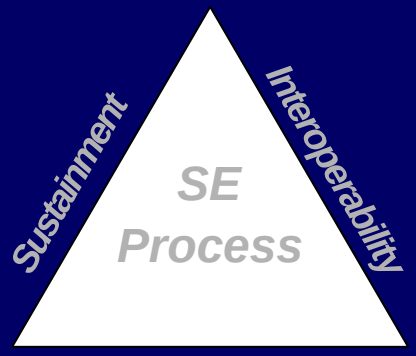
Certified
Naval Battle Groups



Improving the Assessment of Deploying Battle Groups Via Error Budget Analysis

Steven Vipavetz
NAVSEA 53
and
Tony Soltyka
SAIC

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Wayne Altrichter, BAE; CDR Eric LeGear, SEA 53H; Fred Riedel, JHU-AP; James Kuzmick, WBB; John Ladik & James Foltz, NGIT; Ron Beard, NRL

Overview

- Objectives
- Why Improve?
- Big picture
- Utility
- Approach
- Sample Conclusions
- Sample Investigation Results
- Summary

Objectives

- This presentation describes the need and approach for using error budget analysis as an assessment tool for deploying US Navy Battle Groups.
- It discusses how this analysis can highlight and prevent problems stemming from inattention to fundamental physics when both existing and modified systems are integrated to become part of a large-scale system.
- The utility is discussed in terms of an example problem and concludes with a range of sample recommendations.

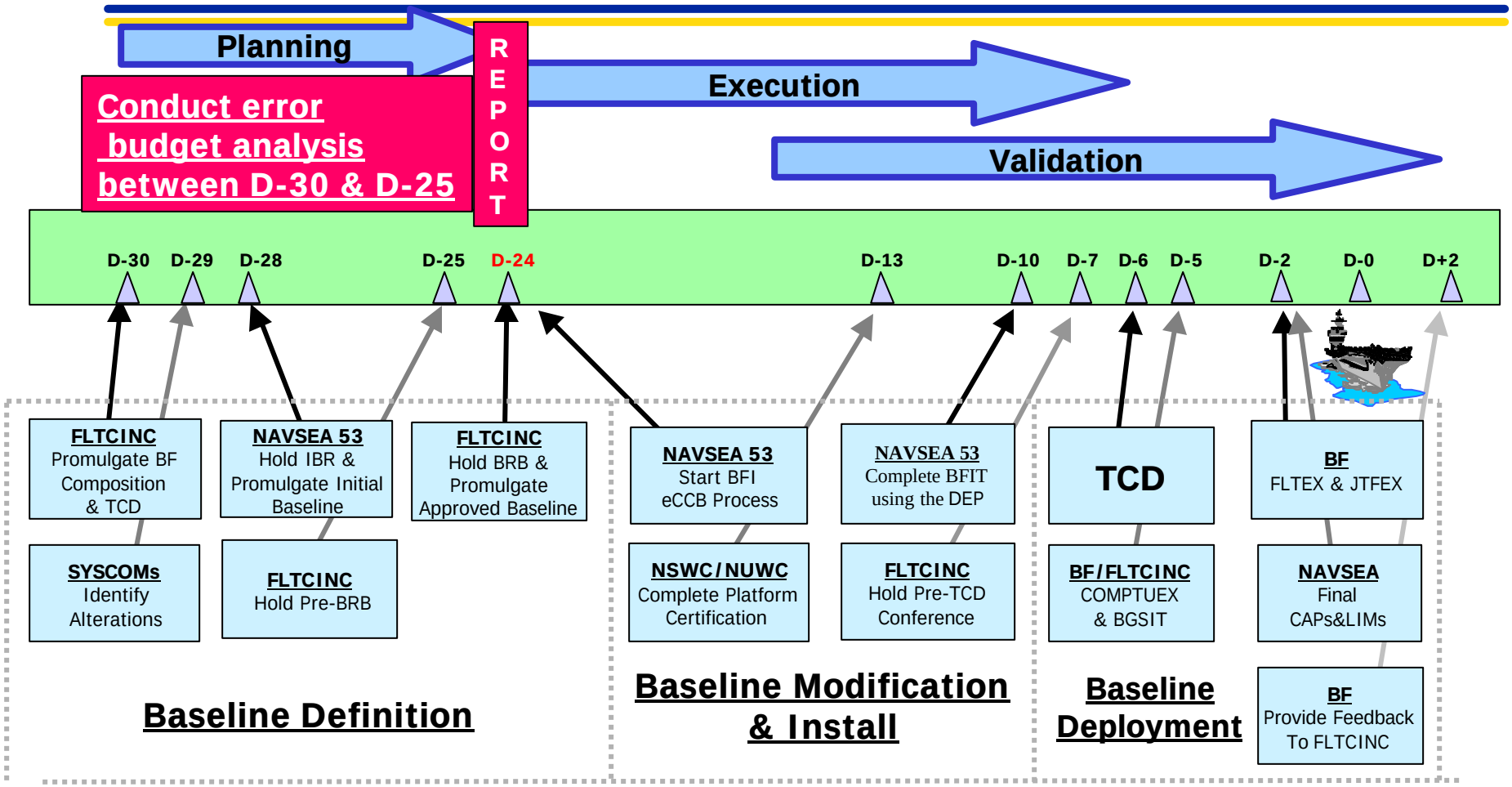
Why Improve?

- Prevent interoperability problems that impact warfighting such as:
  - Dual tracks
  - Ambiguous ID
  - ID conflicts
  - R2 conflicts
  - Bombs on target
- Many of the root causes to these types of problems stem from not paying attention to physics based elements of engineering such as: "Force level" end-to-end error budgets when ever we do initial design or follow-on design.
- Notional Example

$$CEP = \sqrt{\underbrace{(TLE)^2}_{\text{Targeting systems owned by PM \#1}} + \underbrace{(GPS)^2 + (G\&C)^2}_{\text{Navigating and guiding systems owned by PM \#2}}}$$

Error analysis would spotlight problems caused by PM's not doing cross system engineering to ensure the CEP is met.

The Big Picture



Deploying battle Groups have to run through what is called the D-30 process, where its baseline is assessed & controlled. This process lasts 30 months. Error budget analysis can be added between D-30 and D-25.

Utilization of Error Budgets

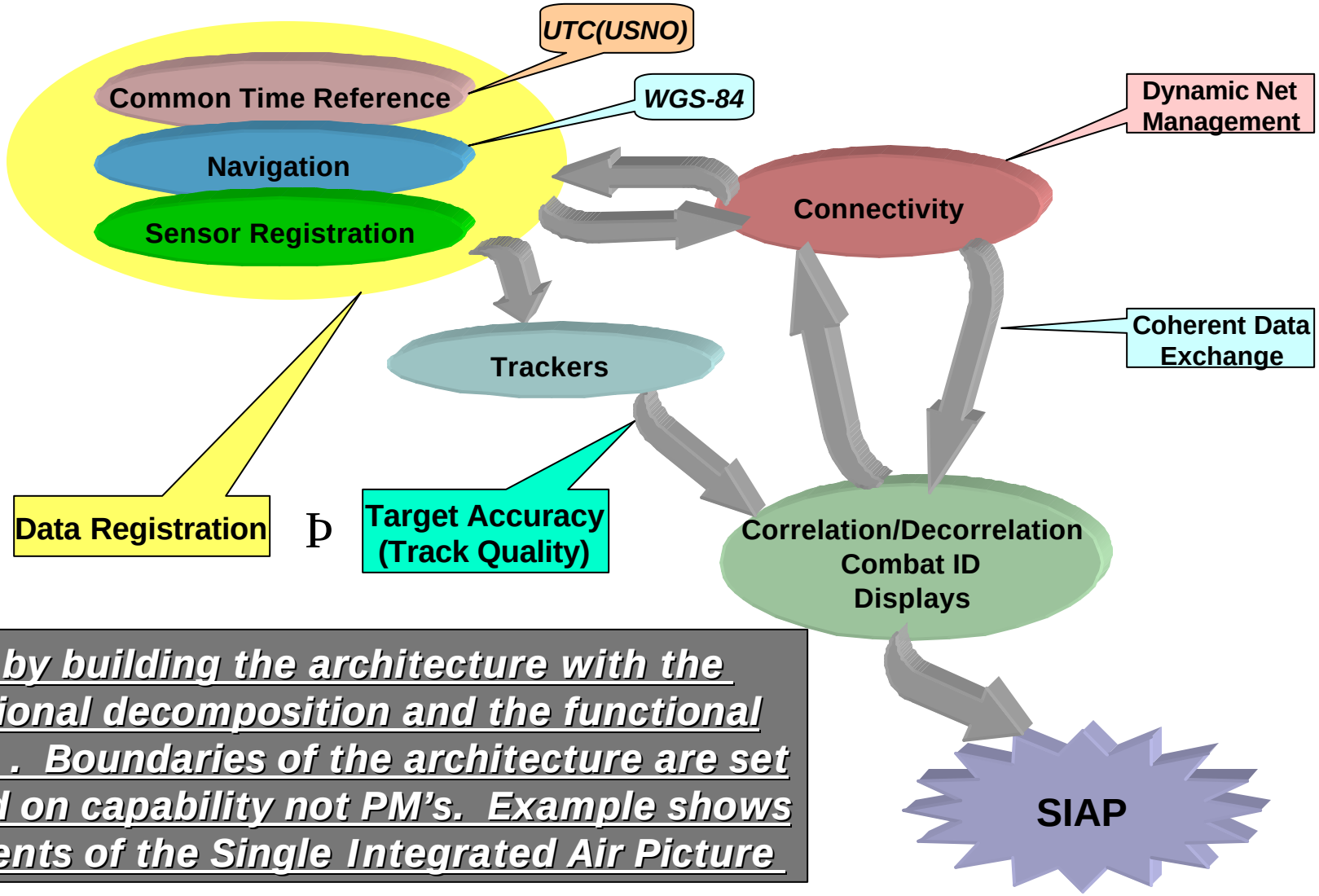
- Error budgets are used to determine how individual systems affect overall, integrated, FoS/SoS performance. Applications include:
  - Determine the improved target location performance due to the addition or removal of a sensor on a network.
  - Determine if timing requirements are achieved across systems and networks to support overall FoS/SoS performance.
  - Determine if overall FoS/SoS requirements are achievable for stressing conditions, e.g. short time line engagements against fast targets.
  - Identify FoS/SoS tradeoffs early, e.g., providing more accurate weapons versus providing more powerful weapons or improved C4ISR capabilities.
  - Balancing the navigation errors and the sensor errors in a netted, common operating environment.
  - Justify integration efforts: E.g., PGWs require highly accurate geo-location, and thus, are a “requirements driver” of other system components that may require enhancements to support the mission.
  - Improve Interoperability with allied systems, e.g, for timing data.
  - Identification of bias errors, which can subsequently be removed.

Approach

- Architecture (baseline & modified)
- Define the errors
- Link error budget equations to measures of performance
- Parametric/Sensitivity analysis (Link errors to BF performance metrics)
- Sub-system performance characteristics & component errors
- Systems analysis (includes model preparations)
- Conclusions/Issues
- Investigate issues and recommended improvements to enhance battle force effectiveness

The following slides illustrate the approach based on example capability needs for a Single Integrated Air Picture (SIAP)

Architecture ☆



Start by building the architecture with the functional decomposition and the functional flows . Boundaries of the architecture are set based on capability not PM's. Example shows elements of the Single Integrated Air Picture

☆ = Source, Wayne Altrichter, BAE

Error Definition ☆

- Time uncertainty and elapsed time since last observation of the target (i.e., errors due to latency resulting in uncertainty of target maneuvers since last observation).
- Uncertainty of own unit navigation WGS-84 geodetic position and attitude errors,
- Uncertainty of the sensor derived target location (i.e., sensor measurements of range, bearing, and elevation w.r.t. the sensor, and sensor alignment w.r.t. own unit WGS-84 navigation),
- Uncertainty in the tracker process (i.e., smoothing errors),

Target Location Error = Time Errors + Navigation Position and Attitude Errors + Sensor Errors + Track Errors

Build the error definition, based on SIAP functional flows, accounting for all major factors in target location error as well as how they promulgate

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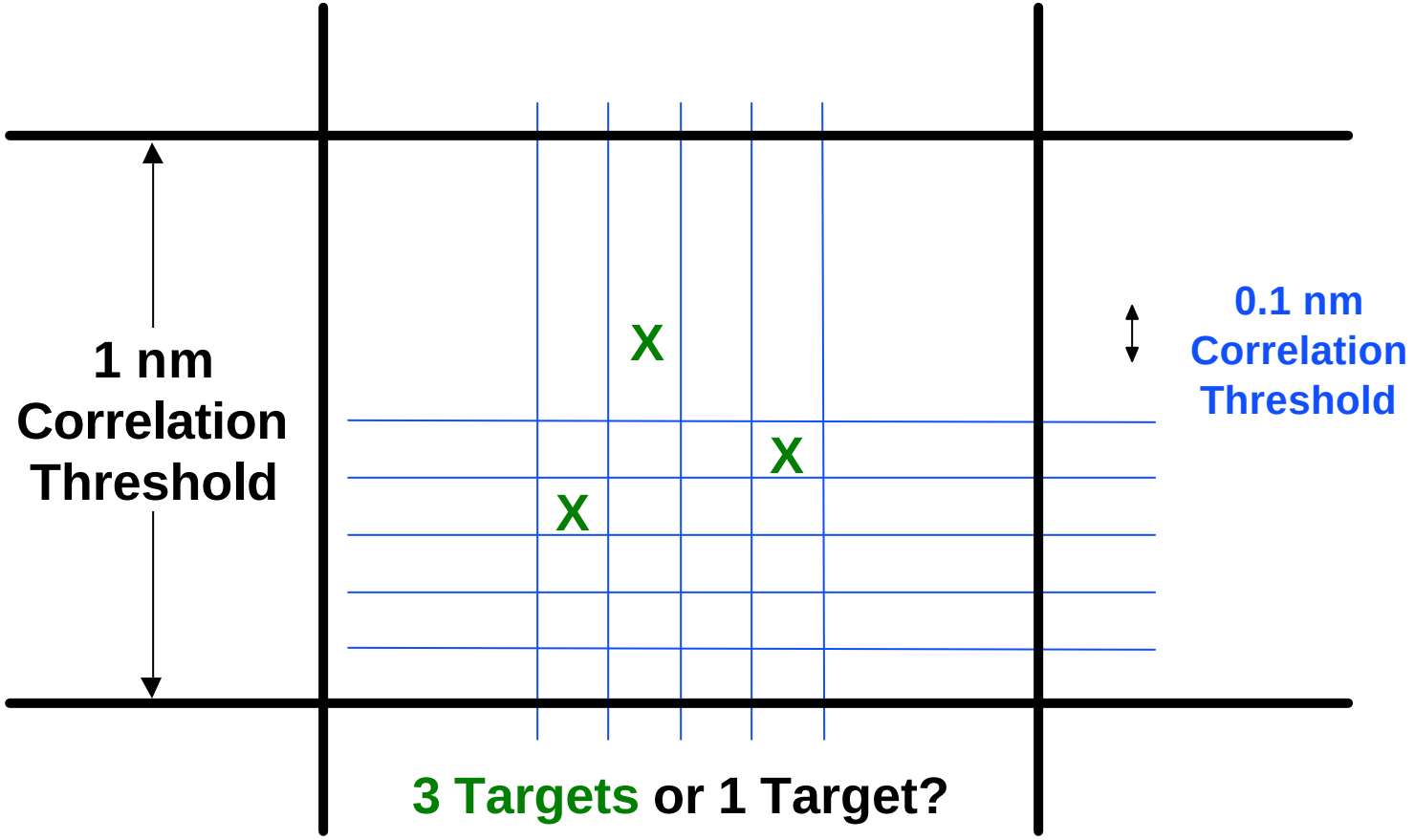
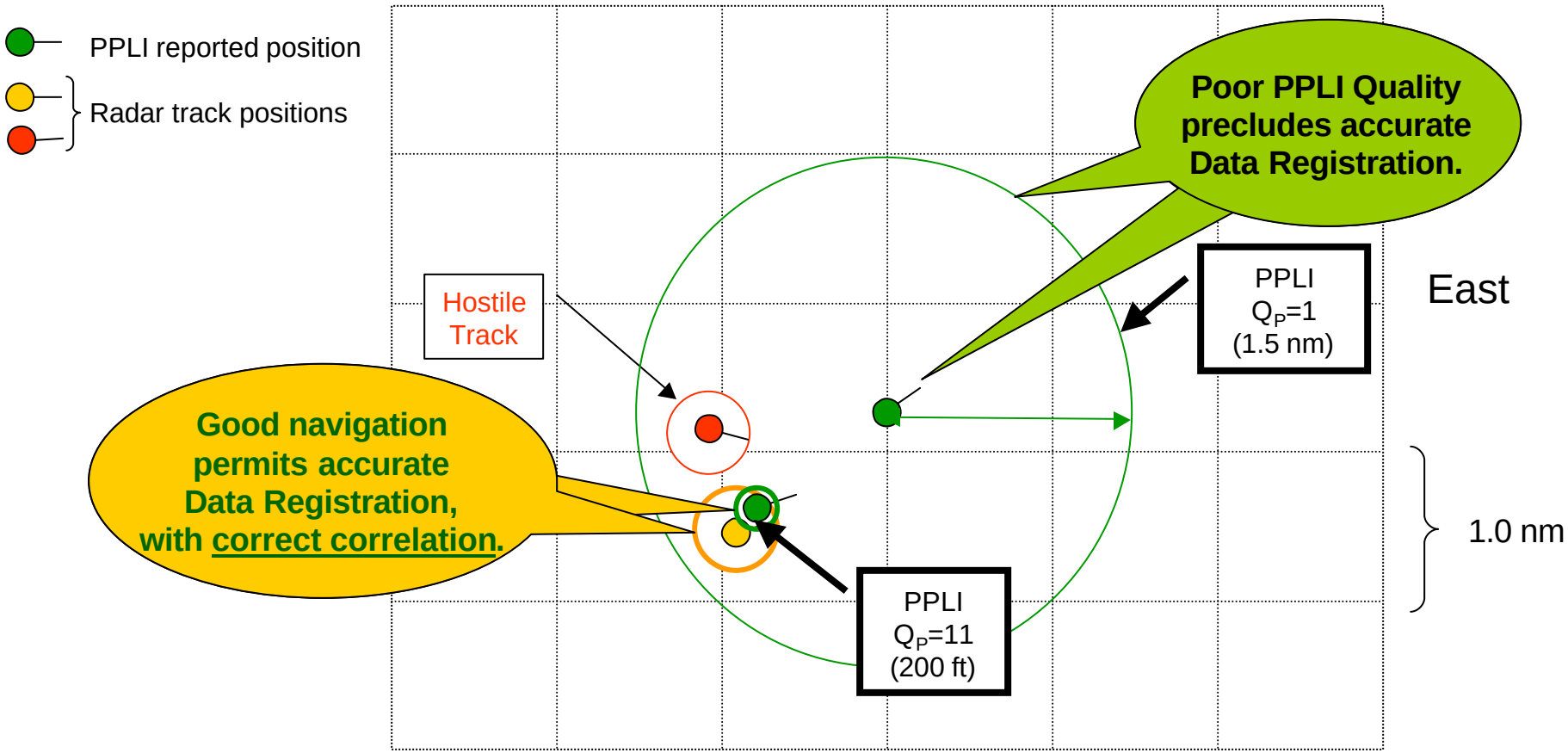
Measures of Performance



Reduction in target location error translates into improved correlation

Measures of Performance



Performance of Terminal Quality is proportional to performance or quality of "navigation" . Example: Good vs Poor PPLI Quality

Parametric/Sensitivity Analysis

Sources of Error ☆

- Correlation/De-correlation errors
- Track filter errors (maneuvering vs. non-maneuvering targets)
- Correlated navigation estimation errors
- Correlated sensor estimation errors
- Connectivity of the TADILs
- Translation errors between TADILs
- Message Standard deficiencies
  - Insufficient resolution or information
- IFF/SIF conflicts in Combat ID
- Remote unit errors (residual data registration errors from other IUs)
  - Unregistered IUs, e.g., coalition operations
- Navigation errors (position and misalignment w.r.t. WGS-84)
- Sensor random measurement errors (range, bearing, elevation)
- Sensor position errors (leverarm between sensor and navigation)
- Sensor alignment errors (misalignment errors between sensor and navigation)
- IU time synchronization errors (between sensor and navigation)
- Community time reference errors (between IUs)
- Algorithm and implementation errors
- Multiple algorithms across platforms

Need to use parametric analysis to determine which errors the performance measure is most sensitive. This reduces the number of error data that needs to be collected

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Host Platform Characteristics

Platform	Navigation Suite	Sensor Suite	Data Links	Navigation Registration	Sensor Registration	IU Registration	Data Registration	Target Correlation	Issues
Cruiser (CG)	WSN-7, NAVSSI Block III	SPY 1 (?), …	Link 16 Link 11 CEC	NAVSSI & Link 16 (TBD)	SGS (?) SRIG (?) (1) SRKF (?) (2)	SRIG (?) IRKF (?) (3)	(?)	(?)	Data Registration
Destroyer (DDG)									
Carrier (CV)									
E-2C									
F-14D									
F/A-18									
E-3									
F-15									
F-15E									
F-16									
JSTARS									
ABCCC									
MCE									
Patriot									
THAAD									
Tornado									
UKADGE									

Need to align systems to the key functions

Error Budget

System	Navigation Registration Errors			Sensor Registration Errors			Target Errors & Track Qual. (l,f,h)	Time Sync Errors	Remote Unit Errors (l,f,h,q_z,r,q_B,q_E)
	Position Errors (l,f,h)	Velocity Errors (v_x,v_y,v_z)	Misalignment Errors (q_x,q_y,q_z)	Sensor Alignment (y_x,y_y,y_z)	Sensor Errors (r,q_B,q_E)	Leverarm Errors			
Ship Gridlock System (SGS)									
C^2P									
ACDS									
Link 11									
SRIG									
CEC									
Link 16									
C&D									
WSN									
NAVSSI									

Need to collect data on system errors that align to key errors and corresponding functions. This budget provides an examination across systems owned by multiple PM offices

Systems Analysis ☆

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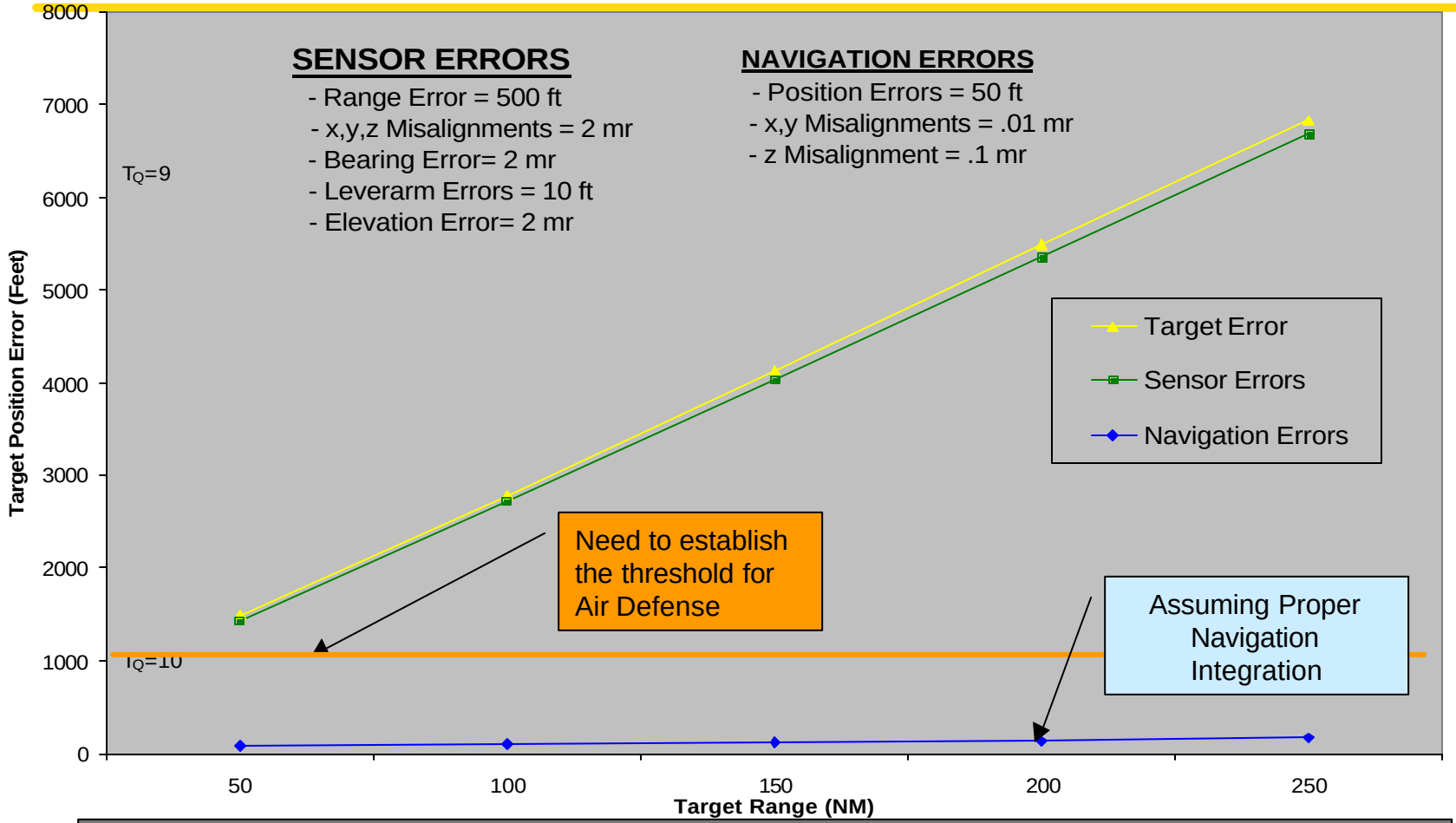

Need to plug in the errors into model to evaluate degree of impact to target location error. This SIAP notional example shows only "roll-up" results

Sample Conclusions

- Sensor errors dominate.
  - Sensor alignment errors, especially in azimuth, are a large problem.
  - The function of sensor registration should be examined to determine whether improvements could be made that would further reduce errors and improve performance
- Time and navigation must be integrated properly to avoid "anomalous error "
  - Enables data registration
  - Supports sensor registration
  - Supports PPLI Q_P

Sample Conclusions ★

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What's needed to avoid navigation anomalous errors is a Common UTC(USNO) Time and **WGS-84 "Common Integrated Navigation"** solution that enables data registration and minimizes target errors:

- **Common Time Reference**
  - Bounded latency and time-accurate w.r.t. UTC(USNO)
- **Integration of INS, GPS, and Link 16**
  - Position, Velocity, and Attitude
- **Robust with respect to vulnerability and degradation of GPS**
  - Jamming
  - Failure
- **Stable element for achieving data registration**
  - Sensor Registration (using Precise Participant Location and Identification (PPLIs) and Low Earth Orbit (LEO) Satellites
    - Alignment
  - Interface Unit (IU) Registration (residual errors)
  - Accurate knowledge of target track error (track covariance/quality)

Conclusions should point to where investigation must occur to support the long term requirements. In this example, time and navigation should be examined to determine whether the planned ship modernization would introduce unwanted error

Sample Investigation Results *

ISSUES	COMMENT
AEGIS (Model 5 C&D): Note that Model 4 C&D does not have these issues. 1) PPLI Op=0 intermittently 2) PPLI Op=7 or 8 at best 3) WSN - C&D - C2P - JTIDS navigation data: ▪ Latency Error > 1 sec ▪ 1 Hz velocity repeated 7 times ▪ 1553 MUX errors > 10% ▪ Link 16 initial TOD > 1 sec error ▪ GPS Position not provided ▪ JTIDS position not used by Aegis 4) GPS 1 PPS Time not provided as input to Link 16.	1) ACDS Blk 1 ships ignore AEGIS tracks. Problem observed during CEC OPEVAL. 2) WSN-7 assumes 0.1 nm (600 ft) error for GPS position 3) NAV SET meetings have identified these system integration issues. DR SET testing at Wallops Island confirms these issues. PMS-400 is investigating solutions for these isssues. 4) This precludes TOD initialization using GPS.

In this older example (circa 1990's), it suggests what might have been found had this process been followed before installation of Model 5 C&D. Recommendations would have been coached to solve these issues in both the short term and long term. Example may not reflect current status

* *Source of data: SSC SD Technical Report 1833; "Joint Tactical Distribution System - Global Positioning System (JTIDS - GPS) Integration Assessment*

Sample Recommendations ★

- In the short-term, existing navigation equipment should be integrated to achieve a UTC(USNO) “Common Time” and WGS-84 Navigation that enables Data Registration and minimizes target error.
  - Existing Navigation Equipment:
    - GPS
    - INS
    - Link 16
- The long-term plan would be to develop the next generation architecture for Integrated Navigation to incorporate:
  - CTRA for UTC(USNO) “Common Time” for all Warfighters.
  - Robust integration of all navigation sensor data, e.g., GPS, INS, Link 16, using an “optimal estimator”

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Summary

- Short term recommendations stemming from error budget analysis
  - Are expected to be directed to protecting the integrity of the existing error budget based on proposed changes to the baseline of the Battle Group
  - Focus is mostly on system architecture, e.g., add or delete a box
- Long term recommendations
  - Are expected to be directed toward changes to the functional architectural baselines, e.g., improve function of Sensor Registration function.
  - Supports justification to budget changes over FYDP
- Warfighting capability is improved by:
  - Finding & preventing problems due to a detailed understanding of complex systems of systems (SoS) that are expensive and time-consuming to test