U.S. Army Research, Development and Engineering Command

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

A Scientific Approach to Consistent Functional Analysis: The System Capabilities Analytic Process (SCAP)

2011 Oct 24

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Outline

- Functional Analysis
- SCAP for Functional Analysis
- SCAP Constructs
- Applications:
  - System of Systems (SOS)
    - Truck Convoy
    - Networked and Antagonistic SOS
  - Sources of Dysfunction
  - Reliability Analysis
- Existing Impact for SCAP
- SLAD's Next Steps

Functional Analysis

- Key process of Systems Engineering, of which many subsequent analysis activities will either reference or utilize.
- Functional Analysis is the process that is used to decompose and correlate system requirements to the design of a system. The general process is:
  - "Translating operational objectives into functions that must be performed." [1]
  - "Allocating functions to subsystems by defining functional interactions and organizing them into a modular configuration." [1]
- Issues:
  - Multiple "Right" answers:
    - Each organization has their own way to execute Functional Analysis
    - Few standard practices and methodologies (i.e.: Functional Analysis Systems Technique)
    - No standard format for output
  - Mandated with Weapon Systems Acquisition Reform Act (WSARA) of 2009
  - Transposition of efforts into other technical endeavors (e.g.: reliability, test, human factors)
  - Contribution of human-in-the-system performance not included in analysis. (i.e.: person driving truck)

Sources: 1) Kossiakoff, A.; Sweet, W. N.; "Systems Engineering Principles and Practice"; pg 124; John Wiley & Sons, Inc.; Hoboken, NJ; 2003.

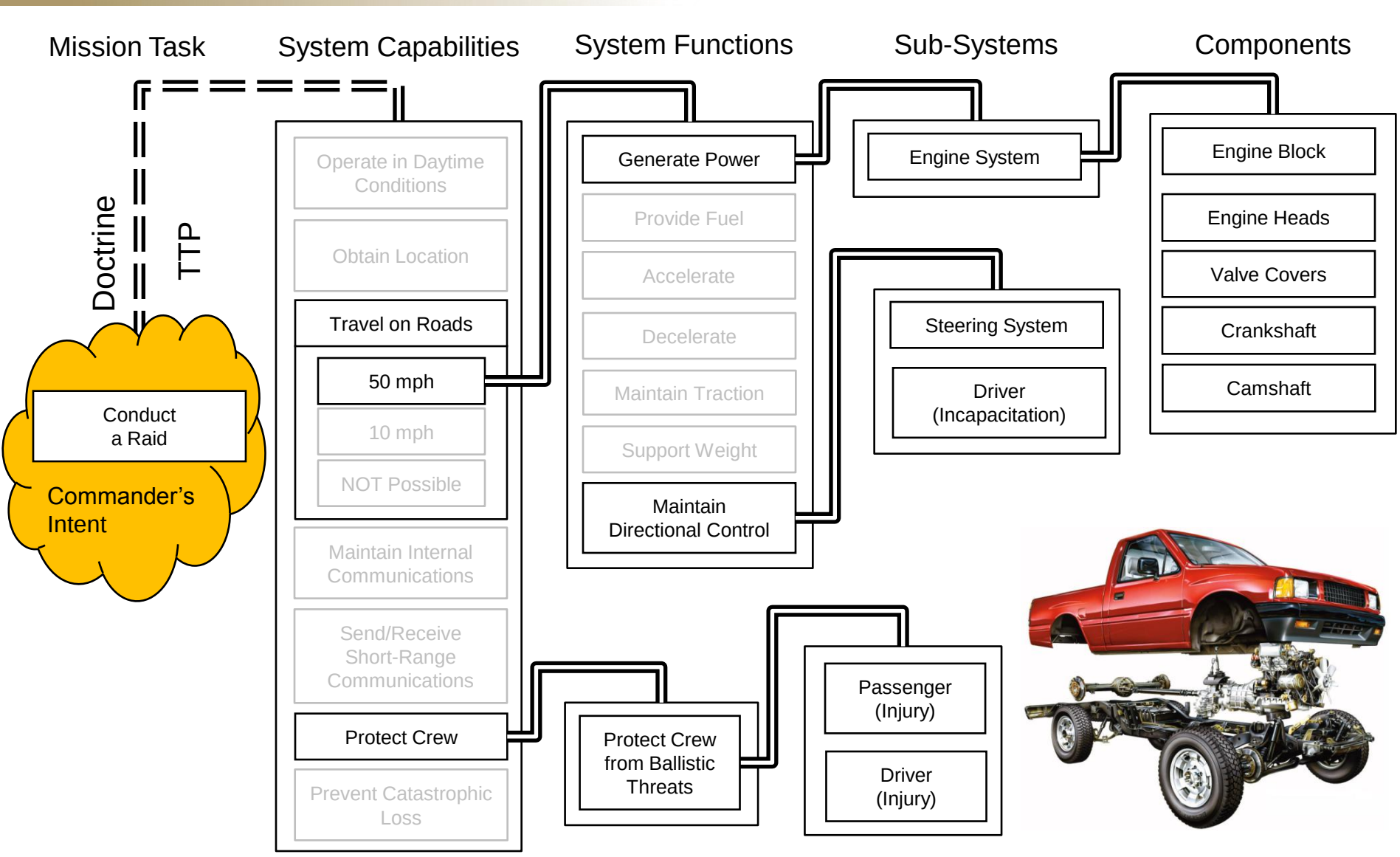
The System Capabilities Analytic Process (SCAP) as Used in Functional Analysis

- The System Capabilities Analytic Process (SCAP) is a methodology that is used to create a rigorous map between a systems components and its capabilities.
  - The map is known as a Functional Skeleton (FS).
  - Determines what functions and capabilities are achievable when components are functional.
  - The FS is both a mathematical and graphical construct.
  - The capabilities of multiple systems can be aggregated to form a rigorous map for an interacting system of systems (SOS).
- The foundations of SCAP are in direct correlation with the principles of functional analysis:
  - Decompose operational objectives into required functions; and
  - Allocate these functions to the physical entities of the system.
- Developed by the Army Research Laboratory for correlating modeling and simulation (M&S) of ground combat vehicle vulnerability and live fire tests (LFT) to the remaining capabilities of a system when components are dysfunctional.

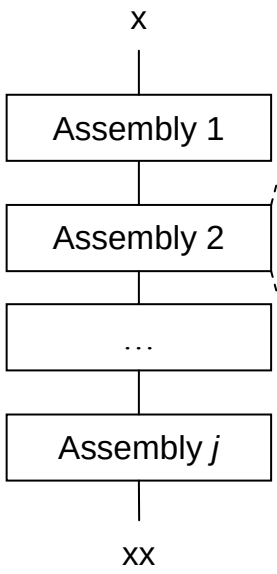
Benefits and Advantages of SCAP

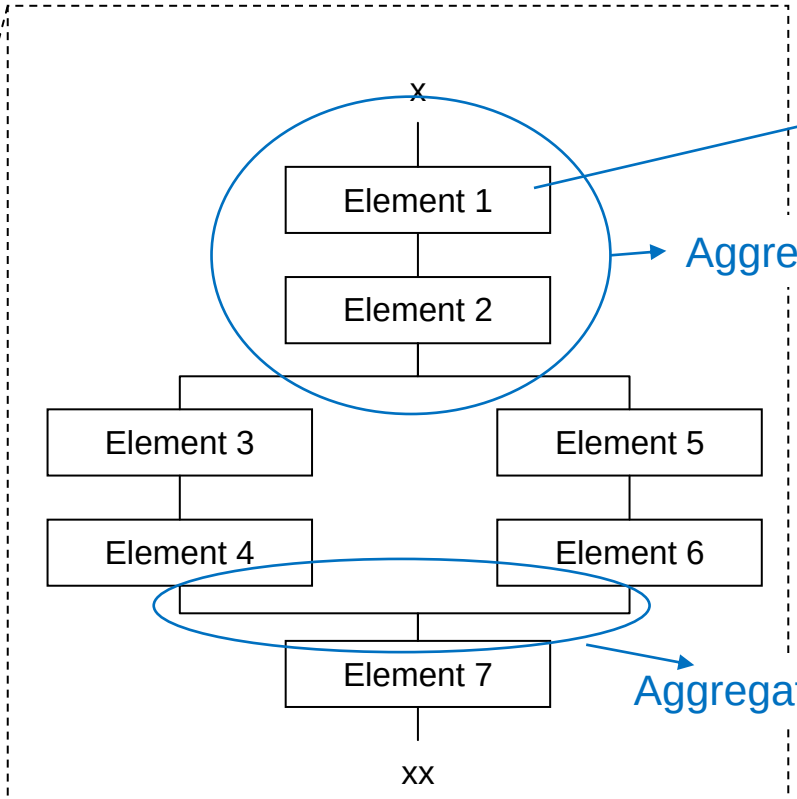
- Because SCAP and the FS are quantitative and scientific constructs of the system and its performance, it is possible to utilize this methodology in efforts such as test and evaluation, reliability analysis, human factors studies, and verification of system requirements.
- Reports ability to complete tasks, missions and requirements.
- Quantitatively define what the system and personnel can accomplish.
- Quantitatively define what components are required to accomplish specified tasks.
- Focus of analysis is remaining capability.
- Maintain terminology familiar to the military user:
  - Attainable Speed
  - Send/Receive Communications
  - Execute Fire Missions

The SCAP Functional Skeleton



Determining Availability within Activation Trees





$$E_i = \begin{cases} 0, & \text{dysfunctional/unavailable} \\ 1, & \text{functional/available} \end{cases}$$

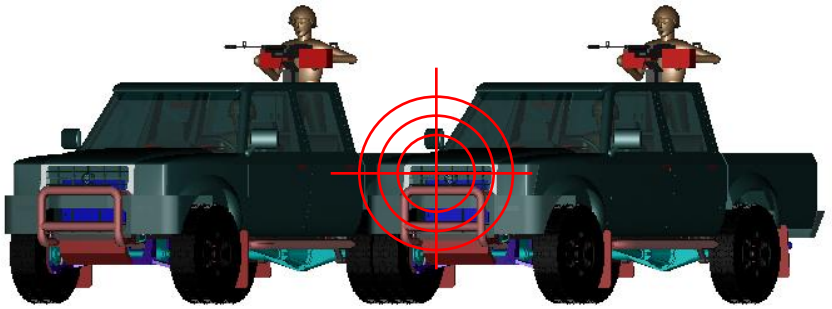
Aggregation for Series: $A_j = \prod_i^n E_i$

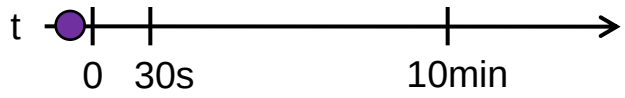
Aggregation for Parallel: $A_j = 1 - \prod_i^n (1 - E_i)$

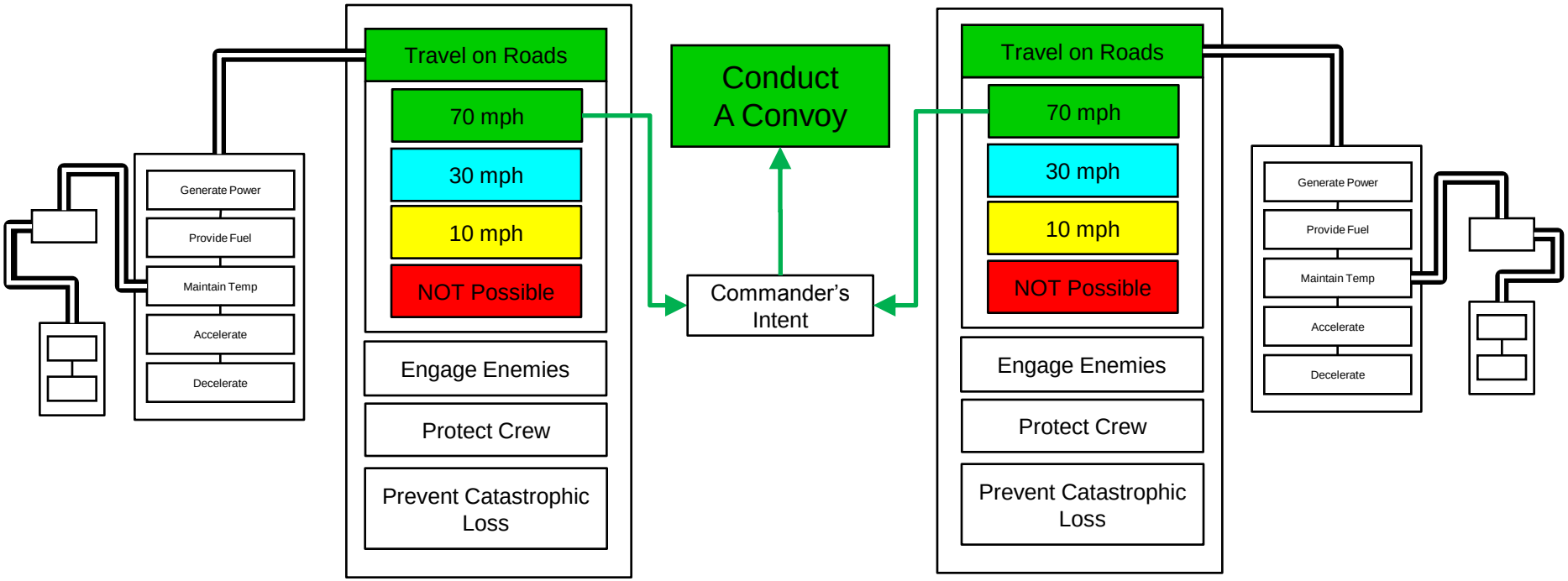
$$A_2 = E_1 \cdot E_2 \cdot [1 - (1 - E_3 \cdot E_4)(1 - E_5 \cdot E_6)] E_7$$

SCAP Can Be Applied to System of System, Time Dependent, and Live Fire Vulnerability Analyses

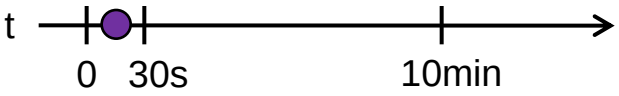
Two trucks are operating in a convoy mission. By the commander's intent, the speed of the convoy is limited to the speed of the slowest vehicle.

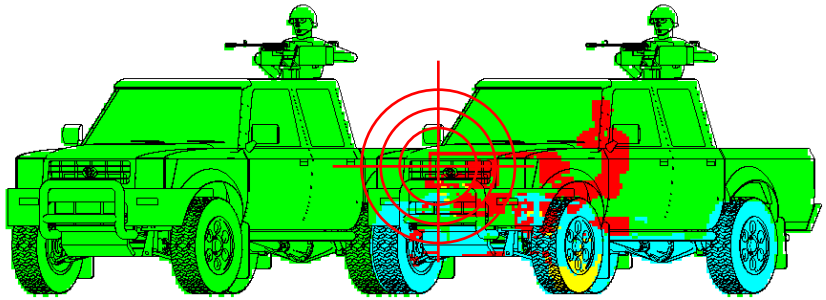


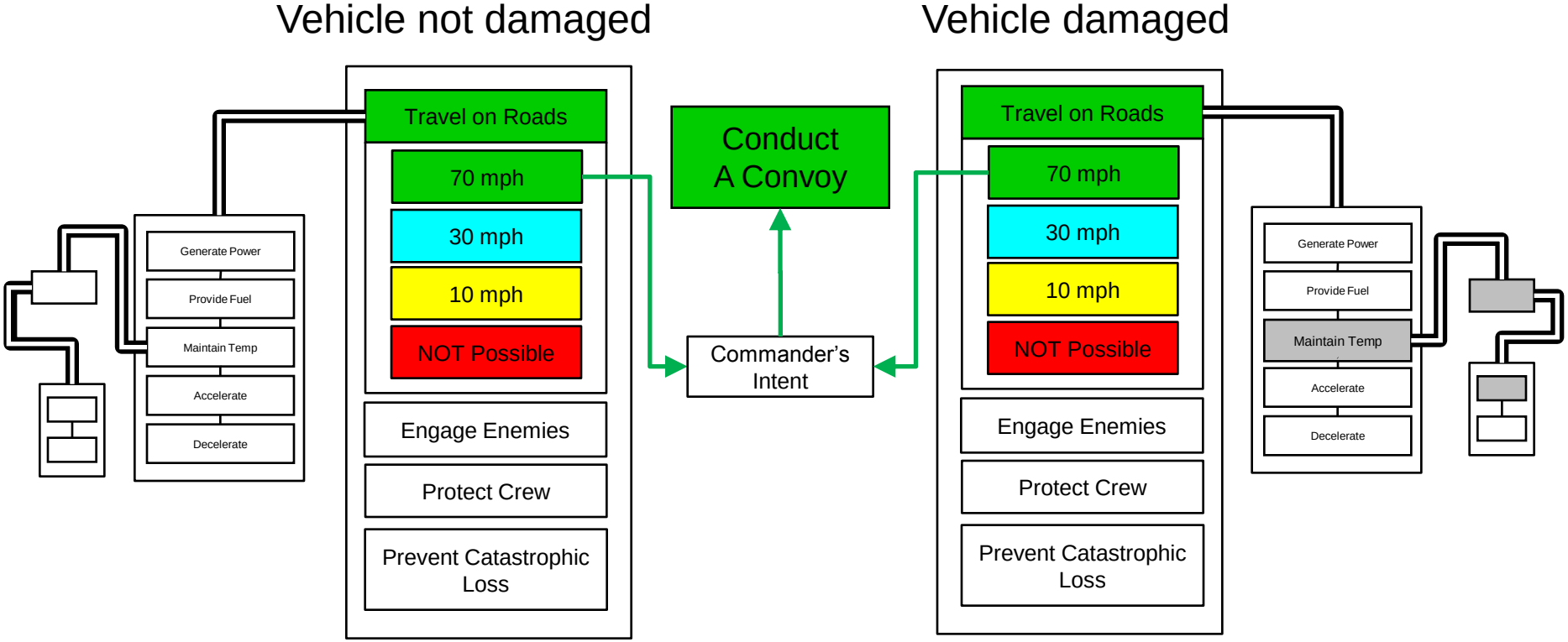




Vehicle 2 has been damaged, but mobility has not yet been affected







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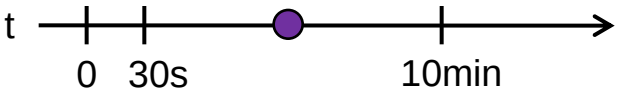
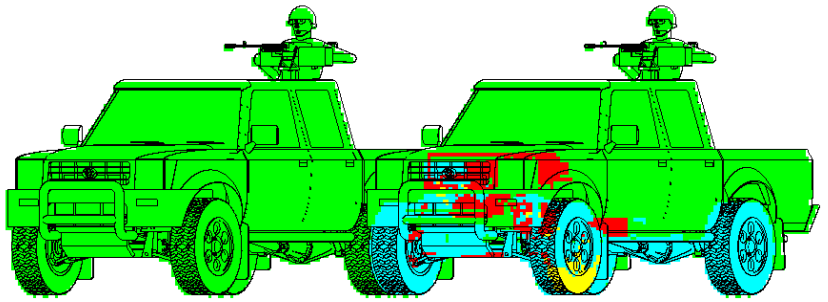
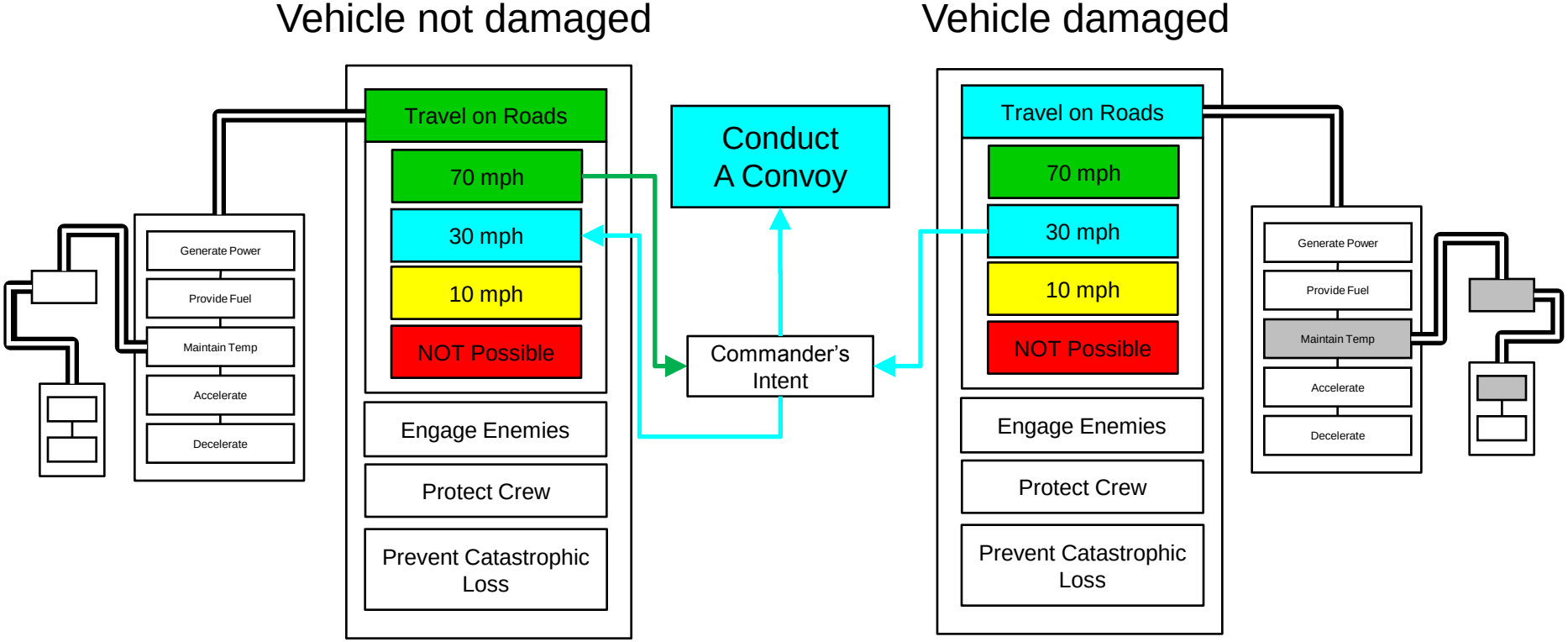
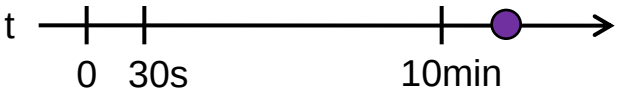
The Mission is Affected as Vehicle Performance Degrades

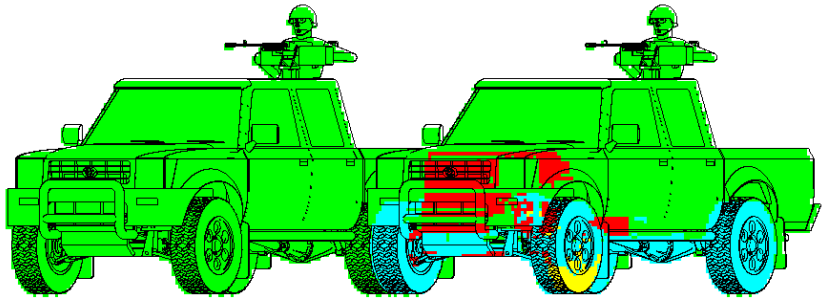


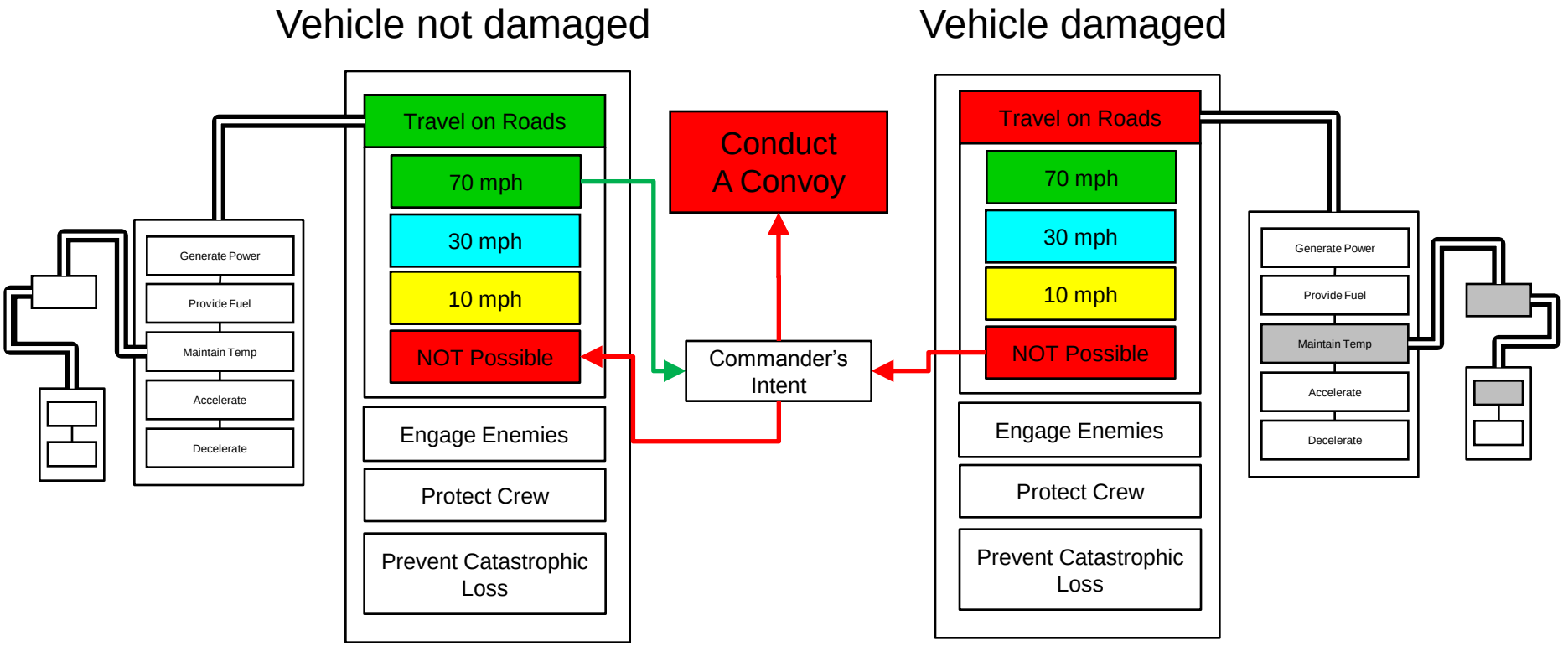




The mission impact is updated as vehicle performance continues to degrade







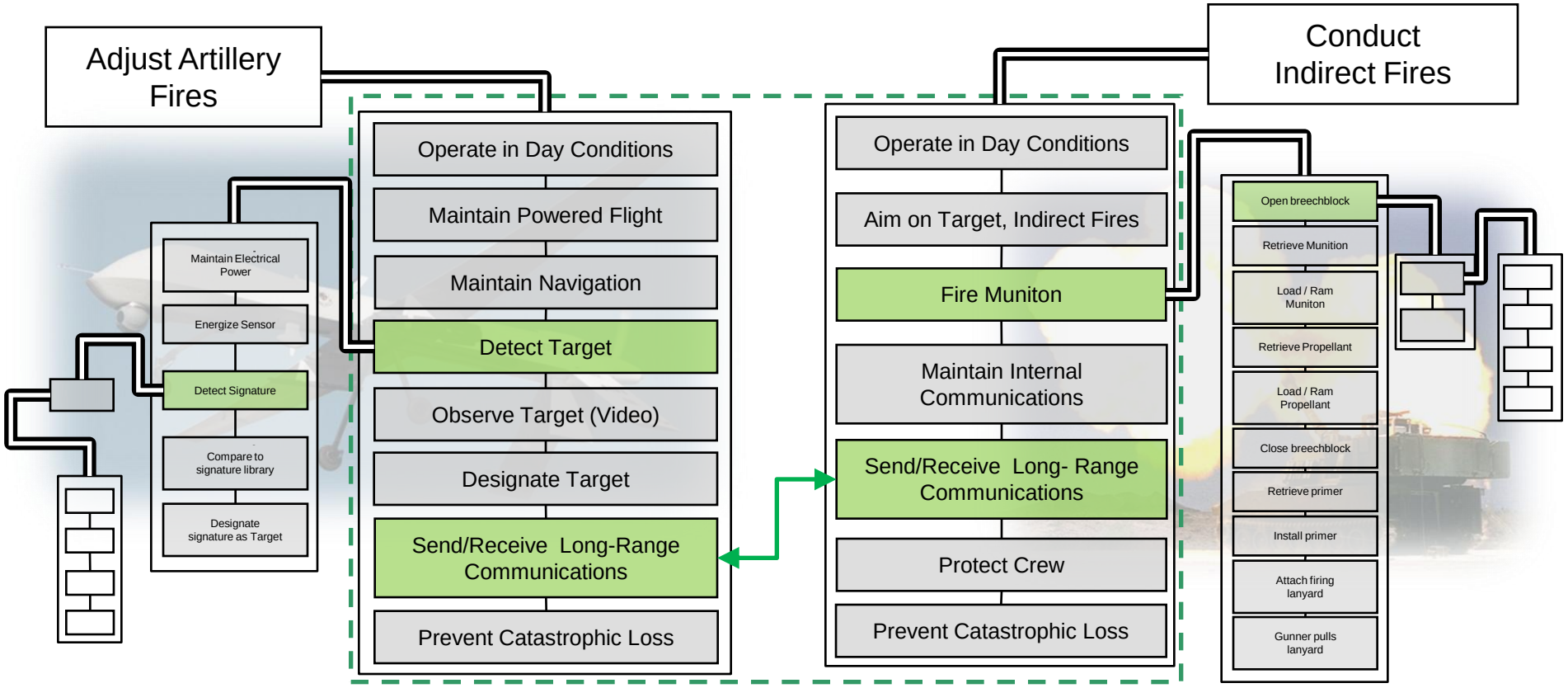
Application of SCAP to Networked and Antagonistic SOS

Storyboard inspired by the SOS example of the UAV and Ground Combat Vehicle in the book:
Deitz, et.al.; "Fundamentals of Ground Combat System Ballistic Vulnerability / Lethality"; pgs 121-126;
American Institute of Aeronautics and Astronautics, Inc.; Reston, VA; 2009.

Using the Functional Skeleton to Link Systems of Systems

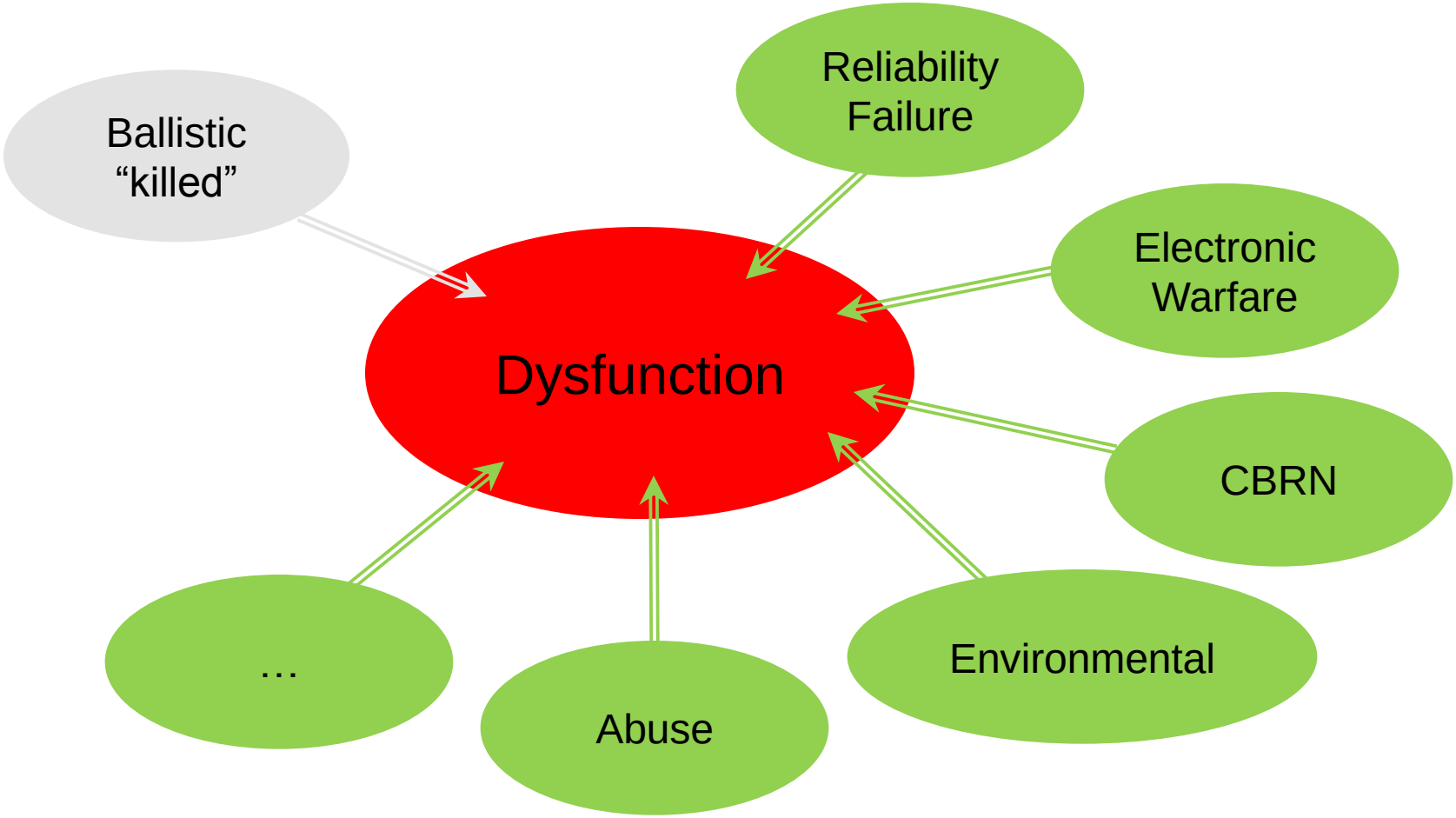
Connect systems by mutual system capabilities.

- If the UAV detects the target, it can send information to the SPH.
- If the SPH is able to receive communications, it can fire on the target.



SCAP can be applied to assess any type of dysfunction

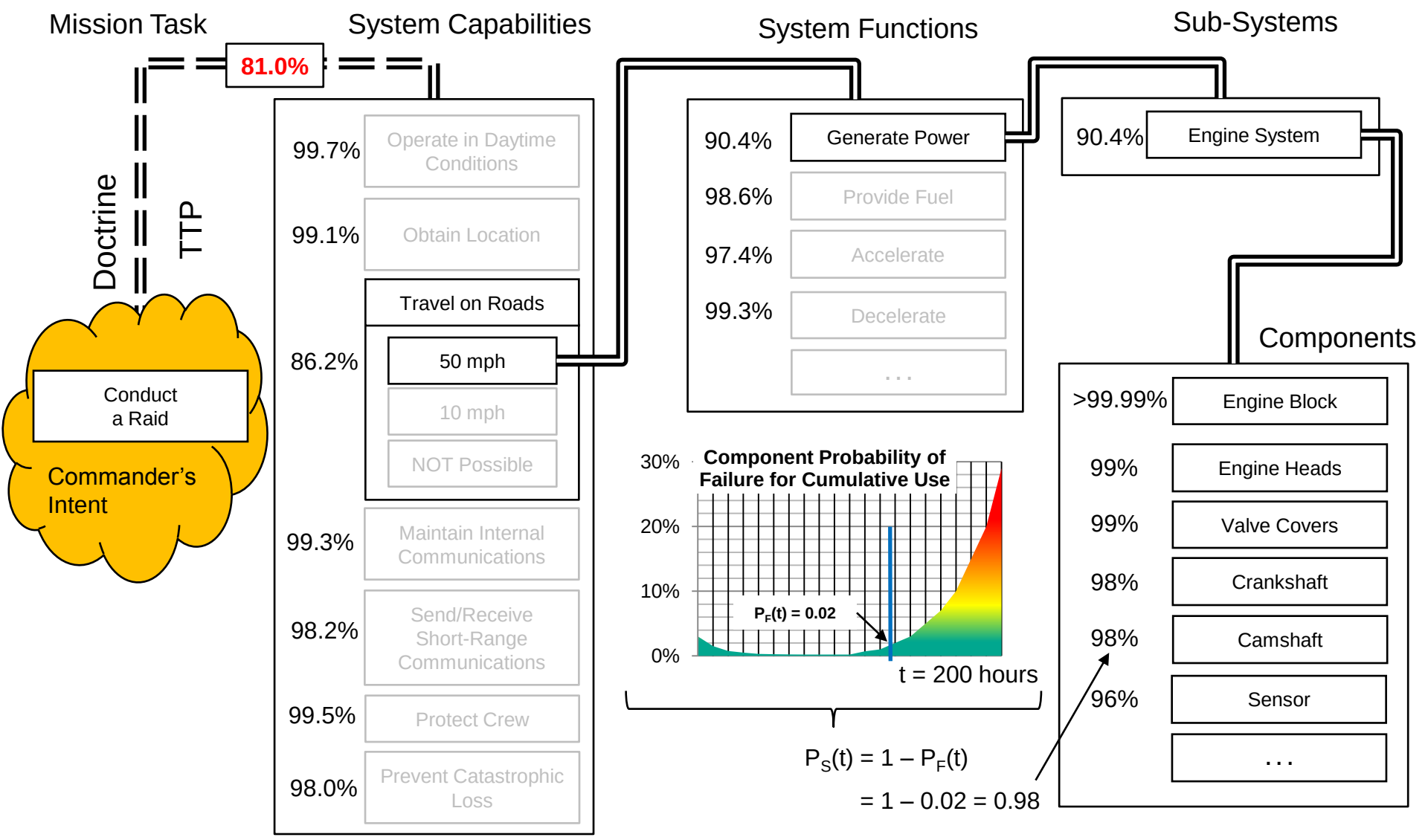
Dysfunction is defined as a component that is not functioning as it is intended.



Process for using the Functional Skeleton in a Numerical Reliability Simulation

- Build use cases using the Mission Tasks. Determine the frequency each use case will be applied relative to the whole set. Assign time duration for each use case.
- Decompose the Mission Tasks with the appropriate System Capabilities.
- Determine the life-consuming load on each System Capability, System Function, Sub System, and Component for each use case.
- Define use-case failure conditions and repair times.
- Run a time analysis:
  - Randomly pick a use case
  - Run through the time of the use case, evaluating component reliability as the simulation runs.
  - If a component fails, use the Functional Skeleton to determine the impact to all the use cases and determine if the current use case continues.
  - Initiate repairs if needed.
  - Iterate time and use cases until either a system abort condition exists or the expected system life is achieved.
- Analyze the data and determine if the system has met the requirements.

Probabilistic Evaluation of Reliability in the Functional Skeleton *



* Reliability numbers are notional and do not represent any system

Existing Impact for SCAP

- Written into the Test and Evaluation Master Plan (TEMP) for both the Joint Light Tactical Vehicle (JLTV) and the Paladin Integrated Management (PIM) as **the** methodology for system-level analysis in the Army Test and Evaluation Command's (ATEC) Mission-Based Test and Evaluation (MBT&E).

JLTV (A potential variant)

PIM

- One of two methodologies that serve as the foundation for ARL's Human Availability Technique (HAT).
  - Evaluates both system performance and human cognitive performance simultaneously to determine total system capabilities
  - Emerging as the Human Availability metric.
  - Presented at Human Factors and Ergonomics Symposium in Sept 2011; nominated for best paper.
- Applied to the Live-Fire Test results of the JLTV to determine remaining capability after a ballistic event.
- Undergoing trial as a system analysis tool for the ARL System of Systems Survivability Simulation (S4).
- Used to develop evolving methodologies for evaluating effectiveness of smoke and obscurant use in warfare.
- Incorporated as the engineering architecture for the ARL Virtual Shot-Line (VSL) Tool.

ARL's Next Steps for SCAP within Live Fire and Vulnerability Analyses

- Apply to production criticality analyses of Red Targets
- Trial Reliability methodology on at least one Army fielded system.
- Develop methodologies to correlate SCAP to theater events and develop vulnerability reductions based on analyses.
- Further exploration and integration of crew metrics in ARL deliverables.
- Trial time-dependent degradation – for example, a leaking cooling system.
- Conduct SCAP-based analyses for the MBT&E pilots (JLTV, PIM, JAGM)
- Trial in S4 and MUVES 3.

Publications

- Significant Briefings:
  - "A Process for Mapping Component Function to Mission Completion"; NDIA 26th Annual National Test and Evaluation (T&E) Conference, Mar 2010
  - 2010 August JLTV LF Integrated Product Team (IPT) Meeting
  - "An Emerging Methodology for Mapping Between a System's Components and Capabilities: The System Capabilities Analytic Process (SCAP)"; 49th Annual Army Operations Research Symposium, Oct 2010
  - "An Emerging Methodology for Mapping Between a System's Components and Capabilities: The System Capabilities Analytic Process (SCAP)"; NDIA 27th Annual National T&E Conference, Mar 2011
  - 2011 Human Factors and Ergonomics Symposium (Human Availability Technique)
  - "SCAP Application to Battlefield Obscuration"; Obscurant Symposium, 2011 May 11

- Technical Publications:
  - Agan, K.; "An Emerging Methodology: The System Capabilities Analytic Process"; ARL-TR-5415; Army Research Laboratory, Aberdeen Proving Ground, MD; Dec 2010
  - Agan, K.; Landis, W.; "A First Review of an Emerging Methodology: The System Capabilities Analytic Process (SCAP), as Presented at the Mission-Based Test & Evaluation (MBT&E) Workshop on January 20"; ARL-SR-0218; Army Research Laboratory, Aberdeen Proving Ground, MD; Dec 2010
  - Landis, W.; "Applying the System Capabilities Analytic Process (SCAP) to the Mission-Based Testing and Evaluation (MBT&E) of the Joint Light Tactical Vehicle (JLTV)"; ARL-SR-206; Army Research Laboratory, Aberdeen Proving Ground, MD; Sep 2010
  - Agan, K.; "The System Capabilities Analytic Process (SCAP) as Presented at the National Defense Industrial Association (NDIA) 26th Annual National Test and Evaluation (T&E) Conference on March 2, 2010"; ARL-SR-0217; Army Research Laboratory, Aberdeen Proving Ground, MD; Dec 2010
  - Mitchell, D.; Samms, C.; Agan, K.; "Both Sides of the Coin: Technique for Integrating Human Factors and Systems Engineering in System Development"; to be published in the annual proceedings of the 2011 HFES

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