OPERATIONAL ANALYSIS OF CBM+ TO ENHANCE SYSTEM SUITABILITY

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SCENARIO:PROBLEM SETTING

- ***ASSETS***:VEHICLES, A/C; for ***MISSIONS***
- ***BECOME FAILURE-PRONE, "UNHEALTHY" WITH WEAR, USAGE, "AGE" (RANDOMLY)***
- ***ASSUME: HEALTH CONDITION "KNOWABLE" (SOMETIMES,… WITH ERROR)***
- →***MONITOR HEALTH CONDITION*** **(e.g. helo rotor vibration ↑)**
- ***DIAGNOST. SYMPTOMS (DS): COST*** ↓
- ***AVAILABILITY***↑

(<u>PROVIDED</u> CBM+ SYSTEM FUNCTIONS & WITH FEW MISTAKES!)

- ***Client: e.g. Army Aviation& Missile Cd., Redstone Ars.; Analyst. Data Whse.***

Condition Indicator (CI) Development Summary

Demonstrated Capabilities:

- Vibration CIs Determined From Analysis of Frequency & Energy Data Recorded By Embedded Sensors
- CI Development Is Iterative And Requires High Quality Field Data To Determine Normal and Abnormal Behavior
- CI Development Is Further Enhanced With Bench Test Data
- Each CI Is Tailored For Individual Fault Modes
- The Complexity Of CI Development Varies With:
  - The Number Of Fault Modes
  - Fault Occurrence Frequency
  - The Monitoring Capability For That Mode

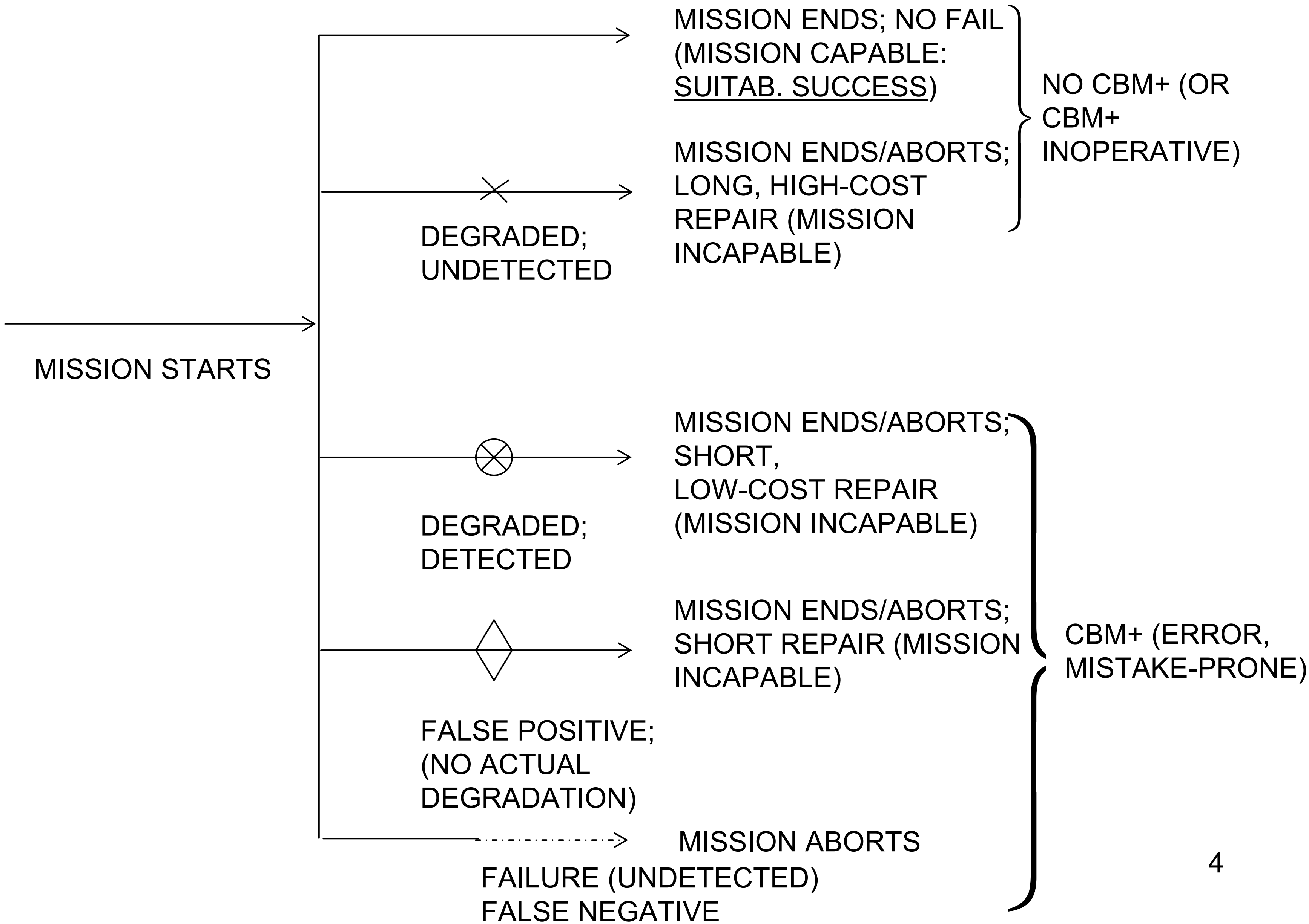
Benefits To The Warfighter:

- Teardown Inspections Are Used To Confirm CI Thresholds
- Replace Manual Inspections With Active Monitoring

Objectives:

- Extends Time Between Overhauls & Extends Service Life
- Increases Safety

OUTCOMES
WITHOUT/WITH CBM+



Additional CBM+ Failure Modes

- CBM+ Physical System Failures
- Prognostic Errors
  - CBM+ False Positives (No Actual Fault)
  - CBM+ False Negatives (Actual Undetected Fault)
- T&E of System, Including CBM+ ≡ IVHM,

VITAL!

  - "End to End"

Periodic Overhaul vs. Prognostics (IVHM or CBM+) Previous Work

- [IDA: FCS] (Macheret, Koehn, & Sparrow)
  - CBM+ system is perfect but not all (series) system components monitored
  - CBM+:

    KNOWN (!) Time from Prognostic→ Failure (*NO ERROR*)
  - Result: CBM+ Cost↓, AVAIL. ↑ vs. Periodic Overhaul (*If* sufficiently many sub-systems successfully monitored)

Periodic Overhaul vs. Prognostics (IVHM or CBM+) Previous Work

- [BOEING] (Z. Williams, S. Cooper, J. Vian)
  - Integrated Vehicle Health Management (IVHM)=CBM+
  - Fault isolation time log-Gauss; outliers. Simulation
  - Result: Optimistic assumptions → Availability ↑, Cost ↓

Preventive Maintenance (Including CBM+)

- Text: Gertzbach, I. **Reliability Theory** with Application to Preventive Maintenance (Chap. 4, Sec 4.2) Springer

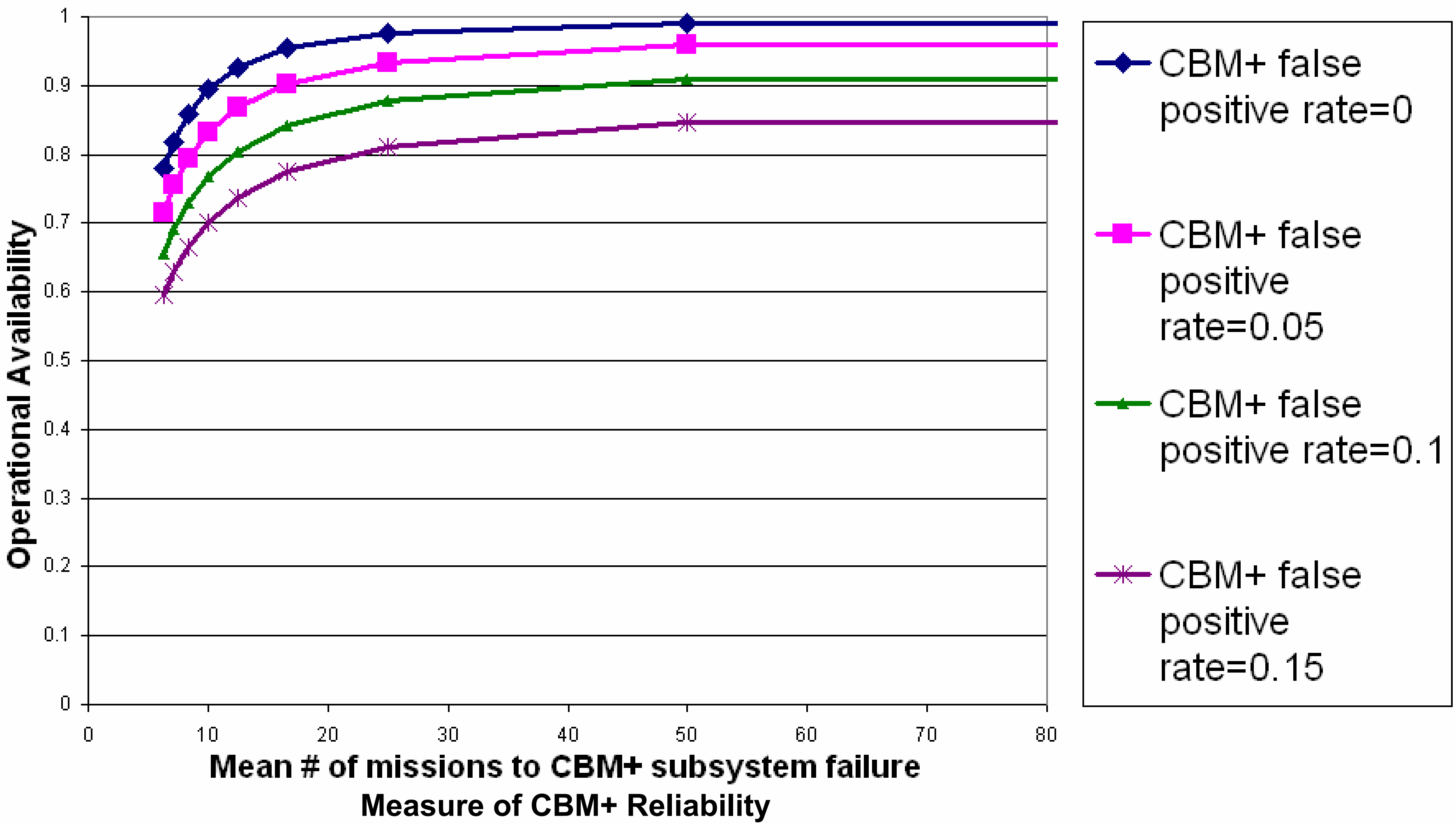
Present Model

- CBM+ subsystem imperfectly reliable: subject to functional/ “physical” failure and repair
- If CBM+ subsystem up prior to a mission & *produces a signal*, the system will undergo repair/replacement
  - True positive: System would have failed during mission
  - False positive: System would not have failed during mission
- If CBM+ subsystem up prior to a mission & *does not produce a signal*, the system is used on the mission
  - False negative: System fails during the mission (catastrophic failure)
  - True positive: System completes mission
- Independent, identically distributed missions

Availability Parameters

- Mean repair times (Multiple of Mission Times, e.g. 4 hrs.)
  - CBM+ subsystem failure: 10 (40 hrs.)
  - Detected failure: 15 (60 hrs.)
  - False Positive: 5 (20 hrs.)
  - Catastrophic Failure: 35 (140 hrs.)
- Mean number of missions between operational system failures (not CBM+)
  - 100 (400 hrs.)

Operational Availability



System Operational Availability Depends Upon

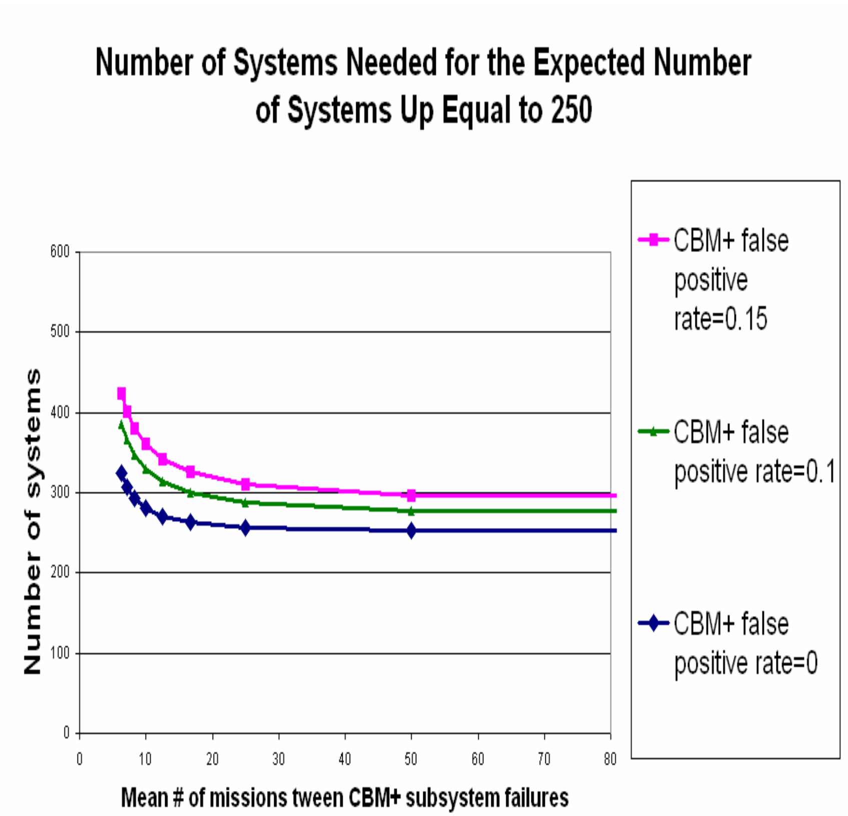
- Reliability of the CBM+ subsystem
- The false positive rate
- The rate of true positives (repair time of failures)
- The rate of false negatives (repair time is larger for catastrophic failures)

Number of Systems

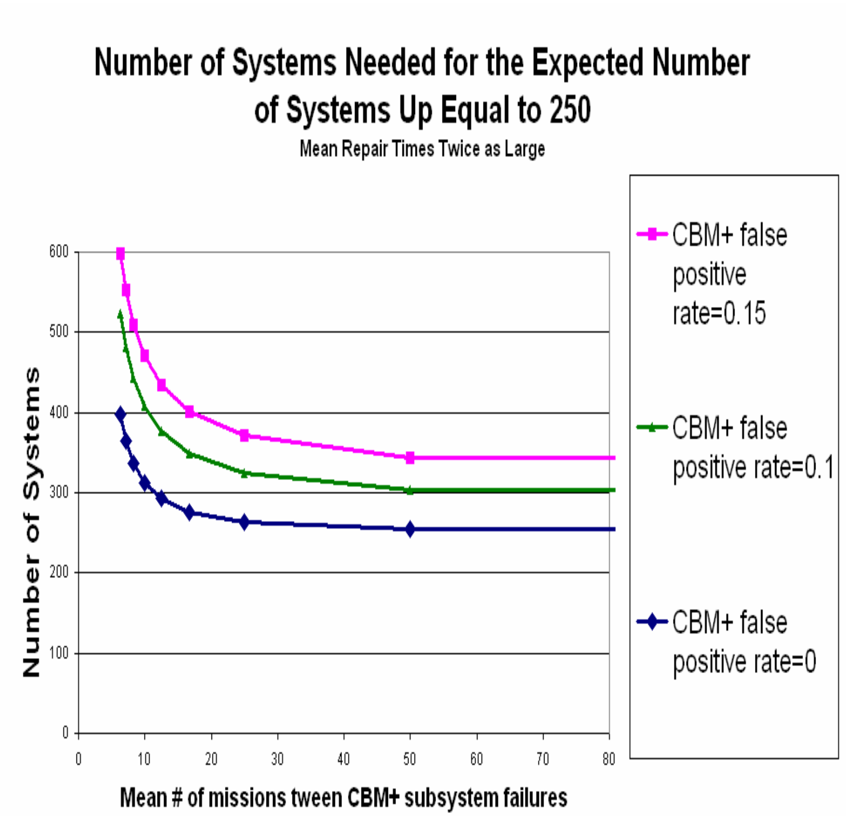
- Systems operate and are repaired independently of each other, and have the same parameters.
- There is a need for 250 systems to be available that can be assigned to missions

Number of Systems Required

All mean repair times twice as large



(CBM+ Reliability)



(CBM+ Reliability)

Number of Systems Needed Depends Upon

- Reliability of the physical system
- Reliability of CBM+ subsystem
- Mean repair times
- Rate of false positives

Suitability

- Not just a “requirement”: Essential for Mission Success
- Affordability issue:

  Reliability of CBM+ & System (A/C) ↑

  Spare (Logistics) Cost ↓

Fixed Budget B

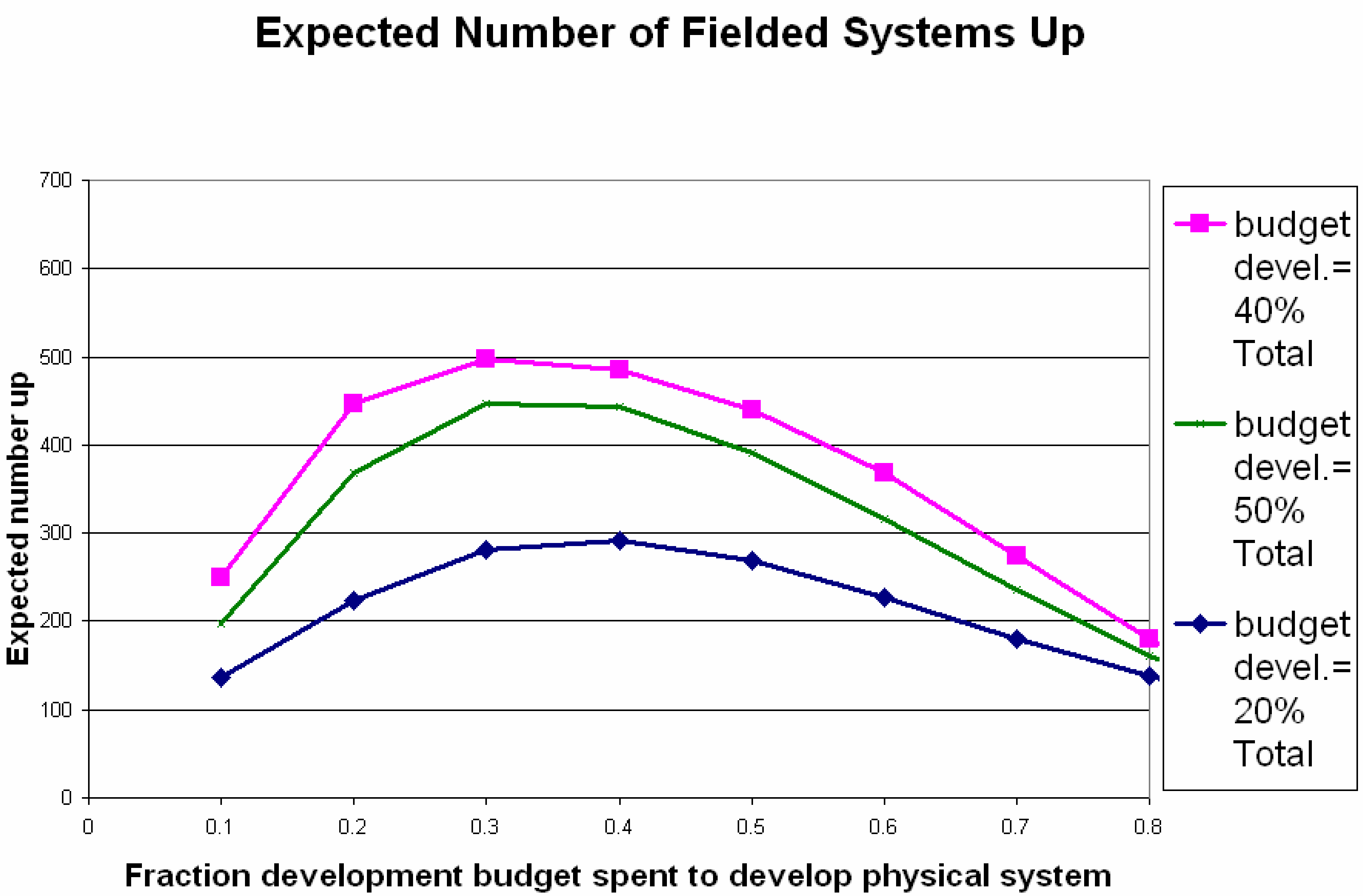
- Develop/Test Physical System & CBM+ subsystem
  - MTTF
  - Operational Availability
- Use remaining budget to buy systems to be fielded
- Mean number of fielded systems up

Tradeoffs

- Less $ spent on development/testing
  - Buy more systems
  - Less operational availability
- More $ spent on development/testing
  - Buy fewer systems
  - More operational availability
- Fraction of development/testing budget spent on CBM+
  - Less: operational availability ↓

Decision Variables

- Amount of budget to spend on development/testing
- Fraction of development budget
  - Physical system
  - CBM+ subsystem
- Rest of budget to buy systems



Expected Number of Fielded Systems Up
700
600
500
400
300
200
100
0
Expected number up
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Fraction development budget spent to develop physical system
budget devel.= 40% Total
budget devel.= 50% Total
budget devel.= 20% Total

Remarks

- The maximum expected number of fielded systems available to start a mission is obtained by allocating (about) 40% of the total budget to development/testing
- The best allocation of the development budget:
  - 30% system development
  - 70% CBM+ subsystem development

Conclusions

- CBM+ has the promise to improve system reliability and to decrease maintenance costs.

However:

- CBM+ can introduce additional failure modes.
- Reliability of CBM+ & System ↑

  Spare (Logistics) Cost ↓
- Developmental and operational testing of the system *MUST* include the CBM+ subsystem.