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LEAPing Ahead – The Space Development Agency's Method for Planning for the Future

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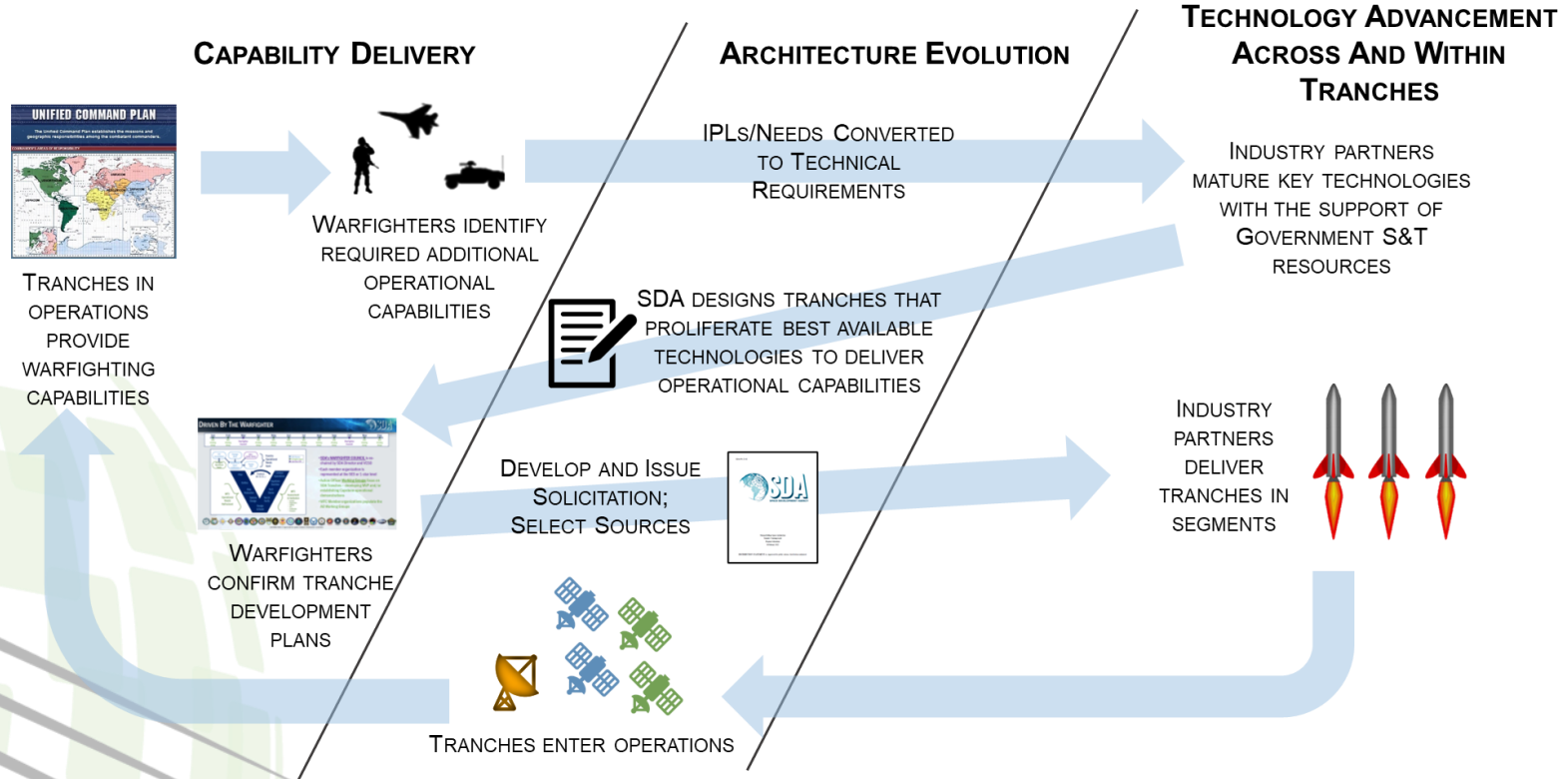
Introduction

- The Space Development Agency (SDA) is a constructive disruptor within the Department of Defense, tasked with rapidly acquiring and delivering space-based capabilities.
- SDA is building the Proliferated Warfighter Space Architecture (PWSA) by delivering hundreds of satellites on “on time, every two years – by employing spiral development methods, adding capabilities to future generations as the threat evolves.”[1]



Background and Motivation

- Technical maturity is correlated with schedule change – less mature systems are more likely to experience schedule slips and budget increases[2]
  - GAO[3] and DoD[4] recommend achieving technical maturity (TRL 6 or TRL 7) by Milestone B (prior to CDR)
- Iterative development requires consideration of dependences between requirements, capabilities, and supporting technologies[5]
- At SDA, maintaining a two-year delivery cycle for a complex system consisting of hundreds of satellites requires extensive planning and trade-offs
  - Requires a process that can manage dependencies across iterations, minimize schedule risk to programs by identifying long-lead technologies, and trace implemented capabilities and developed technologies back to the stakeholder needs

7 types of systems can be fielded quickly[6]

- Commercially purchased products
- Upgrading existing systems by adding existing products and systems
- Integrating existing systems
- New systems developed through direct collaboration with users to identify capabilities to be fielded
- New systems with limited requirements
- New systems developed external to the program
- Modular subsystems that replace legacy subsystems

Related Work – The LEAP Process

- The LEAP process provides a method to **map the temporal and functional delivery of value to the satisfaction of stakeholder needs** and to identify technologies with a high potential for introducing technical debt into the system[7]
- The research is divided into two related presentations at IS 2023
  - *LEAP – A Process for Identifying Potential Technical Debt in Iterative System Development*[7] provides a detailed overview of the mechanics and mathematics of the process
  - This presentation provides an example of the application of the process at the Space Development Agency to identify critical technologies in need of accelerated development

LEAP allows a system developer to make technology ***investment decisions*** to enable ***on time satisfaction*** of stakeholder needs

The LEAP Process[7]

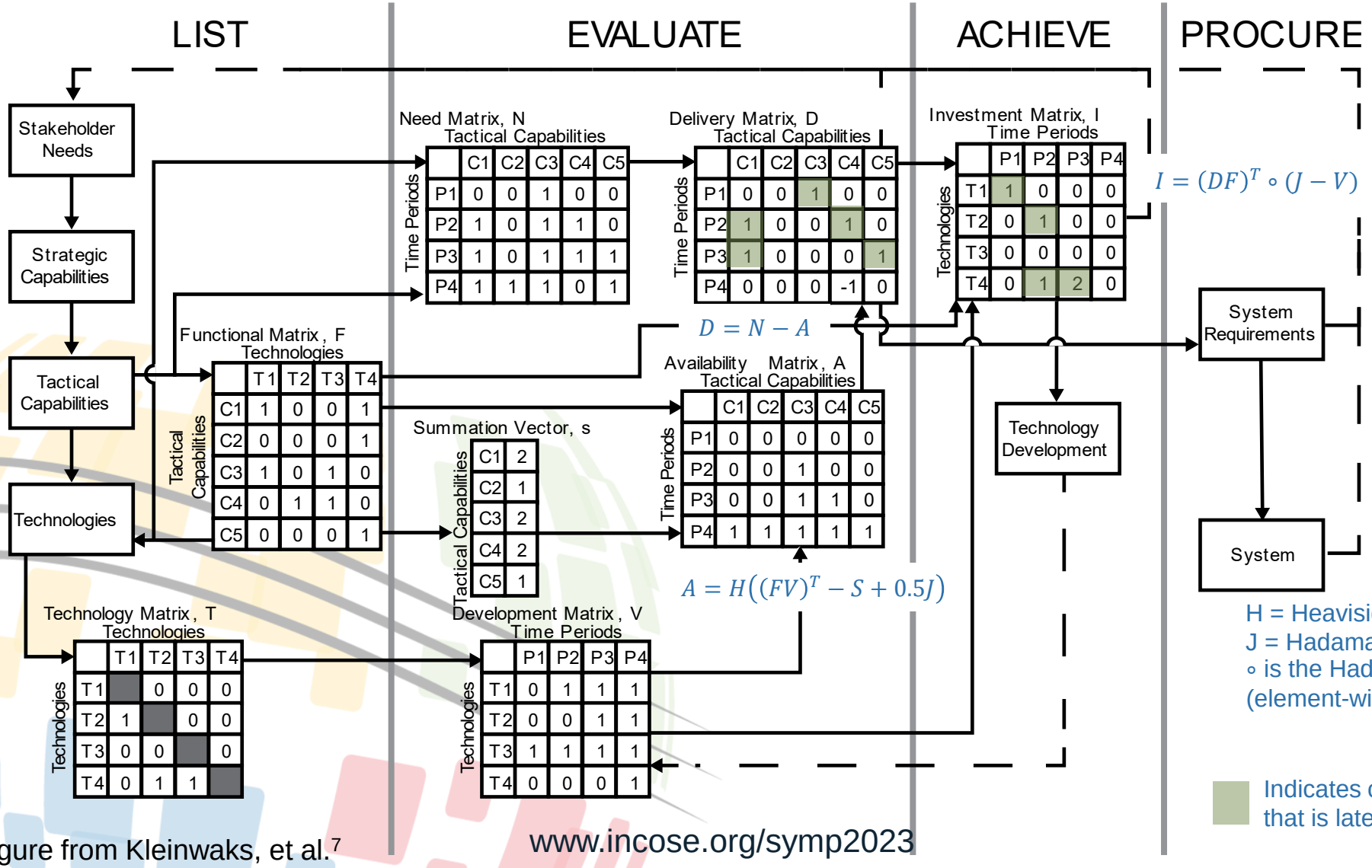
List
Decompose needs into strategic and tactical capabilities
Define enabling technologies

Procure
Release a system that provides one or more tactical or strategic capabilities

Evaluate
Determine the capability need dates and technology development timelines.
Mathematically determine if capabilities meet need dates

Achieve
Identify technology investments that produce largest return on investment

LEAP Process Overview



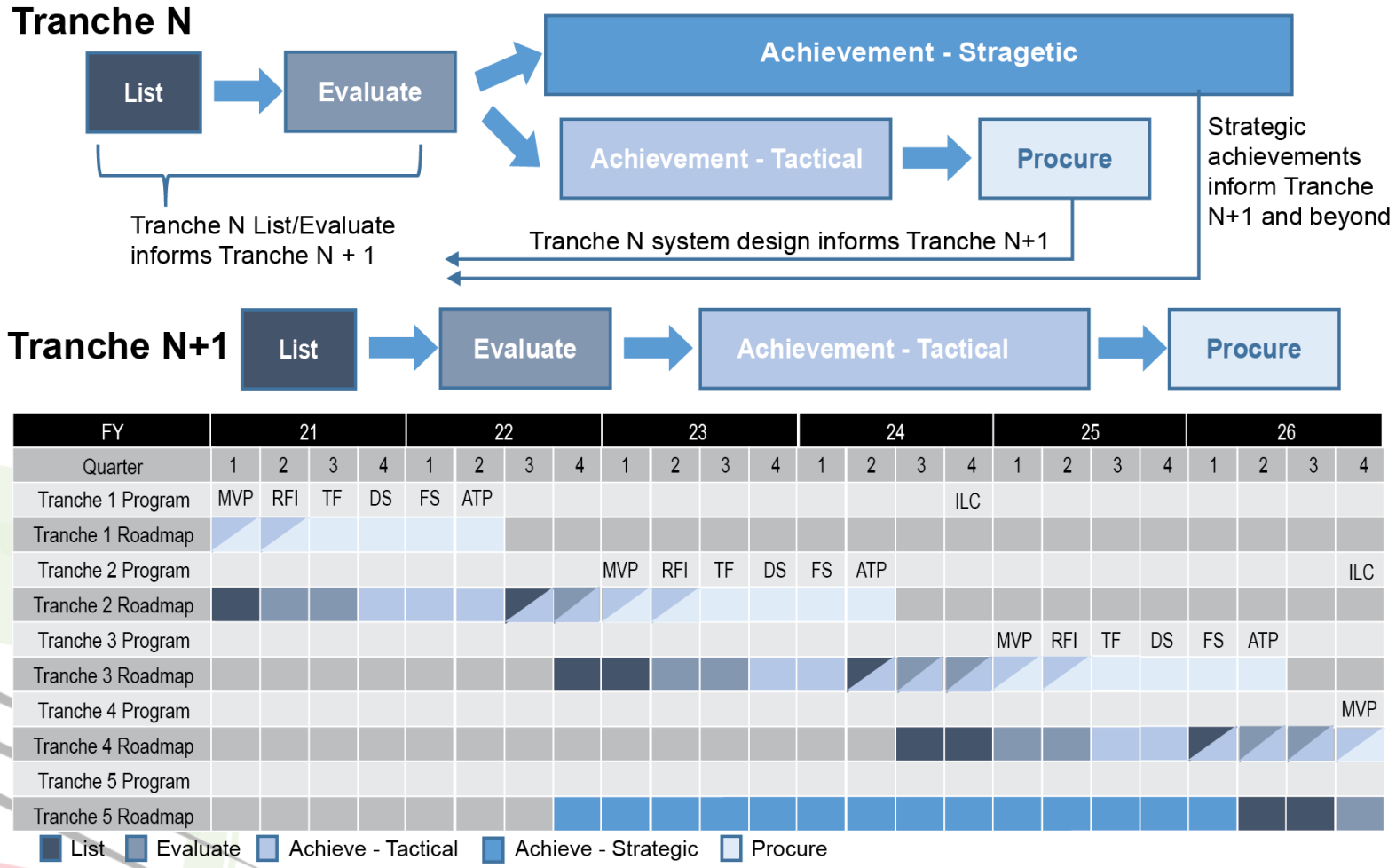
H = Heaviside function
J = Hadamard identity matrix (all ones)
∘ is the Hadamard product operator (element-wise multiplication)

Indicates capability/technology that is late to need

Figure from Kleinwaks, et al.[7]

SDA and the LEAP Process

- Assumptions (actual milestones float within specified quarters)
  - 30 days (on average) for industry proposal development
  - 90 days (goal) from proposal receipt to ATP
  - 30 months from ATP to ILC for SV design, development, AI&T and launch integration
- Procurement process
  - Assume an MVP
  - Query industry via RFI
  - Freeze technical content based on current state of technology/practice to set solicitation requirements and limit NRE
  - Finalize MVP in draft solicitation (DS) for final industry input
  - Final solicitation (FS) only “cleans” up requirements which have been established by draft solicitation

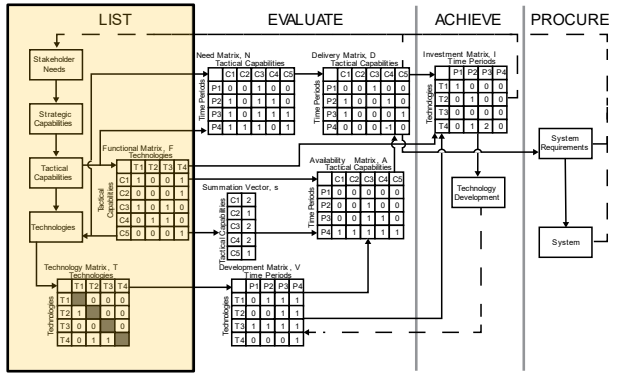


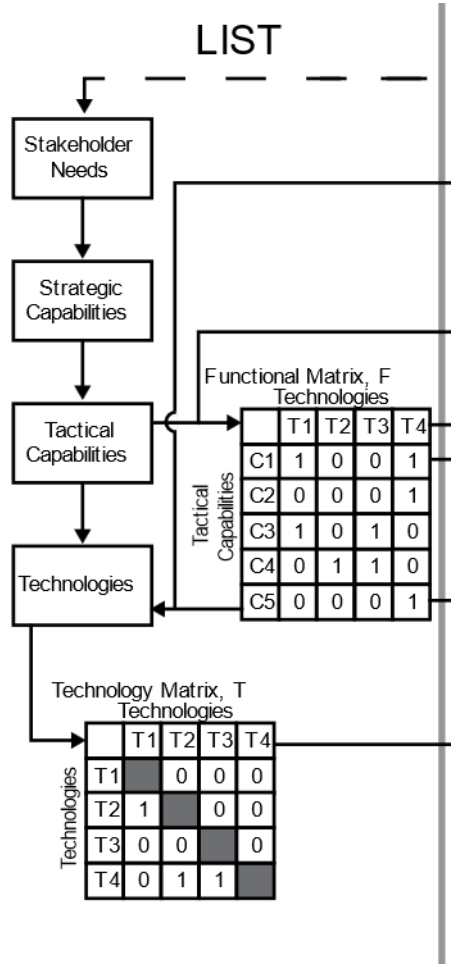
Example Application of LEAP: SDA Optical Communications Terminal Development

- Key pillar of the PWSA is low latency, high data rate, global beyond line-of-sight (BLOS) communications
- SDA includes optical communications terminals on all of its spacecraft to support this pillar
- Space-based free space optical communications in low Earth orbit is a new and evolving technology
- SDA will progressively increase its optical communications in support of high data rate BLOS communications
- The LEAP process is used to guide the iterative development of new optical communications terminal technology
- This presentation shows how the LEAP process can be used to determine timelines for satisfying the need of high data rate, global beyond line-of-sight (BLOS) communications

List Phase

- **List** establishes the system definition and decomposes stakeholder needs into strategic (long-term) and tactical (short-term) capabilities and the capabilities into technologies[7]
  - Strategic Capabilities: ability of a system to perform in its intended environment and meet the intent of its users
  - Tactical Capabilities: part of a strategic capability that delivers value to the user
  - Technology: Methods and devices (hardware or software) resulting from the practical application of knowledge
- Tactical Capability is **required** at a specific point in time
- Technology is **delivered** at a specific point in time
- Two major products:
  - Functional Matrix (F): maps the capabilities to the technologies that support them
  - Technology Matrix (T): design structure matrix that identifies dependencies between the technologies





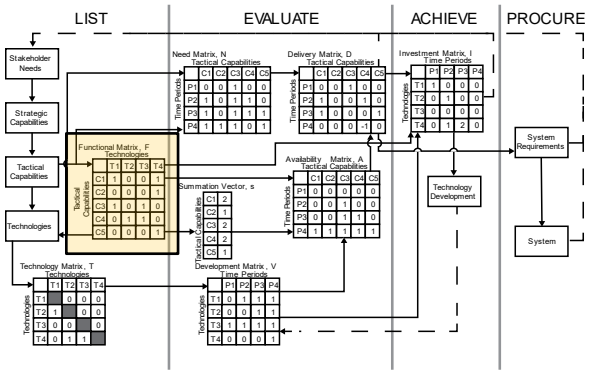
List Phase: Decomposition (1)

Strategic Capabilities	Tactical Capabilities	Technologies
Optical Communications Network	C1. Space-to-ground (S2G) optical communications	T15. Communications standards
		T11. Multiple vendor interoperability
		T12. Tasking and scheduling algorithms
		T13. Common network protocols and routing mechanisms
		T21. Pointing, acquisition, and tracking algorithms
		T22. Bus stability
	C2. Space-to-space (S2S) communications in the same orbital shell (same altitude and inclination)	T11, T12, T13, T15, T22, T21
		T5. Space-based mesh network
		T16. Space-to-space same vendor communications
		T17. Space-to-space different vendor communications
		T18. Space-to-space in-plane communications
		T19. Space-to-space out-of-plane communications
	C3. Space-to-space (S2S) communications in different orbital shells	T5, T11, T12, T13, T15, T16, T17, T21, T22
		T20. Space-to-space out-of-shell communications
	C4. High data rates	T24. 1 Gbps data rates
		T25. 10 Gbps data rates
		T26. 100 Gbps data rates

List Phase: Decomposition (2)

Strategic Capabilities	Tactical Capabilities	Technologies
Optical Global Operations	C5. Regional Access (the ability of the constellation to communicate optically with at least one user within a specified region for a specified period of time)	T5, T12
		T2. Small satellite compliant size, weight, and power (SWAP) for bus and payloads
		T23. Ranges up to 6500 km
	C6. Global Access (the ability of the constellation to communicate optically with at least one user anywhere on the globe for a specified period of time)	T2, T5, T12, T23
		T1. Commoditization of satellite bus and payloads
		T3. Satellite proliferation
		T4. Manufacturing at scale
		T6. Fleet-based environmental testing
	C7. Global Operations (the ability of the constellation to communicate optically with multiple users anywhere on the globe at any time)	T1, T2, T3, T4, T5, T6, T12, T23
		T7. Multiple terrestrial users per space-based communications terminal
		T8. Mobile/transportable ground terminals
		T9. Orbit-aware network routing protocols
		T10. Operation in all lighting conditions
		T14. All weather communications

List: Functional Matrix



- Maps Tactical Capabilities to the Technologies that support them[7]

Functional Matrix, F

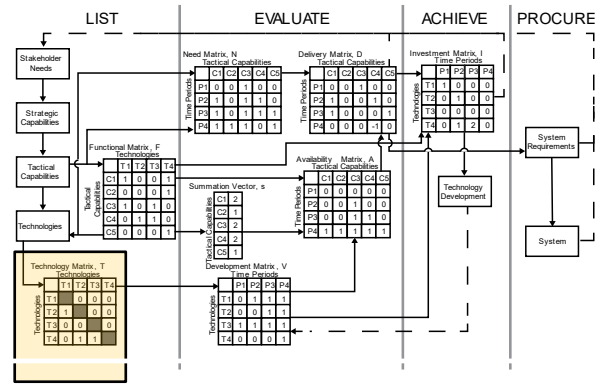
	T1	T15	T2	T4	T6	T3	T8	T10	T11	T12	T7	T13	T5	T9	T14	T22	T21	T16	T17	T18	T19	T20	T23	T24	T25	T26
C1		1							1	1		1				1	1									
C2		1							1	1		1	1			1	1	1	1	1	1					
C3		1							1	1		1	1			1	1	1	1			1				
C4																								1	1	1
C5			1							1			1										1			
C6	1		1	1	1	1				1			1										1			
C7	1		1	1	1	1	1	1		1	1		1	1	1								1			

1 Indicates that the capability is supported by the technology ☐ Indicates that technology does not support the capability

Tactical Capability C7. Global Operations is supported by Technologies:
T1. Commoditization of satellite bus and payload, T2. Small satellite SWAP payloads, T4. Manufacturing at scale, T6. Fleet-based environmental testing, T3. Satellite proliferation, T8. Mobile/transportable ground terminals, T10. Operation in all lighting conditions, T12. Tasking and scheduling algorithms, T7. Multiple terrestrial uses per space-based communications terminal, T14. All weather communications, T23. Ranges up to 6500 km

List: Technology Matrix

- Implemented as a design structure matrix[7]
- Shows interdependencies between technologies
  - Technology in the row is dependent upon the technology in the column
- Partitioning the matrix can give a recommended sequence for development



Technology Matrix, T

	T1	T15	T2	T4	T6	T3	T8	T10	T11	T12	T7	T13	T5	T9	T14	T22	T21	T16	T17	T18	T19	T20	T23	T24	T25	T26
T1																										
T15																										
T2																										
T4	1																									
T6				1																						
T3	1			1	1																					
T8																										
T10																										
T11		1																								
T12				1																						
T7							1			1																
T13		1																								
T5									1			1														
T9										1		1	1													
T14																										
T22																										
T21		1														1										
T16		1															1									
T17		1															1									
T18		1														1	1	1								
T19		1														1	1	1	1							
T20		1														1	1									
T23																										
T24		1														1	1	1	1	1	1	1	1			
T25		1														1	1	1	1	1	1	1	1	1		
T26		1														1	1	1	1	1	1	1	1	1	1	

T3. Satellite proliferation depends on T1. Commoditization of satellite bus and payloads, T4. Manufacturing at scale and T6. Fleet-based environmental testing

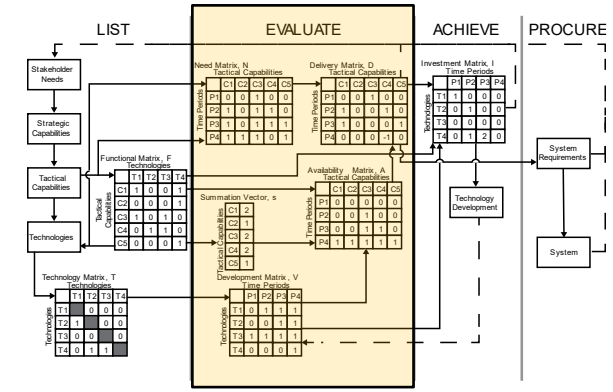
Technology Matrix is partitioned into a lower triangular matrix and provide rough order of development (from top to bottom)

T14. All weather communications has no dependencies on the other technologies

1 Indicates that the technology in the row depends on the technology in the column

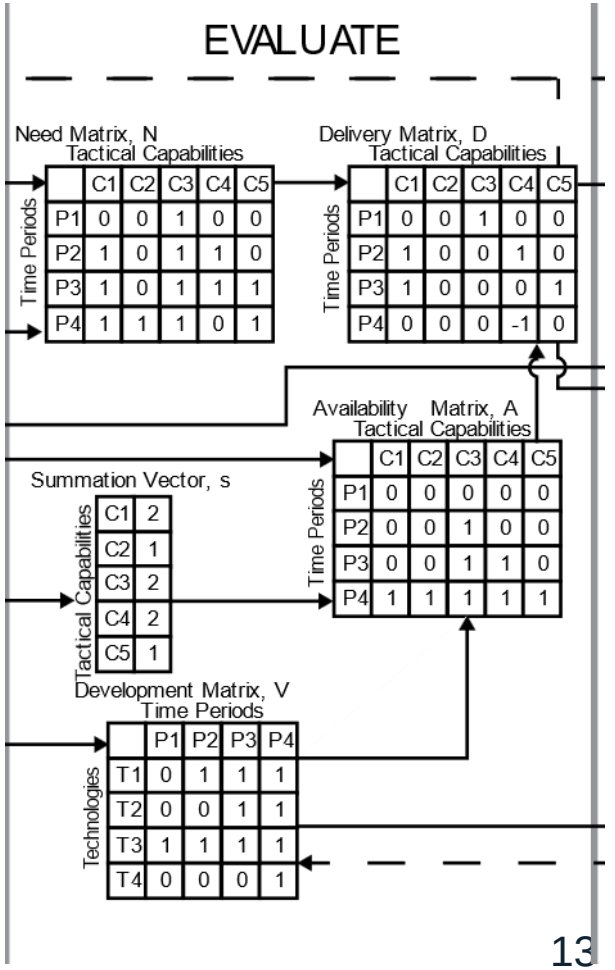
☐ Indicates that there is no dependenc between the technologies

Evaluate Phase

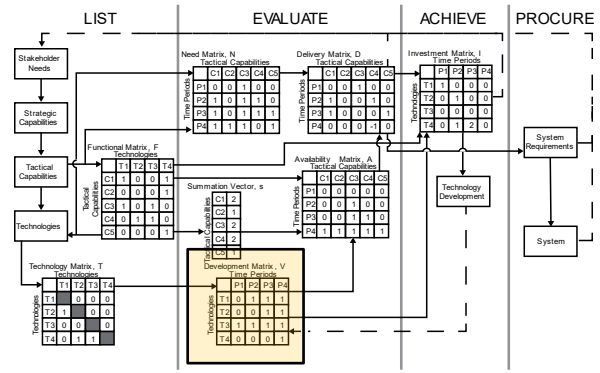


- **Evaluate** assesses the capabilities and the technologies[7]
- Four products:
  - Input matrices:
    - Development Matrix (V): maps the technologies to the time periods where they are expected to be ready
    - Need Matrix (N): maps the tactical capabilities to the time periods in which they are needed
  - Calculated matrices
    - Availability Matrix (A): identifies in which time period each capability is expected to be available
    - Delivery Matrix (D): identifies which capabilities are delivered late to need

$$A = H\left((FV)^T - S + 0.5J\right) \qquad D = N - A$$



Evaluate: Development Matrix



- Development Matrix estimates when a **technology** will be developed – of sufficient TRL to be included in a procurement[7]
- Values are binary – Technology either is or is not developed in the specified time period
- Timelines were estimated based on a review of the current state of industry, without considering any additional investments

Development Matrix, V

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
T1				1	1	1	1	1	1	1	1	1
T15	1	1	1	1	1	1	1	1	1	1	1	1
T2		1	1	1	1	1	1	1	1	1	1	1
T4			1	1	1	1	1	1	1	1	1	1
T6				1	1	1	1	1	1	1	1	1
T3				1	1	1	1	1	1	1	1	1
T8												
T10												
T11		1	1	1	1	1	1	1	1	1	1	1
T12		1	1	1	1	1	1	1	1	1	1	1
T7												
T13	1	1	1	1	1	1	1	1	1	1	1	1
T5		1	1	1	1	1	1	1	1	1	1	1
T9			1	1	1	1	1	1	1	1	1	1
T14												
T22		1	1	1	1	1	1	1	1	1	1	1
T21		1	1	1	1	1	1	1	1	1	1	1
T16		1	1	1	1	1	1	1	1	1	1	1
T17			1	1	1	1	1	1	1	1	1	1
T18		1	1	1	1	1	1	1	1	1	1	1
T19			1	1	1	1	1	1	1	1	1	1
T20					1	1	1	1	1	1	1	1
T23		1	1	1	1	1	1	1	1	1	1	1
T24				1	1	1	1	1	1	1	1	1
T25		1	1	1	1	1	1	1	1	1	1	1
T26										1	1	1

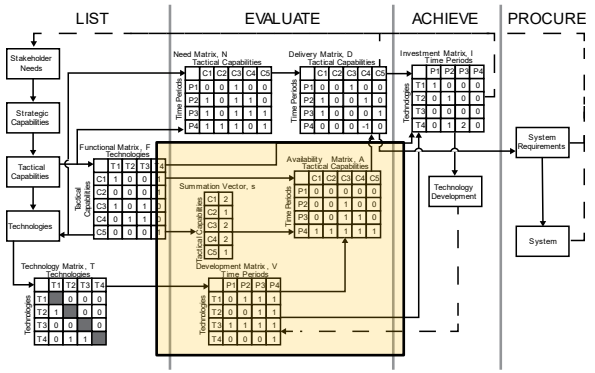
T3. Satellite proliferation is expected to be delivered in 2024 (launch of SDA Tranche 1)

T14. All weather communications is not expected to be ready in the identified time periods

1 Indicates that the technology is developed in this time period and ready for use

☐ Indicates that the technology is not ready for use in this time period

Evaluate: Availability Matrix



- Availability Matrix computes when a **capability** is expected to be available for use[7]
- Values are binary – the capability either is or is not available

$$\boldsymbol{A = H\left((FV)^T - S + 0.5J\right)}$$

Availability Matrix, A

	C1	C2	C3	C4	C5	C6	C7
2021	0	0	0	0	0	0	0
2022	1	0	0	0	1	0	0
2023	1	1	0	0	1	0	0
2024	1	1	0	0	1	1	0
2025	1	1	1	0	1	1	0
2026	1	1	1	0	1	1	0
2027	1	1	1	0	1	1	0
2028	1	1	1	0	1	1	0
2029	1	1	1	0	1	1	0
2030	1	1	1	1	1	1	0
2031	1	1	1	1	1	1	0
2032	1	1	1	1	1	1	0

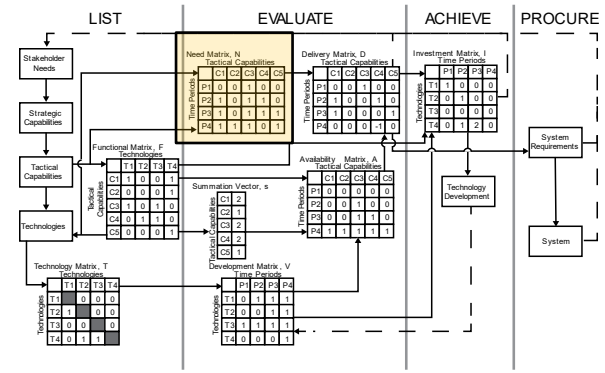
C2. Space-to-space (S2S) communications in the same orbital shell. Expected to be available in 2023 (SDA Tranche 0)

C7. Global Operations is not expected to be available within the listed time periods .
Driven by technologies such as T14 which will not be developed in time

1 Indicates that the capability is expected to be available for use in the time period

0 Indicates that the capability is not expected to be available for use in the time period

Evaluate: Need Matrix



- Need Matrix assesses the time periods where capabilities are **required**, independent of when they can be delivered[7]
- At SDA, these dates are assessed through frequent collaboration with the users and the warfighting community

Need Matrix, N

	C1	C2	C3	C4	C5	C6	C7
2021							
2022					1		
2023	1	1			1		
2024	1	1			1	1	
2025	1	1	1			1	
2026	1	1	1			1	
2027	1	1	1			1	
2028	1	1	1	1		1	1
2029	1	1	1	1		1	1
2030	1	1	1	1		1	1
2031	1	1	1	1		1	1
2032	1	1	1	1		1	1

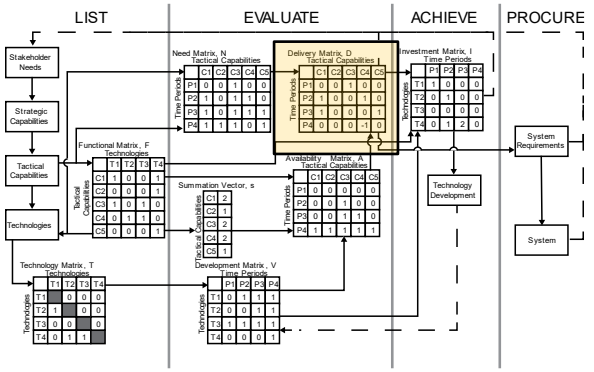
C5. Regional access is only needed until 2024, when it is supplanted by C6. Global access

C7. Global Operations is needed in 2028

1 Indicates that the capability is required in the time period

Indicates that the capability is not required in the time period

Evaluate: Delivery Matrix



- Delivery Matrix provides information about the timeliness of capabilities compared to the needs[7]

$$D = N - A$$

Delivery Matrix, D

	C1	C2	C3	C4	C5	C6	C7
2021	0	0	0	0	0	0	0
2022	-1	0	0	0	0	0	0
2023	0	0	0	0	0	0	0
2024	0	0	0	0	0	0	0
2025	0	0	0	0	-1	0	0
2026	0	0	0	0	-1	0	0
2027	0	0	0	0	-1	0	0
2028	0	0	0	1	-1	0	1
2029	0	0	0	1	-1	0	1
2030	0	0	0	0	-1	0	1
2031	0	0	0	0	-1	0	1
2032	0	0	0	0	-1	0	1

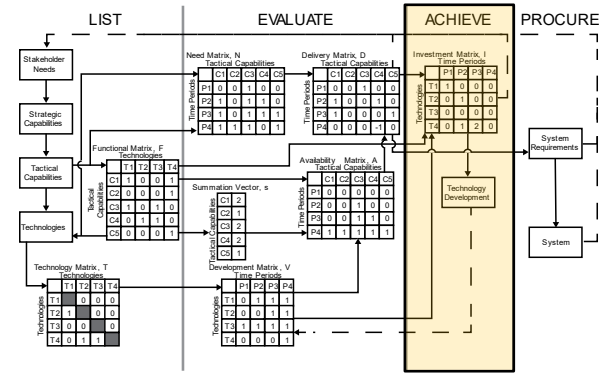
C1. Space-to-ground (S2G) optical communications is ready prior to need

C5. Regional access is available but no longer needed

C4. High data rates and C7. Global Operations are both late to need

On time | Early or not needed | Late

Achieve Phase



- **Achieve** determines which technologies are driving the late delivery of capabilities and which provide the largest return on investment[7]
- Investment Matrix (I): maps technologies to the negative impact they have in each time period[7]

$$\boldsymbol{I = (DF)^T \circ (J - V)}$$

Late deliveries are driven by:
T8. Mobile/transportable ground terminals
T10. Operation in all lighting conditions
T7. Multiple terrestrial users per space-based communications terminal
T14. All weather communications
T26. 100 Gbps data rates

Investment Matrix, I

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
T1	0	0	0	0	0	0	0	0	0	0	0	0
T15	0	0	0	0	0	0	0	0	0	0	0	0
T2	0	0	0	0	0	0	0	0	0	0	0	0
T4	0	0	0	0	0	0	0	0	0	0	0	0
T6	0	0	0	0	0	0	0	0	0	0	0	0
T3	0	0	0	0	0	0	0	0	0	0	0	0
T8	0	0	0	0	0	0	0	1	1	1	1	1
T10	0	0	0	0	0	0	0	1	1	1	1	1
T11	0	0	0	0	0	0	0	0	0	0	0	0
T12	0	0	0	0	0	0	0	0	0	0	0	0
T7	0	0	0	0	0	0	0	1	1	1	1	1
T13	0	0	0	0	0	0	0	0	0	0	0	0
T5	0	0	0	0	0	0	0	0	0	0	0	0
T9	0	0	0	0	0	0	0	0	0	0	0	0
T14	0	0	0	0	0	0	0	1	1	1	1	1
T22	0	0	0	0	0	0	0	0	0	0	0	0
T21	0	0	0	0	0	0	0	0	0	0	0	0
T16	0	0	0	0	0	0	0	0	0	0	0	0
T17	0	0	0	0	0	0	0	0	0	0	0	0
T18	0	0	0	0	0	0	0	0	0	0	0	0
T19	0	0	0	0	0	0	0	0	0	0	0	0
T20	0	0	0	0	0	0	0	0	0	0	0	0
T23	0	0	0	0	0	0	0	0	0	0	0	0
T24	0	0	0	0	0	0	0	0	0	0	0	0
T25	0	0	0	0	0	0	0	0	0	0	0	0
T26	0	0	0	0	0	0	0	1	1	0	0	0

1 Technology drives at least one late capability, number indicates how many late capabilities are impacted by this technology

0 Technology does not drive any late capabilities

Achieve Phase – SDA Investments

- Based on the Investment Matrix, SDA made decisions on which technologies to support for development outside of the SDA Tranches

Investment Matrix, I

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
T1	0	0	0	0	0	0	0	0	0	0	0	0
T15	0	0	0	0	0	0	0	0	0	0	0	0
T2	0	0	0	0	0	0	0	0	0	0	0	0
T4	0	0	0	0	0	0	0	0	0	0	0	0
T6	0	0	0	0	0	0	0	0	0	0	0	0
T3	0	0	0	0	0	0	0	0	0	0	0	0
T8	0	0	0	0	0	0	0	1	1	1	1	1
T10	0	0	0	0	0	0	0	1	1	1	1	1
T11	0	0	0	0	0	0	0	0	0	0	0	0
T12	0	0	0	0	0	0	0	0	0	0	0	0
T7	0	0	0	0	0	0	0	1	1	1	1	1
T13	0	0	0	0	0	0	0	0	0	0	0	0
T5	0	0	0	0	0	0	0	0	0	0	0	0
T9	0	0	0	0	0	0	0	0	0	0	0	0
T14	0	0	0	0	0	0	0	1	1	1	1	1
T22	0	0	0	0	0	0	0	0	0	0	0	0
T21	0	0	0	0	0	0	0	0	0	0	0	0
T16	0	0	0	0	0	0	0	0	0	0	0	0
T17	0	0	0	0	0	0	0	0	0	0	0	0
T18	0	0	0	0	0	0	0	0	0	0	0	0
T19	0	0	0	0	0	0	0	0	0	0	0	0
T20	0	0	0	0	0	0	0	0	0	0	0	0
T23	0	0	0	0	0	0	0	0	0	0	0	0
T24	0	0	0	0	0	0	0	0	0	0	0	0
T25	0	0	0	0	0	0	0	0	0	0	0	0
T26	0	0	0	0	0	0	0	1	1	0	0	0

Investment	Technology Addressed	Projected Change in Development Timeline
Reduction of SWAP-C per bit	T2. Small satellite compliant size, weight, and power (SWaP) for bus and payloads	None
Design for manufacturing considerations to support high-rate production and assembly, integration, and test processes	T4. Manufacturing at scale	None
Demonstration of a path to 100 Gbps for S2S comms	**T26**. 100 Gbps OCTs	2030 → 2026
Development of low-cost, mobile, or fixed optical ground terminals	**T8**. Mobile/transportable ground terminals	Unknown → 2030
Demonstration of enhanced S2G and space-to-air (S2A) links	**T14**. All weather communications	Unknown → 2026
Development of compact systems capable of supporting coherent (e.g., QPSK) and non-coherent (e.g., OOK) links	T13. Common network protocols and routing mechanisms T17. Space-to-space different vendor communications	Unknown → 2027
Demonstration of one-to-many optical terminal links	**T7**. Multiple terrestrial users per communications terminal	2035 → 2032

T10. Operation in all lighting conditions not addressed via investment. Instead SDA will leverage on-orbit data to assess requirement need

Achieve Phase – Delivery Updates

- Investments change the predicted development times of technologies
- Accelerated technology development changes times at which capabilities are available
- Accelerated capability satisfaction increases satisfaction of stakeholder needs, as seen in the Delivery Matrix
  - C4 needed in 2028
    - Previously delivered late in 2030
    - Investments deliver it early in 2026
  - C7 needed in 2028
    - Previously not delivered
    - Investments deliver it in 2032
- Additional investments may still be required in future iterations
  - T7: Multiple terrestrial users per space-based communications terminal
  - T8: Mobile/transportable ground terminals

Delivery Matrix, D

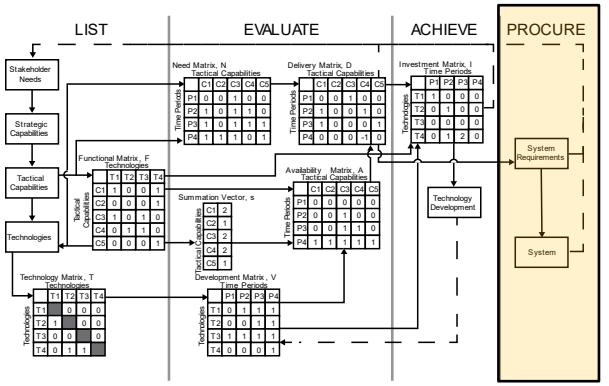
	C1	C2	C3	C4	C5	C6	C7
2021	0	0	0	0	0	0	0
2022	-1	0	0	0	0	0	0
2023	0	0	0	0	0	0	0
2024	0	0	0	0	0	0	0
2025	0	0	0	0	-1	0	0
2026	0	0	0	-1	-1	0	0
2027	0	0	0	-1	-1	0	0
2028	0	0	0	0	-1	0	1
2029	0	0	0	0	-1	0	1
2030	0	0	0	0	-1	0	1
2031	0	0	0	0	-1	0	1
2032	0	0	0	0	-1	0	0

Change due to predicted outcome of investments

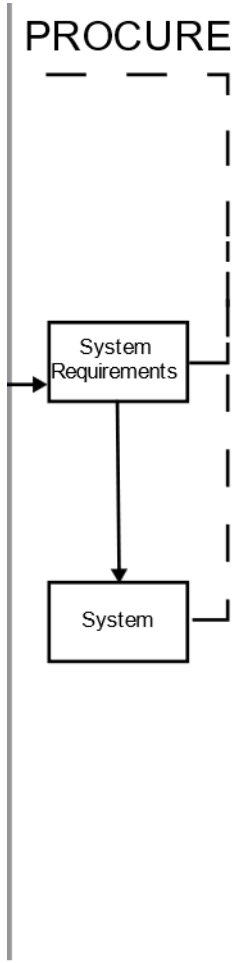
Investment Matrix, I

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
T1	0	0	0	0	0	0	0	0	0	0	0	0
T15	0	0	0	0	0	0	0	0	0	0	0	0
T2	0	0	0	0	0	0	0	0	0	0	0	0
T4	0	0	0	0	0	0	0	0	0	0	0	0
T6	0	0	0	0	0	0	0	0	0	0	0	0
T3	0	0	0	0	0	0	0	0	0	0	0	0
T8	0	0	0	0	0	0	0	1	1	0	0	0
T10	0	0	0	0	0	0	0	0	0	0	0	0
T11	0	0	0	0	0	0	0	0	0	0	0	0
T12	0	0	0	0	0	0	0	0	0	0	0	0
T7	0	0	0	0	0	0	0	1	1	1	1	0
T13	0	0	0	0	0	0	0	0	0	0	0	0
T5	0	0	0	0	0	0	0	0	0	0	0	0
T9	0	0	0	0	0	0	0	0	0	0	0	0
T14	0	0	0	0	0	0	0	0	0	0	0	0
T22	0	0	0	0	0	0	0	0	0	0	0	0
T21	0	0	0	0	0	0	0	0	0	0	0	0
T16	0	0	0	0	0	0	0	0	0	0	0	0
T17	0	0	0	0	0	0	0	0	0	0	0	0
T18	0	0	0	0	0	0	0	0	0	0	0	0
T19	0	0	0	0	0	0	0	0	0	0	0	0
T20	0	0	0	0	0	0	0	0	0	0	0	0
T23	0	0	0	0	0	0	0	0	0	0	0	0
T24	0	0	0	0	0	0	0	0	0	0	0	0
T25	0	0	0	0	0	0	0	0	0	0	0	0
T26	0	0	0	0	0	0	0	0	0	0	0	0

Procure Phase



- **Procure** determines technologies to include in the system procurement and feeds the development of the system[7]
- SDA uses the results of its investments to establish which technologies to include in the program solicitations
  - Minimizing NRE within the procurement where possible to enable rapid development and deployment of systems
- Requirements contained in each procurement influence the next iteration of LEAP
- Performance of the system can identify new requirements



Future Work

- The LEAP process will continue to be refined through implementation[7]
  - Add a prioritization matrix to enable ranking of needs
  - Add probabilistic estimates of technology delivery
  - Directly link the Technology Matrix and the Development Matrix
  - Continued verification and validation

Conclusion

- This presentation provided an example of using the LEAP process to identify critical technologies that require investments in order to deliver capabilities in time to meet stakeholders' needs
- The LEAP process identifies the functional and temporal dependencies between the capabilities and the technologies
- Application of LEAP at SDA has set the development of optical communications terminals on a path to meet most stakeholder needs in future Tranches
  - The process identified that additional investments are still required for some of the more complicated technologies

Questions

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