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EUROCONTROL

Future Communication Study – Action Plan 17 Final Conclusions and Recommendations Report

DASC 2007
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Briefing Outline

- AP17 overview
- Technology Investigations
  - Europe (Step 1 and 2)
  - US (Phase I, II and III)
- Recommendations
  - Required Actions

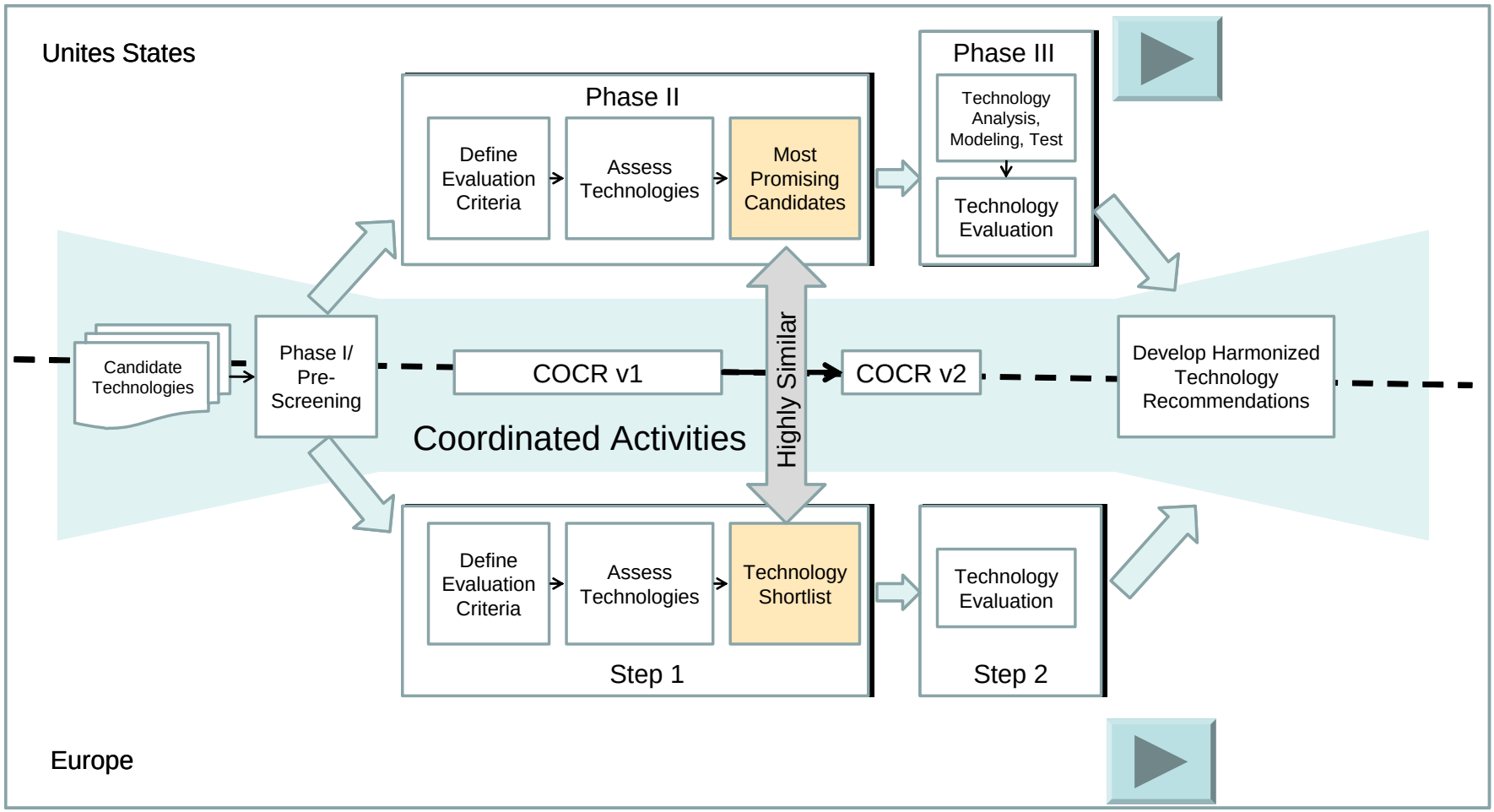
AP17 in a slide

- ☑ FAA/NASA and EUROCONTROL
- ☑ Response to AN-Conf/11 outcome
- ☑ Support by ITT, MITRE and QinetiQ
- ☑ Contributions from France, Germany, Spain, Sweden, UK and ESA
- ☑ International Coordination and Communication (ICAO, Conferences)

6 Technical Tasks	3 Business Tasks
– Improvements to current systems	– International Perspective
– Concept and Requirements	– Industry Participation
– Technology Evaluations	– Business Aspects
– Communication Roadmap	
– Integration Aspects	
– Spectrum Aspects	

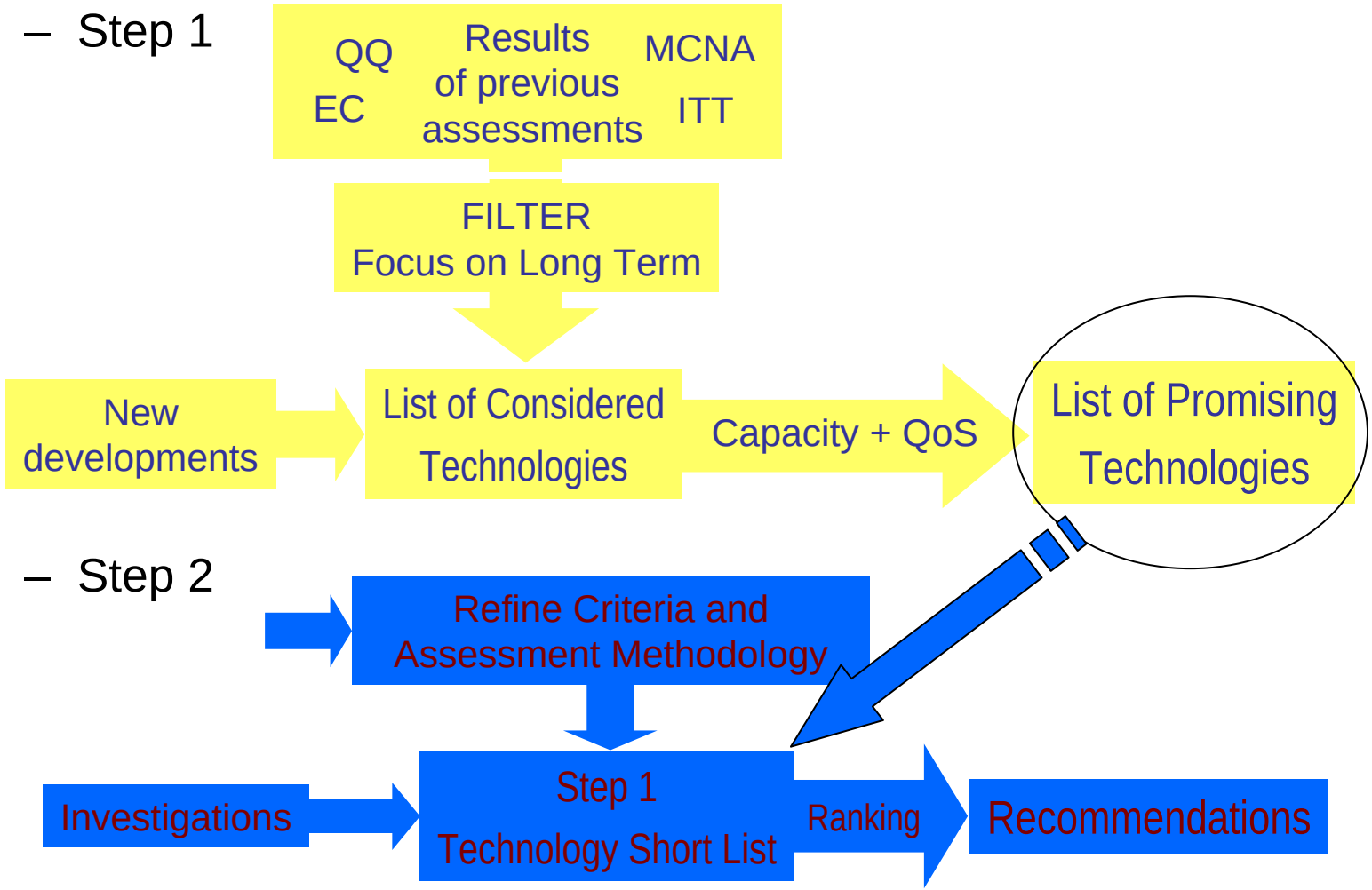
- ☑ Support to SESAR and NextGEN
- ☑ Recommendations and Actions

AP17 Activities



European Assessment Methodology

- Two step approach:
  - Step 1
  - Step 2



European Assessment: Evaluation Criteria

- Essential Criteria
  - Spectrum Compatibility
  - Openness of Standards
- Desirable Criteria
  - RF Robustness
  - Technical Readiness Level
  - Flexibility
  - Ground Infrastructure Cost
- Performance Criteria
  - Capacity
  - Integrity
  - Availability
  - Latency

European Assessment - Metrics

- Ranking was seen as the best way to compare technologies
  - 4 Classes have been defined each with an acceptance mask

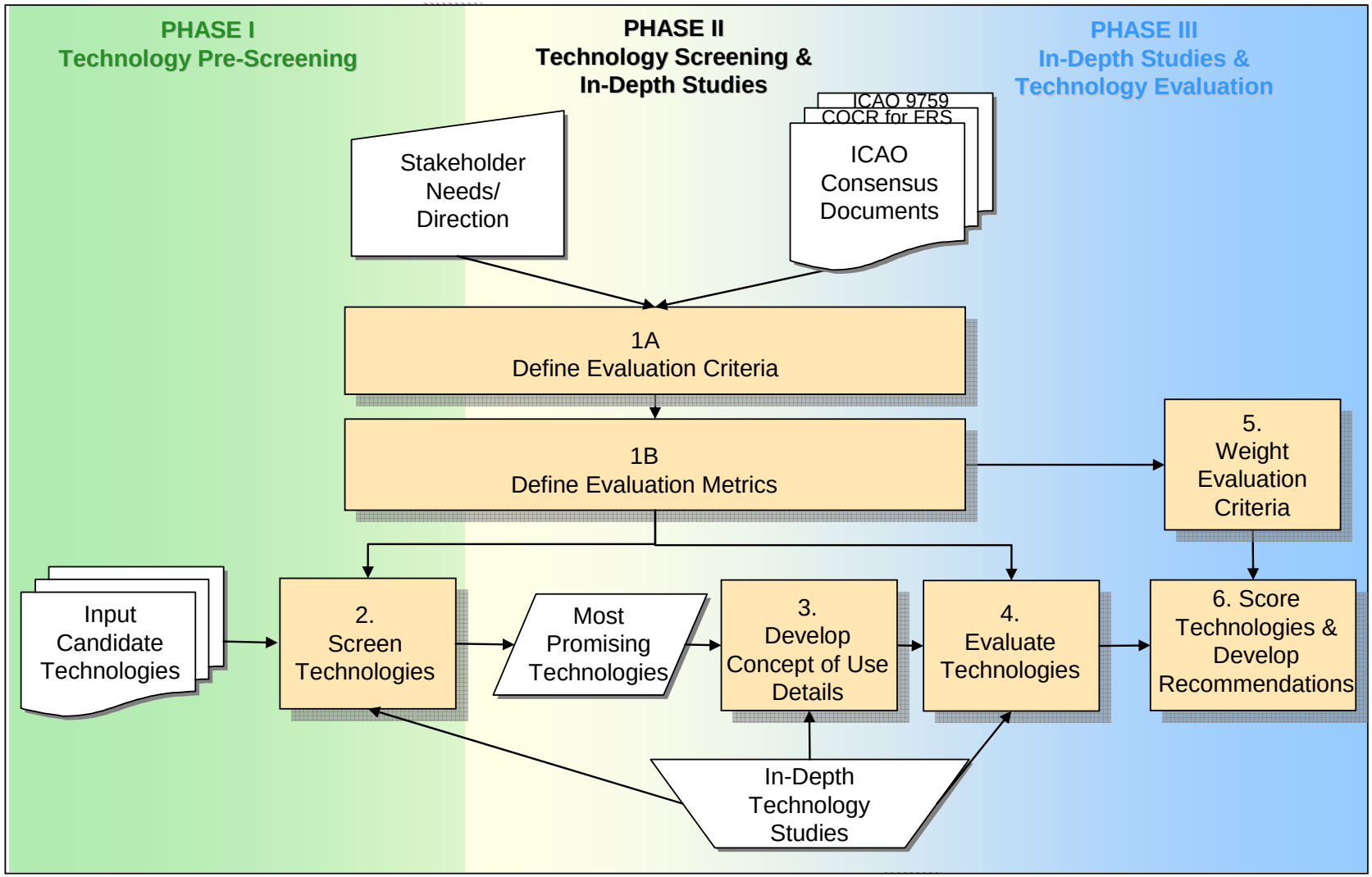
Criterion Value	Security	TRL	Flexibility	Cost	Capacity	Integrity	Availability	Latency
1								
2								
3								
4								
5								

Class 3

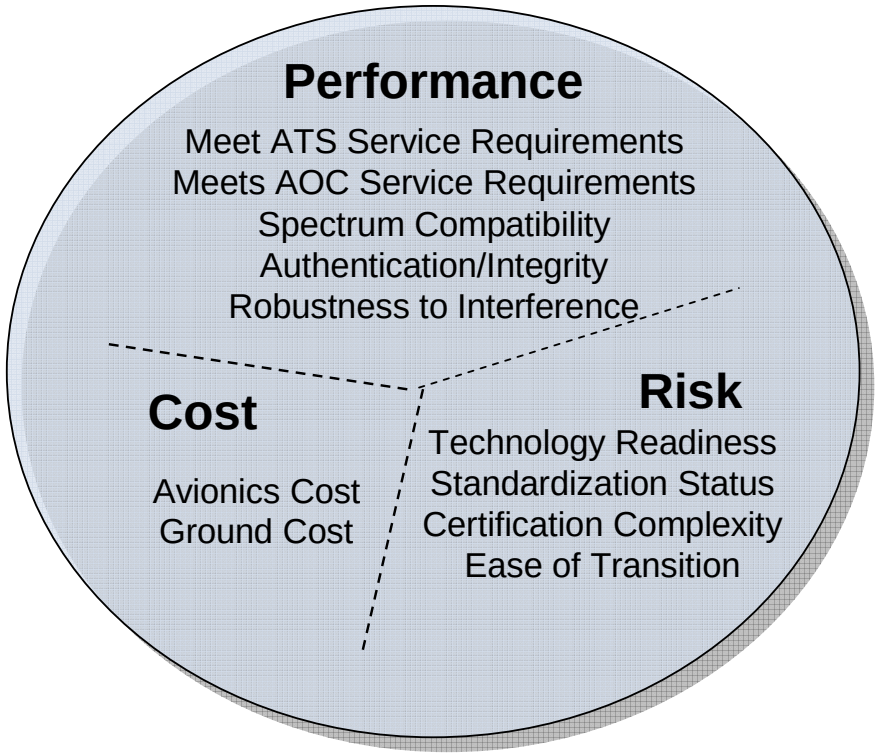
Criterion Value	Security	TRL	Flexibility	Cost	Capacity	Integrity	Availability	Latency
1								
2								
3								
4								
5								

Class 4

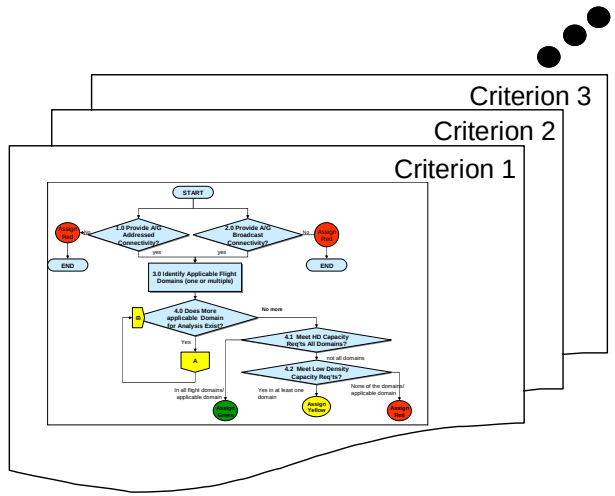
US Assessment Methodology

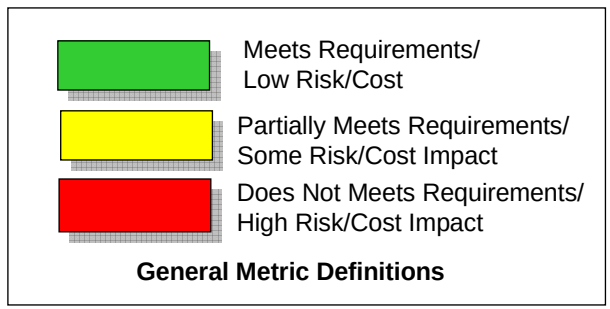


US Assessment: Evaluation Criteria



11 criteria traceable to the COCR and consensus ICAO documents were derived in FCS Phase II





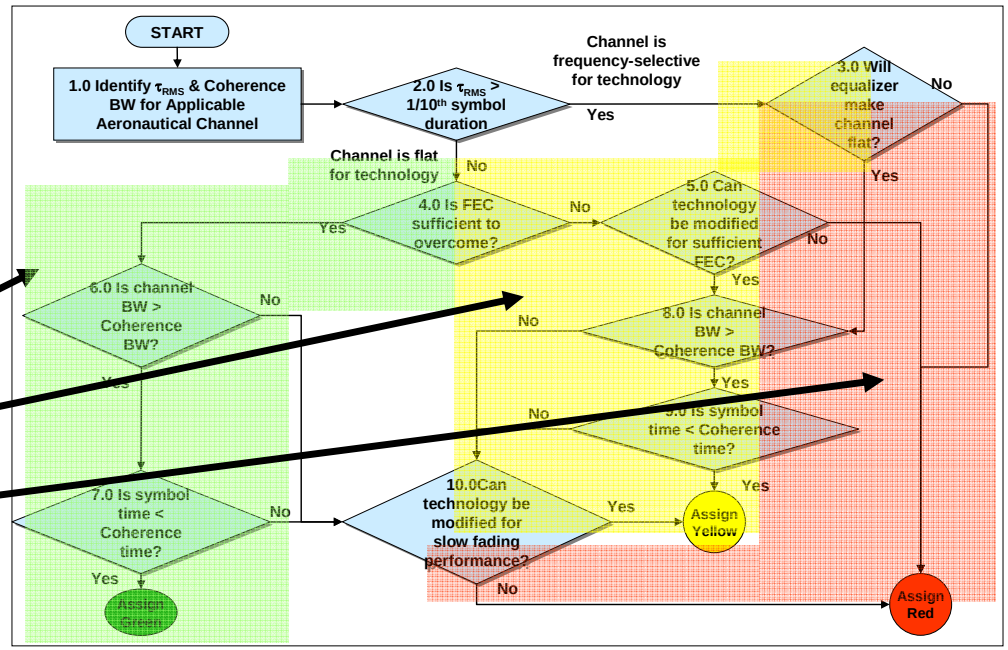
In FCS Phase III, criteria definitions and associated metrics were revised to reflect updates to the COCR and process diagrams to define the evaluation steps were developed

US Assessment: Metrics

Example Metrics

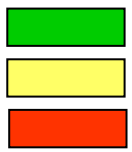
Criteria	Metrics
1-D: Provides ATS A/G Data Services within Requirements (sans A-EXEC) - Environment	This provides a measure of a technology's ability to provision ATS services within the COCR-defined airspace environment **GREEN**: Technology performance in intended channel is characterized by flat/slow fading **YELLOW**: Technology can be readily modified to be characterized by flat/slow fading (e.g. physical layer modifications; equalization techniques) **RED**: Technology cannot be easily modified to be characterized by flat/slow fading

Associated Evaluation Flow Diagram

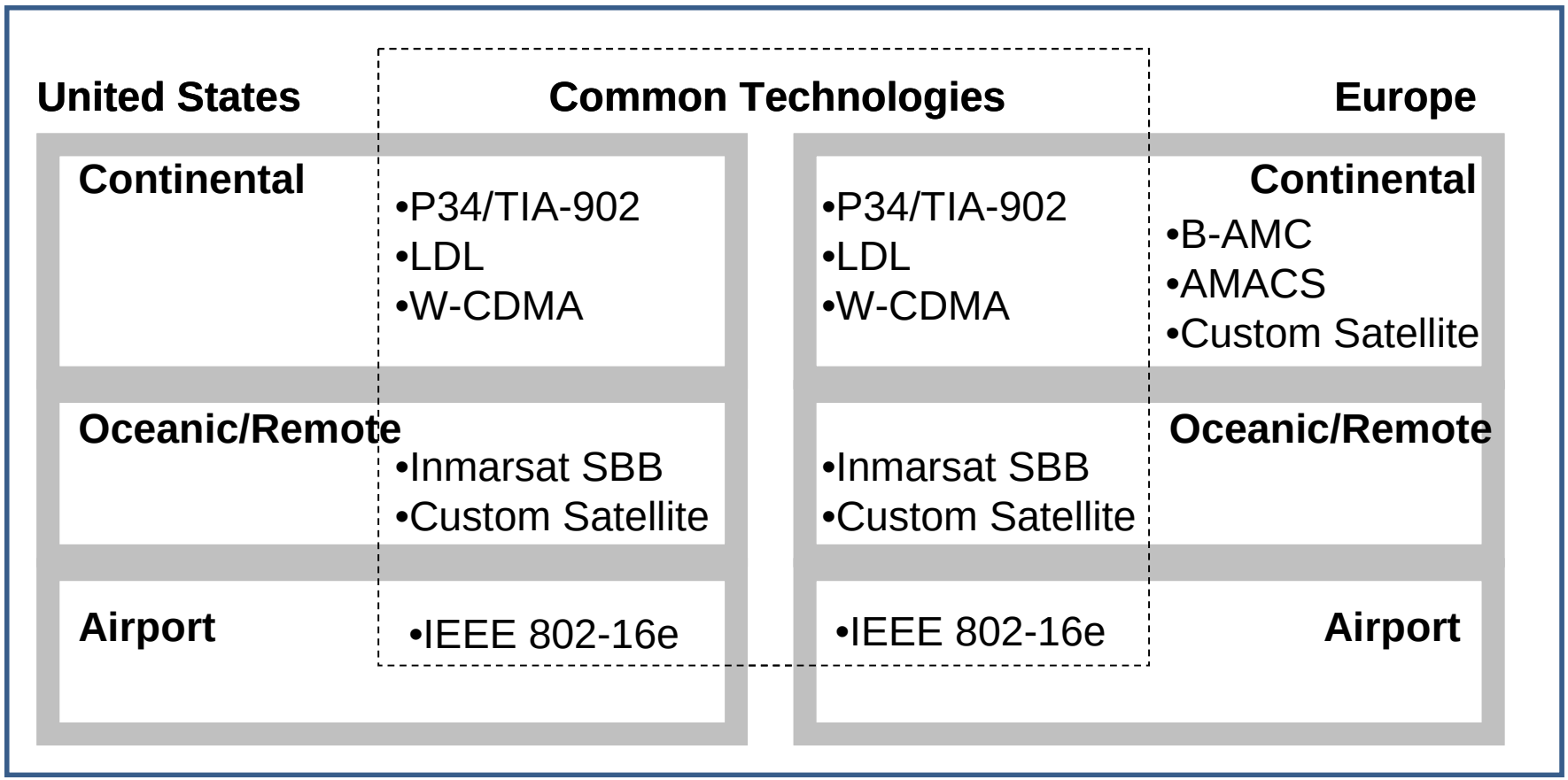


Evaluation Criteria -- Comparison

Criteria Category	European Criteria	US/ITT Criteria
Technical Performance	• Capacity • Integrity • Availability • Latency • Spectrum Compatibility • RF Robustness	• Meets ATS Service Requirements • Meets ATS&AOC Requirements • Spectrum Compatibility • Authentication/Integrity • Robustness to Interference
Cost	• Openness of Standards • Flexibility • Cost	• Avionics Cost • Ground Cost
Risk	• TRL	• TRL • Standardization Status • Certification Complexity • Ease of Transition

Scale	Numerical scale between 1 ~ 5	

Evaluated Technologies



US Detailed Technology Studies

	In-Depth Study Topic	Note
1	**L-Band Air/Ground Communication Channel Characterization**	Created ray-tracing simulation to develop tap-delay line models of the L-band aeronautical channel (960-1024 MHz) supporting evaluation of LDL and P34/TIA-902
2	**TIA-902 (P34) Performance Assessment**	1. OPNET simulation of P34 net entry and data transfer performance 2. MATLAB Simulink® model developed to assess P34/TIA-902 physical layer performance in the defined L-Band A/G channel
3	**TIA-902 (P34) Technology Intellectual Property Assessment**	Assessment IP impact for patents claimed in P34/TIA-902 standards
4	**L-Band Digital Link (LDL) Technology Performance Assessment**	MATLAB Simulink® model developed to assess LDL physical layer performance in the defined L-Band A/G channel
5	**Wideband Code Division Multiple Access (WCDMA) Functional Assessment**	Functional analysis of UMTS/WCDMA network architecture
6	**L-Band Technology Cost Assessment for Ground Infrastructure**	L-Band business case analysis for an L-Band aeronautical ground infrastructure
7	**L-Band Interference Testing**	UAT, Mode S interference modeling and simulation using SPW modeling tool for P34 and LDL waveforms 1.Bench tests conducted to evaluate DME susceptibility to candidate FCS waveforms (based on WCDMA, P34, LDL definitions)
8	**Satellite Technology Availability Performance**	Evaluation of satellite technology availability performance using fault-tree model of RTCA DO-TBD
9	**IEEE 802.16e Performance Assessment in Aeronautical C-Band Channel**	MATLAB Simulink® modeling of 802.16e on the surface environment implementing OU aeronautical C-band channel model

European Detailed Technology Studies

- Detailed technology studies were undertaken by various entities in Europe
  - AMACS was progressed by DSNA (France) and LFV (Sweden). Support was provided by NATS/Helios on performance evaluation
  - P34 (TIA-902) was investigated by NATS/Helios in terms of performance and compatibility
  - B-AMC studies were funded by EUROCONTROL through the B-AMC Consortium to define the overall system including performance and compatibility
  - Review of previous EUROCONTROL activity on WCDMA
  - Drew on work carried out in the U.S. for LDL and 802.16
  - New satellites was progressed by ESA through the SATCOM for ATM Study, and INMARSAT SBB was evaluated based on the outcome of previous ECTL work.
  - QinetiQ applied the evaluation criteria and developed a critique of each system
    - Developed joint technology conclusions with ITT and the Step 2 report

European Evaluation Results

Technology	Class	Frequency band	Application airspace
802.16e	2	C-Band	Airport surface
B-AMC	3	L-Band	Airport surface, TMA, En-route
P34 (TIA-902)	4	L- Band	Airport surface, TMA, En-route
AMACS	4	L-Band	Airport surface, TMA, En-route
LDL	4	L-Band	Airport surface, TMA, En-route

European Evaluation Results (2)

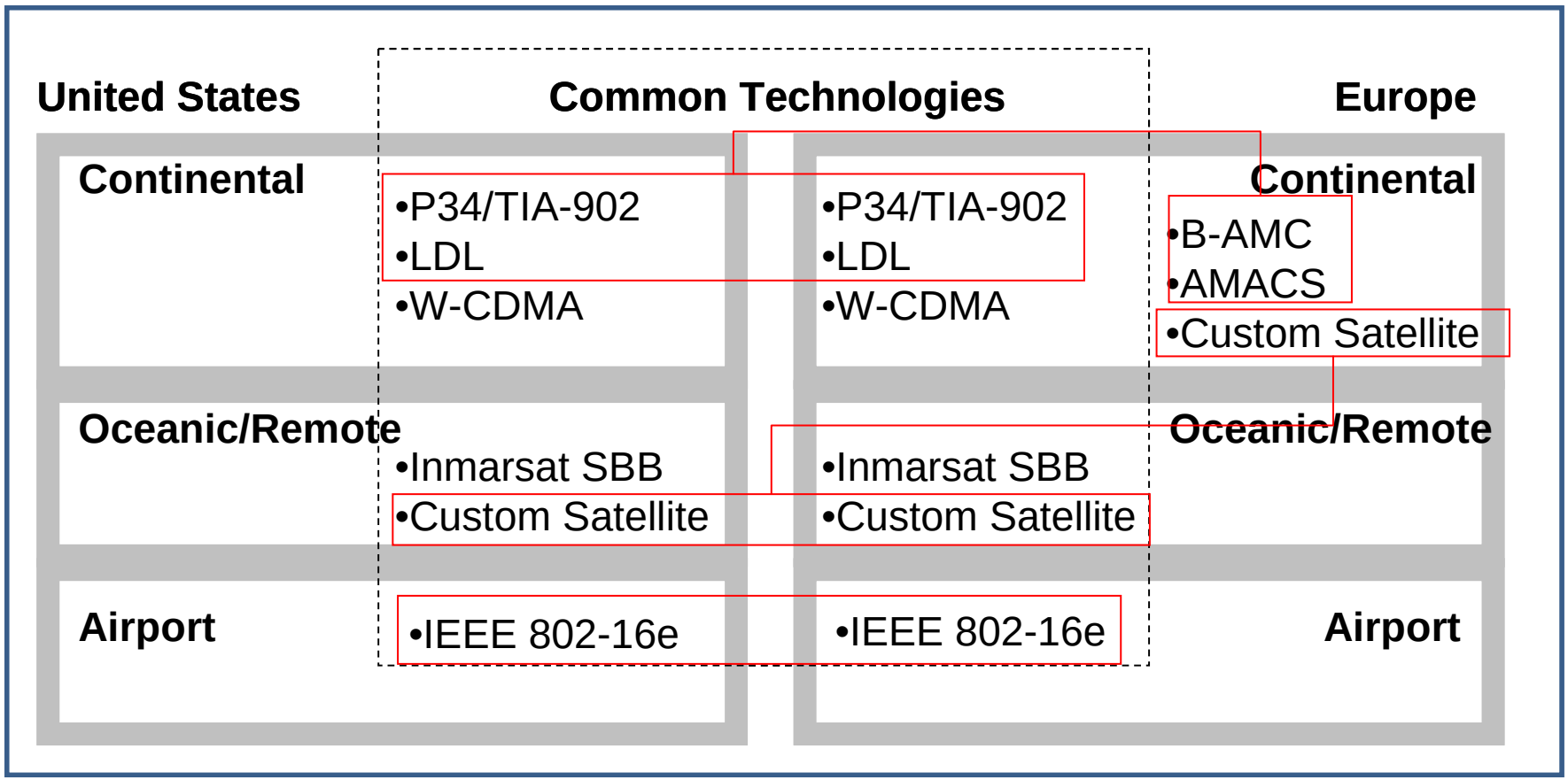
- Two technologies have been removed from further consideration
  - SBB
    - Does not meet all performance requirements
    - Satellite will reach the end of life by 2020
  - WCDMA
    - Need for large “clean” bands in L-Band
- New Satellite Systems
  - Placeholder for future developments
  - Emerging systems have been identified that could be considered as part of the FCI

U.S. Evaluation Results

	Evaluation Criterion		TIA-902 (P34)	LDL	WCDMA	B-AMC	AMACS
1	Provides ATS A/G Data Services within Requirements (sans A-EXEC)	A - Capacity					
		B - PIAC					
		C - QoS					
		D - Environment					
2	Provides ATS AOC A/G Data Services within Requirements (sans A-EXEC)	A - Capacity					
		B - PIAC					
		C - QoS					
		D - Environment					
3	Technical Readiness Level						
4	Standardization Status						
5	Certification						
6	Ground Infrastructure Cost						
7	Avionics Cost						
8	Spectrum						
9	Authentication and Integrity						
10	Robustness to Interference						
11	Transition						

* Gray indicates insufficient information at the time of evaluation

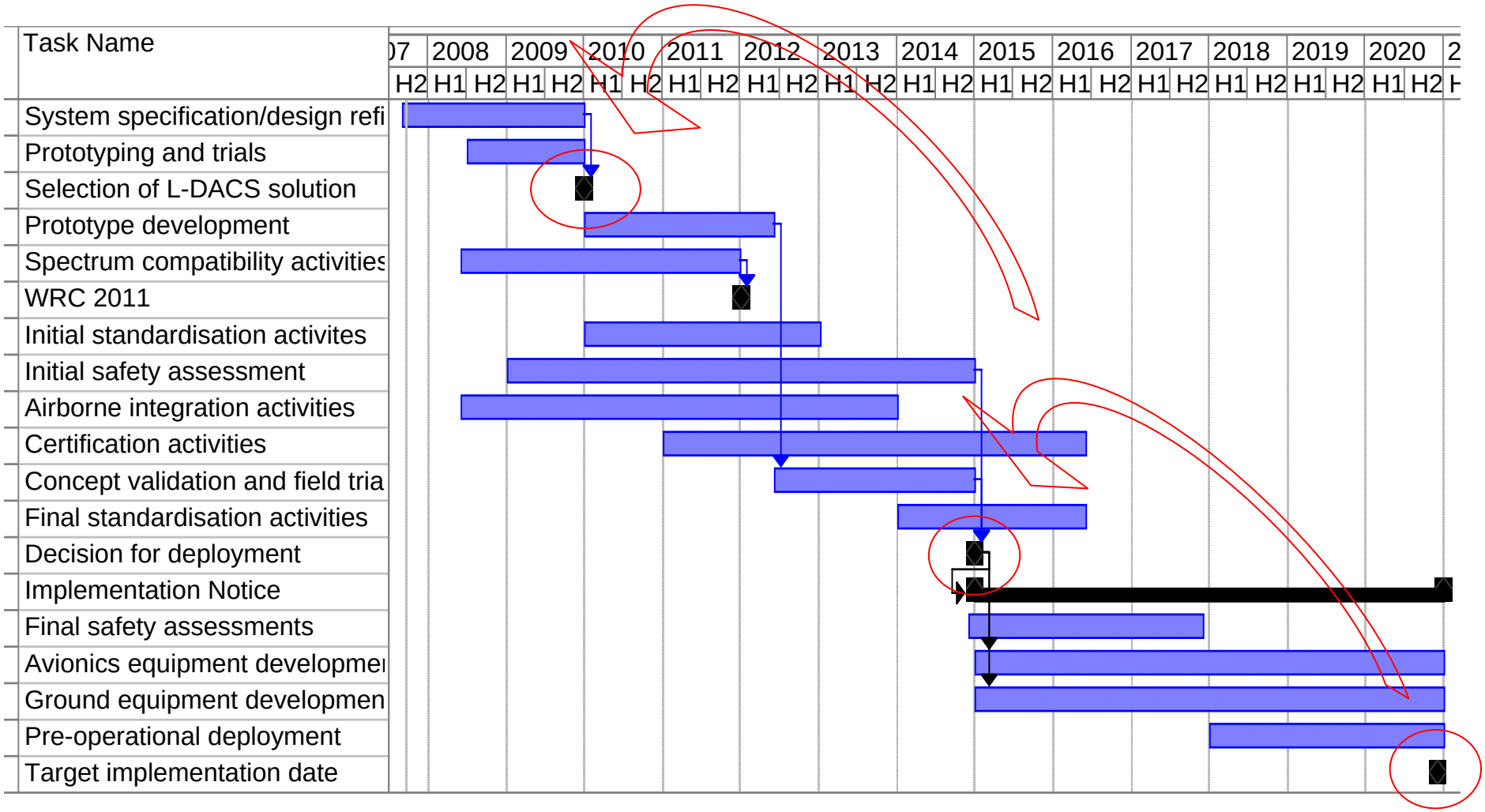
Joint Proposals



L-band Digital Aeronautical Communication System (L-DACS) Key Characteristics

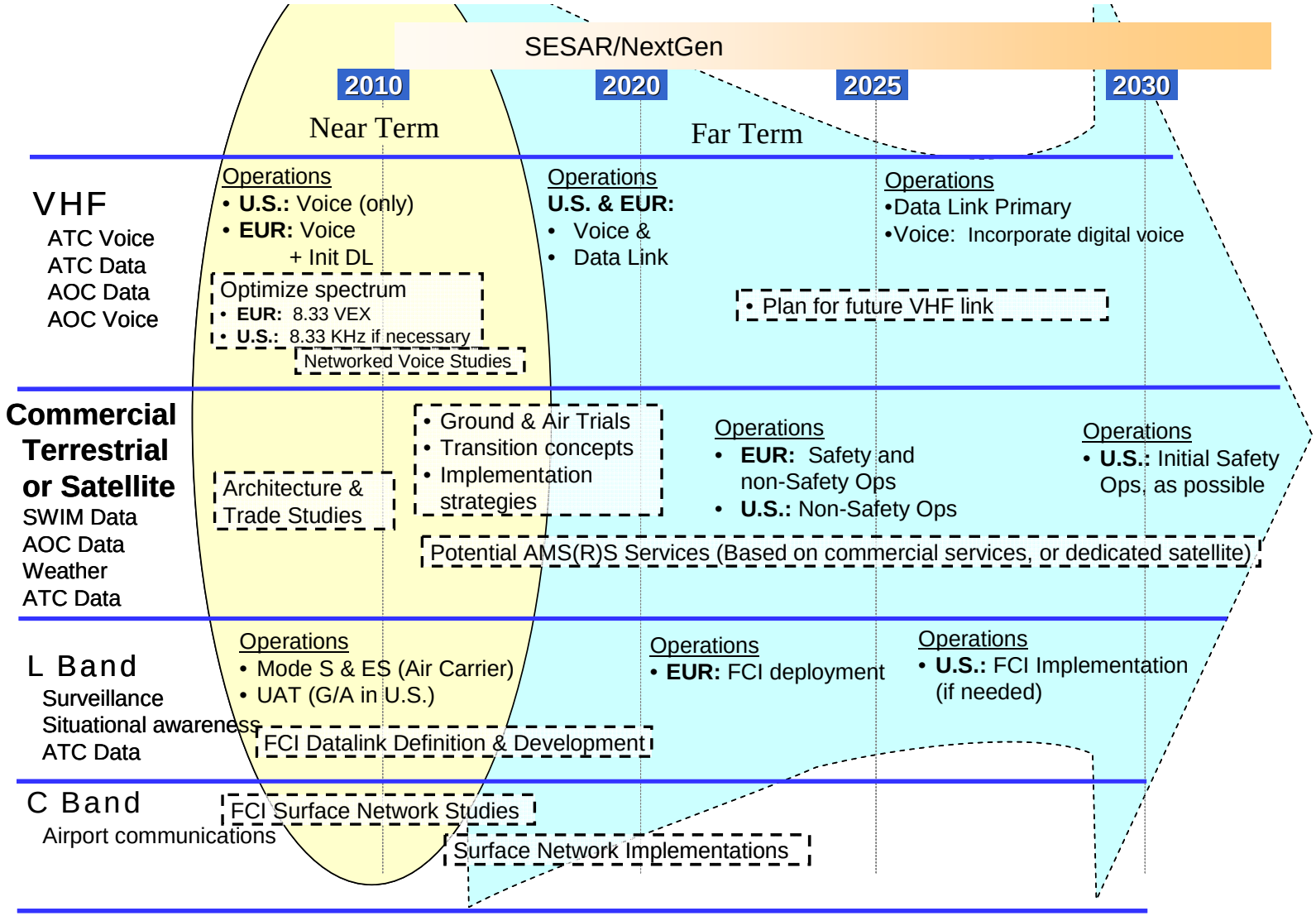
Options	**Access scheme**	**Modulation type**	**Origins**
L-DACS 1	FDD	OFDM	B-AMC, TIA 902 (P34)
L-DACS 2	TDD	CPFSK/GMSK type	LDL, AMACS

L-band data link: Expedited Development and Deployment Plan



Roadmap

Future Comm Study: Communication Evolution Overview



Observations: General

- The FCI must support ATS and AOC end-to-end communications including air/ground and air/air
- New communication components of the FCI will be supporting primarily data communications
- No single technology meets all requirements across all operational flight domains
- To meet the diverse range of communications the FCI will be a **system of systems** integrating **existing communication systems** (voice, VDL) as well as **new communications systems** to meet the operational requirements
- No COTS technologies have been identified that can be adopted as new components of the FCI without some modification
  - However, reuse of emerging technology and standards should be considered to the maximum extent possible to reduce risk and shorten development time

Data Link Recommendations

[R1] Develop a new system based on the IEEE 802.16e standard operating in the C-band and supporting the airport surface environment

[R2] Complete investigations (with emphasis in proving the spectrum compatibility with other systems) for finalising the selection of a data link operating in L-band (L-DACS) and supporting the continental airspace environment, aiming at a final decision by 2009, to enable system availability for operational use by 2020

[R3] Recognising that satellite communications remain the prime candidate to support oceanic and remote environments and that the considered future satellite systems may also be able to support continental environments possibly complementing terrestrial systems, monitor and support developments that will lead to globally available ATS satellite communications

General Recommendations

[R4] Recognising the importance of spectrum for the realisation of FCI, ensure the availability of the required spectrum in the appropriate bands.

[R5] Promote/support activities that will enable/facilitate the airborne integration of the selected technologies.

[R6] Incorporate in any new data link system, provisions for supporting high QoS requirements in an end to end perspective.

[R7] Continue the close cooperation between the interested stakeholders and in particular between the FAA and EUROCONTROL in the realisation of the above recommendations

Actions

- Per actor/stakeholder group
  - ANSPs, EUROCONTROL, FAA
  - Industry
  - Standardization Bodies

- Per activity type
  - C-band system
  - L-band system
  - Satellite system
  - End to end QoS
  - Spectrum
  - Airborne Integration
  - Standardization

C-band Datalink Actions

[R1] Develop airport surface system based on IEEE 802.16e standard.

[A1.1] Identify the portions of the IEEE standard best suited for airport surface wireless communications, identify and develop any missing functionality and propose an aviation specific standard to appropriate standardisation bodies;

[A1.2] Evaluate and validate the performance of the aviation specific standard to support wireless mobile communications networks operating in the relevant airport surface environments through trials and testbed development;

[A1.3] Propose a channelisation methodology for allocation of safety and regularity of flight services in the band to accommodate a range of airport classes, configurations and operational requirements

[A0.4] Complete business analysis in relation to the FCI components and implementation from the perspective of the ground infrastructure and the airlines.

L-band Datalink Actions (1/2)

[R2] Complete investigations for selection of L-band datalink.

[A2.1] Refine and agree on the interference environment and assumptions for the L-band compatibility investigations;

[A2.2] Develop L-DACS prototypes for testing and trials to facilitate the technology investigations for the selection of the L-band data link;

[A2.3] Complete the investigation of compatibility of candidate L-band data link with existing systems in the L-band particularly with regard to the onboard co-site interference and agree on the overall design characteristics;

…

L-band Datalink Actions (2/2)

[R2] Complete investigations for selection of L-band datalink.

…

[A2.4] Complete evaluation of performance of candidate L- band data link against the appropriate requirements in the various environments; and

[A2.5] Considering the design trade-offs, propose the appropriate L-DACS solution for input to a global aeronautical standardisation activity; and

[A2.6] Evaluate and validate the performance of the proposed solution in the relevant environments through trials and test bed development.

[A0.4] Complete business analysis in relation to the FCI components and implementation from the perspective of the ground infrastructure and the airlines.

Satellite Datalink Actions

[R3] Monitor and support globally available ATS satellite communications.

[A3.1] Continue monitoring the satellite system developments and assessment of specific technical solutions to be offered in the timeframe defined in the COCR as these next generation satellite systems become better defined;

[A3.2] Update existing AMS(R)S SARPs performance requirements to meet future requirements; and

[A3.3] In order to support the new AMS(R)S SARPs, consider the development of a globally applicable air interface standard for satellite communication systems supporting safety related communications.

[A0.4] Complete business analysis in relation to the FCI components and implementation from the perspective of the ground infrastructure and the airlines.

General Datalink Actions

[R6] Incorporate provisions for high QoS in an end to end perspective.

[A0.5] In order to finalise the selection of the new components of the FCI, carry out testing and validation within an end-to-end environment to ensure that the required QoS and performance can be achieved.

Spectrum Related Actions

[R4] Ensure the availability of the spectrum

[A4.1] Continue to provide rationale to spectrum regulators on the need for additional AM(R)S spectrum to facilitate advances in aeronautical communication capabilities;

[A4.2] Provide support for compatibility studies between the FCI and other incumbent systems in any newly-allocated AM(R)S bands. This will include studies within ICAO regarding FCI compatibility with other aeronautical systems, and studies within the ITU regarding FCI compatibility with non-aeronautical systems; and

[A4.3] Continue to support the need for priority to AMS(R)S in the satellite L-band.

[A4.4] In the longer term, reconsider the potential use of the VHF-band for new technologies when sufficient spectrum becomes available to support all or part of the requirements.

Industry Actions

[R5] Promote the airborne integration of the selected technologies.

[C1.1] Investigate the feasibility of a flexible airborne architecture and enablers such as software defined avionics, and multi-function, multi-mode antennas; and

[C1.2] Support activities to ensure that a flexible airborne architecture evolves to ease the cost and time of certification and readily accommodate new applications and technologies.

FAA, EUROCONTROL, ANSPs, Airlines and ICAO Actions

[R1 to R7]

C-band, L-band and Satellite Data link and Spectrum Actions

+

[A0.1] Continue close cooperation in carrying out the actions and relevant activities.

[A0.2] Support activities and engage with aircraft manufacturers, aircraft operators and industry standard groups to ensure that a flexible airborne architecture evolves to ease the cost and time of certification and readily accommodate new applications and technologies; and

[A0.3] Encourage industry investigations into flexible airborne architectures, software defined avionics, and multi-function, multi-mode antennas.

Standardisation & Certification Actions
(including ICAO, RTCA, EUROCAE)
Supporting recommendations R1, R2, R3, R5

[B1.1] Initiate development of appropriate aviation specifications covering the 802.16e based system operating in the C-band;

[B1.2] Await the outcome of actions 3.X to initiate development of appropriate aviation specifications covering the selected L-band data link;

[B1.3] Update existing AMS(R)S SARPs performance requirements to meet future requirements;

[B1.4] Consider the development of a globally applicable air interface standard for satellite communication systems supporting safety related communications; and

[B1.5] Consider the re-evaluation of actual certification procedures (e.g. DO178/ED12) and/or development of an integrated SW development environment in order to decrease certification cost for future components (particularly SDR)

What next

- Dissemination of outcome
- SESAR/NextGEN: coordination and input (already in place)
- Continue cooperation (FAA and ECTL) and other interested parties
  - ..
  - L-band data link
  - ..
- Work with Industry to address integration aspects

Thank you!

Back up slides

EUR Technology Evaluation: AMACS

- Essential criteria
  - Compatibility – studies undertaken indicate that co-site interference may be overcome – affected by duty cycle. Results inconclusive and requires further work
  - Open standards– it will be developed in an open manner - passed
- Desirable
  - Robustness – designed to have robust physical layer
  - TRL – 3 – still at early stage of development
  - Flexibility – as several design options
  - Ground costs – expected to need more ground sites than VHF hence increased cost
  - Performance – meets most requirements in APT, TMA, ENR, and AOA.
  - Air/air performance needs to be considered further

EUR Technology Evaluation: B-AMC

- Essential criteria
  - Compatibility – considerable work undertaken and results show promise as an inlay system. However further work is recommended on the L-band interference models to confirm results - inconclusive
  - Open standards - it will be developed in an open manner - passed
- Desirable
  - Robustness – design shows good robustness
  - TRL – 4 – Considerable theoretical studies on the design – draws on earlier B-VHF system
  - Flexibility – it can be deployed in several ways
  - Ground costs – estimated as similar to current system
  - Performance – meets all requirements in APT, TMA, ENR, and AOA
  - Air/air performance seems OK but needs to be considered further

EUR Technology Evaluation: LDL

- Essential criteria
  - Compatibility – similar to all other L-band interference studies. Results inconclusive and requires further work – inconclusive.
  - Open standards – expected to be open standard - passed
- Desirable
  - Robustness – designed to be robust
  - TRL – 4. Draws on VDLM3 design
  - Flexibility – several data channel options
  - Ground costs - estimated as similar to current system
  - Performance – not comprehensively simulated

EUR Technology Evaluation: P34 (TIA-902)

- Essential criteria
  - Compatibility - studies undertaken indicate that co-site interference may be overcome. Results inconclusive and requires further work – inconclusive.
  - Open standards – patents apply to some standards but can either be overcome – passed.
- Desirable
  - Robustness – designed to have good robustness
  - TRL – 3 – although COTS changes are required
  - Flexibility – can be deployed with 3 channel bandwidths (50,100, 150 kHz)
  - Ground costs - expected to need more ground sites than VHF hence increased cost
  - Performance – initial results indicate that throughput values can be achieved in small/medium en route airspace using 100/150kHz channels. Further work needed in other airspace volumes.

EUR 2 Technology Evaluation: WCDMA

- Essential criteria
  - Compatibility – requires 2x5 MHz ‘clean’ portion of an increasing crowded band + guard bands. Not practical to deploy based on information available
  - Open standards
    - Passed – standards are available
- Desirable
  - Robustness – adequate robustness
  - TRL – 5 – reasonably mature and can be deployed with little modification
  - Flexibility – design options were not finally chosen
  - Ground costs – similar cell size to those of VHF so similar costs
  - Performance – study showed that performance can be achieved but needs further validation. Different methodology was applied.
  - Not recommended for the FCI due to difficulty in introduction into the L-band

EUR Technology Evaluation: INMARSAT SBB

- Essential criteria
  - Compatibility
    - Passed subject to planning meetings and adequate spectrum. Maybe an issue with Iridium
  - Open standards – not currently available but assumed would if offer to support ATS.
- Desirable
  - Robustness – currently not robust for ATS – minimal link margin
  - TRL – 7 for ATS
  - Flexibility – some flexibility due options for channel rates with various antenna gains
  - Ground costs – not estimated
  - Performance – performance cannot be guaranteed due to lack of priority and pre-emption. Little performance information available - failed
  - SBB will reach the end of its lifetime around 2020
  - Not recommended for the FCI

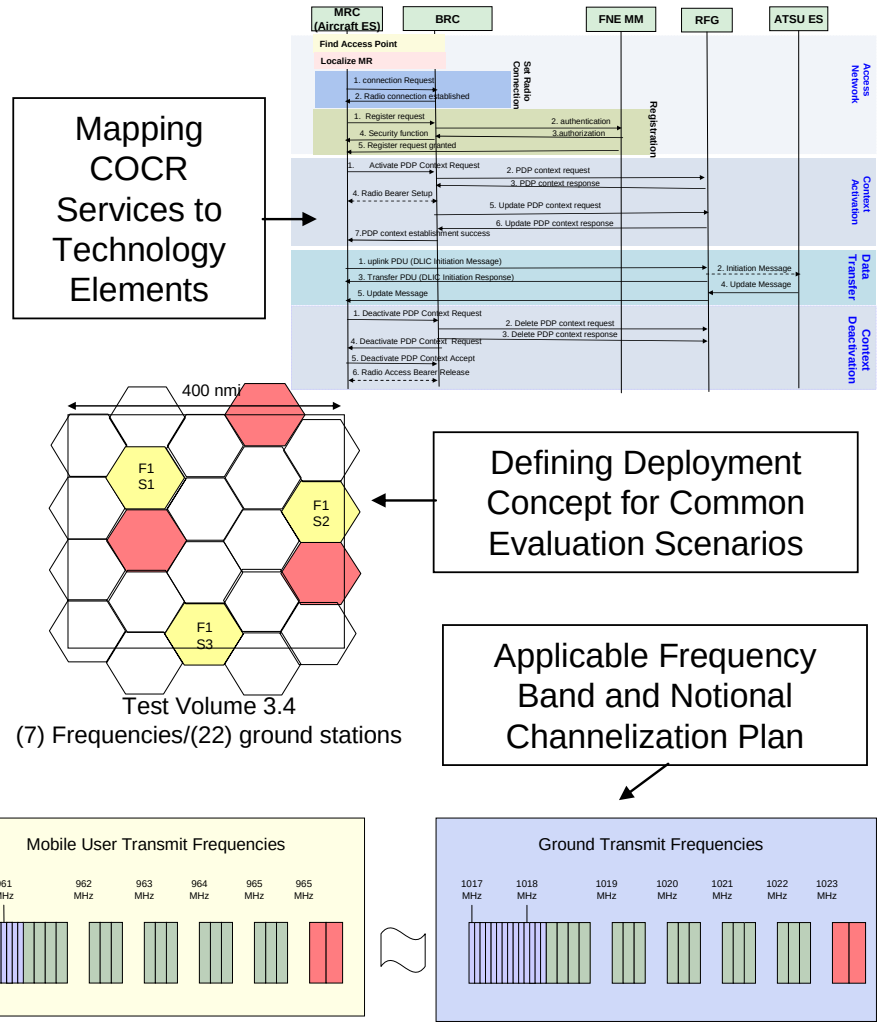
EUR Technology Evaluation: IEEE 802.16e

- Essential criteria
  - Compatibility – introduced into an under utilised band so compatibility is expected
  - Open standards – open standards available. Aviation specific variant needed
- Desirable
  - Robustness – good robustness with QoS management
  - TRL – 6 – mature as WiMAX but need tailoring to aviation use
  - Flexibility – many design options
  - Ground costs – not currently covered by VHF systems
  - Performance – studies showed that performance can be achieved. Needs further validation through practical trials

U.S. Technology Evaluations

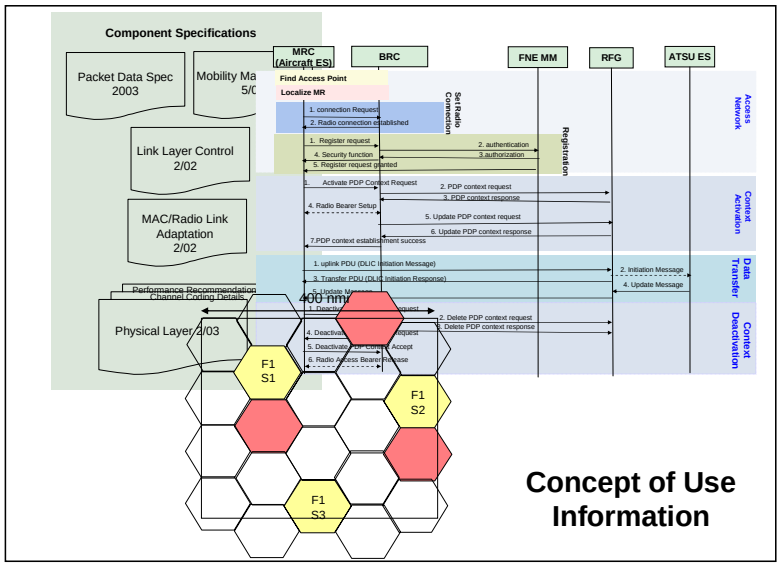
- Develop Concept of Use for the selected technologies (P34, LDL, WCDMA, B-AMC, AMACS)

- Each Concept of Use includes:
  - Applicable technology features/specifications
  - Functional architecture
  - Deployment concept for common evaluation scenarios
  - Deployment frequency band and channelization considerations

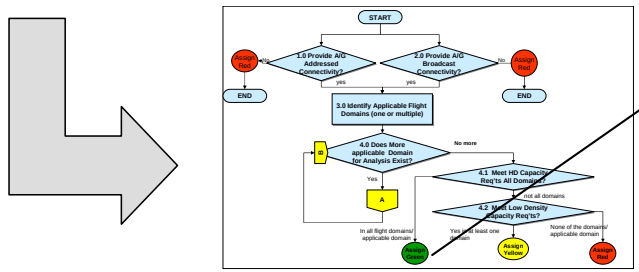


U.S. Technology Evaluations (2)

- Assess technologies using the process diagrams defined for each evaluation criterion



Concept of Use Information



Evaluation Process Flow Diagrams

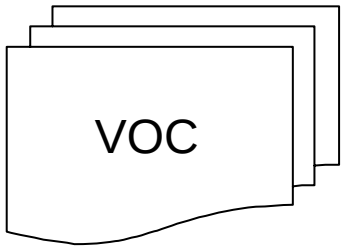
Criteria Evaluation Results Table

		Candidate 1	Candidate 2	Candidate 3
Provides ATS Services within Requirements (sans A-EXEC)	A Capacity			
	B # of Users			
	C QoS			
	D Environment			
Provides ATS & AOC Services within Requirements (sans A-EXEC)	A Capacity			
	B # of Users			
	C QoS			
	D Environment			
TRL				
Standardization Status				
Certification				
Gnd Cost				
Avionics Cost				
Spectrum				
Authentication & Integrity				
Robustness to Interference				
Transition				

U.S. Technology Evaluations (3)

Weight/Rank Criteria (Applying AHP Process)

Rule Set



	Rules	Notes
1	Spectrum compatibility and Providing ATS services (meeting performance requirements) are equally important and more important than all other criteria	This rule reflects key aspects relating to need for a new data link service (pursue after exhausting other options (thus new data link only viable if it meets requirements) and ability to use target spectrum band (compatibility with legacy equipment is required) Notes: WRC-07 Preparation Material proposing AM(R)S allocation in 960-1024 MHz indicates compatibility with existing systems required (cause harmful no interference to nor claim protection from)[ref 1],[ref 2]; Many stakeholders reflect position that existing systems should be used to their fullest extent[ref 3],[ref 4],[ref 5]; new data link system, for which technologies are evaluation; would only be needed when ATS requirements can no longer be met; thus, ability to meet ATS requirements is necessary; ATMAC indicates desire to maintain ATS&AOC separate [ref 6] and FAA has indicated they will follow ATMAC recommendations

Quantitative Weights

Scale:		Instructions:							
1 - equally important		Fill the CTQ's in the rows. The are automatically copied into the column headers							
5 - more important		Fill in the bottom half of the matrix and the top calculates itself as the invers							
10 - much more important		These criteria and scores are pulled into the Decsion Matrix weighting column							
1/5 - less important		Note: Grey boxes are calculated fields (do not edit)							
1/10 - much less important									
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

Qualitative Ranking

Weight	Criteria
Most Important	Spectrum
	Meet ATS Service Requirements
Moderately Important	TRL
	Ground Cost
	Avionics Cost
	Authentication & Integrity
	Standardization Status
Less Important	Robustness to Interference
	Certification
	Meets ATS & AOC Service Requirements
	Transition