A Modeling Approach for Developing System Performance Requirements

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Issues to be Addressed

- The concept of system performance and how to measure effectiveness has been the topic of numerous papers of over the years.
- Typically the focus is on one system characteristic such as reliability (R) or operational availability (A_0) though the Air Force Weapons System Effectiveness Industry Advisory Committee (WSEIAC) recommended that both are required along with system capability (C).
- This is in recognition that performance measures are extremely useful to the system engineer in five key areas:
  1. Establishing requirements;
  2. Assessing successful mission completion;
  3. Isolating problems to gross areas;
  4. Ranking problems relative to their potential to impact the mission; and
  5. Providing a rational basis for evaluating and selecting between proposed problem solutions and their resulting configurations.

Goal

- This presentation will present a top-down modeling approach based on functional flow block diagrams that shows how the system engineer can develop an overall system performance measure that is inclusive of R, A_0, and C.
- It starts with the system concept and allows the system engineer to allocate performance at each layer of analysis, from system to components, ultimately providing detailed performance requirements which will provide a basis for evaluating candidate solutions.

Prediction

- Effectiveness calculations are about prediction
- Objective of prediction is twofold:
  1. System effectiveness predictions form a basis for judging the adequacy of system capabilities
  2. Cost-effectiveness predictions form a rational basis for management decisions.

Outline

- Three key studies
- Overview of the approach
- An example
- Summary
- References

Three Key Studies

- WSEIAC (Weapons System Effectiveness Industry Advisory Committee) Study (1964)
- MORS C2 Measures of Effectiveness Study (1986)
- Paper by John Marshall (1991)
- Other support work listed in references

1: WSEIAC Study

- Developed for the Air Force in 1964 and follows AFSC-375 series
- Looked at two approaches:
    1. Immediately commit resources to an intuitively plausible (re)design and surmount the problems as they arise, or
    2. Explore in the “minds eye” the consequences of the (proposed) system characteristics in relation to mission objectives before irrevocably committing resources to any specific approach
- It is a framework for evaluating effectiveness

System Effectiveness

- Concluded that system effectiveness can be defined as a measure of the extent to which a system may be expected to achieve a set of specific mission requirements.
- System effectiveness is a function of three primary components: availability (A), dependability (D), and capability (C).
- Definition allows one to determine the effectiveness of any system type in the hierarchy of systems

Definitions

- Availability (A) – a measure of the condition of the system at the start of a mission, when the mission is called for at some random point in time.
- Dependability (D) – a measure of the system condition during the performance of the mission given its condition (availability) at the start of the mission.
- Capability (C) – a measure of the results of the mission given the condition of the system during the mission (dependability)

Mathematical Formulation

$$\vec{A} = \begin{bmatrix} a_1 & a_2 \end{bmatrix}$$

System state (up/down)

$$\vec{C}_0 = \begin{bmatrix} c_1(0) \\ c_2(0) \end{bmatrix}$$

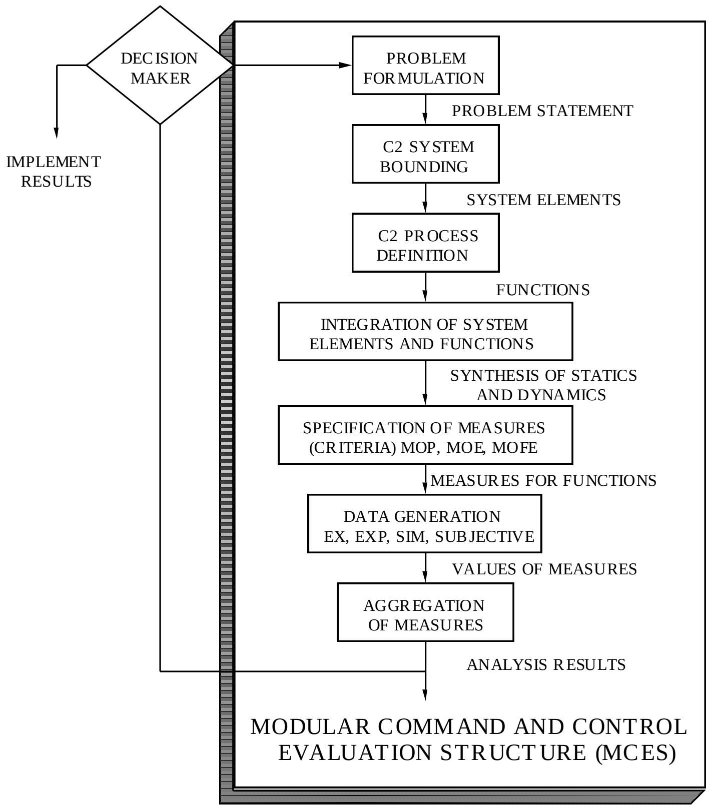
Capability at t_0

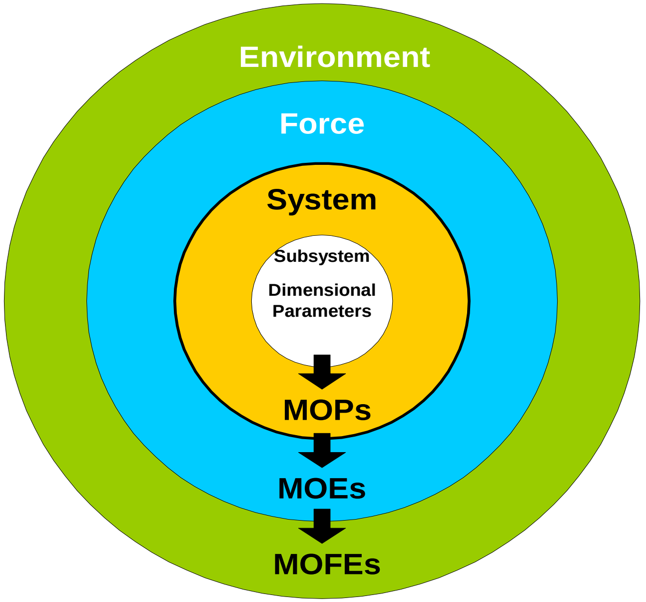
$$D = \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}$$

d_{11} = probability of operational at end given operational at start
d_{12} = probability of fail at end given operational at start
d_{21} = probability of operational at end given fail at start
d_{22} = probability of fail at end given fail at start

$$E = \begin{bmatrix} a_1 & a_2 \end{bmatrix} \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix} \begin{bmatrix} c_1(0) \\ c_2(0) \end{bmatrix}$$

#2: MORS C2 Study

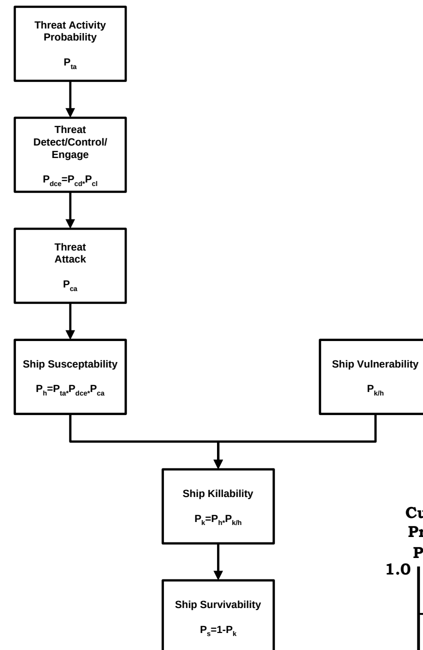


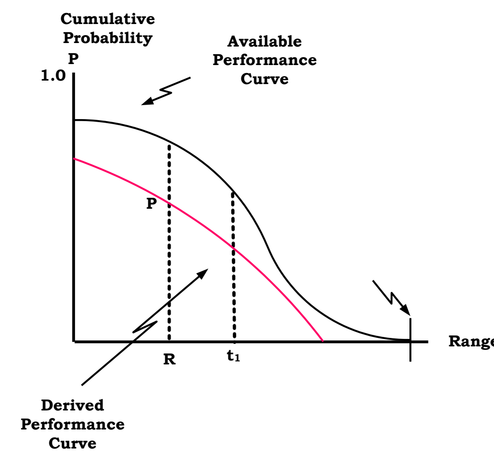


$$MOP = f\left(p_1, p_2, p_3, \ldots\ldots, p_n\right)$$

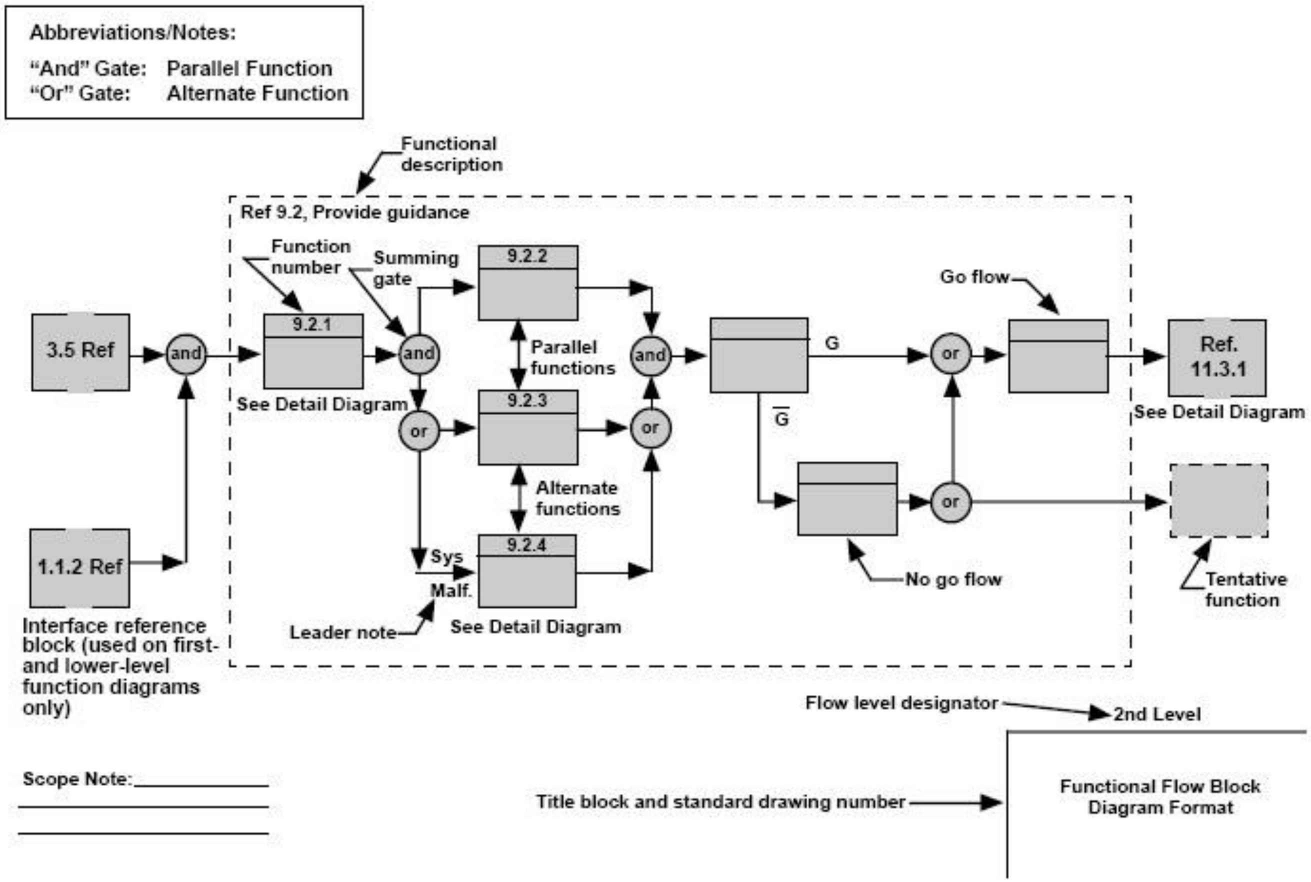
#3: John Marshall Paper

- Marshall developed a mathematical relationship between D, A, C, and S based on the work of Ball and Habayeb
- Related concept to an operational characteristics curve
  - Initial Curve is based solely on the physics involved
  - Subsequent shape of the curve is defined by variance in system design, operational usage, and environmental conditions



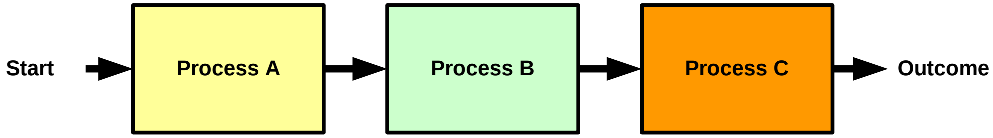


A FFBD Example

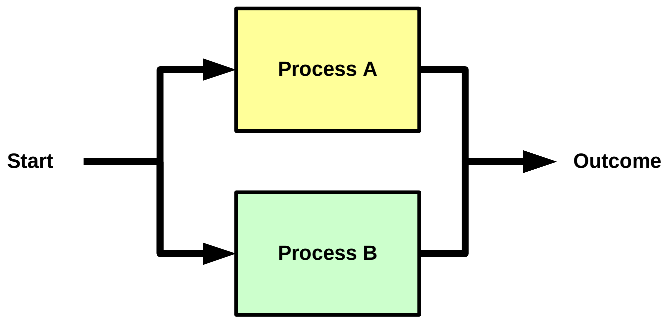


http://en.wikipedia.org/wiki/Functional_flow_block_diagram

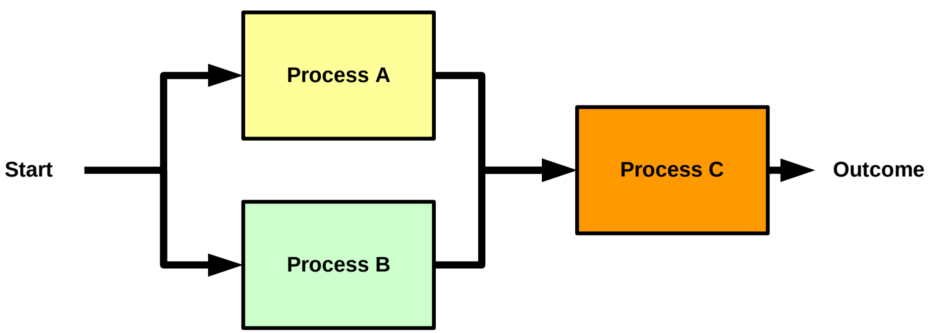
Aggregating Processes



$$P_t = P_A P_B P_C$$



$$P_t = P_A + P_B - P_A P_B$$



$$P_t = P_c(P_A + P_B - P_A P_B)$$

Overview of the Approach

1. Establish the intended purpose of the system
2. Establish those system characteristics which contribute to the designed ability of the system to accomplishment of the system purpose.
3. Measure/compute the numerical value that describes the degree to which each of these characteristics affects the accomplishment of the system purpose
4. Combine all computed/measured values into a form suitable to obtain a system operational value.

A SIMPLIFIED EXAMPLE

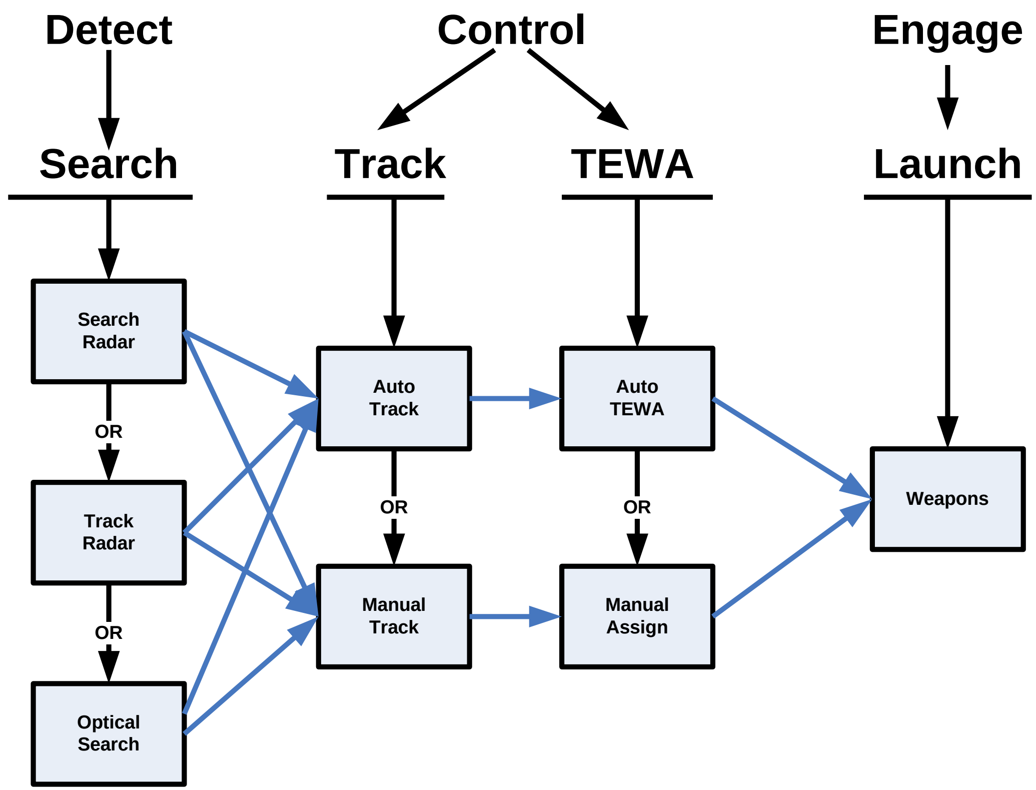
From the Ship's Perspective

Prime Directive: **Defend Ship against Cruise Missile Threats**

Process

Functions

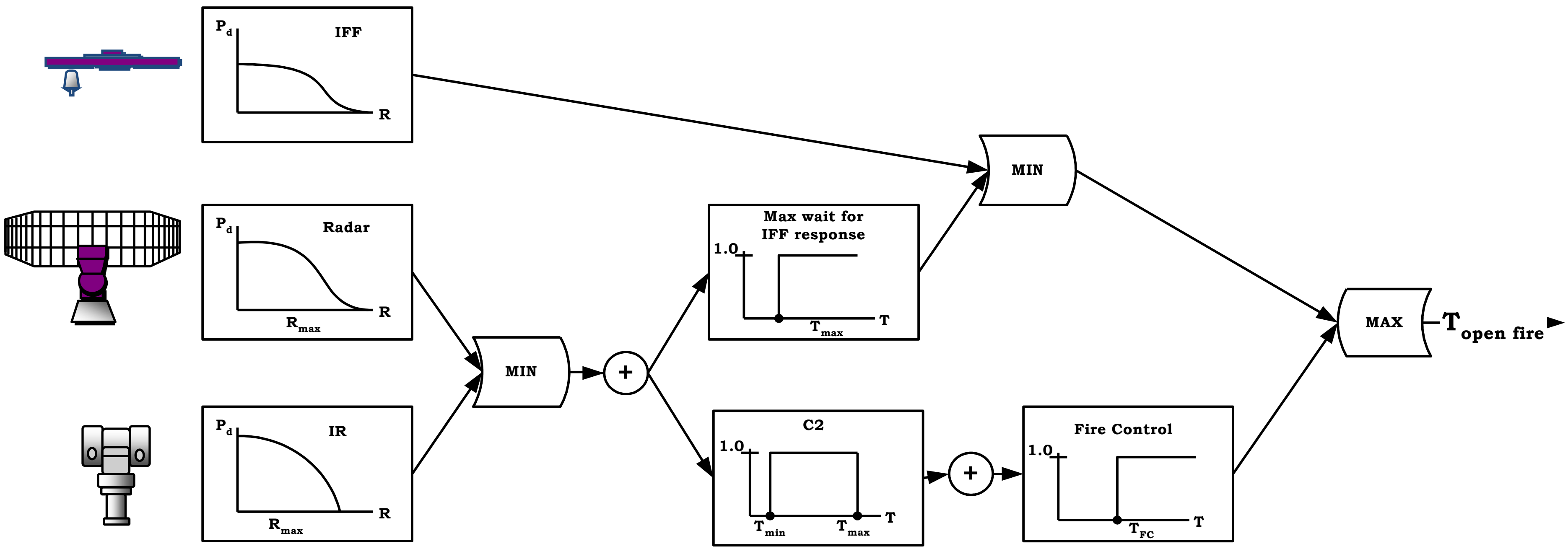
Allocated to:



Sensor Operational Objectives

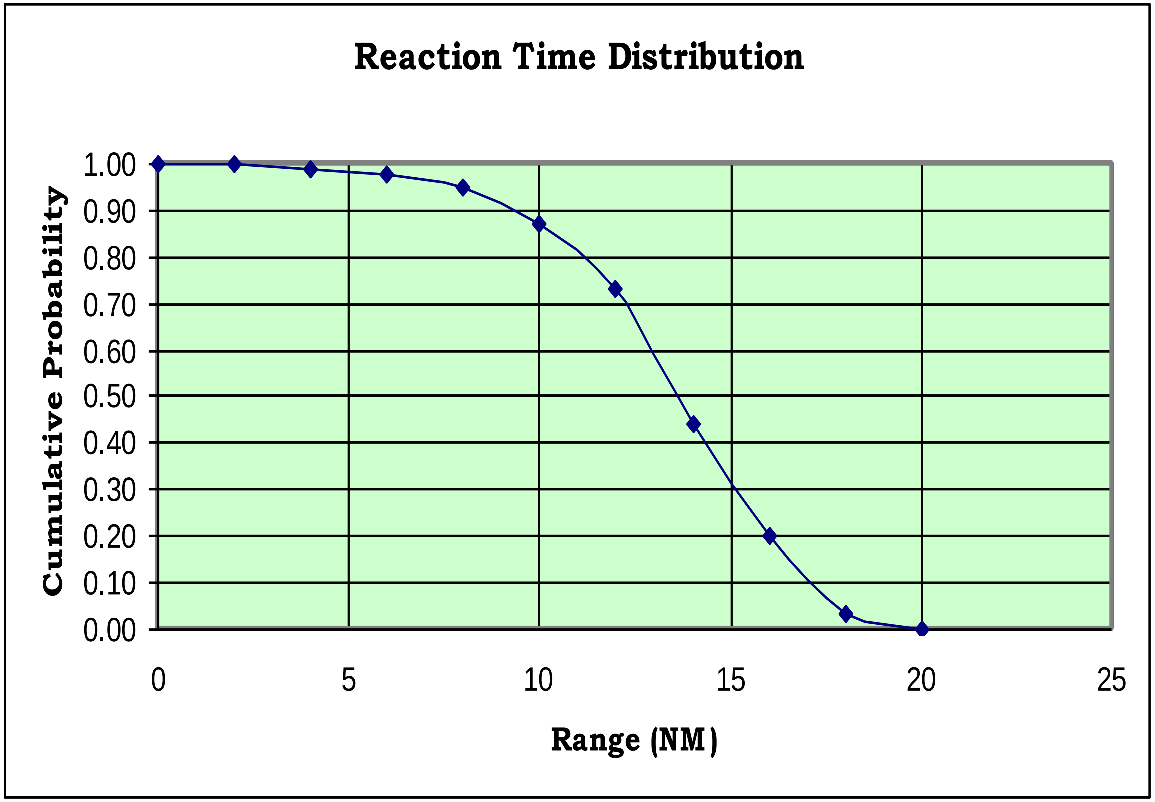
- Required functions to be performed:
  - Detection, Tracking, Classification, ID, Ranging
- Target characteristics and separation
- Coverage volume or area and background
- Atmospheric and weather conditions

Baseline Network



IFF	Raleigh	C2	Uniform
Radar	Swerling	FC	Fixed Time Delay
IR	Exponential	IFF Wait	Fixed Time Delay

System Reaction Time Distribution



Shown without effects of D, A, or S

Sensor Operational Objectives into Effectiveness

Performance Parameters (C)

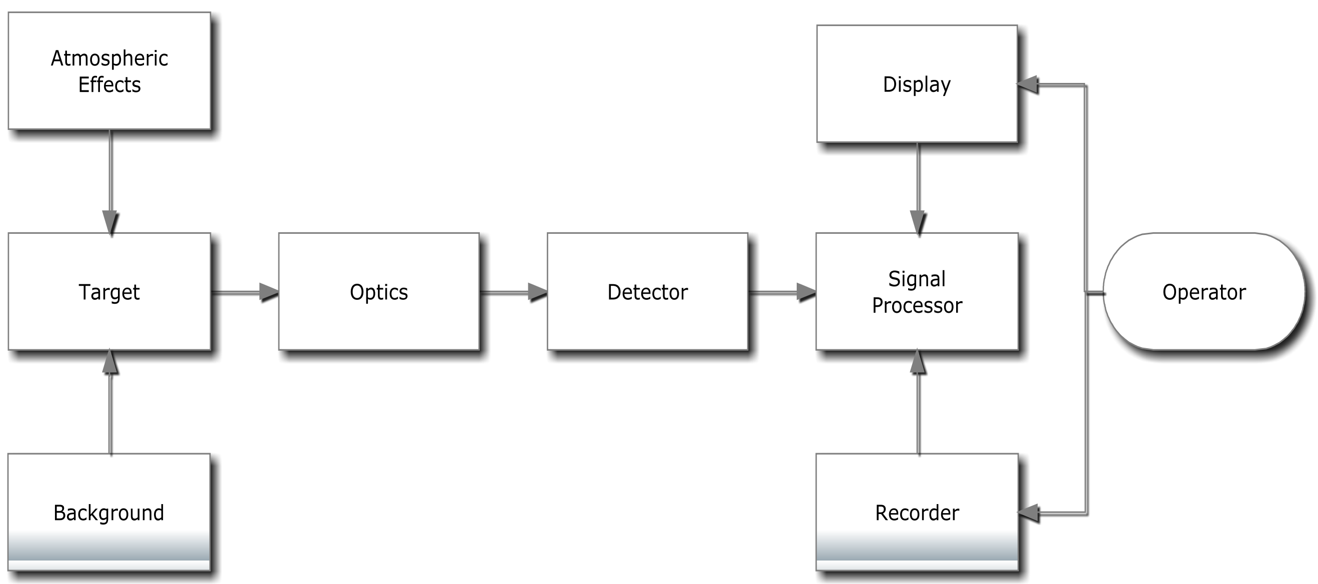
- Detection range
- Tracking range
- Classification range
- ID range
- Pd
- SNR minimum
- Spatial resolution
- Sensitivity
- Total FOV (look angle)
- False alarm time
- Frame time
- Physical characteristics

Reliability Parameters

- Dependability
- Availability
- Survivability

Parameters Drive IR Sensor Design

- Optics
- Detectors
- Signal processing
- Display and recording



In Summary

- Presented a top-down modeling approach based on functional flow block diagrams that shows how the system engineer can develop an overall system performance measure that is inclusive of R, A_0, and C.
- It started with the system concept which allows the system engineer to allocate performance at each layer of analysis, from system to components, ultimately providing detailed performance requirements which will provide a basis for evaluating candidate solutions.
- Approach can be useful to the system engineer in five key areas:
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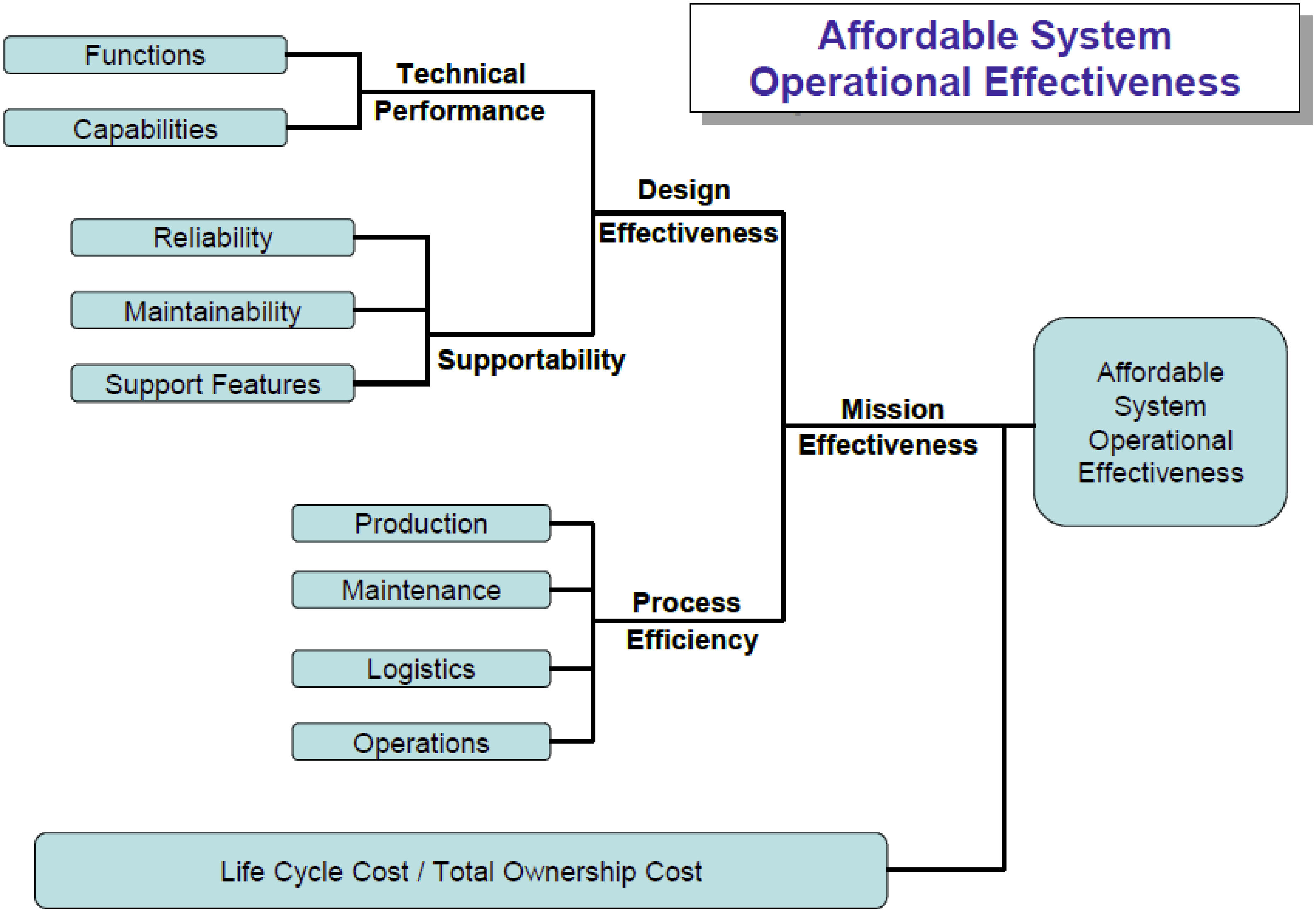
Functional and Non-functional Performance



Questions?

References

- Ball, Robert. *The Fundamentals of Aircraft Combat Survivability Analysis and Design*, AIAA Press, 1985
- Bard, Jonathon. *An Analytical Model of the Reaction Time of a Naval Platform*. IEEE Vol. SMC-11, No. 10 Oct. 1981, pp. 723-726
- DARCOM-P 706-101 CH. 24
- Habayeb, A. R. *Systems Effectiveness*, Pergamon Press, 1987
- Hitchens, Derek.
- Friddell, Harold G. and Herbert G. Jacks. *System Operational Effectiveness (Reliability, Performance, Maintainability)*, 5th National Symposium on Reliability and Quality Control, January 1959
- Marshall, John. *Effectiveness, Suitability & Performance*, 59th MORS, 12 June 1991