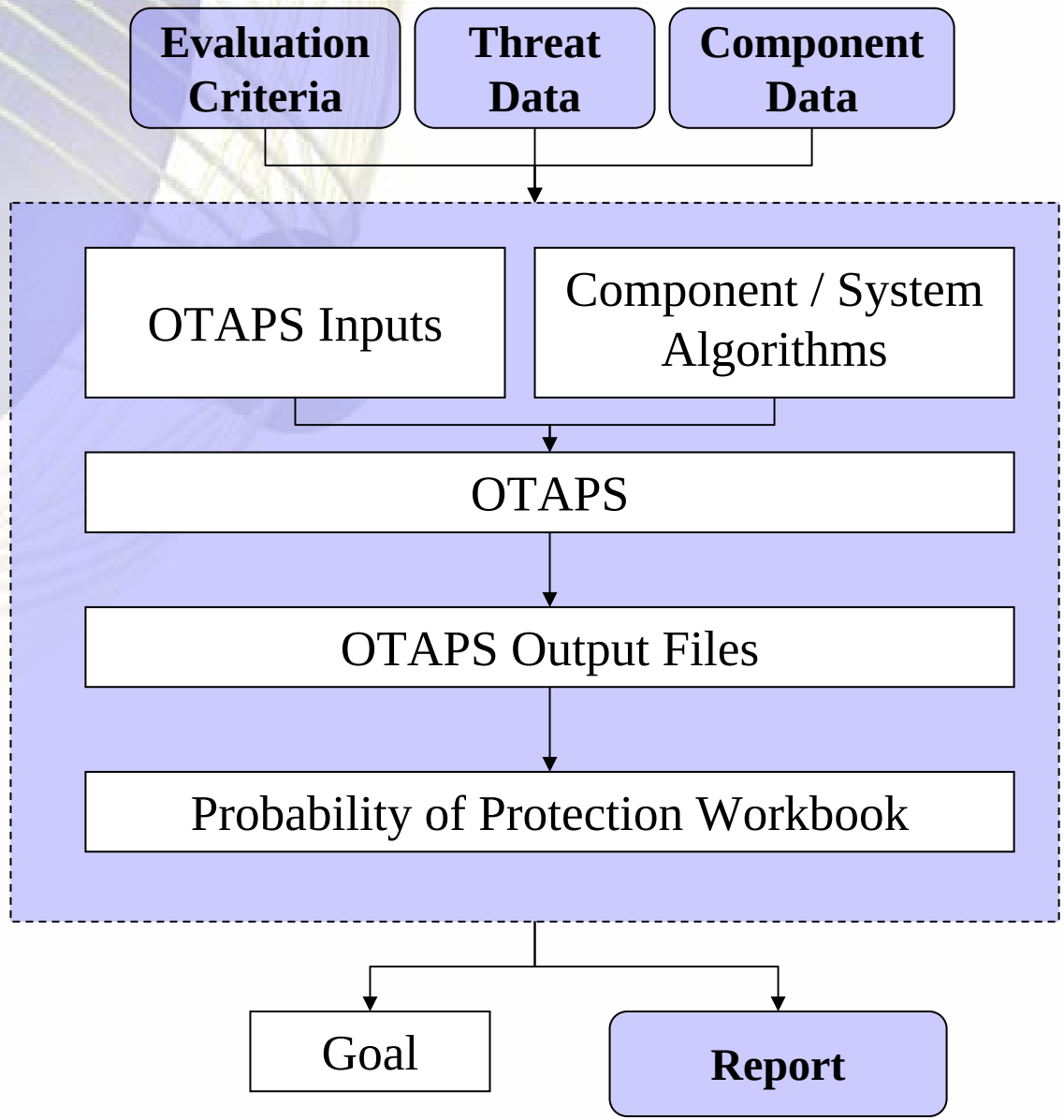
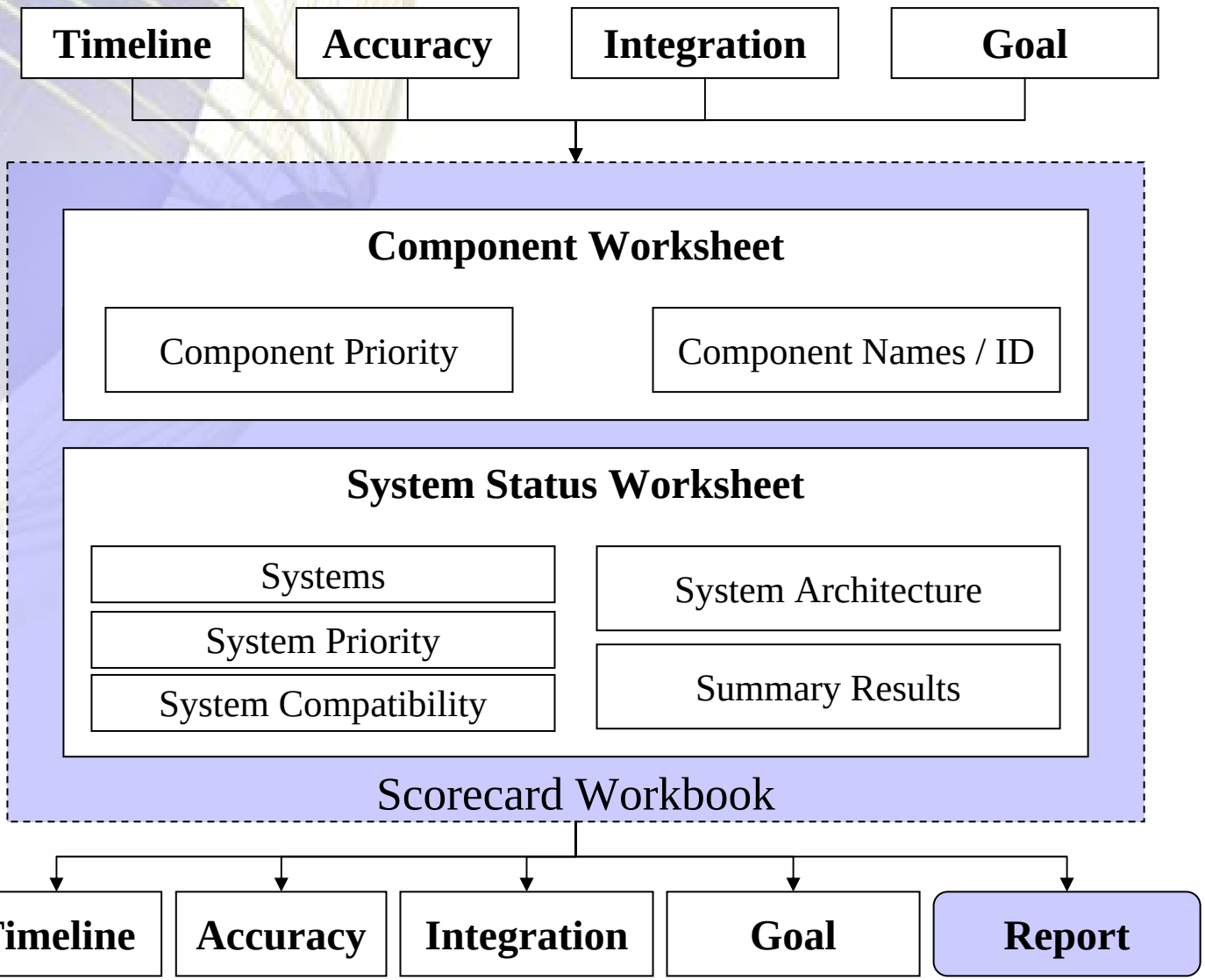
Integration
Fratricide
OTAPS Simulation
Scorecard
Goal
Report

OTAPS Simulation



Home
Threat Data
Component Data
Evaluation Criteria
Timeline
Accuracy
Integration
Fratricide
OTAPS Simulation
Scorecard
Goal
Report

Scorecard



Goal

Scorecard | **Goal** | **Fratricide** | **Component Data**

Goal Component Database Workbook

- Cue Worksheet
- Launch Worksheet
- Track Worksheet
- Intercept Worksheet

Power Point Files

Goal Workbook

Systems & Data Worksheet	Rules Worksheet	Perf vs LR Cost	Shapes
Goal 1-6 Worksheets	Utility Worksheets	Fratricide vs LR Cost	Rules Worksheet

Goal

Report

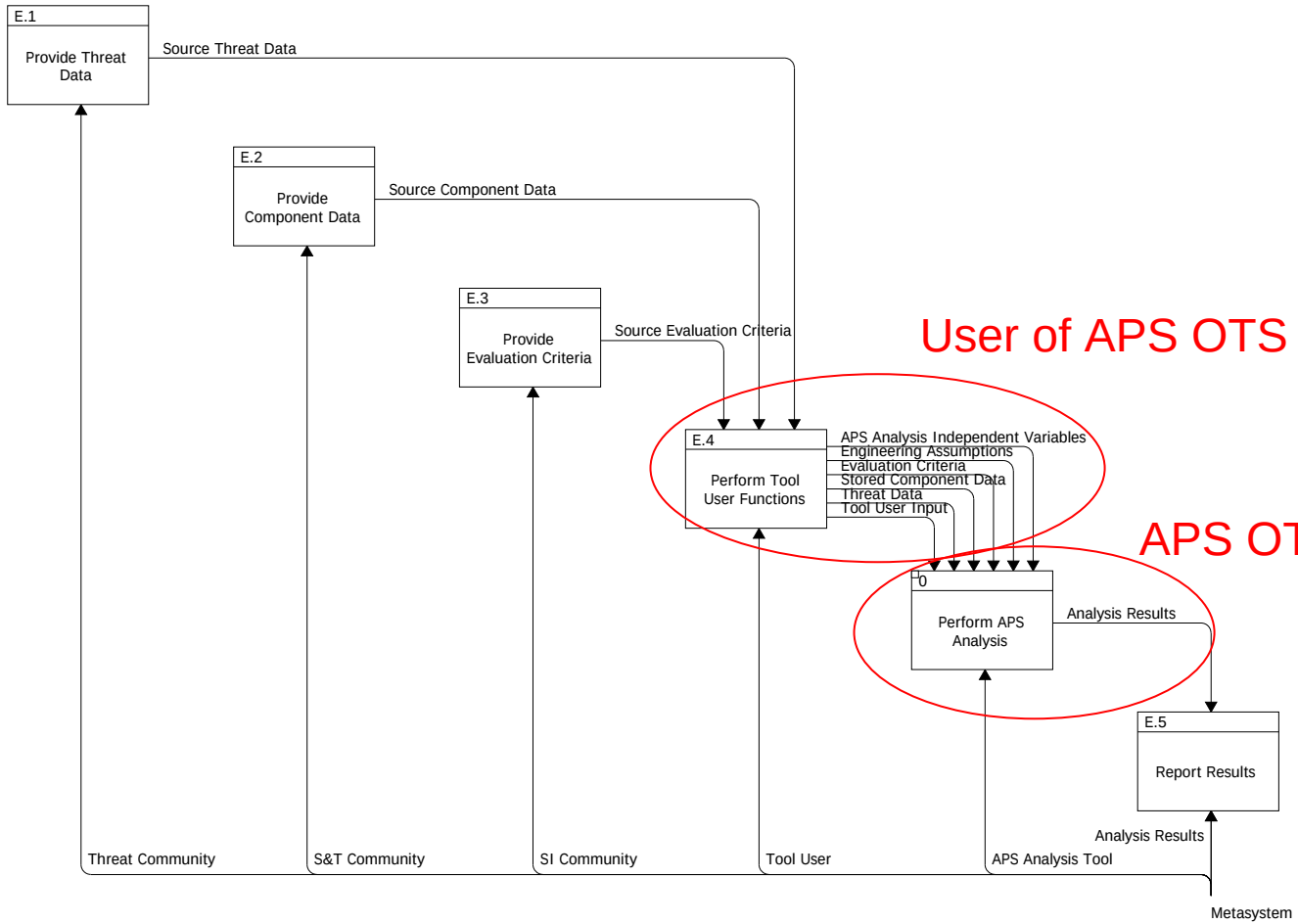
Report

- Accuracy Analysis Results
- Timeline Analysis Results
- Fratricide Analysis Results
- Systems Traded
- Component Traded
- Architectures Traded
- Threats Evaluated
- Evaluation Criteria
- OTAPS Results
- Goal Results
- Insights

APS Trade Study Tool Architecture

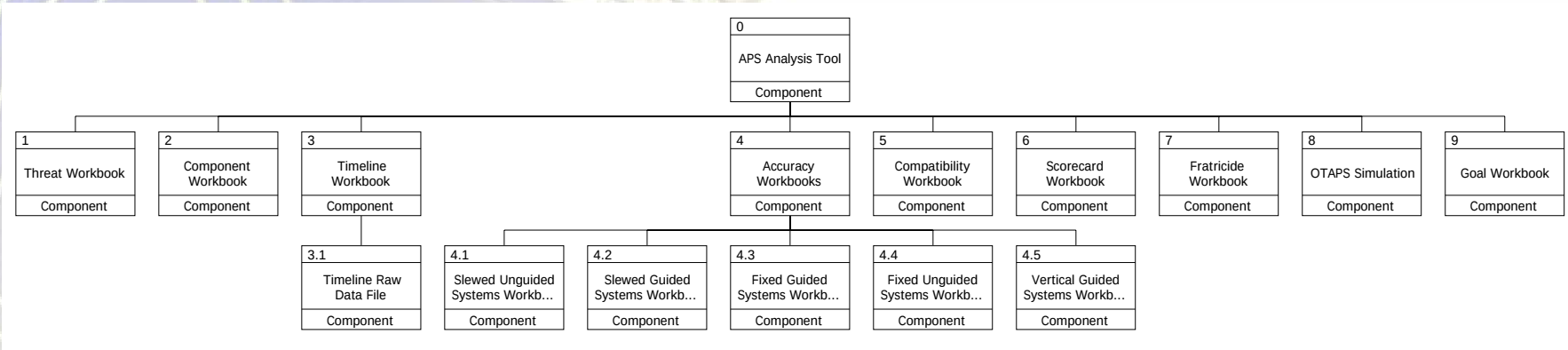
Core Architecture Model

Analysis Tool Context Diagram IDEF0



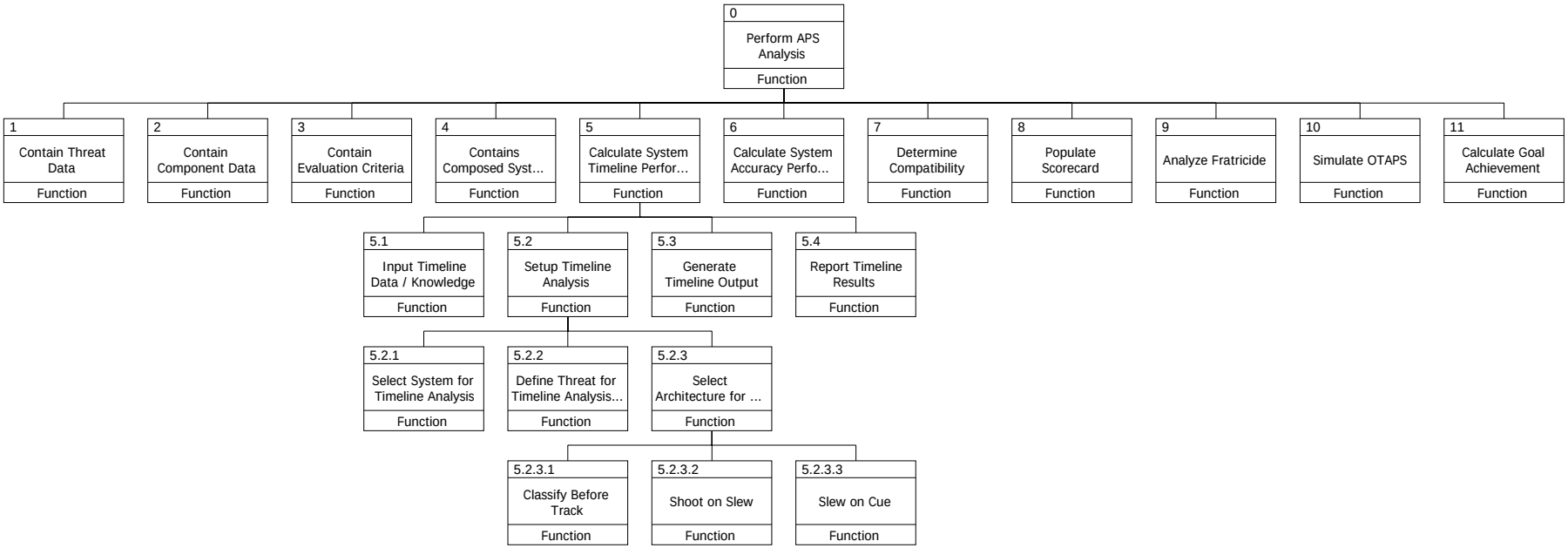
The context diagram shows the information interactions of the APS OTS Tool with the external system functions with which it interfaces

APS Analysis Tool Hierarchy Diagram



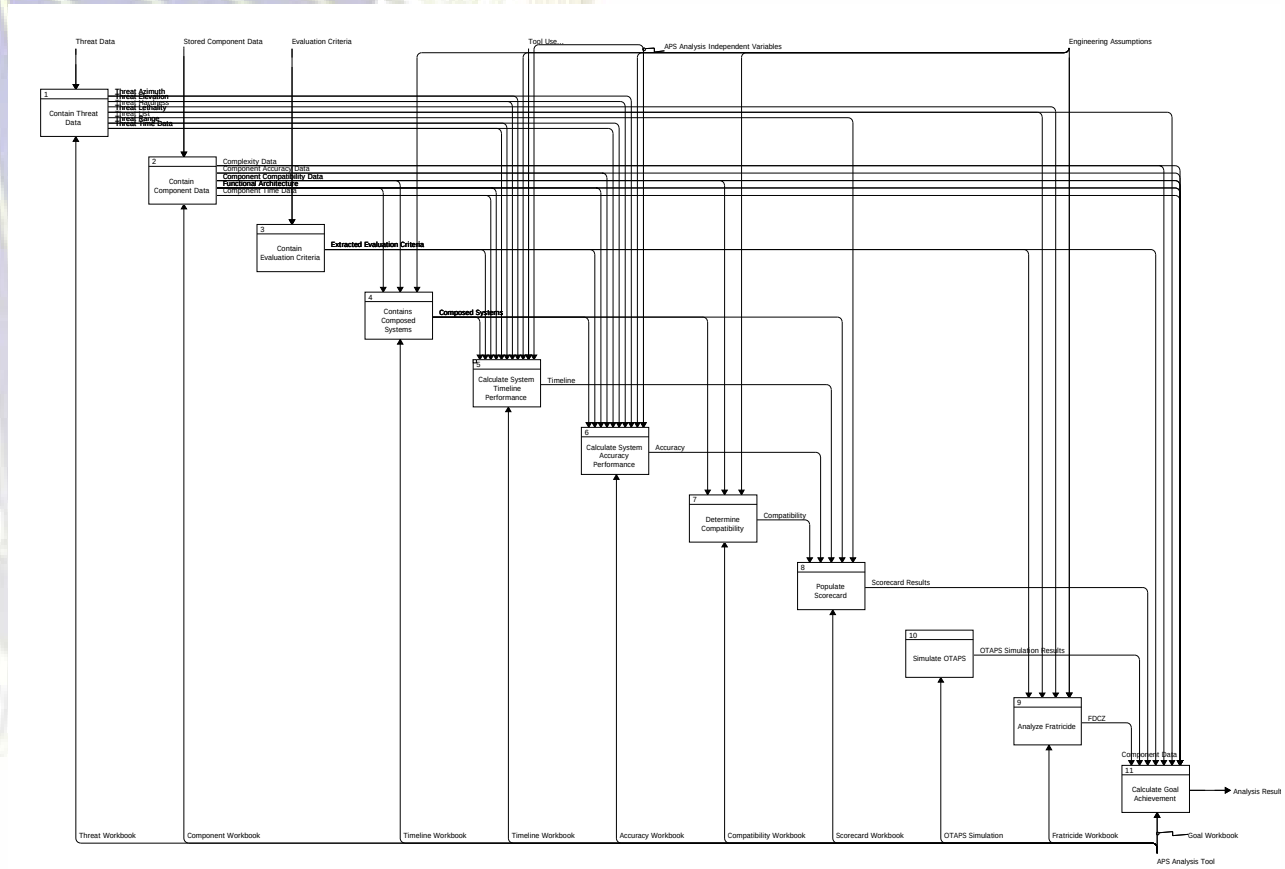
The Hierarchy Diagram was a quick way to quickly capture all the Trade Study Tools and their Hierarchical relationships. These ultimately became the configuration items that were kept under version control.

Perform APS Analysis Function Hierarchy Diagram



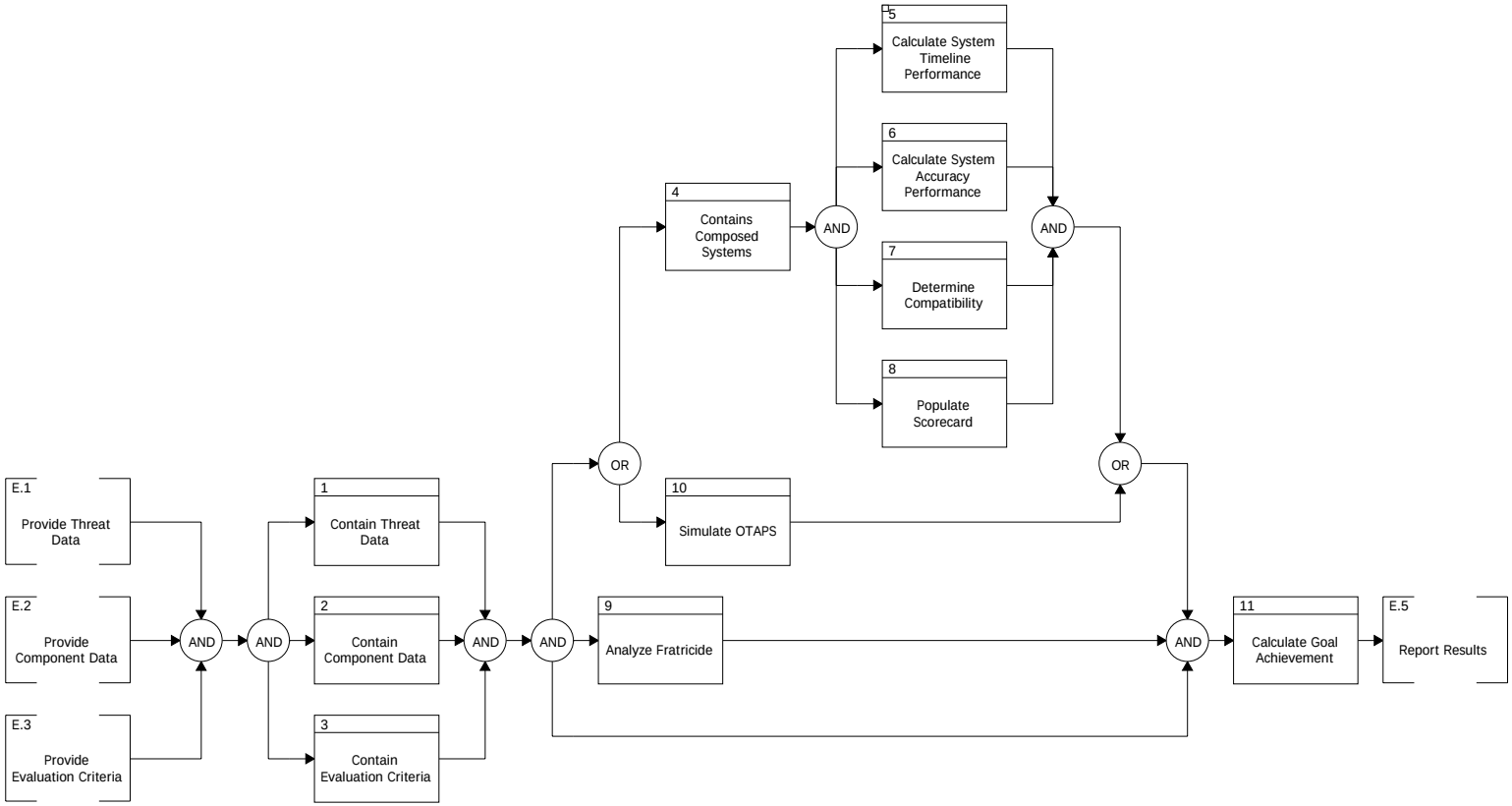
The functional hierarchy diagram emerged from the architecting process as a functional decomposition of the trade study analysis effort.

Perform APS Analysis IDEF0



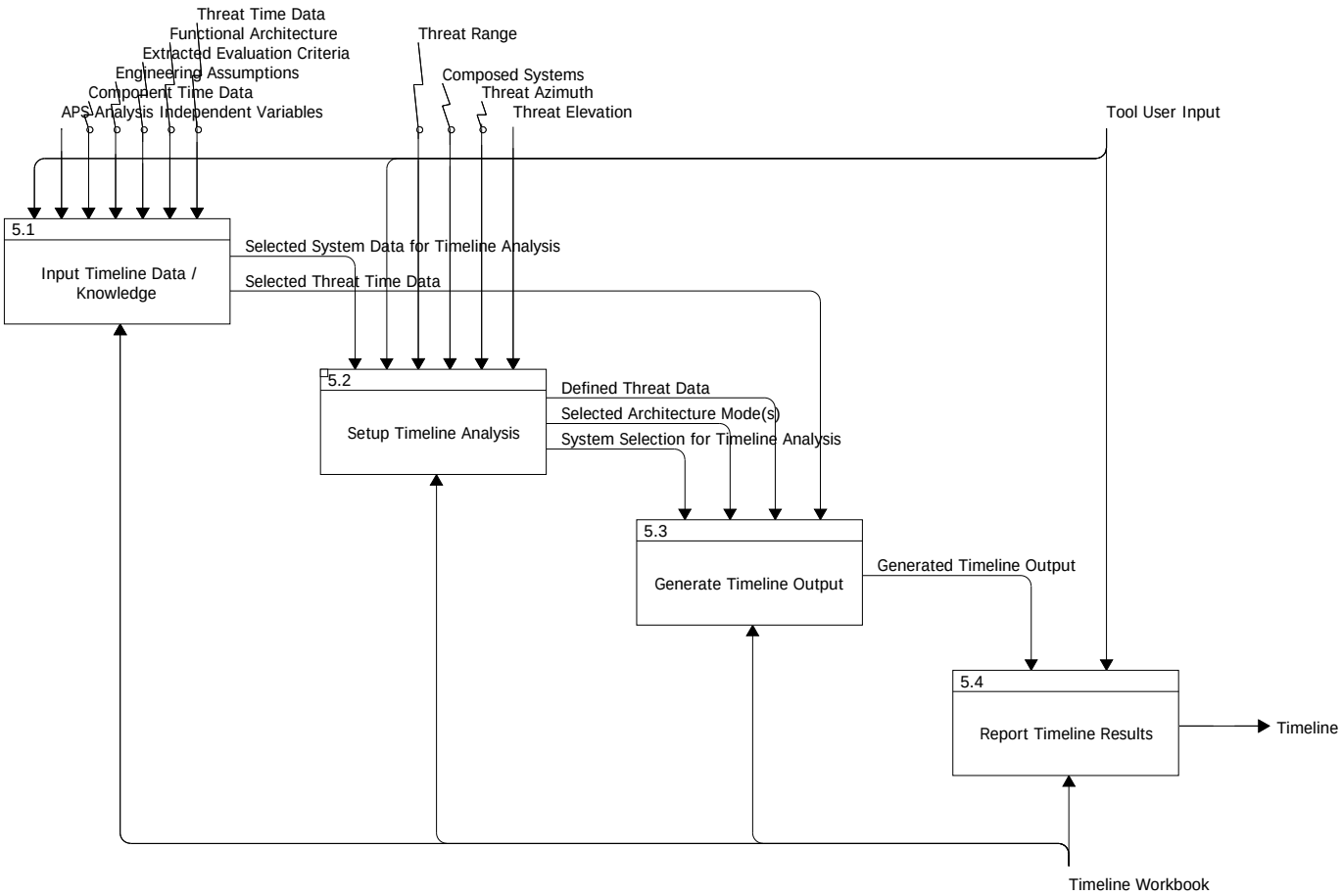
The IDEF0 diagram of the APS Tool shows both external and internal information interactions between functions and the components performing functions

Perform APS Analysis FFBD



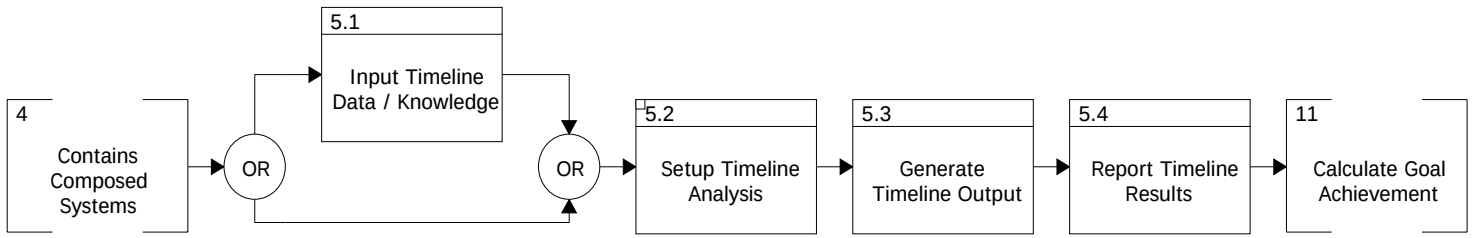
The FFBD (Function Flow Block Diagram) of the APS Tool shows the sequencing and control flow of the functions of the Tool

Calculate System Timeline Performance IDEF0

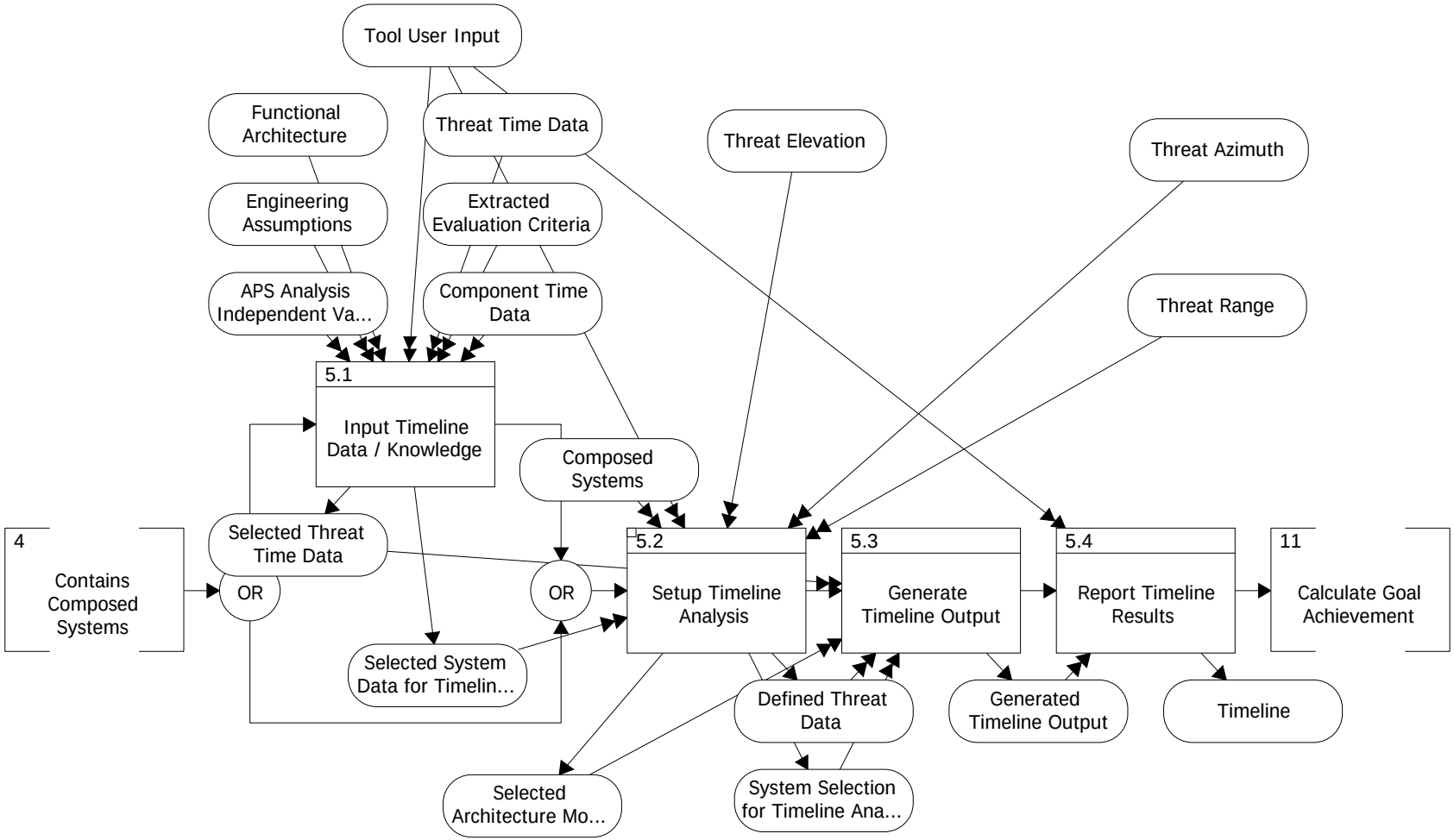


The IDEF0 proved to be a rigorous analysis of each tools inputs and outputs. The process of building this diagram resulting in discovering several tool interface issues that we had to go back and fix.

Calculate System Timeline Performance FFBD

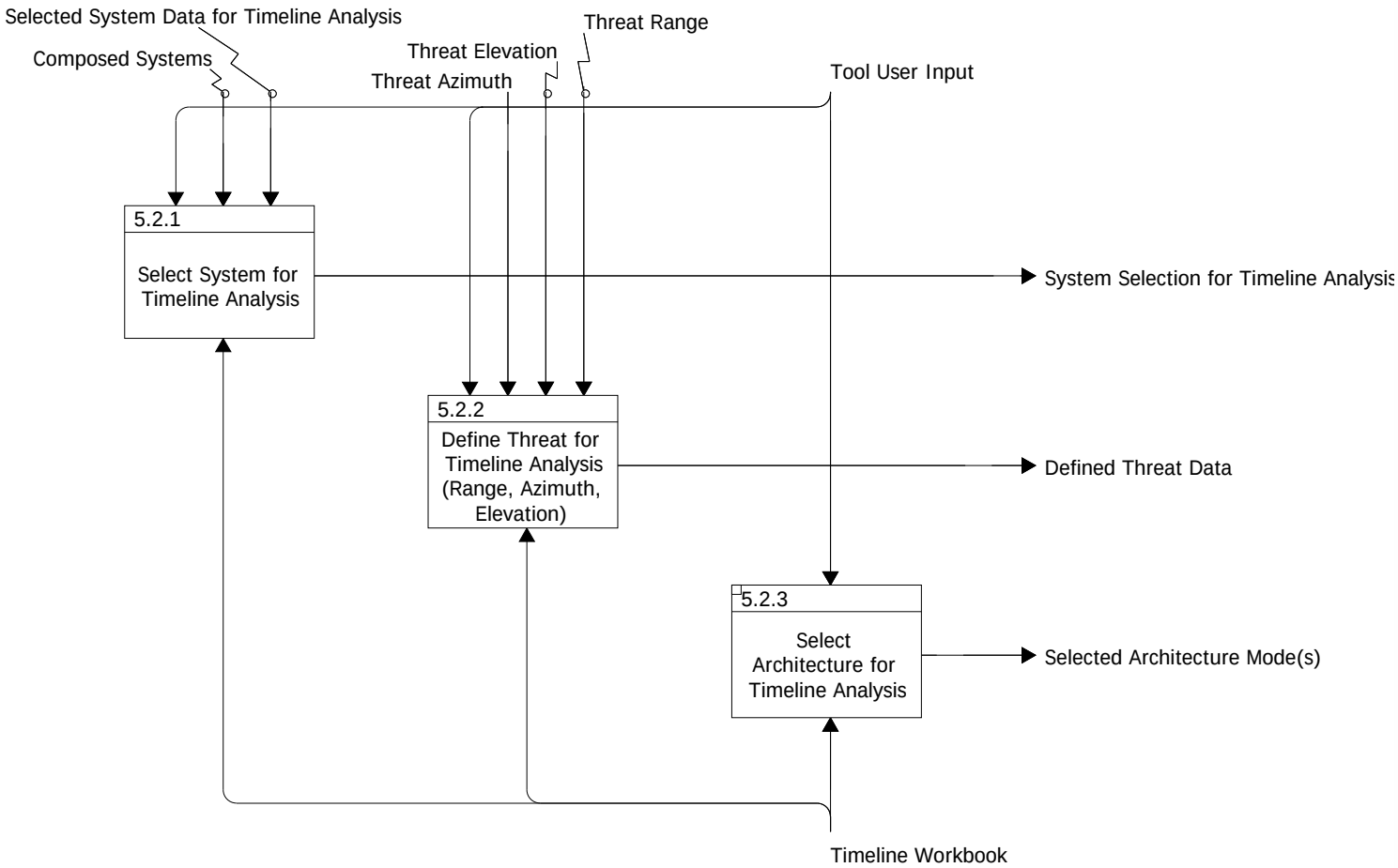


Calculate System Timeline Performance EFFBD

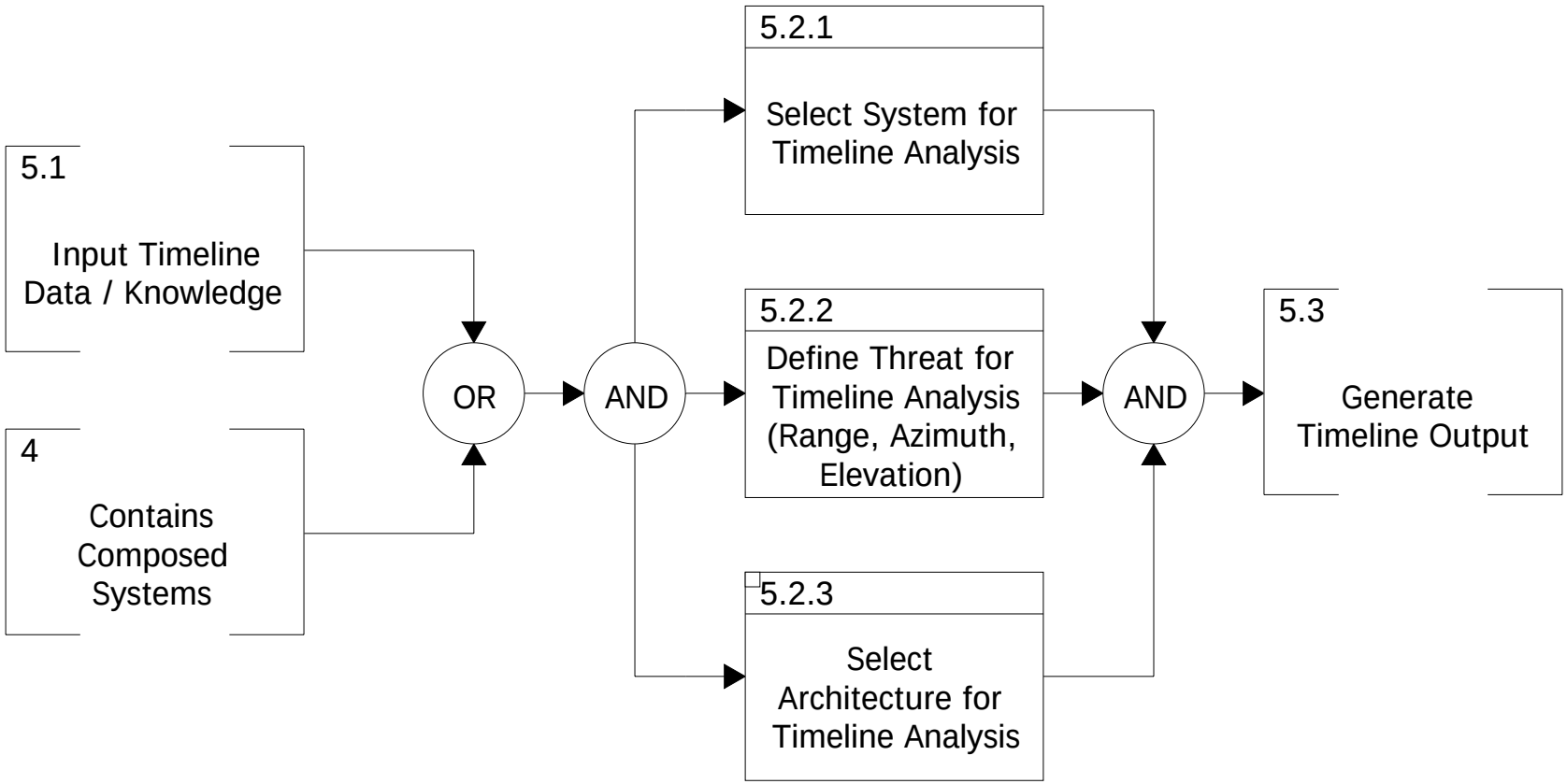


The EFFBD (Enhanced Function Flow Block Diagram) of the APS Tool shows both the data flow and control flow of the Tool

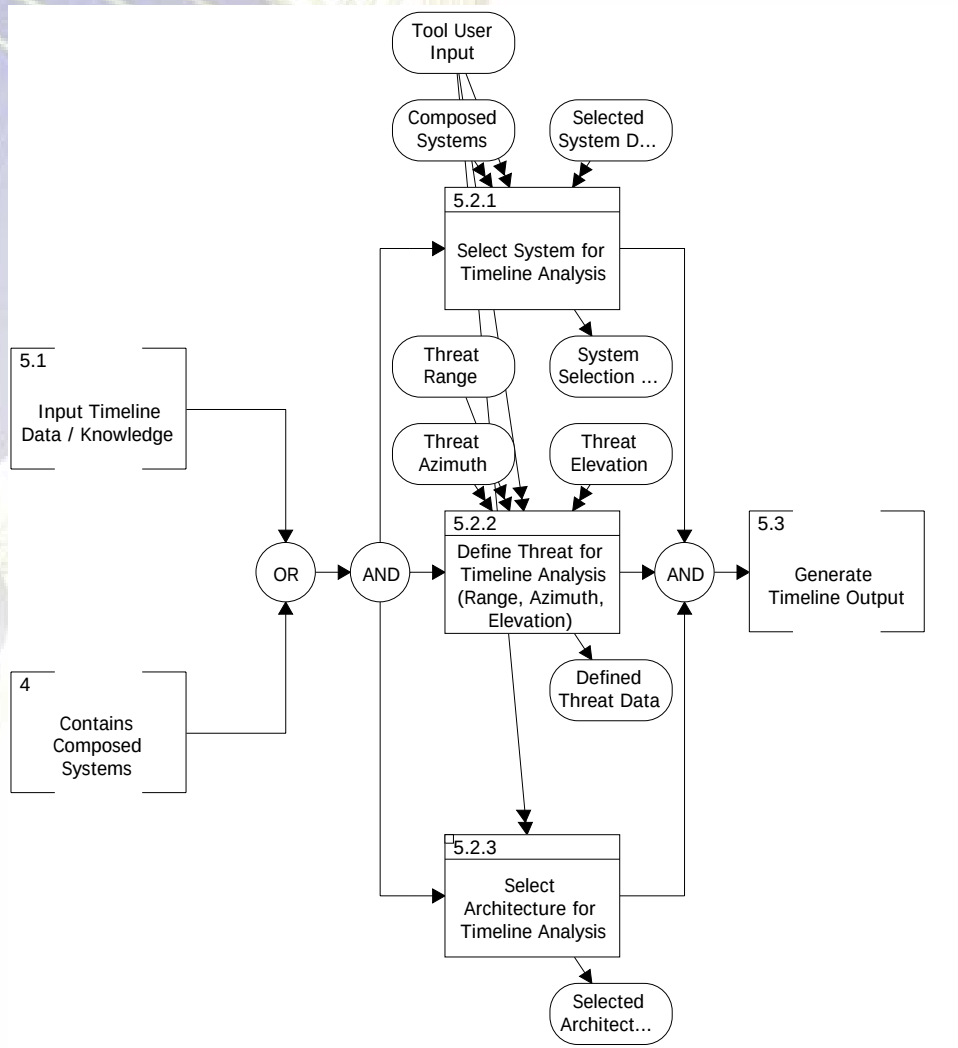
Setup Timeline Analysis IDEF0



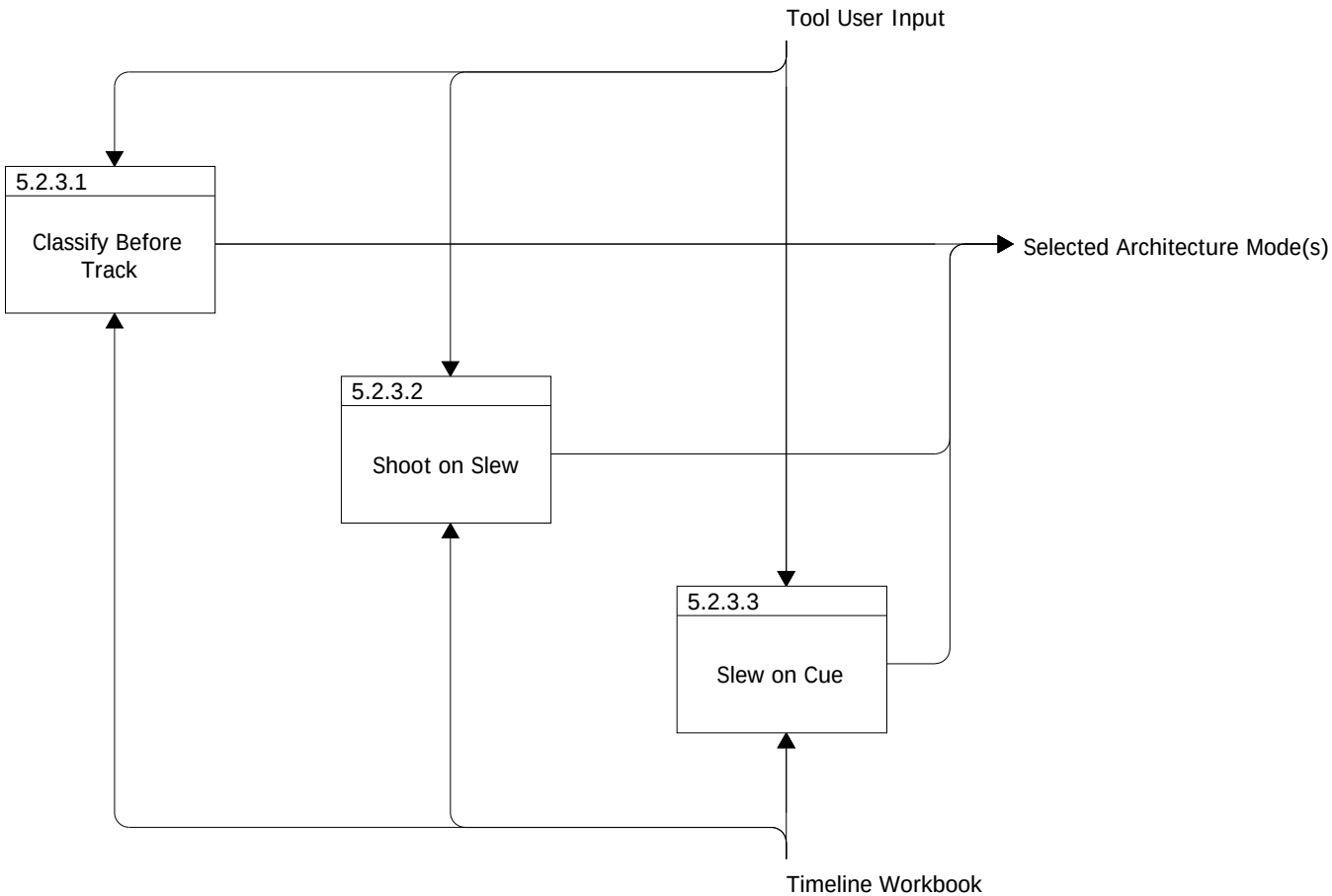
Setup Timeline Analysis FFBD



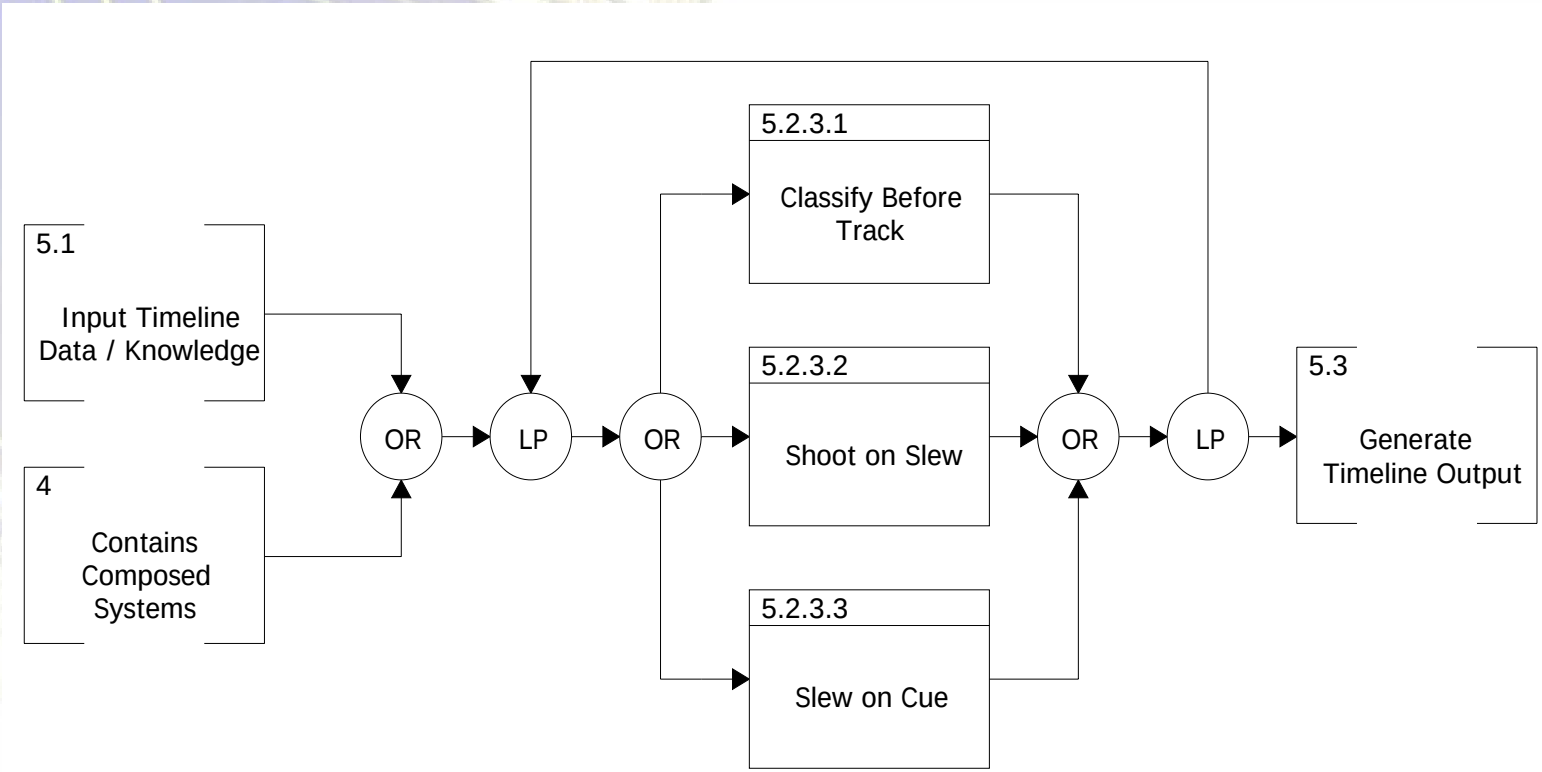
Setup Timeline Analysis EFFBD



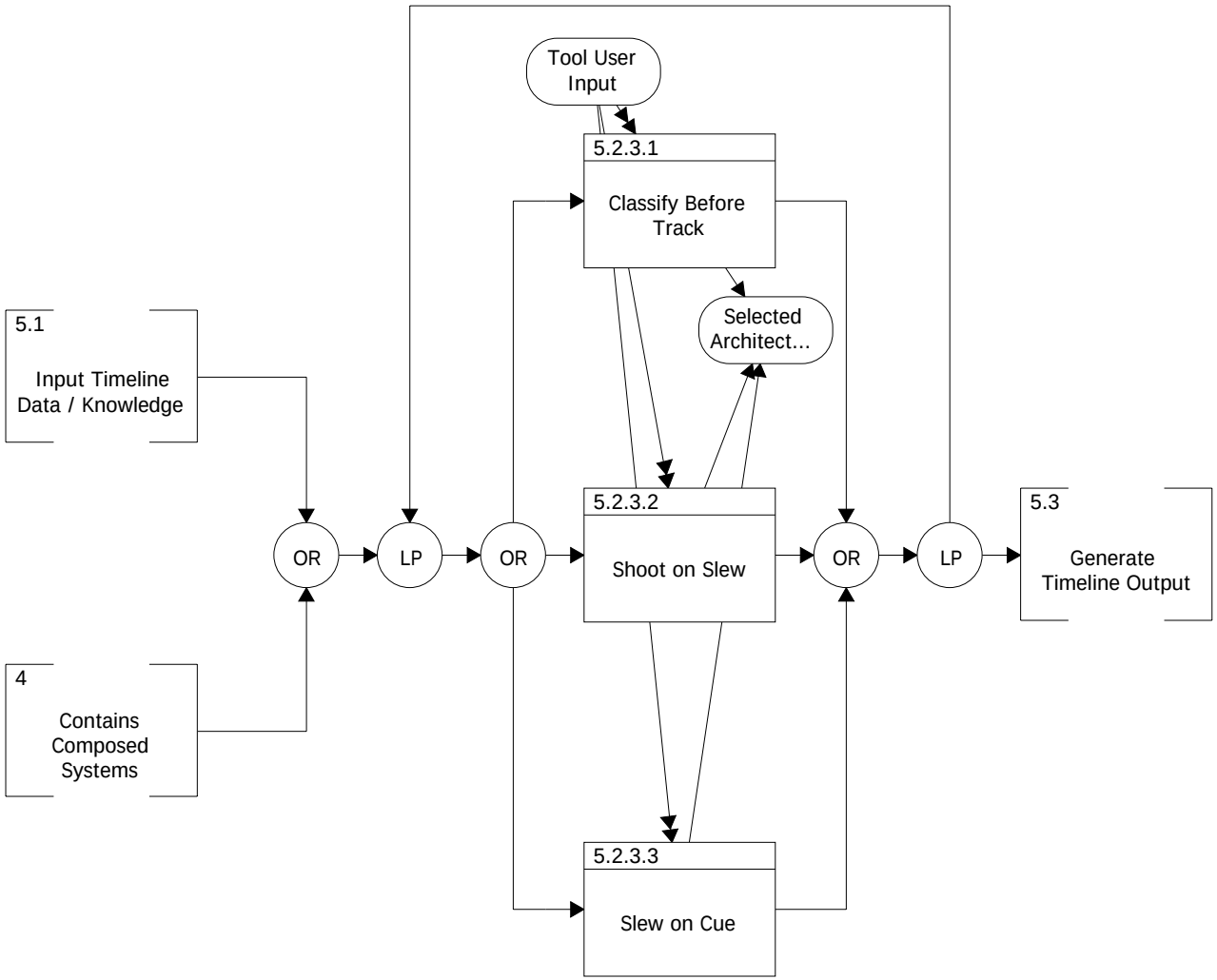
Select Architecture for Timeline Analysis IDEF0



Select Architecture for Timeline Analysis FFBD



Select Architecture for Timeline Analysis EFFBD



Summary

- Using the program requirements to derive the evaluation criteria made the trade study results tradeable to user needs.
- Involving all stakeholders early and often allowed for acceptable end results.
- Establishing a System ID scheme was key to configuration control and essential to manage resulting data.
- Capturing System Architectures was essential to understand how to model system time function and communicate it to the community.
- Tool Architecture helped to communicate how each tool was used in the trade study process.
- As a result of capturing the tool architecture
  - ✓ many tool interface gaps were identified and fixed.
  - ✓ The Schematic Block diagram was updated to be more correct.
- Tool Architecture was valuable to communication to each tool developer interfaces
- Modeling and Simulation was a key player in conducting the APS Trade Study and helped to drive decisions. This study could not be don't without using models.
- Using a defined process were all stakeholders were involved and had a voice yielded results the community could accept.

The Systems Engineering Process was instrumental to the success of the APS Trade Study.