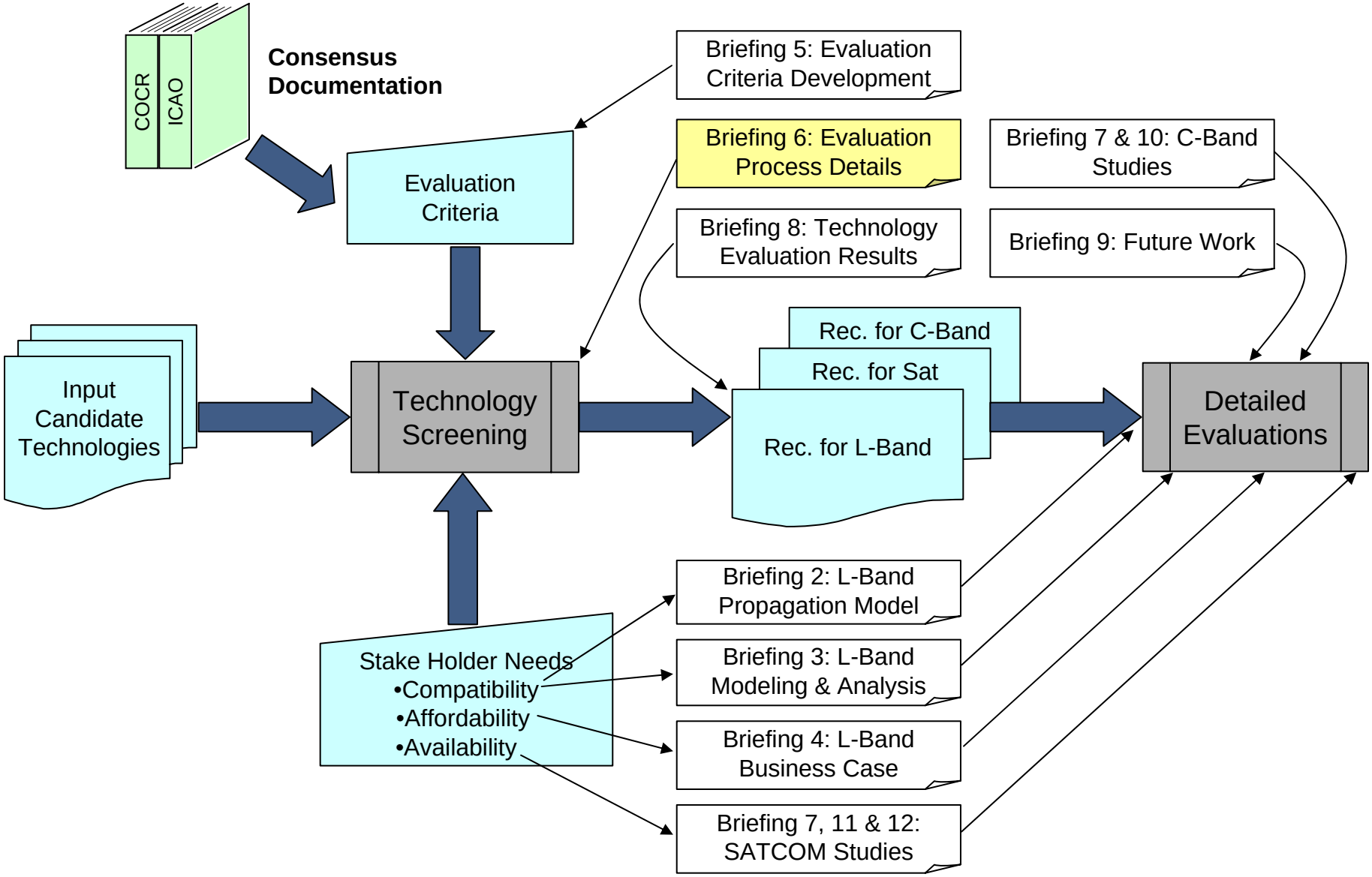
Briefing #6 - Evaluation Process Details

Future Communications Study

Phase II End of Task Briefing

June 21, 2006

Structure and Content of the Presentations



Outline

- Introduction of Technology Evaluation Process
- Augmenting Technology Inventory
- Define Screening Filter
- Screen Technologies
  - Define/Update Technology Concept of Use
- Derive AHP Evaluation Criteria (recap)
- Develop Decision Hierarchy
- Evaluate Technologies vs. Criteria
- Compare AHP Criteria Pairwise
- Calculate Evaluation Scores & Sensitivity Analysis

Introduction of Technology Evaluation Process

Introduction of Technology Evaluation Process

- The decision-making for the aeronautical environment is complex
  - There are a large number of stakeholders with differing needs/desires
  - Many and sometimes conflicting factors influence stakeholder decisions regarding appropriate technology for the future radio system
    - Capability, performance, technology maturity, cost, security, etc
  - Many alternative technologies to consider
- The defined decision-making process for FRS technology evaluation must support the complex decision environment

Introduction of Technology Evaluation Process (2)

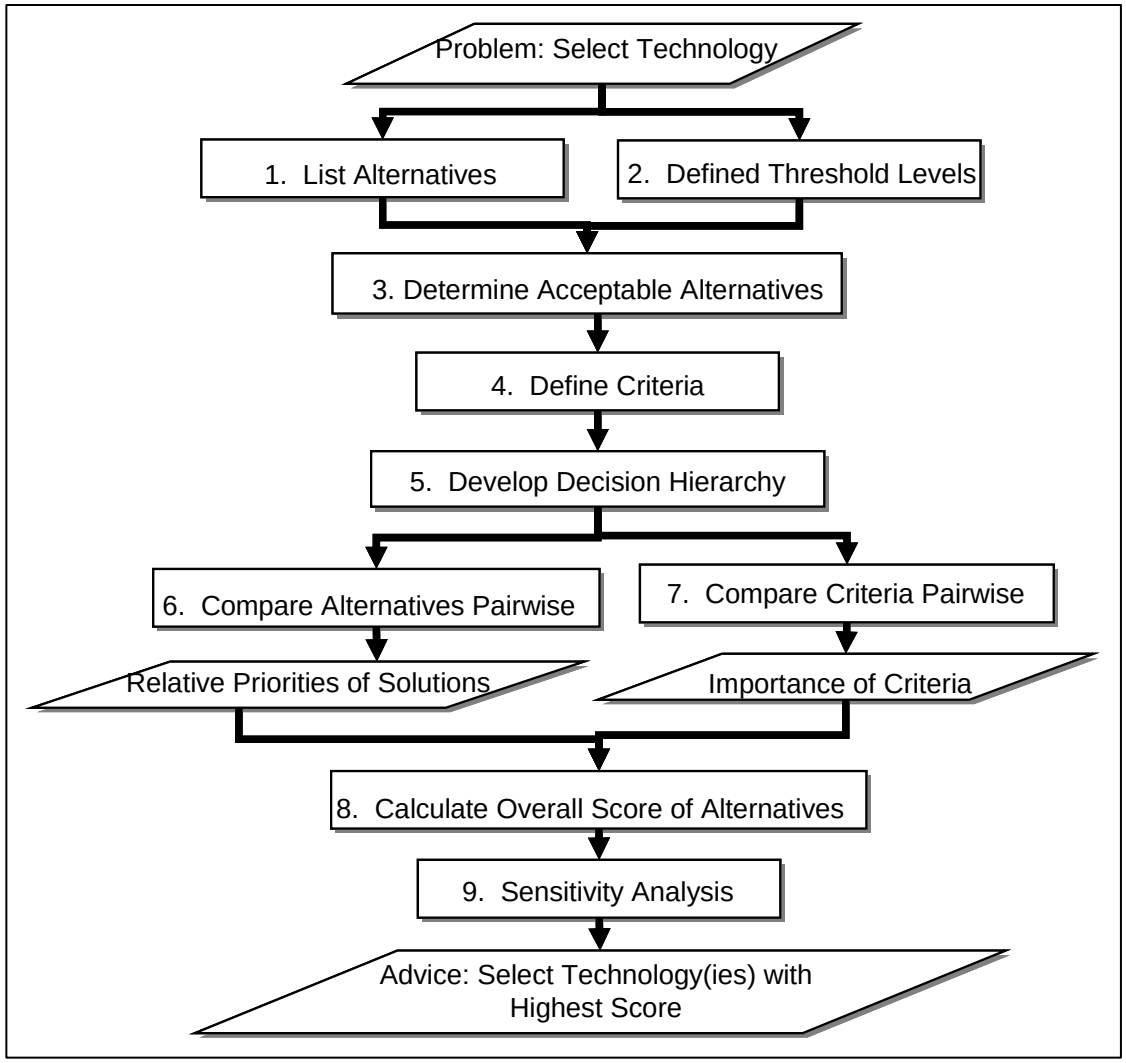
- Decision-making methodologies were researched
  - Considered wide range of methodologies including FAA System Engineering Manual and those within umbrella of Six Sigma
  - Searched for process-oriented, customer-focused strategies that accommodate multi-criteria decisions
- The “Analytical Hierarchy Process” (AHP) was identified as a tool that is highly applicable to the FCS technology evaluation task
  - Process was developed in late 70s/early 80s by Thomas Saaty of Wharton School of Business
  - Used in major decision-making software applications such as Expert Choice
  - Identified as a tool supporting structured decision making, especially with large groups or ensembles of groups that have different needs and goals

Introduction of Technology Evaluation Process (3)

- Strengths of AHP
  - Addresses all aspects of a decision by incorporating them into a decision hierarchy
  - Can support group decision making
    - Users can reach consensus on each pair-wise comparison of decision factors, or judgments can be combined
  - Clearly structures the decision making process
  - There is no restriction on whether criteria can be qualitative or quantitative
  - Provides a means of assessing relative importance of decision factors
  - Provides a comprehensive methodology
- Weaknesses of AHP
  - Assumes decision factors are independent
  - Calculations are complex – often requires custom software
  - Can be time intensive – requires stakeholder pair-wise comparison of decision factors

Introduction of Technology Evaluation Process (4)

- There are nine phases of the standard Analytical Hierarchy Process model



Introduction of Technology Evaluation Process (4)

- Phases of the Standard Analytical Hierarchy Process

	Name	Description
1	List Alternatives	First step in AHP; identify and list all alternatives
2	Define Threshold Levels	Define minimum requirements that an alternative has to fulfill
3	Determine Acceptable Alternatives	Review all alternatives with respect to threshold levels; alternatives that do not meet these requirements are dismissed
4	Define Criteria	Criteria used to judge the alternatives are defined; several techniques are possible (e.g. pro/con analysis, critical success factor technique, etc)
5	Develop Decision Hierarchy	A hierarchy that identifies the decision goal, and provides an organization of analysis criteria

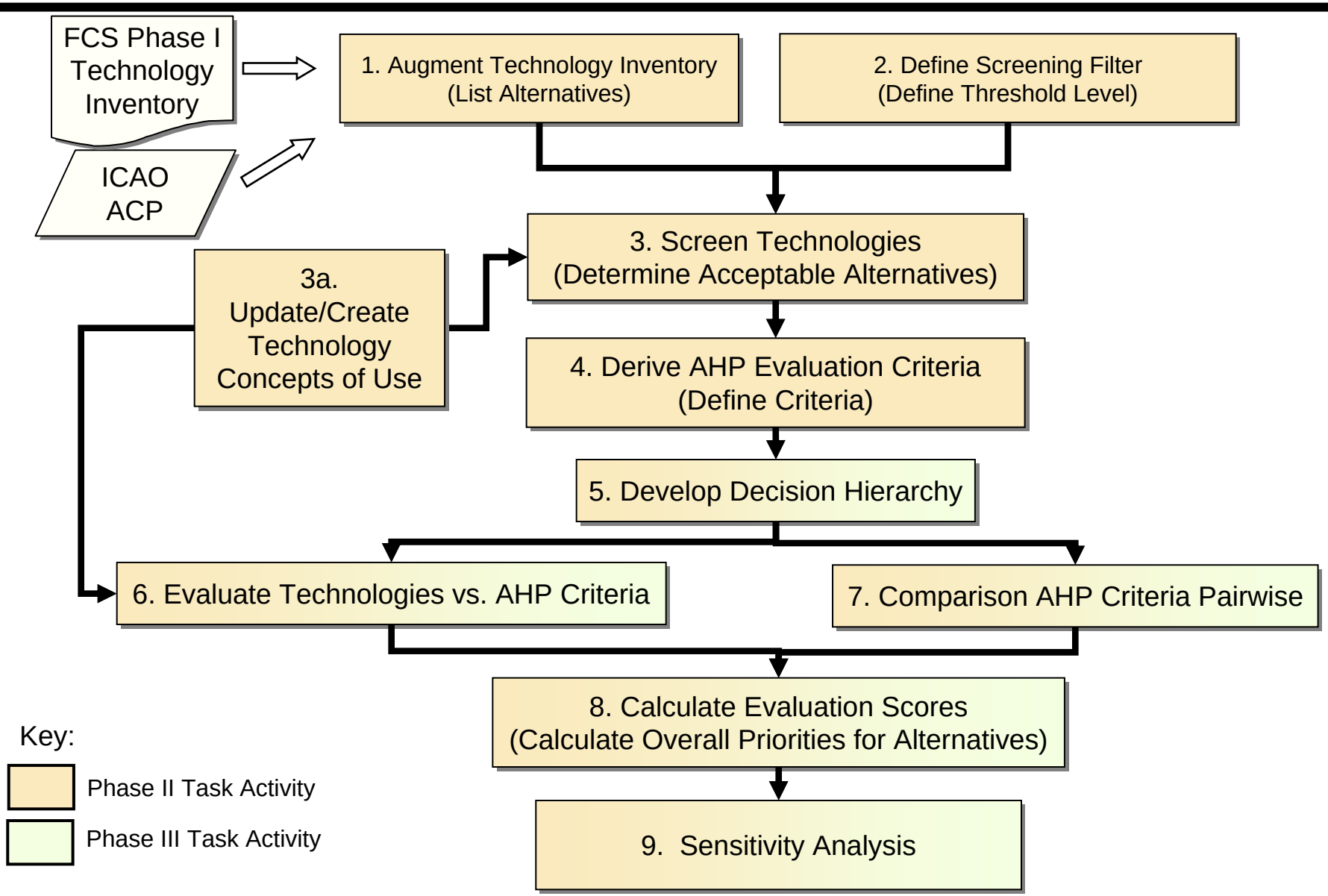
Introduction of Technology Evaluation Process (5)

	Name	Description
6	Comparison of Alternatives Pairwise	For each criterion, stakeholders evaluate all candidate solution alternatives pairwise (every possible combination of alternatives is judged with respect to each criterion); this results in a relative ranking of each alternative
7	Comparison of Criteria Pairwise	Stakeholders perform a pairwise comparison of all evaluation criteria; this results in the relative importance of each criterion
8	Calculate Overall Priorities for Alternatives	A linear additive function is used to calculate the overall ranking of an alternative (the relative rankings of an alternative are multiplied by the importance of the corresponding criteria and summed over all criteria)
9	Sensitivity Analysis	"What-if" analysis is used to identify the sensitivity of results to changes in rankings of alternatives and criteria

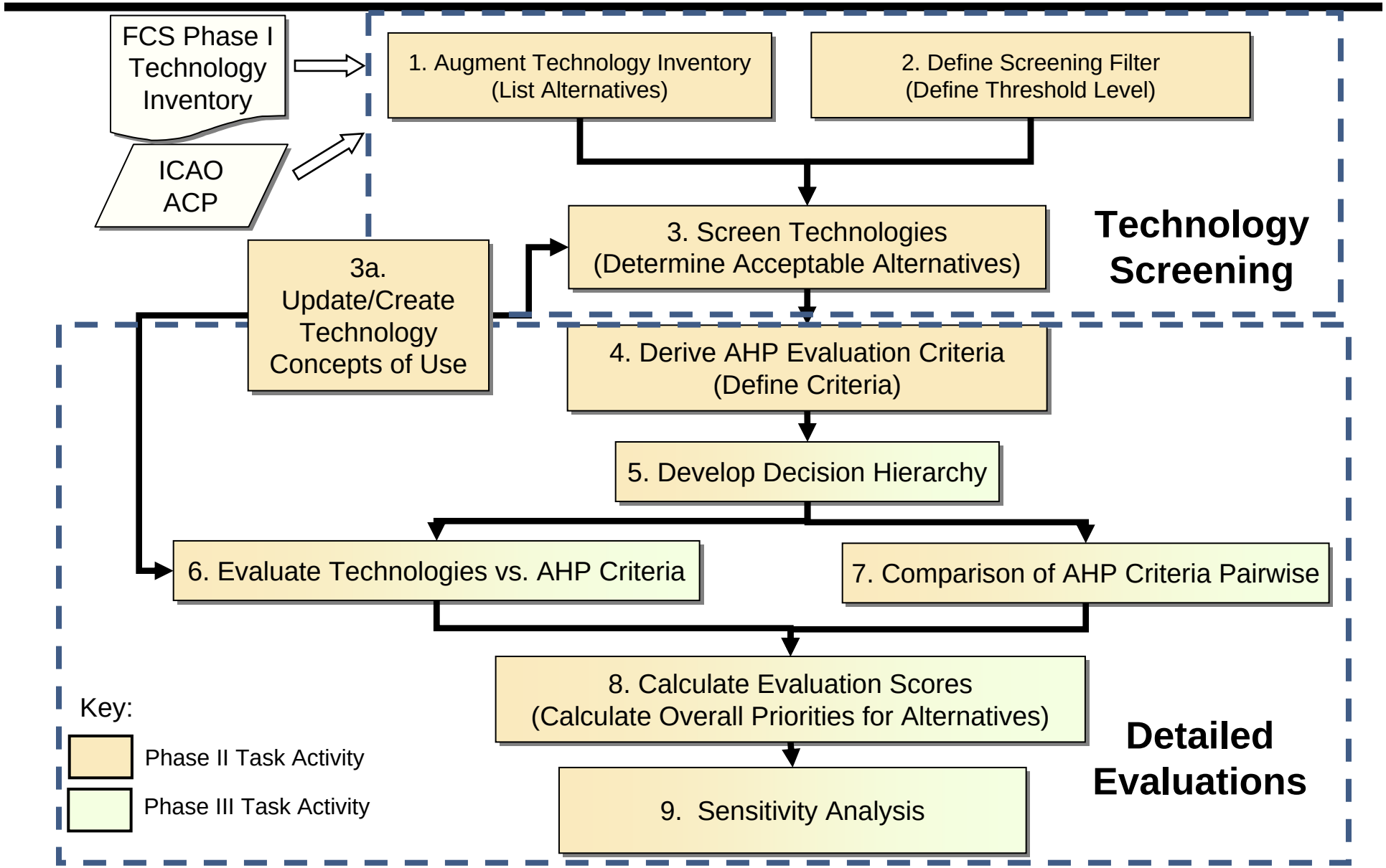
Introduction of Technology Evaluation Process (5)

- Analytical Hierarchy Process has been adapted for evaluation of technologies for the FRS
  - Substantive change: define step 6 as absolute evaluation of technologies vs. evaluation criteria
    - AHP suggests relative comparison of technology solutions with respect to each evaluation criteria
      - This comparison results in the identification of the relatively best technology solution, but it does not identify if any solution can meet the criteria and hence the needs of aviation
    - An alternative approach is to perform an absolute evaluation of technologies against criteria, and in the process evaluate which technologies meet most or all of the criteria
      - This alternative process identifies the best relative solution as well as determine which solutions meet the needs of aviation
  - Minor change: added supplemental step addressing creation of technology concept of use (supports steps 3 & 6)

Introduction of Technology Evaluation Process (6)



Introduction of Technology Evaluation Process (7)



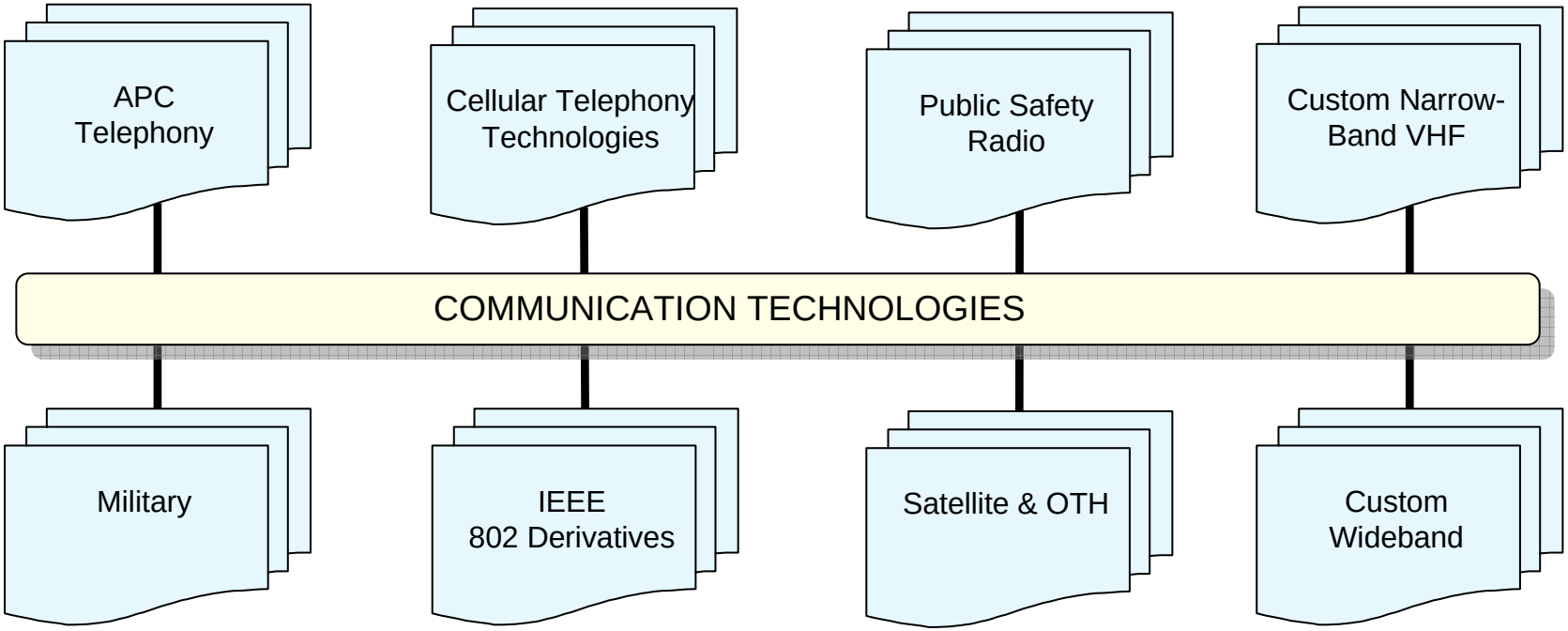
Step 1: Augment Technology Inventory

Augmenting Technology Inventory

- During FCS Phase I (May – Dec, 2004), a technology inventory was developed through
  - Survey of widely used and successful commercial and military technologies
  - Release of two NASA Requests-for-Information (RFIs) soliciting technology candidate inputs from industry
  - Identification of technologies candidates defined by the ICAO Aeronautical Communication Panel, Working Group – C (ACP WG-C)
- The augmentation of the original inventory list in Phase II was undertaken to account for changes in technology and new candidates suggested through ICAO ACP WG-C
- Through participation in ACP meetings and review of ACP WG-C material, additional candidate technologies were identified and added to the technology inventory

Organization of Technologies into Families

- Within the technology inventory, candidate technologies for aeronautical communications were grouped into families
  - Technology families exhibit many similarities
    - Technology has evolved to meet common user requirements
    - Technologies have similar services offered
    - Technologies have similar reference and physical architectures



Step 2: Define Screening Filter

Screening Motivation

- Two-fold motivation
  - A technology downselect vs. minimum threshold criteria is defined as Step 2 of the AHP
  - Stakeholder feedback to the original technology screening included:
    - Focus on solutions for data-link (voice to remain as provisioned)
    - Show direct relationship between evaluation criteria and requirements document (COCR)
    - Re-visit prescreening decisions

Selection of Screening Threshold

- A clear and traceable screening threshold that supports the identification of applicable technology candidates within technology families for the future radio system is needed
  - Desire to identify manageable number of “most promising candidates” from technology families that are most applicable to the needs of aviation
- Selected threshold is the <u>ability to use protected spectrum</u>, the <u>data loading requirements</u>, and the <u>technology communications range</u>

Selection of Protected Spectrum Threshold

- A technology that inherently relies on unprotected spectrum [i.e., not AM(R)S or AMS(R)S] is not a viable candidate for the Future Radio System
  - If the technology is a specific implementation that utilizes unprotected spectrum, the technology was removed from further consideration
  - A technology that is a general specification or associated with a specific implementation that does utilize protected spectrum was considered further

Selection of Data Rate and Range Thresholds

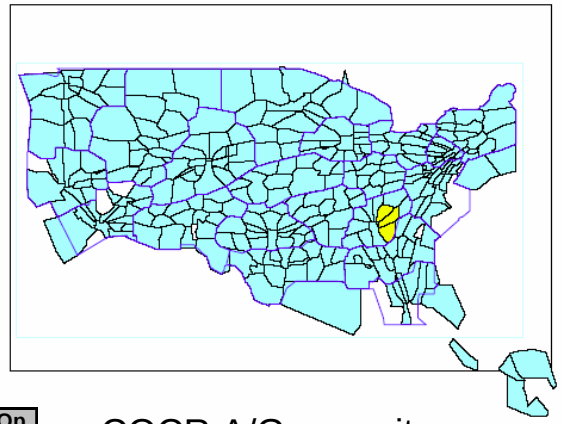
- As calculated, the COCR capacity requirements are reflective of all COCR performance requirements
  - Data rate required is associated with the maximum number of users
    - While provisioning the required QoS
    - While meeting the latency requirements
- Data rate required is directly proportional to technology coverage volume
  - The COCR capacity requirements are scaled as appropriate

Selection of Data Rate and Range Thresholds (2)

- Data rate thresholds were derived from the rate requirements provided in the COCR
  - Phase I and Phase II data rate requirements were parsed to identify the maximum data rate requirement across all flight domains
    - Separate requirements were identified for ATS Only and ATS & AOC combined traffic load configurations

PHASE 1		Airport SV		TMA SV		ER SV			OR SV	
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD
Separate ATS	UL	4.0	1.2	2.3	2.2	1.2	1.5	1.2	0.3	0.3
	DL	4.3	1.9	4.1	3.9	3.7	4.9	3.7	2.7	2.2
	UL&DL	7.4	2.0	5.3	5.0	4.1	5.6	4.1	2.8	2.2
Separate AOC	UL	15.6	2.7	0.3	0.3	8.6	11.9	8.6	3.3	2.8
	DL	3.5	0.7	0.8	0.8	0.8	1.3	0.8	0.4	0.3
	UL&DL	19.9	2.9	0.8	0.8	9.1	13.8	9.1	3.3	2.8
Combined ATS&AO	UL	18.4	2.9	2.3	2.2	9.0	12.7	8.9	3.3	2.8
	DL	6.7	2.0	4.3	4.1	3.8	5.2	3.8	2.7	2.2
	UL&DL	25.5	3.3	5.6	5.3	11.4	17.7	11.3	4.5	3.4

Table 6-19: Air/Ground Capacity Requirements (kbps) – Phase 1



PHASE 2		Airport SV		TMA SV AEXEC		ER SV AEXEC			OR SV AEXEC		Auto Op Area
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD	
Separate ATS	UL	12.8	7.1	22.0	22.2	20.9	22.4	21.0	19.8	19.6	7.1
	DL	11.3	5.2	10.3	10.7	9.8	13.5	10.5	8.5	8.3	13.3
	UL&DL	19.6	7.3	24.5	25.1	23.5	27.0	24.0	20.3	19.9	13.6
Separate AOC	UL	113.0	14.1	0.3	0.2	52.4	96.1	64.1	24.0	18.2	56.2
	DL	6.7	1.2	2.4	2.2	1.4	2.7	1.8	0.6	0.4	1.1
	UL&DL	131.2	14.1	2.6	2.3	58.6	106.9	72.6	24.4	18.2	62.8
Combined ATS&AO	UL	120.0	24.6	22.0	22.2	119.1	168.3	134.8	82.1	62.8	76.7
	DL	13.4	5.4	11.1	11.8	10.2	13.9	10.9	8.6	8.3	13.4
	UL&DL	144.3	24.8	25.2	25.8	119.4	168.9	135.2	82.2	62.9	80.5

Table 6-20: Air/Ground Capacity Requirements (kbps) – Phase 2

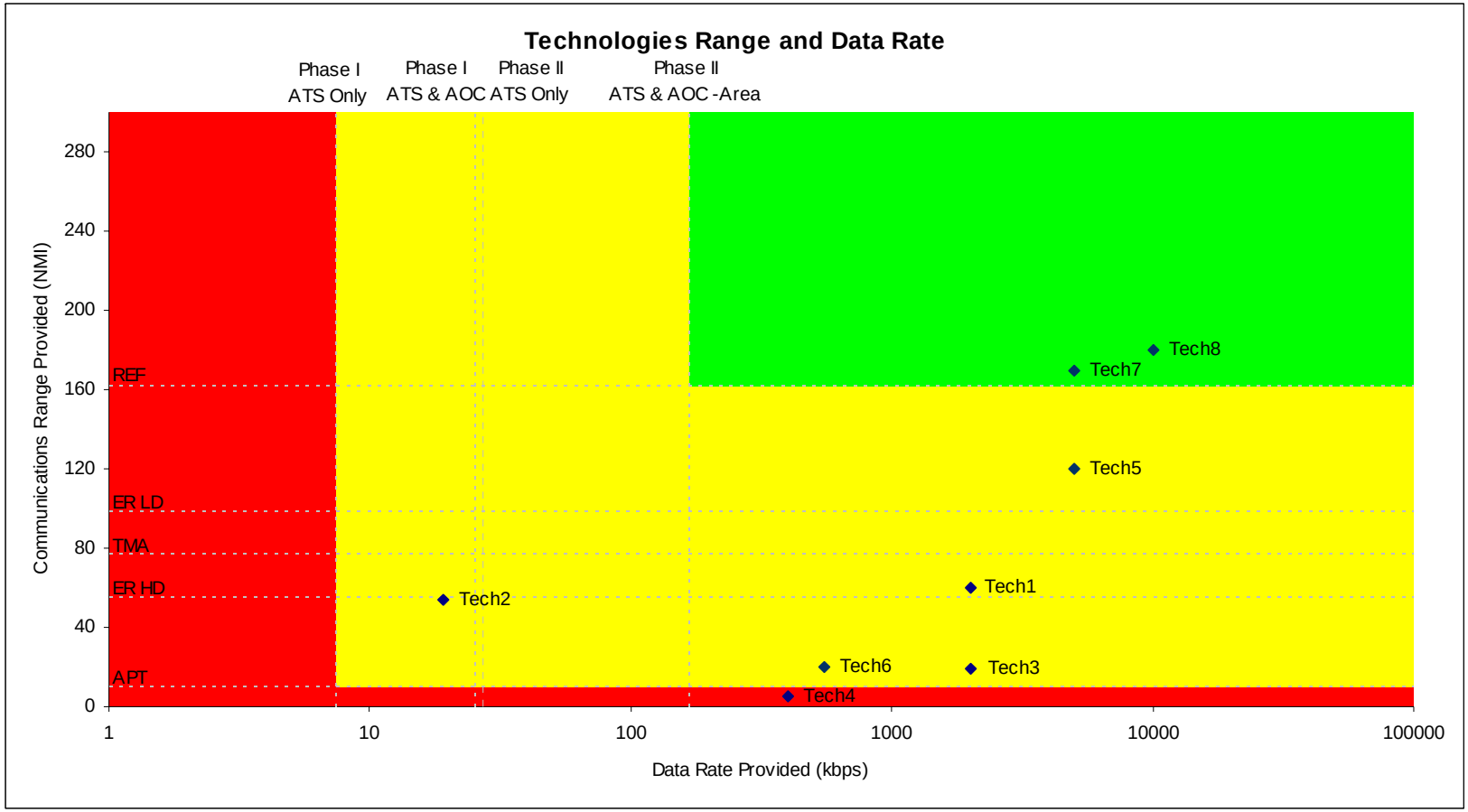
- COCR A/G capacity requirements (UL & DL) range from 7.4 to 168.9 kbps
- Maximum requirement is for the NAS 2030 “Super Sector” shown on the map

Selection of Data Rate and Range Thresholds (3)

- Communication range thresholds used for technology screening are associated with sector sizes derived from the COCR
  - COCR describes sector sizes/volumes for the Airport, Terminal Maneuvering Area (TMA), En Route (high and low density) (ER-HD) and (ER-LD) domains
- A reference range was also added as a screening filter
  - The defined reference sizes may not accommodate all feasible sector sizes
    - Current en route sector sizes are larger than those derived from COCR data
  - Some technologies could be implemented as a regular grid of ground stations providing area based coverage
    - This is a potentially a low cost implementation as compared to sector based terrestrial infrastructure
  - The reference range corresponds to radio horizon range above FL180

Selection of Data Rate and Range Thresholds (4)

- Data Rate/Range Threshold Filter for Terrestrial Technologies
  - Horizontal axis identifies Data Rates
  - Vertical axis identifies Communication Range values



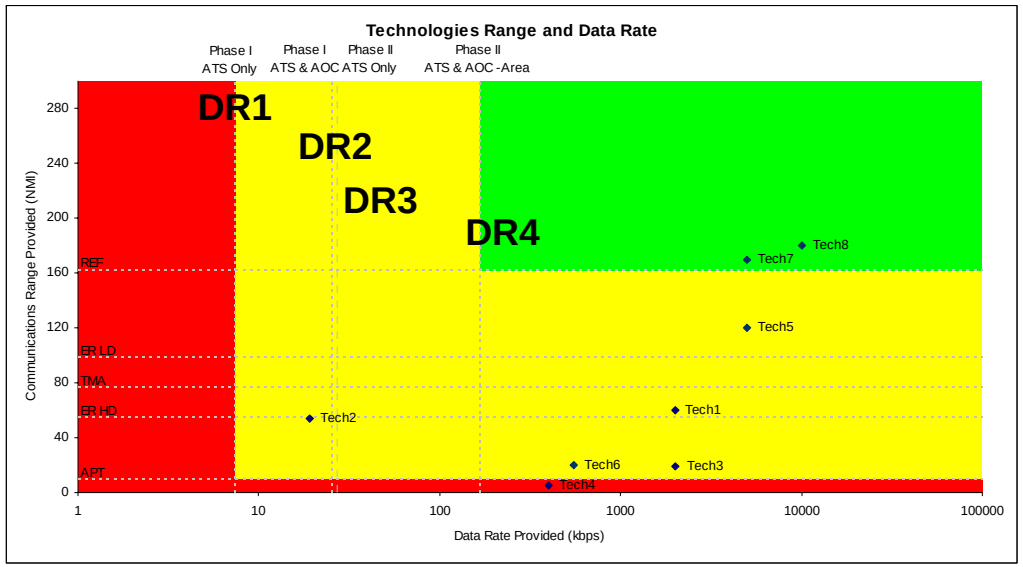
Selection of Data Rate and Range Thresholds (5)

- Reference data rate values included on the threshold filter include ATS-Only and ATS & AOC combined data rates for both Phase I and Phase II
- Red/Yellow/Green metrics were applied to specific data rate values on the threshold filter

Technologies that cannot, at a minimum, meet ATS-Only Phase I requirements are not applicable

Technologies within this data rate region have some applicability

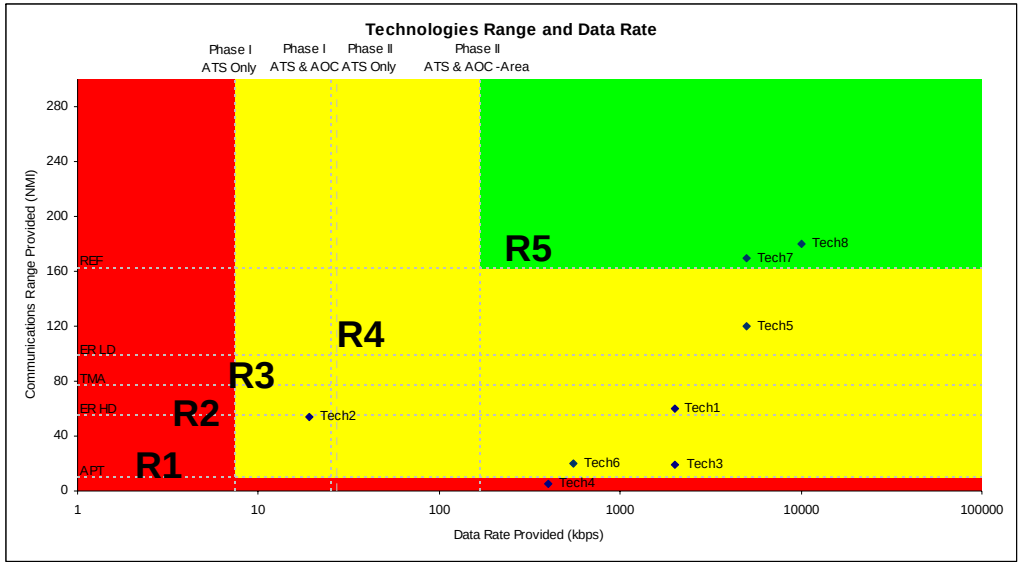
Technologies that exceed Phase II ATS & AOC combined data rate requirements are highly applicable



DR1 – ATS-Only Phase I requirement (max across domains)
DR2 – ATS & AOC Phase I requirement
DR3 – ATS-Only Phase II requirement
DR4 – ATS & AOC Phase II requirement

Selection of Data Rate and Range Thresholds (6)

- Reference communication range values included on the threshold filter include APT, ER-LD, TMA, ER-HD, and Radio Horizon Reference
- Red/Yellow/Green metrics were applied to specific coverage range values on the threshold filter



R1 – Required Airport Communication Range
R2 – Required En Route – Low Density Communication Range
R3 – Required Terminal Area Communication Range
R4 – Required En Route – High Density Communication Range
R5 – Require Radio Horizon Reference Communication Range

Technologies that cannot, at a minimum, meet Airport Coverage requirements are not applicable

Technologies within this communication range region have some applicability

Technologies that exceed the domain-specific and radio horizon reference coverage range highly applicable

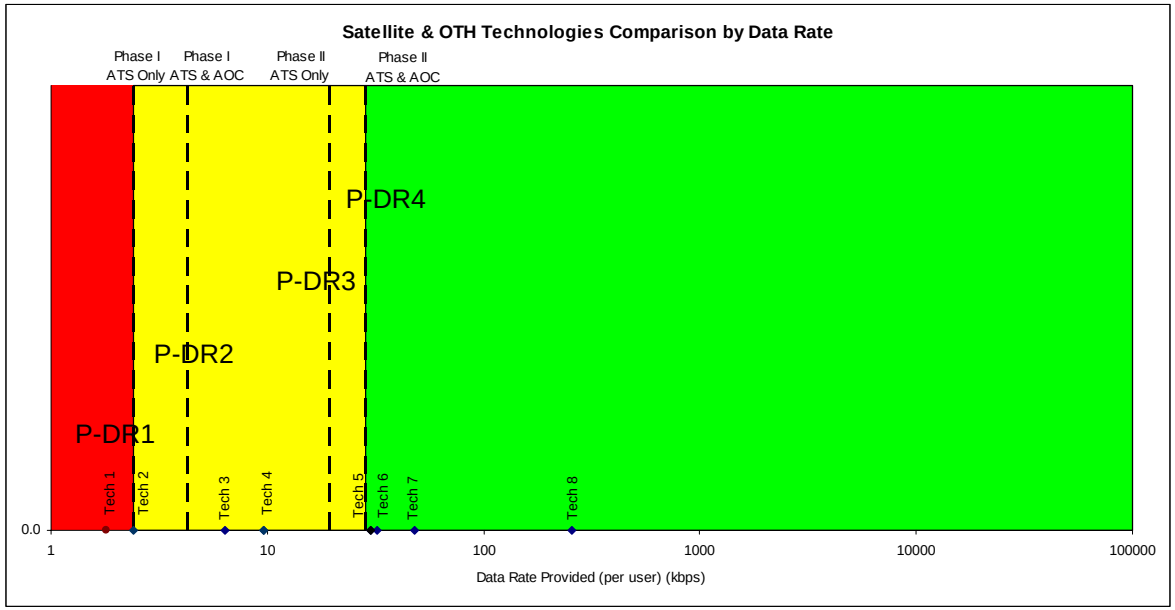
Selection of Data Rate and Range Thresholds (7)

- SATCOM technologies provide area-based communication coverage (typically larger than the derived terrestrial communication reference range)
  - Coverage area among SATCOM & OTH technologies provides no meaningful comparison of technologies
  - Used data rate offered per user connection as a common comparison metric
- To provide a meaningful comparison among these technologies, focus is on "per-user" data rate

Technologies that cannot, at a minimum, meet ATS-Only Phase I per-user data rates are not applicable

Technologies within this data rate region have some applicability

Technologies that exceed Phase II ATS & AOC combined per-user data rates are highly applicable



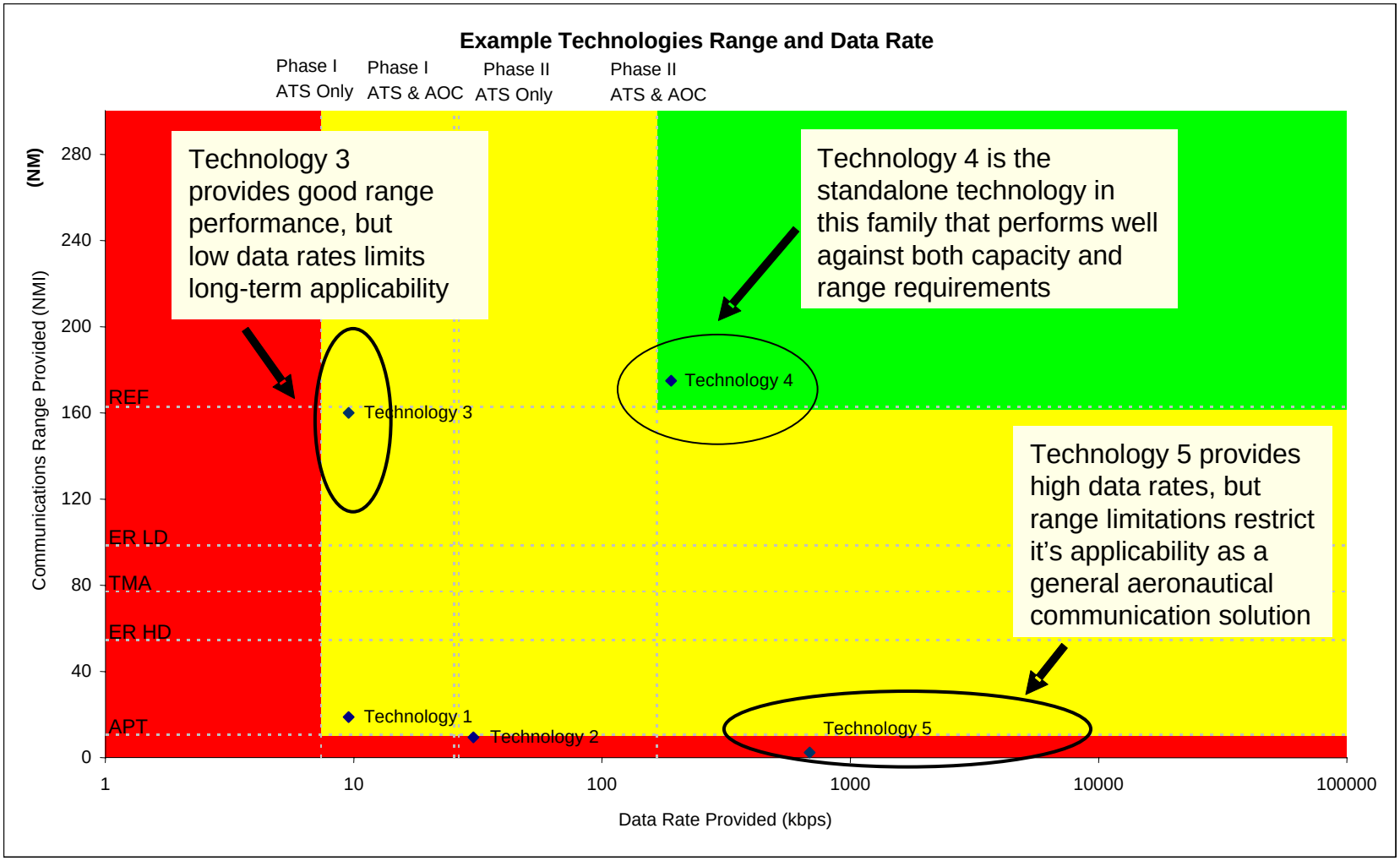
P-DR1 – Per-User ATS-Only Phase I requirement (max across domains)
P-DR2 – Per-User ATS & AOC Phase I requirement
P-DR3 – Per-User ATS-Only Phase II requirement
P-DR4 – Per-User ATS & AOC Phase II requirement

Step 3: Screen Technologies

Screening Technology Process

- The process for screening includes
  - Use the data rate and communication range (defined in the technology concept of use) to plot each technology on the threshold filter chart
  - All technologies that fall within the “green” zone on the chart are selected for further analysis
    - These technologies meet or exceed COCR data rate and range requirements
  - Other technologies that come close to falling within the “green” zone are also selected for further analysis

Example Application of Screening Process



3a. Update/Create Technology Concept of Use

Technology Concept of Use

- Fundamental tenet – When assessing a technology, a *concept of use* must be defined
  - The concept of use can be defined as a mapping of a technology into a system; it provides the basic description of how the required ATS & AOC services (functions) would be provisioned
  - Technology capacities and performance are evaluated in accord with the operational environment for the given concept of use
- Elements of a "concept of use"
  - Services Appropriate for Aeronautical Communications
    - Maps technology services into required aeronautical services
  - Integration of the Candidate's Architecture for Aeronautical Communications
    - Describes technology architecture for both the service provider and the aircraft
      - Includes ground infrastructure, frequencies used, coverage volumes, number of ground sites (satellites) required – in other words, the *system* that provisions communications

Technology Concept of Use (2)

- Defined concept of use is used to support application of screening thresholds and technology evaluation against criteria
  - Initial Technology Concepts of Use were defined during FCS Phase I activities
  - As required, concepts are defined for new technologies added technology inventory
  - Additionally, existing concepts are updated to reflect technology advancements/changes
- A representation of key technology information to be captured in a concept of use supporting technology screening is illustrated

Key Technology Information
(Values have to be determined for a fielded system)

	Parameter	Options	Selected Value for Pre-Screeing	Comments
1	Modulation	Uplink: QPSK Downlink: QPSK	QPSK	
2	Coding	Rate 1/2	Rate 1/2	
3	Data Rate	Varies on uplink and downlink with spreading factor; Uplink is limiting capacity. For FDD operations Uplink: 15 kbps – 960 kbps	**960 kbps**	Assume spreading factor of 4
4	User Data bits/frame	Varies on uplink and downlink with spreading factor ; Uplink limits capacity; For FDD operation: Uplink: 150 - 9600 bits		
5	User Data Frames/Second	100		
6	Operational Mode	Circuit Service – Transient Circuit Service – Persistent Packet Service	Circuit Service	
7	Range	Dependent on propagation environment; from simulation results (e.g. EUROCONTROL study) ranges is from 10 – 300 km considering C-Band and VHF band	**300 km = 162 nmi**	Maximum range does not include special architecture accommodates (e.g. high gain antennas or mobile antenna diversity)
8	Issues for further Investigation	Call Setup Time		

4. Derive AHP Evaluation Criteria

Derive AHP Evaluation Criteria

- The AHP provides flexibility in the definition of evaluation criteria
  - Can include looking at pros/cons of alternatives; using standardized technical comparison norms; identification of critical-to-quality factors, etc.
- For the technology evaluation process, direction from stakeholders specifically requested traceability of criteria to the COCR
  - A rigorous analysis of the COCR was performed to identified technical evaluation criteria for technology analysis
  - Additionally, review of ICAO consensus document led to the definition of institutional criteria
- The derived criteria, described in a previous briefing, are applied directly as inputs to the analytical hierarchy process

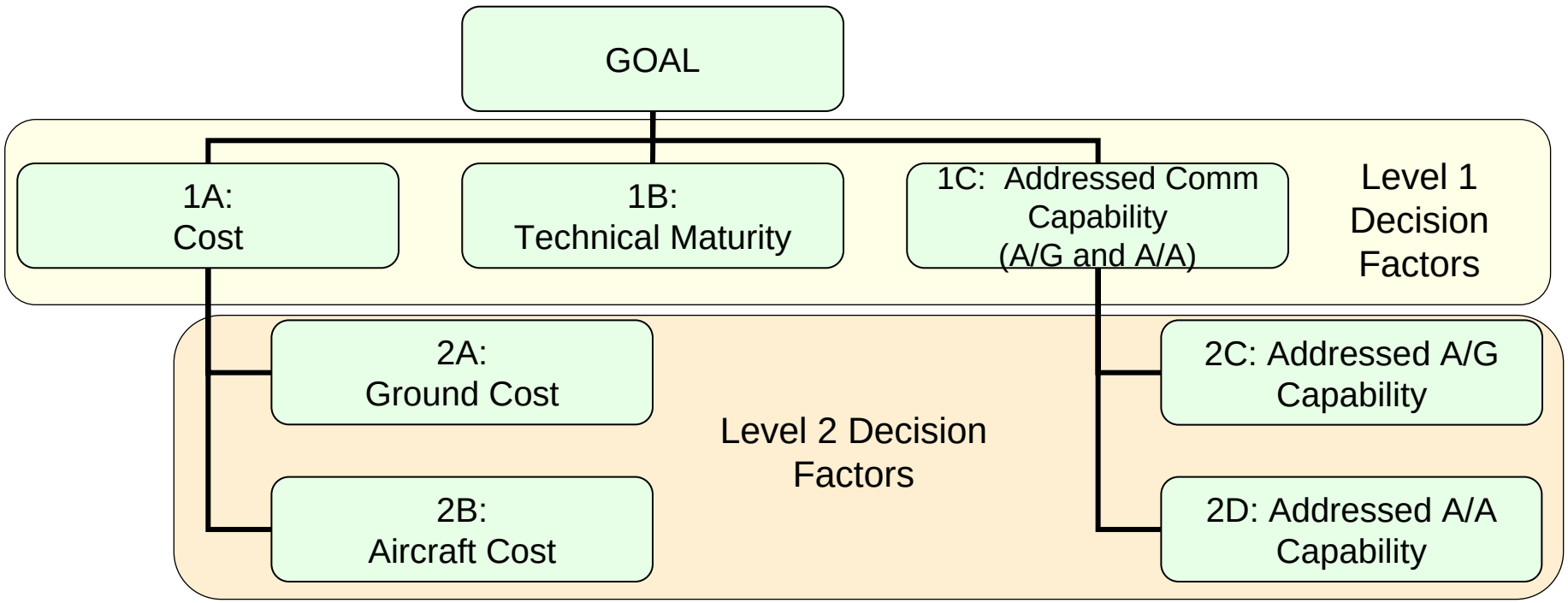
5. Develop Decision Hierarchy

Develop Decision Hierarchy

- After identification of applicable criteria, the analytical hierarchy process includes the definition of a decision hierarchy
  - Various alternatives exist for defining this structure, but some common traits exist
    - At the highest level, the structure identifies the analysis goal (e.g. identify FRS technology)
    - In the first branch of the hierarchy, high-level or global decision factors are defined
      - These can be directly traceable to the derived COCR requirement or can be a high-level roll-up of several requirements (supported by the definition of explicit derived evaluation criteria in a lower level of the hierarchy)

Develop Decision Hierarchy (2)

- For clear traceability of analysis process to the COCR, the most basic unit within the decision hierarchy is defined to be the derived evaluation criteria
  - Factors in the hierarchy can be a roll-up of these criteria, but not a decomposition of them



Develop Decision Hierarchy (3)

- The defined hierarchy can have multiple levels; however, the creation of each level can add significant complexity to the analysis
  - Each branch of the hierarchy is evaluated in a subsequent step of the AHP (beginning at the lowest level) to assess relative importance of decision factors (e.g., evaluation criteria or factors derived from evaluation criteria)
    - There are [N * (N-1)]/2 pairwise comparisons if there are N decision factors within a level of the hierarchy
  - Results from lower levels are then rolled up with results from higher levels of the hierarchy in later steps of the AHP
- Typical decision hierarchies have 3 – 4 levels

6. Evaluate Technologies vs. AHP Criteria

Evaluate Technologies vs. AHP Criteria

- The process for evaluation of technologies vs. AHP criteria includes two steps
  - Step 1: Assess performance of technologies against defined evaluation criteria
    - Note that the evaluation criteria are the basic units of the decision hierarchy and results may be rolled-up for higher-level hierarchy analyses
  - Step 2: Assessment of technologies against decision factors at each level of the defined hierarchy
    - These factors can be defined directly as evaluation criteria, or can be a roll-up of certain criteria

Evaluate Technologies vs. AHP Criteria (2)

- Step 1: Assess performance of technologies against defined evaluation criteria
  - 1A: Technical criteria assessment:
    - Capabilities and performance defined for a technology (in a concept of use) are compared with COCR requirements (individually)
    - A meets/doesn't meet decision is then applied

Technology Family	Cellular
Flight Domain	
APT	Yes
TMA	Yes
ENR	Yes
OR	No
P	No
AOA	Yes
Functionality	
A/G & G/A Addressed	Yes
Ground Originated Broadcast	Yes
A/A Addressed	No
Air Originated Broadcast	No
Data Rate (kbps)	
Data Rate for ATS (kbps)	500
Data Rate for ATS+AOC (kbps)	500
Max Number Users	300
Max Number of Users (SATCOM architectures)	N/A
QoS	Yes
Latency	Yes
	N/A

PHASE 2		Airport SV		TMA SV AEXEC		ER SV AEXEC			OR SV AEXEC	
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD
Separate ATS	UL	12.8	7.1	22.0	22.2	20.9	22.4	21.0	19.8	19.6
	DL	11.3	5.2	10.3	10.7	9.8	13.5	10.5	8.5	8.3
	UL&DL	19.6	7.3	24.5	25.1	23.5	27.0	24.0	20.3	19.9
Separate AOC	UL	113.0	14.1	0.3	0.2	52.4	96.1	64.1	24.0	18.2
	DL	6.7	1.2	2.4	2.2	1.4	2.7	1.8	0.6	0.4
	UL&DL	131.2	14.1	2.6	2.3	58.6	106.9	72.6	24.4	18.2
Combined ATS&AOC	UL	120.0	24.6	22.0	22.2	119.1	168.3	134.8	82.1	62.8
	DL	13.4	5.4	11.1	11.8	10.2	13.9	10.9	8.6	8.3
	UL&DL	144.3	24.8	25.2	25.8	119.4	168.9	135.2	82.2	62.9

Table 6-20: Air/Ground Capacity Requirements (kbps) – Phase 2

Evaluate Technologies vs. AHP Criteria (3)

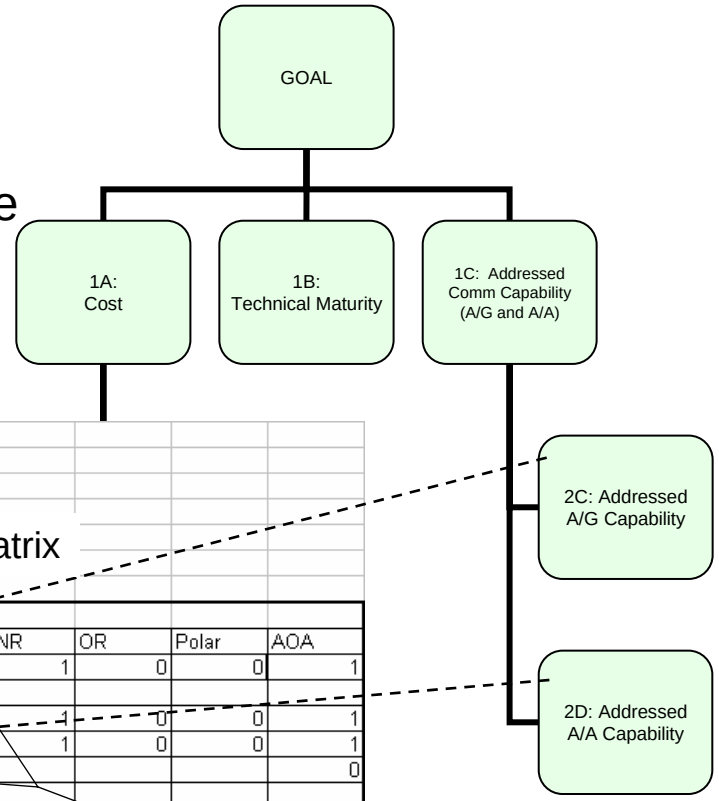
- 1B: Institutional criteria assessment:
  - Evaluate criteria applying the metrics defined for institutional criteria in the 2004 technology assessment report
    - Similar set of criteria; same metrics can be applied

Technology Family	Cellular
Flight Domain	
APT	Yes
TMA	Yes
ENR	Yes
OR	No
P	No
AOA	Yes
Functionality	
A/G & G/A Addressed	Yes
Ground Originated Broadcast	Yes
A/A Addressed	No
Air Originated Broadcast	No
Data Rate (kbps)	
Data Rate for ATS (kbps)	500
Data Rate for ATS+AOC (kbps)	500
Max Number Users	300
Max Number of Users (SATCOM architectures)	N/A
QoS	Yes
Latency	Yes
	N/A
Technical solution maturity	0
Technical Readiness Level	2
Standardization Status	1
Certifiability	0
Ground infrastructure cost solution	1
Avionics installation cost	2
Security	1
Spectrum Protection	1
Security - Authentication and Integrity	2
Security - Robustness to Deliberate Interference	1
Transition	1

Standardization Status
[G, Y, or R status is assigned based upon the existence of applicable standards for the candidate] **Assessed as:** Green: candidates that have a publicly available aeronautical standard; Yellow: candidates are supported by a mature commercial standard Red: candidates for which a supporting standard does not exist or is not publicly available

Evaluate Technologies vs. AHP Criteria (4)

- Step 2: Assessment of technologies against decision factors
  - For any roll-up of evaluation criteria, combine individual meets/doesn't meets decision to determine ability to meet decision factors



Technology Evaluation

Technology Family	Cellular
General Solution	0
Provided Data Rate is Per User?	N
Flight Domain	
APT	Yes
TMA	Yes
ENR	Yes
OR	No
P	No
AOA	Yes
Functionality	0
A/G & G/A Addressed	Yes
Ground Originated Broadcast	Yes
A/A Addressed	No
Air Originated Broadcast	No
Data Rate (kbps)	0
Data Rate for ATS (kbps)	500
Data Rate for ATS+AOC (kbps)	500
Max Number Users	300
Max Number of Users (ATS-only for area-based architectures)	N/A
QoS	Yes
Latency	Yes
Average Coverage Area Volume (per area) (nm^3)	N/A
Technical solution maturity	0
Ground infrastructure cost solution	1
Avionics installation cost	2
Security	1
Transition	1

Binary Decision Matrix

Phase II	APT	TMA	ENR	OR	Polar	AOA
Domain	1	1	1	0	0	1
	1	1	1	0	0	1
	1	1	1	0	0	1
		0				0
		0				
ATS	1	1	1	1	0	1
ATS_AOC	1	1	1	1	0	1
	1	1	1	1	0	1
	1	1	1	1	0	1
	1	1	1	1	0	1
	1	1	1	1	0	1

Combine to assess 1C decision factor

7. Compare AHP Criteria Pair-Wise

Compare AHP Criteria Pairwise

- In parallel with technology evaluations, the defined decision factors in the AHP decision hierarchy can be evaluated to determine relative importance
  - This step requires input from system stakeholders
- In the AHP process, each branch within all levels of the decision hierarchy requires a pairwise comparison of decision factors
  - This results in local weighting of decision factors
  - Local results are combined with comparison results at the next higher level of the hierarchy to build a cumulative weighting value
  - At the highest level of the hierarchy, Level 1, a global weight is assigned to each

Compare AHP Criteria Pairwise

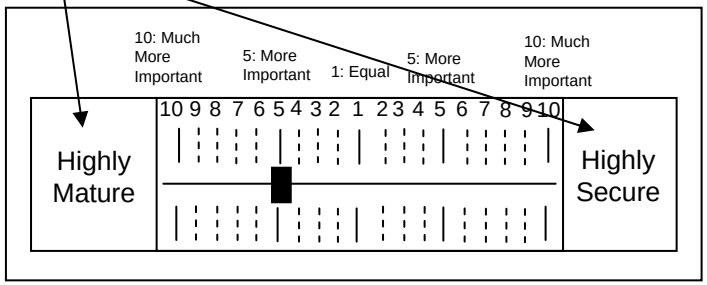
- To evaluate relative importance of criteria, the AHP requires solicitation of stakeholder inputs on the decision factors
  - Methods for obtaining inputs vary
    - Can include stakeholder interview, simple ranking exercises, and various survey techniques
    - There is a trade-off in granularity of results and stakeholder time/resource requirements for different methods
- Once stakeholder inputs are received, they are then translated into a quantitative comparison value for each pair of decision factors
  - Translation can be direct or indirect depending on methods used to collect stakeholder inputs

Compare AHP Criteria Pairwise

- Inputs from individual stakeholders, from common groups of stakeholders or across all stakeholders, are processed to develop a relative ranking of decision factors
- Application of matrix algebra leads to a weighted set of decision factors, directly or indirectly traceable to evaluation criteria

Compare AHP Criteria Pairwise

CTQs



Pair-wise Comparisons are used to populate an AHP comparison matrix

Scale:
1 - equally important
5 - more important
10 - much more important
1/5 - less important
1/10 - much less important

Instructions:
Fill the CTQ's in the rows. The are automatically copied into the column headers
Fill in the bottom half of the matrix and the top calculates itself as the invers
These criteria and scores are pulled into the Decsion Matrix weighting column
Note: Grey boxes are calculated fields (do not edit)

Is [row] more important than [column]? (>1)	Meets ATS_AOC_Cont_I COCR Requirements	Meets ATS_Cont_I COCR Requirements	Meets ATS_AOC_Cont_II COCR Requirements	Meets ATS_Cont_II COCR Requirements	Meets ATS_AOC_OR_I COCR Requirements	Meets ATS_OR_I COCR Requirements	Meets ATS_AOC_OR_II COCR Requirements	Meets ATS_OR_II COCR Requirements	Meets ATS_AOC_P_I COCR Requirements
Meets ATS_AOC_Cont_I COCR Requirements		10	0.2	1	5	5	1	1	10
Meets ATS_Cont_I COCR Requirements	0.1		0.1	0.1	0.1	5	0.1	0.1	0.1
Meets ATS_AOC_Cont_II COCR Requirements	5	10		5	5	5	1	1	5
Meets ATS_Cont_II COCR Requirements	1	10	0.2		5	5	1	1	5
Meets ATS_AOC_OR_I COCR Requirements	0.2	10	0.2	0.2		5	0.2	0.2	5
Meets ATS_OR_I COCR Requirements	0.2	0.2	0.2	0.2	0.2		0.2	0.2	0.2
Meets ATS_AOC_OR_II COCR Requirements	1	10	1	1	5	5		5	0.2
Meets ATS_OR_II COCR Requirements	1	10	1	1	5	5	0.2		5
Meets ATS_AOC_P_I COCR Requirements	0.1	10	0.2	0.2	0.2	5	5	1	
Meets ATS_P_I COCR Requirements	5	10	0.2	0.2	5	5	0.2	0.2	1
Meets ATS_AOC_P_II COCR Requirements	1	10	0.2	1	5	5	5	0.2	0.2
Meets ATS_P_II COCR Requirements	0.2	0.2	1	1	0.2	5	5	1	0.2
Meets ATS_AOC_APT_I COCR Requirements	0.2	10	1	0.2	5	5	5	1	1
Meets ATS_APT_I COCR Requirements	0.1	10	0.2	0.2	5	5	0.2	0.2	1
Meets ATS_AOC_APT_II COCR Requirements	5	10	0.2	1	0.2	5	5	1	0.2

Compare AHP Criteria Pairwise

Scale:
1 - equally important
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1/10 - much less important

Instructions:
Fill the CTQ's in the rows. The are automatically copied into the column headers
Fill in the bottom half of the matrix and the top calculates itself as the invers
These criteria and scores are pulled into the Decsion Matrix weighting column
Note: Grey boxes are calculated fields (do not edit)

Is [row] more important than [column]? (>1)	Meets ATS_AOC_Cont_I COCR Requirements	Meets ATS_Cont_I COCR Requirements	Meets ATS_AOC_Cont_II COCR Requirements	Meets ATS_Cont_II COCR Requirements	Meets ATS_AOC_OR_I COCR Requirements	Meets ATS_OR_I COCR Requirements	Meets ATS_AOC_OR_II COCR Requirements	Meets ATS_OR_II COCR Requirements	Meets ATS_AOC_P_I COCR Requirements
Meets ATS_AOC_Cont_I COCR Requirements		10	0.2	1	5	5	1	1	10
Meets ATS_Cont_I COCR Requirements	0.1		0.1	0.1	0.1	5	0.1	0.1	0.1
Meets ATS_AOC_Cont_II COCR Requirements	5	10		5	5	5	1	1	5
Meets ATS_Cont_II COCR Requirements	1	10	0.2		5	5	1	1	5
Meets ATS_AOC_OR_I COCR Requirements	0.2	10	0.2	0.2		5	0.2	0.2	5
Meets ATS_OR_I COCR Requirements	0.2	0.2	0.2	0.2	0.2		0.2	0.2	0.2
Meets ATS_AOC_OR_II COCR Requirements	1	10	1	1	5	5		5	0.2
Meets ATS_OR_II COCR Requirements	1	10	1	1	5	5	0.2		5
Meets ATS_AOC_P_I COCR Requirements	0.1	10	0.2	0.2	0.2	5	5	1	
Meets ATS_P_I COCR Requirements	5	10	0.2	0.2	5	5	0.2	0.2	1
Meets ATS_AOC_P_II COCR Requirements	1	10	0.2	1	5	5	5	0.2	0.2
Meets ATS_P_II COCR Requirements	0.2	0.2	1	1	0.2	5	5	1	0.2
Meets ATS_AOC_APT_I COCR Requirements	0.2	10	1	0.2	5	5	5	1	1
Meets ATS_APT_I COCR Requirements	0.1	10	0.2	0.2	5	5	0.2	0.2	1
Meets ATS_AOC_APT_II COCR Requirements	5	10	0.2	1	0.2	5	5	1	0.2

Apply linear analysis techniques to calculate eigenvalues/eigenvectors; normalize eigenvector to calculate CTQ Requirement Weights

Meets ATS_Cont_II COCR Requirements	0.1306
Meets ATS_OR_II COCR Requirements	0.1128
Provides low ground infrastructure cost solution	0.1097
Provides highly secure/safe solution	0.1097
Provides low-risk/low complexity service provider transition	0.1097
Meets ATS_Cont_I COCR Requirements	0.0947
Meets ATS_OR_I COCR Requirements	0.0892
Meets ATS_APT_II COCR Requirements	0.05

Calculate Evaluation Scores & Sensitivity Analysis

Calculate Evaluation Scores

- Overall technology scores result from the combination of technology evaluation outputs with weighted ranking of AHP Level-1 decision factors
  - Technology evaluations result in a meets/doesn't meet decision for each AHP Level-1 decision factor
  - For each decision factor that is "met" by the technology, the weighted value of the decision is added to the system score
  - Resulting scores can range from 0 to 1
- Technologies typically have different evaluation scores for different stakeholders
  - Weighted ranking of AHP decision factors are likely different for different stakeholders

Calculate Evaluation Scores

Technology under Evaluation:	0		
Selected Ranking Perspective:	CAA (sample)		
Technology Decision Factor Assessment			
Level 1 Decision Factor	**Meets**	AHP Assessment Value	**SCORE**
Meets ATS_G-A-Addressed_COCR Requirements	☑	18.20%	0.182
Meets ATS_G-A-Broadcast_COCR Requirements	☑	2.79%	0.0279
Meets ATS_A-A-Addressed_COCR Requirements	☐	12.22%	
Meets ATS&AOC_G-A-Addressed_COCR Requirements	☑	7.93%	0.0793
Meets ATS&AOC_G-A-Broadcast_COCR Requirements	☑	7.23%	0.0723
Meets ATS&AOC_A-A-Addressed_COCR Requirements	☐	2.85%	
Provides highly mature technical solution	☐	4.03%	
Provides low ground infrastructure cost solution	☑	9.20%	0.092
Provides low avionics installation cost solution	☑	4.80%	0.048
Provides highly secure/safe solution	☑	23.27%	0.2327
Provides low-risk/low complexity service provider transition	☑	7.48%	0.0748
	☑	TOTAL	0.809

Sensitivity Analysis

- To perform sensitivity analysis, subsets of the AHP Level -1 decision factors can be isolated and results computed
- The selected sensitivity analysis methodology for this evaluation was to select subsets of the overall decision factors and evaluate technologies against these subsets
  - The suggested subsets are technical criteria and institutional criteria
    - Decision factors associated with technical evaluation criteria and institutional criteria are isolated and the evaluation process iterated
    - Results identify sensitivity of technology scores to technical decision factors vs. institutional decision factors

Looking Ahead

- Rigorous application of the Analytical Hierarchy Process requires
  - Consensus stakeholder inputs from multiple stakeholder populations
    - Results for a limited set of contributors from representative of a stakeholder population have been included in Phase II; expansion of this efforts is envisioned for Phase III
  - Detailed technology information to assess technology performance against evaluation criteria
    - A subset of screened technologies have undergone detailed analysis; evaluation results of the AHP can be used to identify other candidate technologies for detailed investigation in Phase III