Kinetic Energy Interceptors

Estimating Program Risk Through Schedule Normalization

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Outline

- **Cost Estimating in an Evolutionary Acquisition Environment**

- **Kinetic Energy Interceptors (KEI)**

- **Schedule Normalization**

- **Schedule-Dependent Cost Estimate**

- **"Work-to" & "Normalized" Results**

KE Interceptors

Cost Estimating in an Evolutionary Acquisition Environment

"History"
"Set the Stage"

MDA Conference 2003

KE Interceptors

- **Presented "Cost Estimating in an Evolutionary Acquisition Environment" @ MDA Conference 2003**
  - **Issue: Historic cost databases don't reflect current program acquisition strategies**

- **MDA Environment (reflect shorter RDTE projects)**
  - **Capabilities-based**
  - **Spirals**

- **Cost Databases (reflect longer RDTE projects)**
  - **Requirements-based**
  - **Grand Design**

Solution: Use schedules to scale estimates until new databases developed

Kinetic Energy Interceptors (KEI)

KE Interceptors

- **KEI**
  - **New MDA program**
    - **Capabilities-based**
    - **Spiral/Block development**
  - **Source Selection occurred April-December 2003**

- **Schedule-based estimating**
  - **Allows us to use historical cost databases to estimate current MDA programs**

- **Schedule normalization**
  - **Allows us to generate estimates/budgets that include risk (cause and effect)**
  - **Address Dept. of Defense program overruns (schedule/cost)**

KEI program presented opportunity for schedule normalization

KE Interceptors

KEI Program Overview
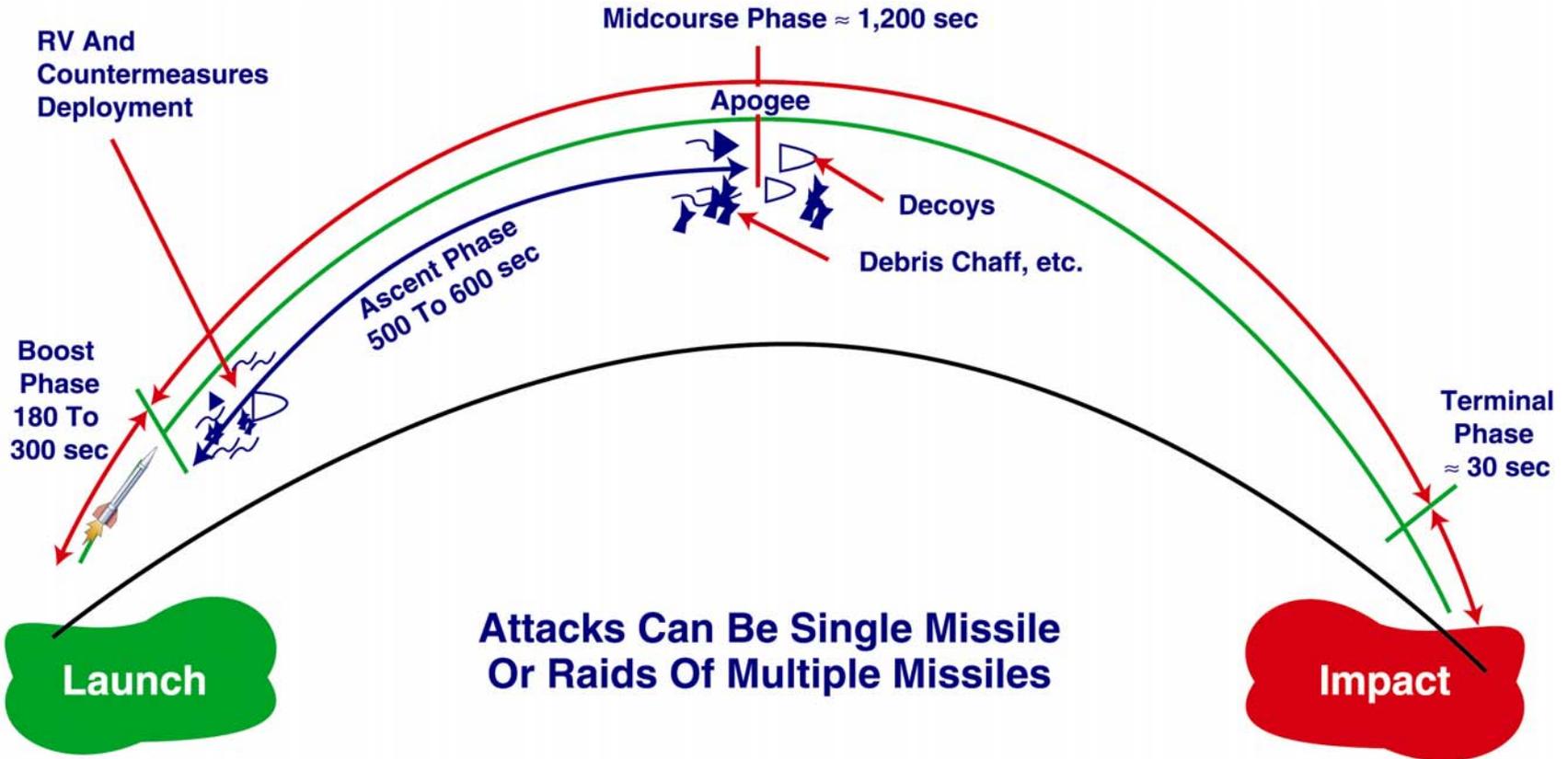
"Understand Technical Baseline of Program"
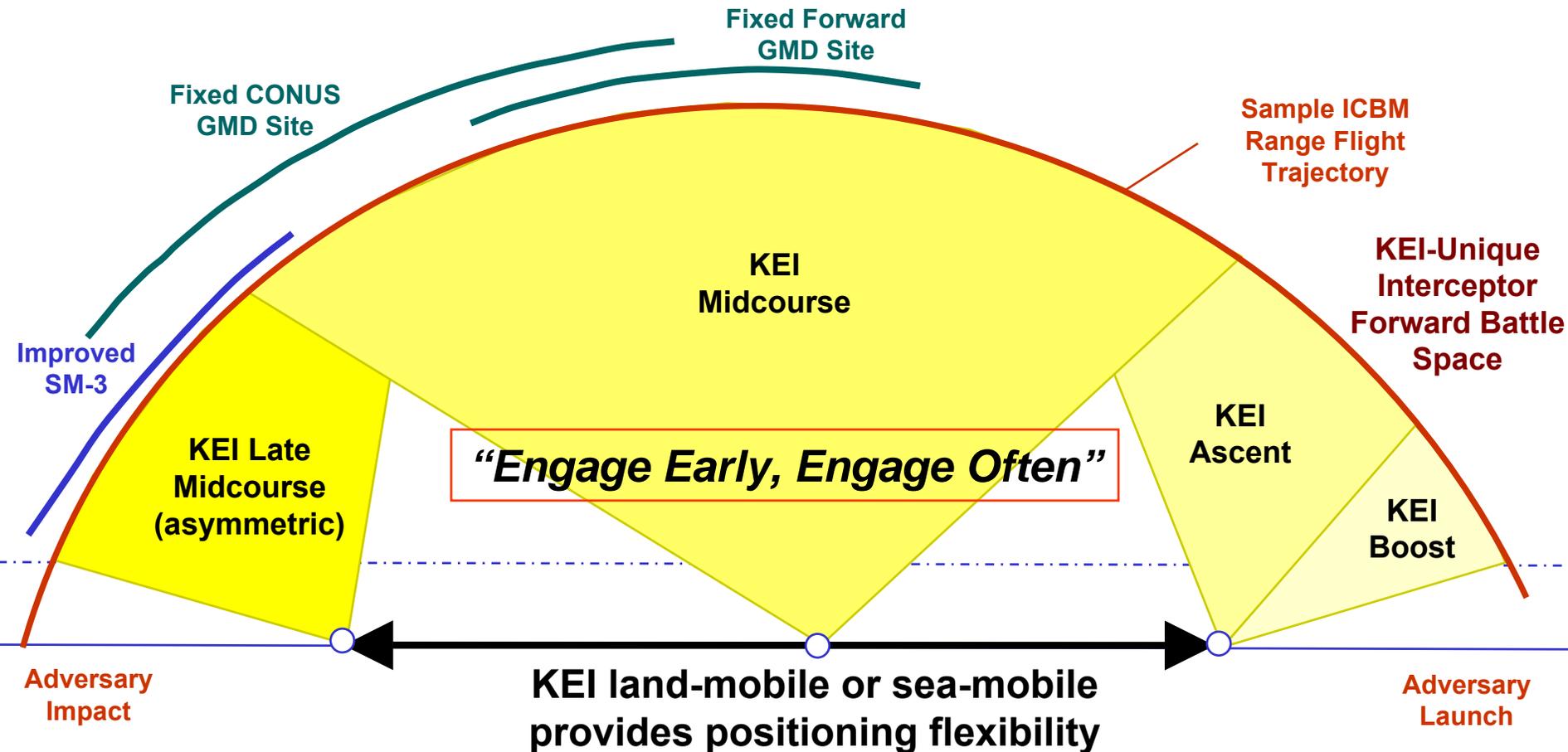
Engagement Phases

KE Interceptors

RV And Countermeasures Deployment

Midcourse Phase ≈ 1,200 sec

Apogee

Ascent Phase 500 To 600 sec

Boost Phase 180 To 300 sec

Decoys

Debris Chaff, etc.

Terminal Phase ≈ 30 sec

Launch

Attacks Can Be Single Missile Or Raids Of Multiple Missiles

Impact

BMDS Interceptors
Mobility & Full Battle Space Engagement

KE Interceptors

Fixed Forward GMD Site

Fixed CONUS GMD Site

Sample ICBM Range Flight Trajectory

KEI-Unique Interceptor Forward Battle Space

KEI Midcourse

Improved SM-3

KEI Late Midcourse (asymmetric)

"Engage Early, Engage Often"

KEI Ascent

KEI Boost

Adversary Impact

KEI land-mobile or sea-mobile provides positioning flexibility

Adversary Launch

Mobile KEI adds forward layers to defeat countermeasures, fills asymmetric coverage gaps and provides robust depth-of-fire

KEI Element Description - Land Block 12

KE Interceptors

Common Land/Sea Interceptor

- 40" diameter, 466" Length, 23,000 lb
- High V_{bo}, High Acceleration Booster
- Multi- Use 2 Color Seeker
- High Delta V, High Acceleration KV

Mobile C2BMC

- ONIR Direct Downlink
- Flexible BMDS Sensor Interfaces
- Integrate to BMDS through CNIP
- C-Band, Shout Back Data Link
- Nuclear Hardened
- C-17 Transportable

Mobile Launcher

- 2 Interceptors Per Launcher
- Oshkosh M1070 HET Tractor
- 4 axis Trailer
- C-17 Transportable
- CONUS and NATO Road Mobility

KEI Design Features

KE Interceptors

Sea-Mobile SM-3

Land-Based GBI

Land/Sea Mobile KEI

Treaty-unconstrained integration of mature technology

Exploits BMDS sensor capabilities

Full battle space engagement

SM-3
Diameter: .53m
Length: 6.6m
Mass: 1,504kg

GBI
Diameter: 1.27m
Length: 16.5m
Mass: 22,300kg

KEI
Diameter: 1.02 m
Length: 12m
Mass: 10,300kg

Kinetic Energy Interceptors (U)
Land-Based Concept of Operations

KE Interceptors

Play Video

SCEA April 2005

Schedule

KE Interceptors

	CY03	CY04	CY05	CY06	CY07	CY08	CY09	CY10	CY11	CY12	CY13
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13

◆ **Launch**

Near Field Experiments

TERRESTRIAL

Concept Design

SDR
Booster
Flight DR-0
DR-1
DR-2

Verification Demos

CTV
ECF
IT-1

◆

Ongoing

Future

Block 12/14 Land Mobile KEI

Block 12/14 Sea Mobile KEI

SPACE

Block 12/14 Space Test Bed

FY08 Decision Point ◆
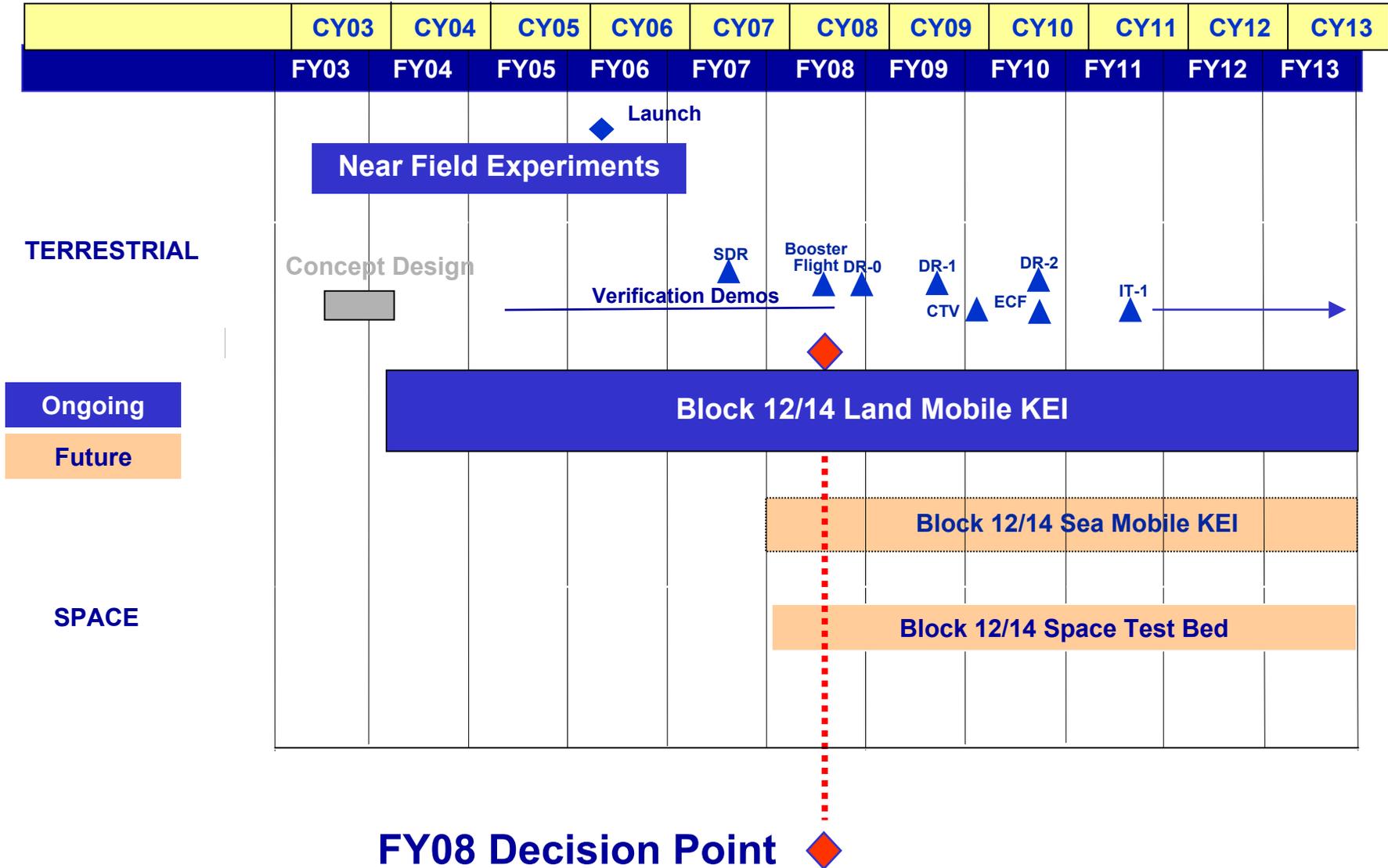
Source Selection Process

KE Interceptors

- ## Employ Acquisition Reform Initiatives
  - Capability-Based Evolutionary Acquisition
  - Open Source Selection
  - Rolling Down-Select
  - Oral Proposals
  - Teaming Approach – Govt. Helper Teams

- ## *Normalize Schedule for Risk*
  - *Initial Cost/IMP/IMS Proposal is "Work-To"*
  - *Final Cost/IMP/IMS Proposal is "Normalized"*

- ## Affordability evaluation leverages all of the above

Program Expectations
("Normalized" vs. "Work-to" Schedules)

KE Interceptors

- **"Normalized" Schedule**
  - **Used for development and test down select**
  - **Sets KEI's program expectations**
  - **Forms the basis for developing the contract baseline**

- **"Work-to" Schedule**
  - **Sets KEI's program goal**
  - **Forms the basis for detailed work planning**
  - **Award Fee tied to "Work-to" schedule test flights**

KE Interceptors

Schedule Normalization

"How to Normalize a Schedule for Risk"

Why Schedule Normalization?

KE Interceptors

EMD Overrun (Months)
(34 weapon programs 1980 to 1996)
(Ref: DSMC TR 1-99)

< 5% were on time (about the same fraction were > 8 years late)
~ 20% were less than 8 months late
~ 50% were less than 24 months late
~ 80% were less than 58 months late
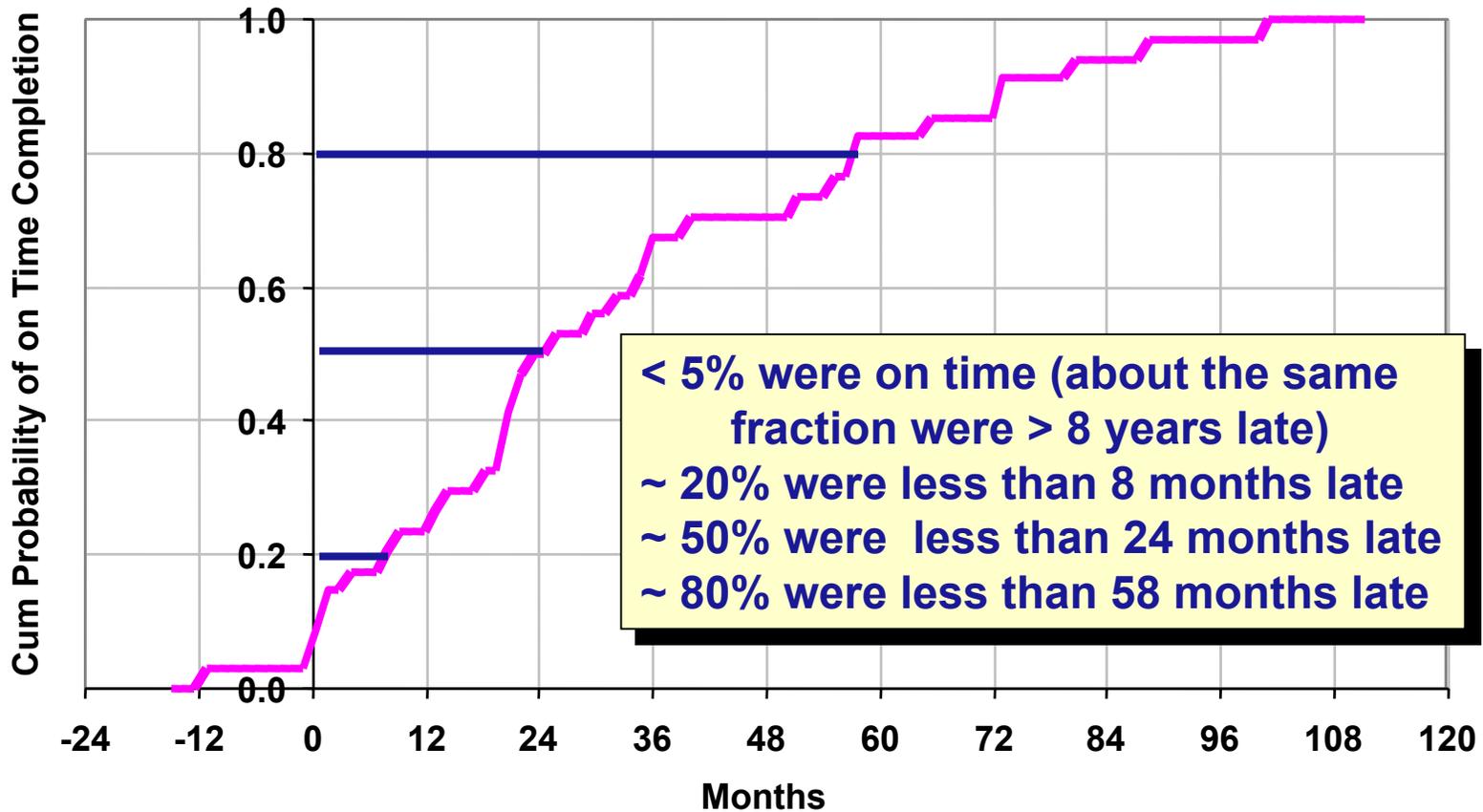
Schedule Normalization
(Two Methods)

KE Interceptors

- **Quantitative Assessment**
  - **Step 1 Build a generic intermediate level schedule (initial source selection tool)**
  - **Step 2 Obtain contractor's detailed schedules and ensure horizontal & vertical links**
  - **Step 3 Emulate contractors schedule at intermediate level by modifying generic schedule**
  - **Step 4 Determine Risk and apply probability distribution using @Risk**
- **Qualitative Assessment**
  - **Delphi technique using "Gray Beards"**

Two Independent Methods to Crosscheck Each Other

Build a Generic Schedule
(Step 1)

KE Interceptors

Step 1

- **Define the tasks (activities) that must occur**
  - Processes (design, fabrication, integration)
  - Events (contract awards, test dates)
  - Reviews (PDR, CDR) **– Now DR-0, DR-1, DR-2**

- **Establish the interrelationships and dependencies between tasks**
  - Predecessors and successors
  - Segment activities to support reviews and oversight events

- **Construct the integrated schedule for all tasks and events**
  - Consecution of activities based on dependencies and expected durations
  - Temporal input based on historical precedent, maturity, heuristics, and domain expertise
  - Expected value / best estimate of program timeline

Requirements – Design – Build - Test

Obtain Contractor's Schedules & Emulate
(Steps 2 & 3)

KE Interceptors

Step 2

- **Obtain Contractor's Detailed Schedules**
  - Ensure horizontal & vertical links
  - Verify program content (IMP/IMS Compliance)

Step 3

- **Emulate contractors schedule by modifying generic schedule**
  - Collapse 13,000+ element schedule into tailored medium level (650 line emulation)
  - Highlights key tasks, events, and risks
  - Fully linked functional tool to evaluate schedule perturbations

Fully Linked Schedule Tool

Determine Risk & Apply Probability Dist.
(Step 4)

KE Interceptors

Step 4

- **Qualitatively**
  - **Assess the technical risk**
    - **Technology maturity, contractor experience, system complexity**
    - **Determine relative probability and consequence of failure**

- **Quantitatively**
  - **Estimate schedule risk distributions**
    - **Duration probability distributions (min, max, & expected values)**
    - **Probabilities of test event outcomes (success, failure, or no test)**
    - **Conditional development paths**
    - **Based on technical risk, history, maturity, heuristics, and domain expertise**

- **Employ intermediate level schedule model**
  - **Run Monte Carlo simulations using @Risk**
    - **Probability of completion vs. time or by date (S curves)**
    - **Identify high probability risk drivers (tornado charts)**

Qualitatively Assign Risks
(Example List)

- **XX Critical Risks**
  - **Algorithms**
  - **Software**
  - **Element Integration**
  - **Etc.**

- **XX Significant Risks**
  - **Component Fabrication/Test**
  - **HW/SW Integration**
  - **Sea Based flight tests**
  - **Etc.**

- **XX Nominal Risks**
- **XX Minimal Risks**

Assign Probability Risk Distributions
(CAIG Risk Factors – Triangular Distributions)

KE Interceptors

Risk	Earliest	Latest
	(% Relative to Most Likely)	
Minimal (CAIG Low)	-15%	+25%
Nominal (CAIG Medium)	-20%	+50%
Significant (CAIG Interpolated)	-25%	+75%
Critical (CAIG High)	-35%	+135%

100 Day Most Likely Example

Durations Rounded to +/- 5 Days

.35 | .65
85 100   125

Probability of Being Early or Late

.30 | .70
80 100   150

.25 | .75
75 100   180

.20 | .80
65   100   235
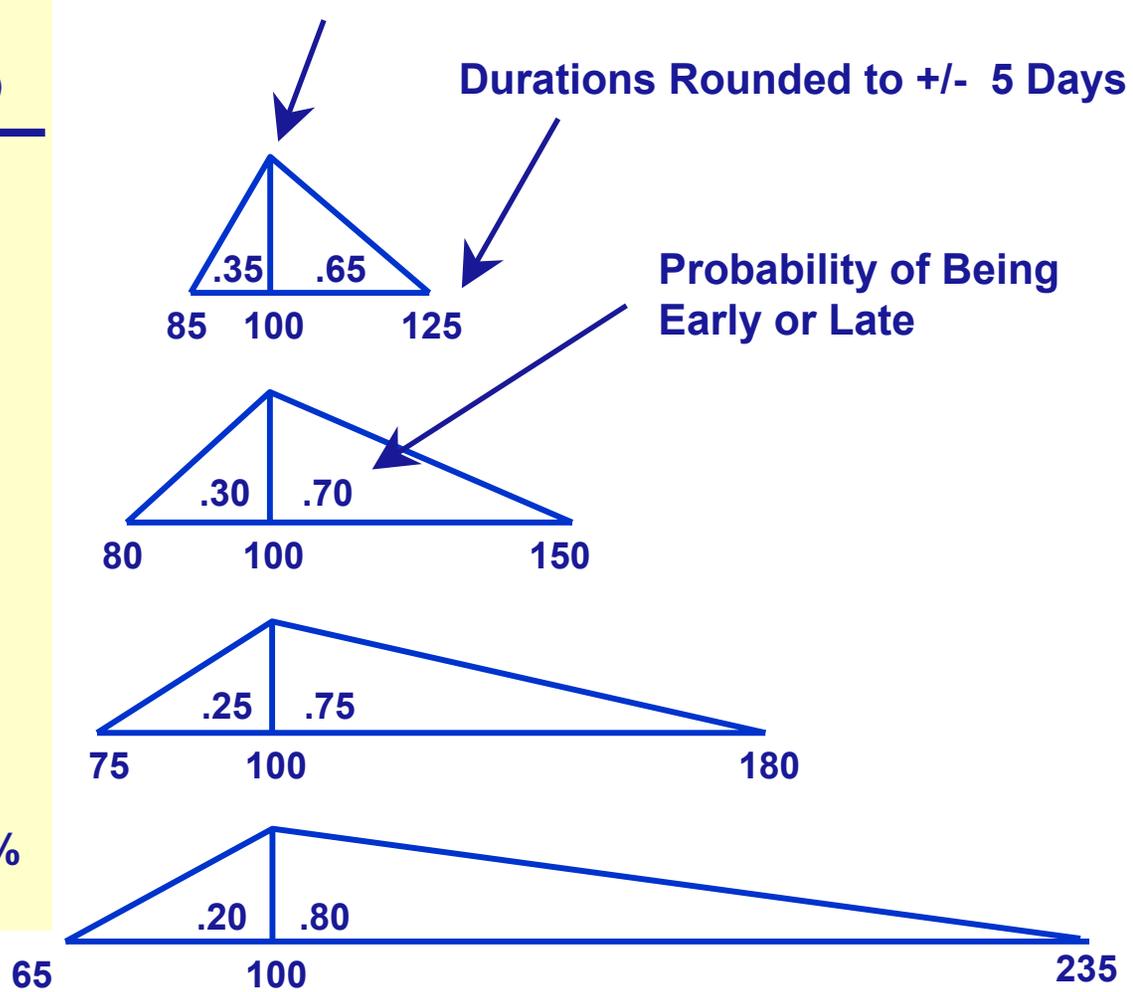
Model Probability of Test Success
(Notional Approach)

KE Interceptors

Conduct Test → Probability

Pass → Test Analysis → Next Event

~ 3 Months (Minimal Risk)

Fail

Contractor Tests

Test Analysis Resolve Anomalies

~ 5+ Months (Critical Risk)

IT / IFT → Repeat Test → Probability

Pass → Test Analysis → Next Event

Fail

~ 9+ Months (Critical Risk)

Repeat? Redesign?
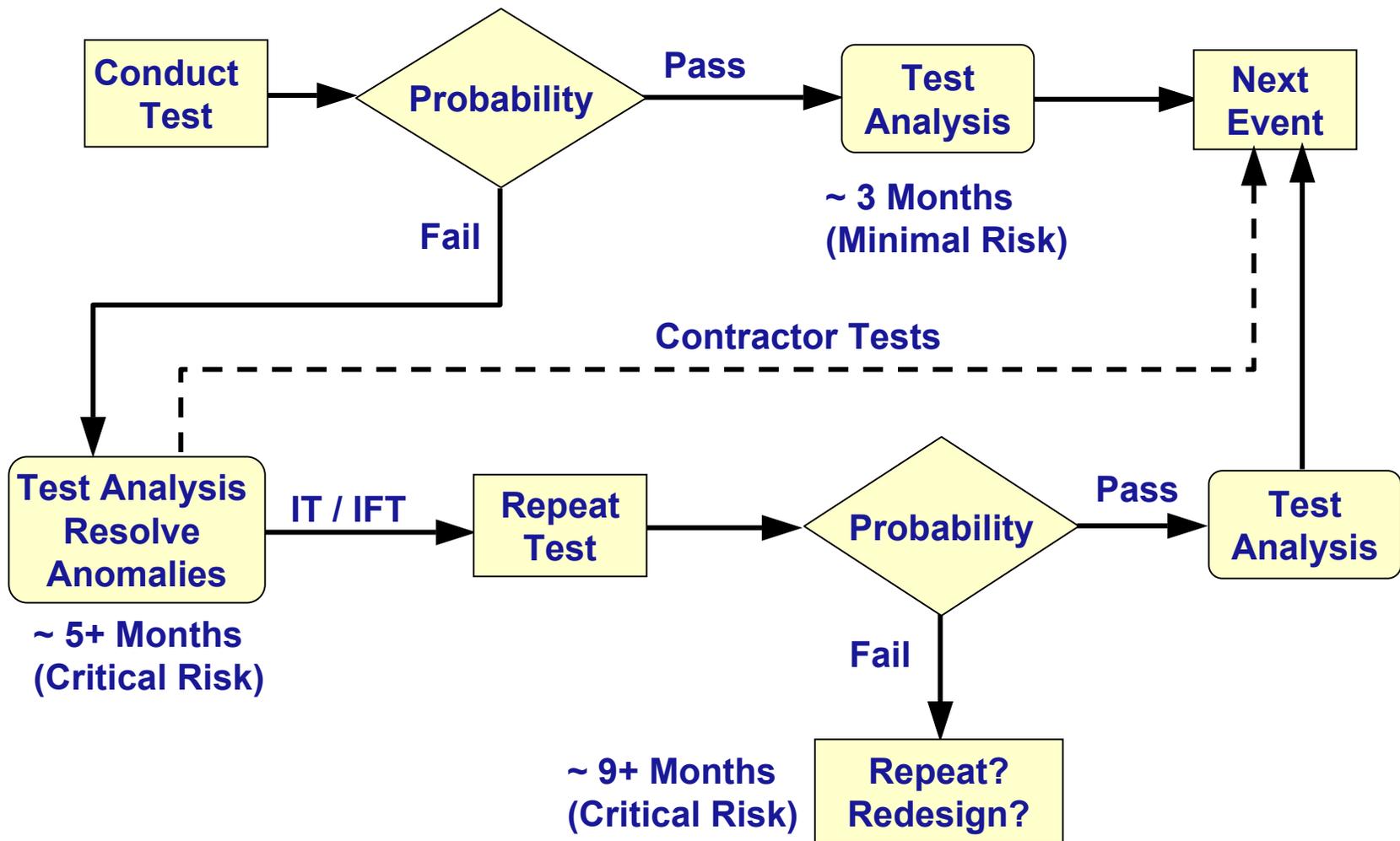
Determine Test Success Probabilities
(Notional Example)

KE Interceptors

	IT-1	IT-2	IT-3	IT-4	IT-5
Sensors	.975	.975	.975	.975	.975
C2BMC	.975	.975	.975	.975	.975
Canister & Launcher	.975	.975	.975	.975	.975
Interceptor (Total)	.830	.865	.865	.865	.950
Boost Vehicle	.950	.950	.950	.950	.975
KV	.875	.910	.910	.910	.975
Range & Targets	.950	.950	.950	.950	.950
Total Probability	.700	.760	.760	.760	.850

Probability of Success Improves as System Matures

Employ Intermediate Level Model
(Probability of Completion vs. Time) – Notional Example
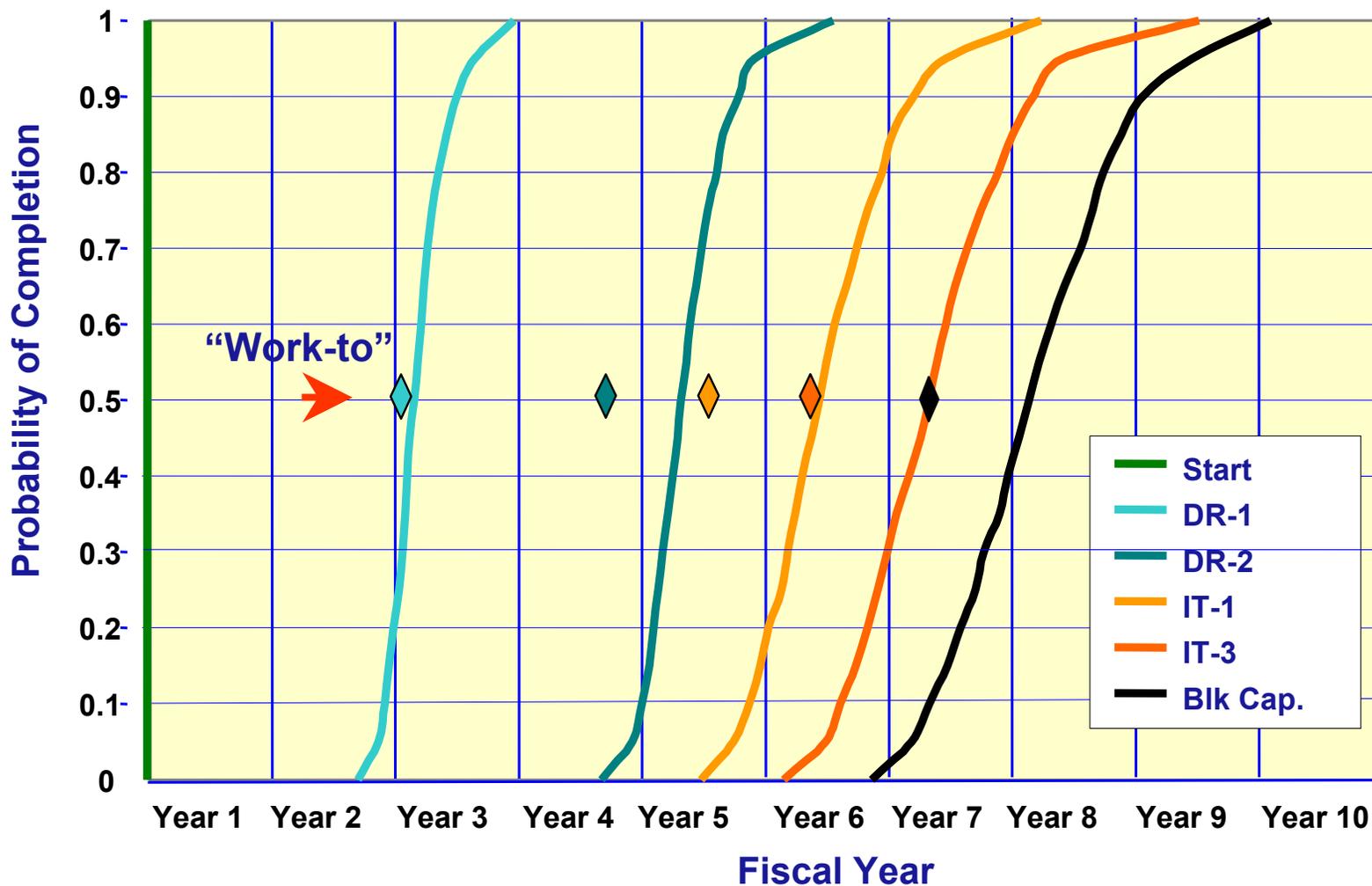
KE Interceptors

Schedule Results
(Quantitative Tool – 80% Confidence) – Notional Example

KE Interceptors

Legend:
- To DR-1
- To DR-2
- To IT-1
- To IT-3
- To IT-5
- To Blk Cap

Categories: "Work to", "Norm" 50%, "Norm" 80%

X-axis: Year 1, Year 2, Year 3, Year 4, Year 5, Year 6, Year 7, Year 8, Year 9, Year 10 — **Date**
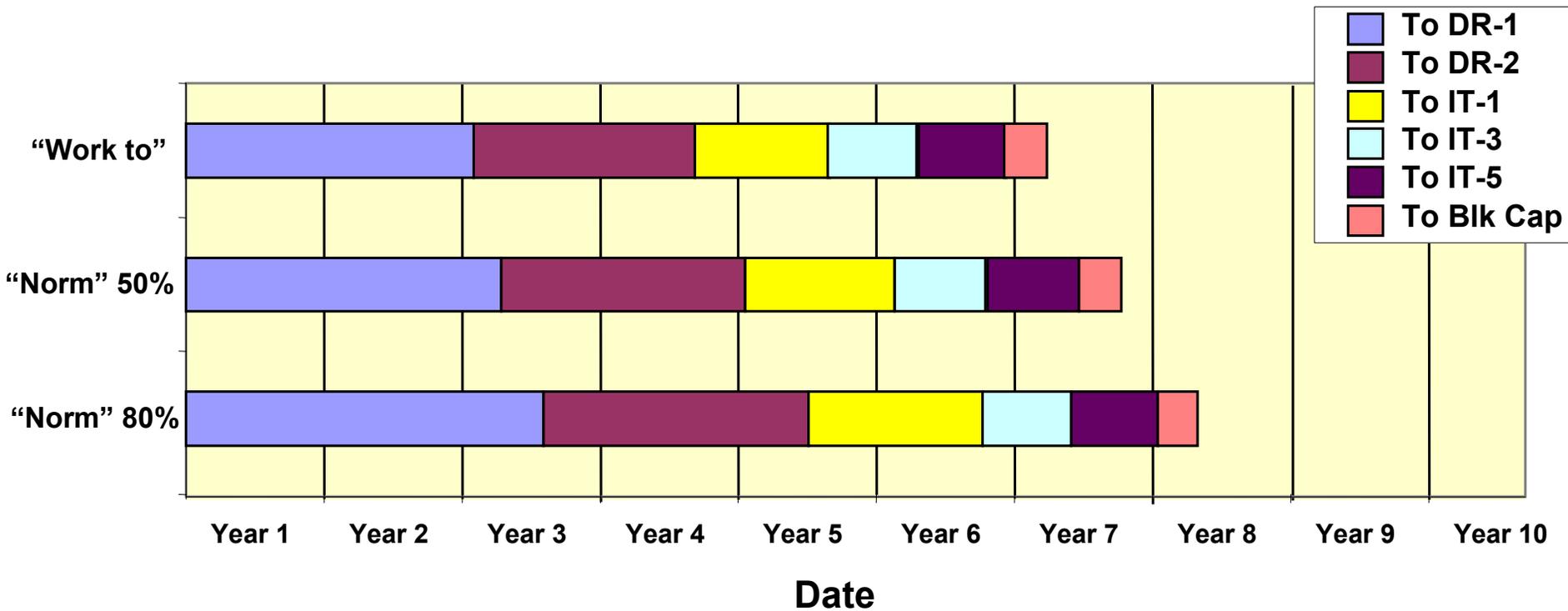
Notional Example

Risk Analysis Adds ~ 13 months to Schedule at 80% Confidence

Schedule Results – Notional Example
(Delphi Method)

KE Interceptors

	Milestone/Event	"Work-to"	"Normalized"
A	D&T Start	0	
B	Element SRR	12	
C	DR-1	28	
D	KEI Flt Test Bed Ready	40	
E	DR-2 (HW/SW)	44	51
F	Element Char Complete	48	
G	IT-1	51	
H	IT-3	64	
I	IT-5	71	
J	KEI BMDS Capability Validated	75	89

Expert consensus that risk items could cause program delays

⬇

Schedule slips 7 months due to redesign

⬇

Schedule slips additional 7 Months due to Flight Test failure

Notional Example

Delphi Analysis Adds 14 Months to Schedule

KE Interceptors

Schedule-Dependent Cost Estimate

"How to Estimate the Costs of the Work-To and Normalized Schedules"

COST ESTIMATE METHODOLOGY

KE Interceptors

KEI PROGRAM

GOVERNMENT

NON-RECURRING

RECURRING

HARDWARE

SOFTWARE

SE/PM; DESIGN; TEST

GROUND TEST UNITS

INTERCEPTOR

LAUNCHER

C2BMC

Analogy (time)

~ 65-70% of total costs

SLOC & Prod. Factors

Parametris, Analogies, Actuals
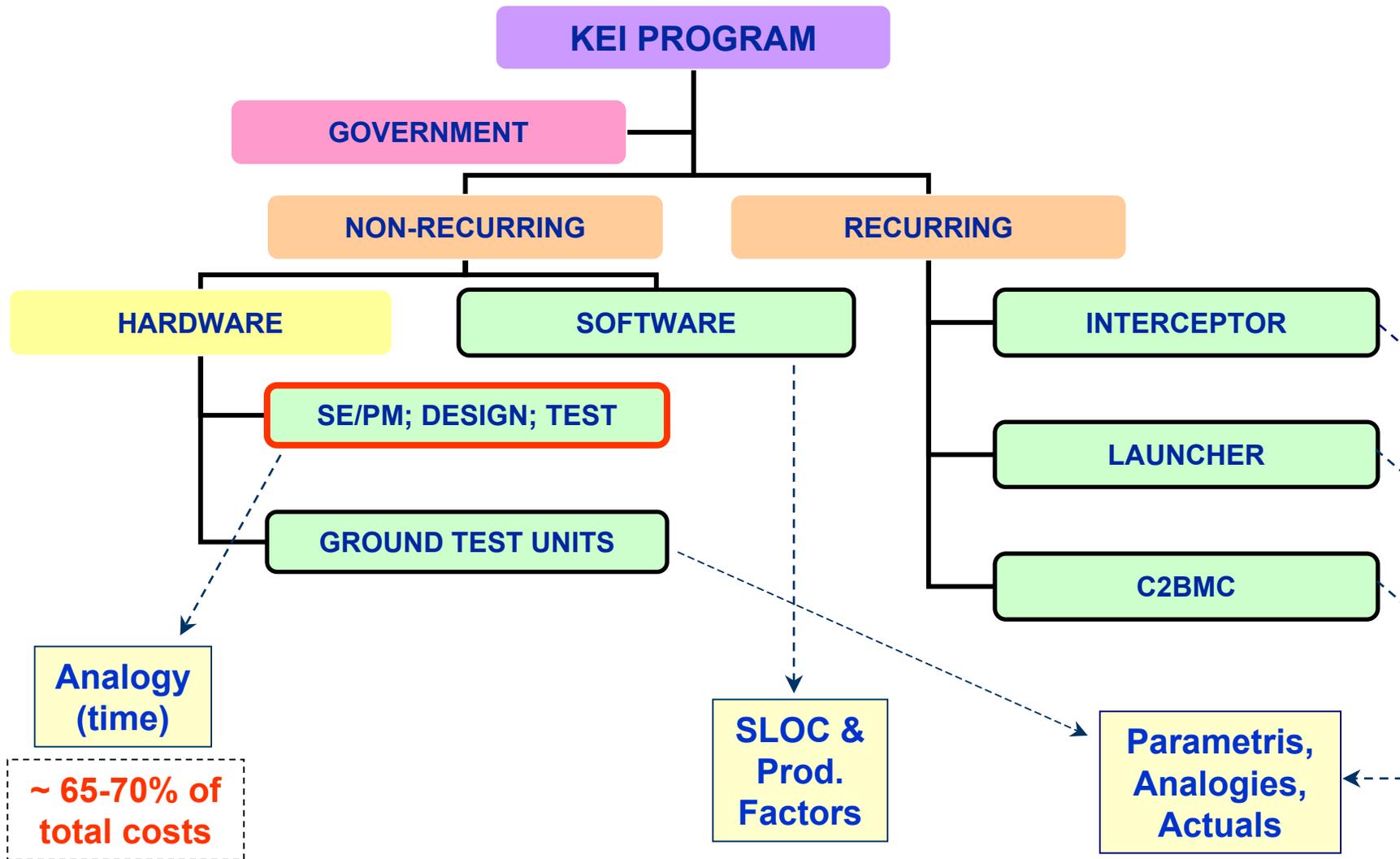
Estimate Approach

KE Interceptors

Start: **Program X raw PDRR & EMD accounting data**

Step 1:   **Raw data adjustments (to get to NR HW data)**

Step 2:   **Determine the burn rates for each key event**

Step 3:   **Adjust burn rates to represent the KEI program**

Step 4:   **Apply the KEI schedule to the new burn rates**

Program X *PDRR* Monthly Accounting Data Notional - (Step 1)

KE Interceptors

Interceptor
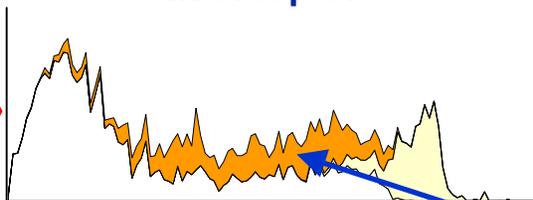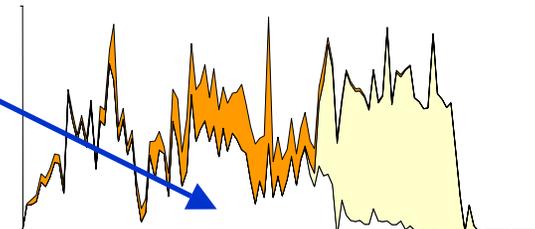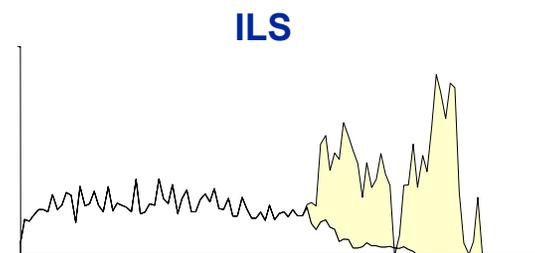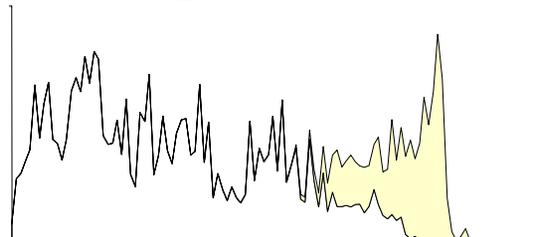
Example

Launcher

SE

PM

Remove Software

Remove Anomalies
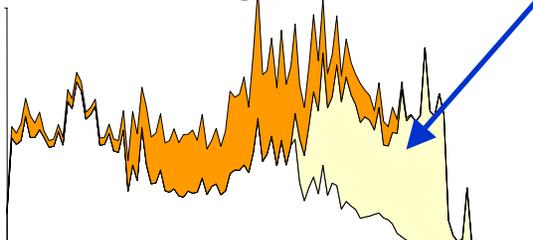
Remove Content
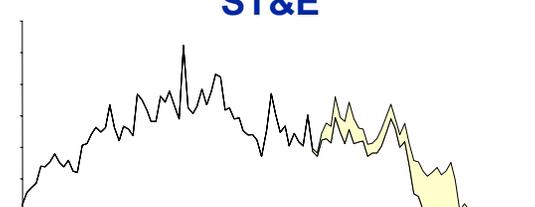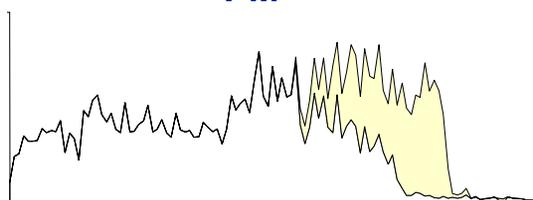
Remove Sensor
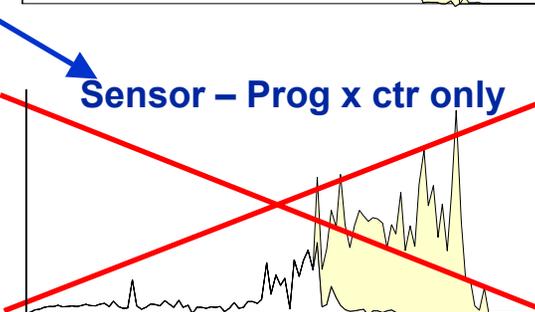
Separate Recurring from Non-Recurring

C2BMC

ILS

ST&E

Sensor – Prog x ctr only

Program X *PDRR* Burn Rates
(Step 2 - Interceptor Example)

KE Interceptors

Interceptor IPT

Award to IDR

IDR to FDR

FDR to 1st Flight

Flight Test Phase

——	**PDRR Missile Total**
——	**Estimated Burn Rate**
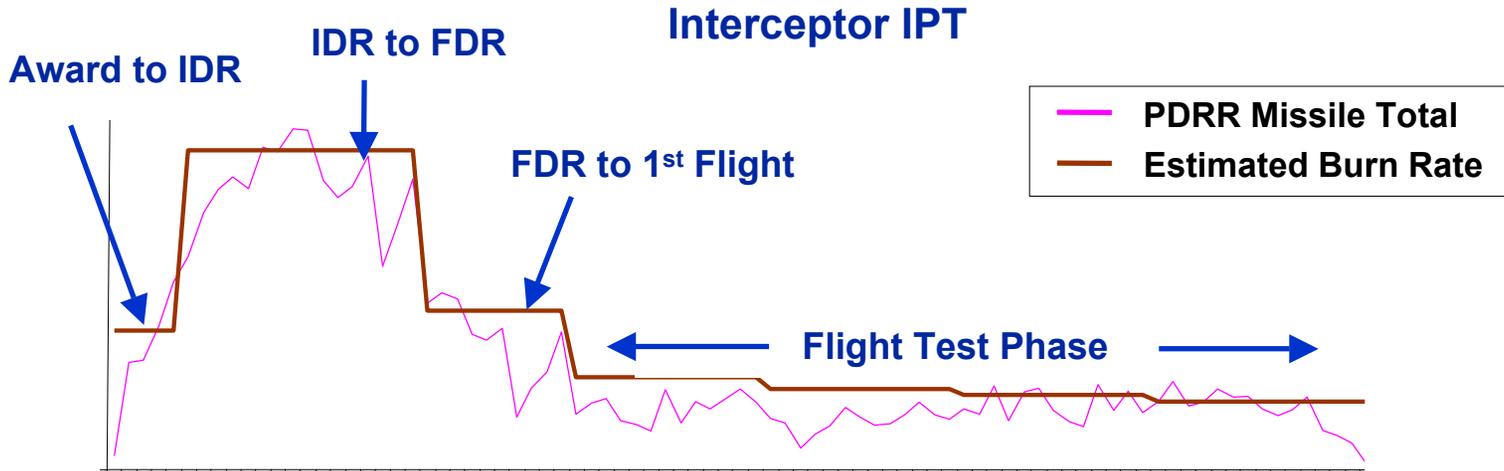
Program X Schedule Duration

Key Events	Months
Award to IDR	5
IDR to FDR	16
FDR to 1st Flight	10
1st Flight to Last Test + 4 mos	57
Total PDRR Months	**88**

(accounting logs lasted ~116 months)

Program X Burn Rate

Key Events	FY04$M
Award to IDR (DR1 minus)	VV$M
IDR to FDR (DR2 minus)	XX$M
FDR to 1st Flight	YY$M
1st Flight to Last Test + 4 mos	ZZ$M

(actually broke out more than 4 windows
Example to illustrate approach/method)

KEI Adjustments to Program X Data
(Step 3 - Interceptor Example)

KE Interceptors

Interceptor *PDRR*

Interceptor *EMD*

Interceptor *KEI* (Prog. X Schedule)
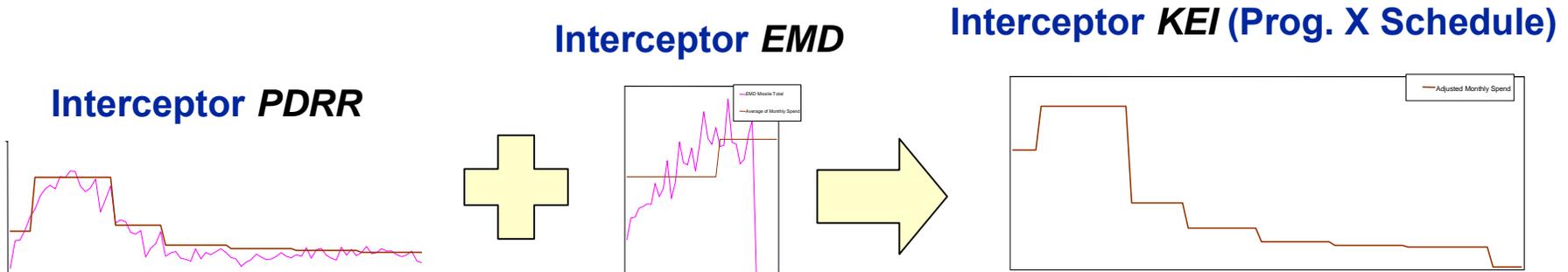
- **Combine PDRR & EMD Program X Data**
  - **Use adjusted EMD for first two periods**
  - **Scale PDRR based on ratio of PDRR to EMD actuals for last 2 periods**
    - **Account for –ilities, additional systems engineering**
    - **Interceptor example is >20%**

- **KEI Scope Adjustments to Program X Data**

Develop a KEI Specific Burn Rate

Raise the "Y axis" or "Size of the Army"

Apply KEI Schedule – Notional Example
(Step 4 - Interceptor Example)

KE Interceptors

Program X schedule with KEI Burn Rates
(Interceptor Example)
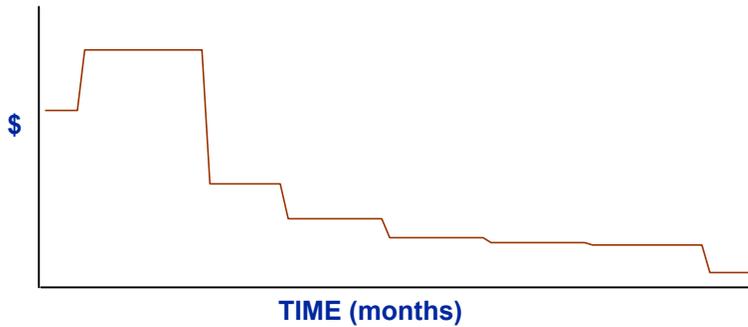
KEI schedule with KEI Burn Rates
(Interceptor Example)
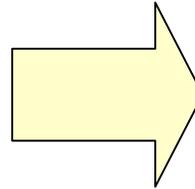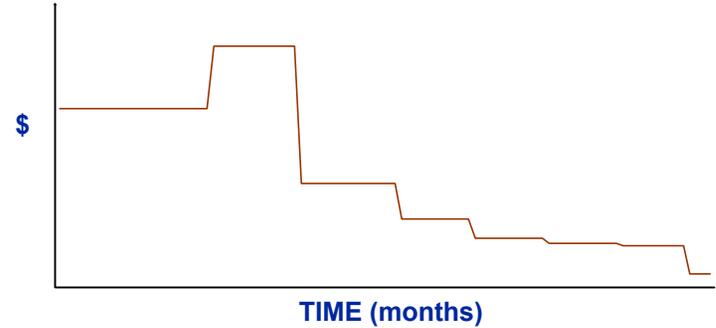
Program X PDRR Schedule

Key Events	Months
Award to IDR	5
IDR to FDR	16
FDR to 1st Flight	10
1st Flight to Last Test + 4 mos	57
Total PDRR Months	**88**

(accounting logs lasted ~116 months)

KEI Normalized D&T Schedule

Key Events	Months
Award to IDR (DR-1 less 5 mos.)	23
IDR to FDR (DR-2 less 15 mos.)	13
FDR to 1st Flight	15
1st Flight to Last Test + 4 mos	38
Total D&T Months	**89**

(actually broke out more than 4 windows)

Develop a KEI Specific Estimate ----- "Adjust the X axis"

Sum D&T Burn-Rate Estimated Efforts Example
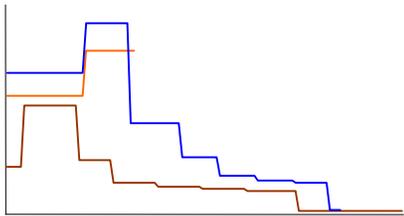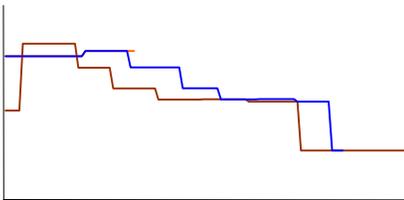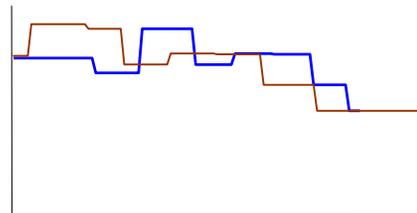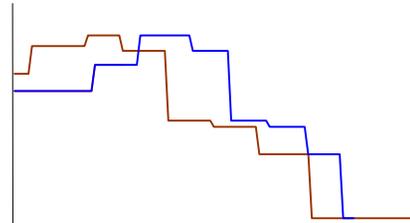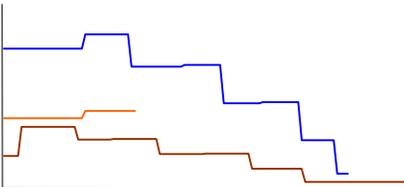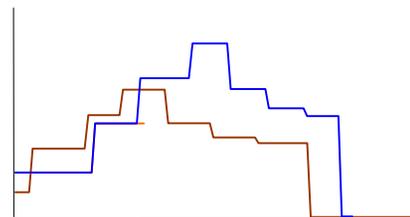
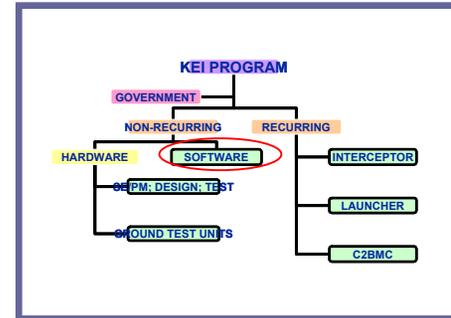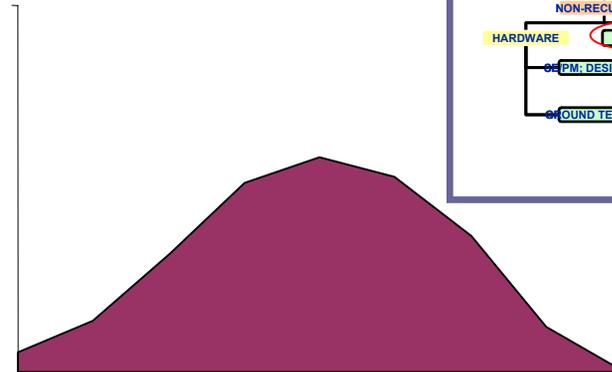*KE Interceptors*
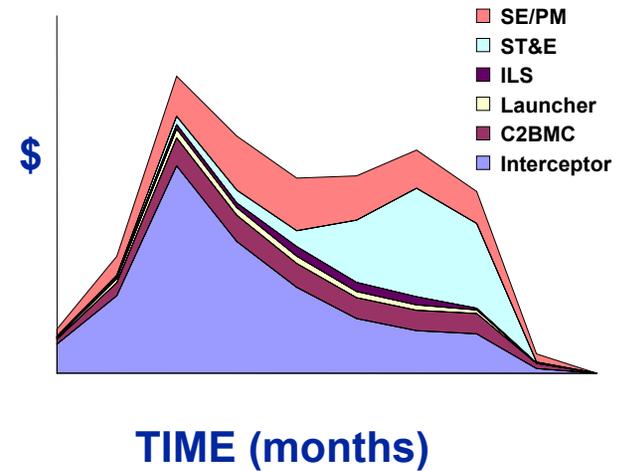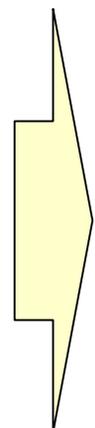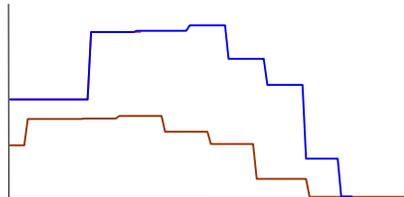
Combine Non-recurring Estimates

# Software & NR Tooling Distribution Example

KE Interceptors

- **Software Estimate**
  - **Northrop SLOC Estimates w/22% Growth Factor on SLOC Counts**
  - **Contractor Historical Productivity**
  - **Estimate Crosschecked with COCOMO Parametric Model**
  - **Point estimate spread using Program X software burn profile**

- **Non-Recurring tooling Estimate**
  - **Interceptor tooling**
    - **Analogy to Program Y Tooling**
    - **Spread 50/50 over two years**
  - **C2BMC & Launcher tooling**
    - **% of HW Recurring**
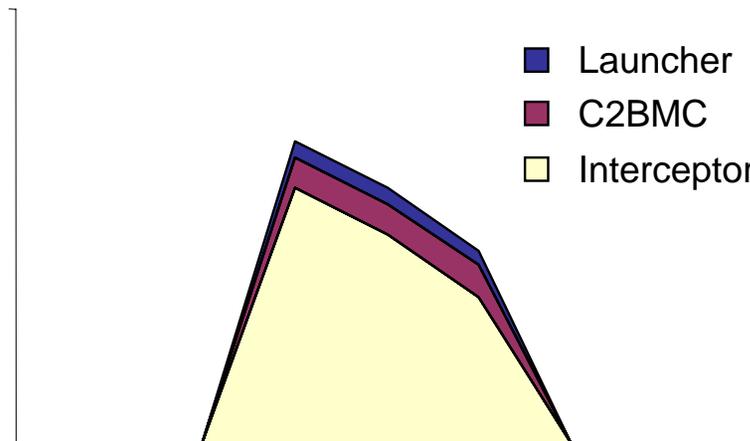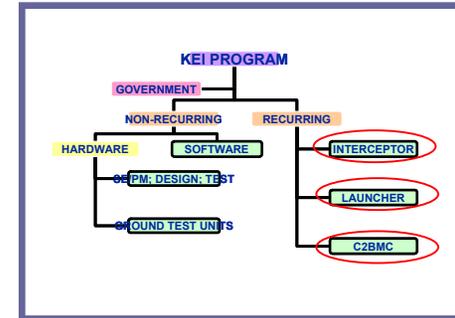
Software

Non-Recurring Tooling
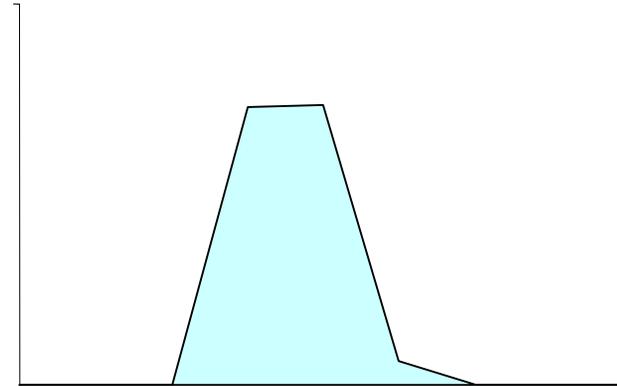
Recurring Hardware Example

KE Interceptors

- **Interceptor**
  - **Estimate based on historical parametrics**
    - **Weight, Volume, Thrust, ΔV, Aperture Size, etc.**
    - **Production learning adjusted for TSRM priors**
- **C2BMC & Launcher**
- **Estimate based on analogy with Program X**
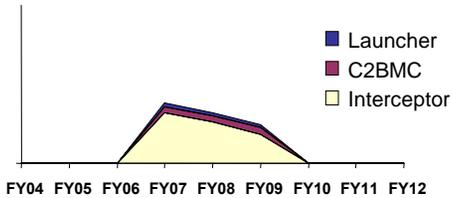 - **Scope adjustments made for size and complexity differences**

- Launcher
- C2BMC
- Interceptor

Sum All D&T Efforts
Notional Example

KE Interceptors

Recurring Hardware

- Launcher
- C2BMC
- Interceptor

Software

Non-Rec Tooling

Combine Non-recurring and Recurring Estimates

- Recurring Hardware
- Software
- Non-Rec Tooling
- Non-Rec
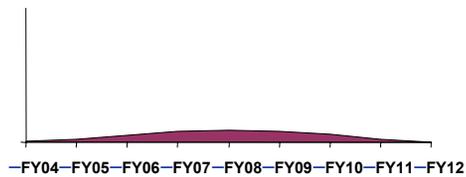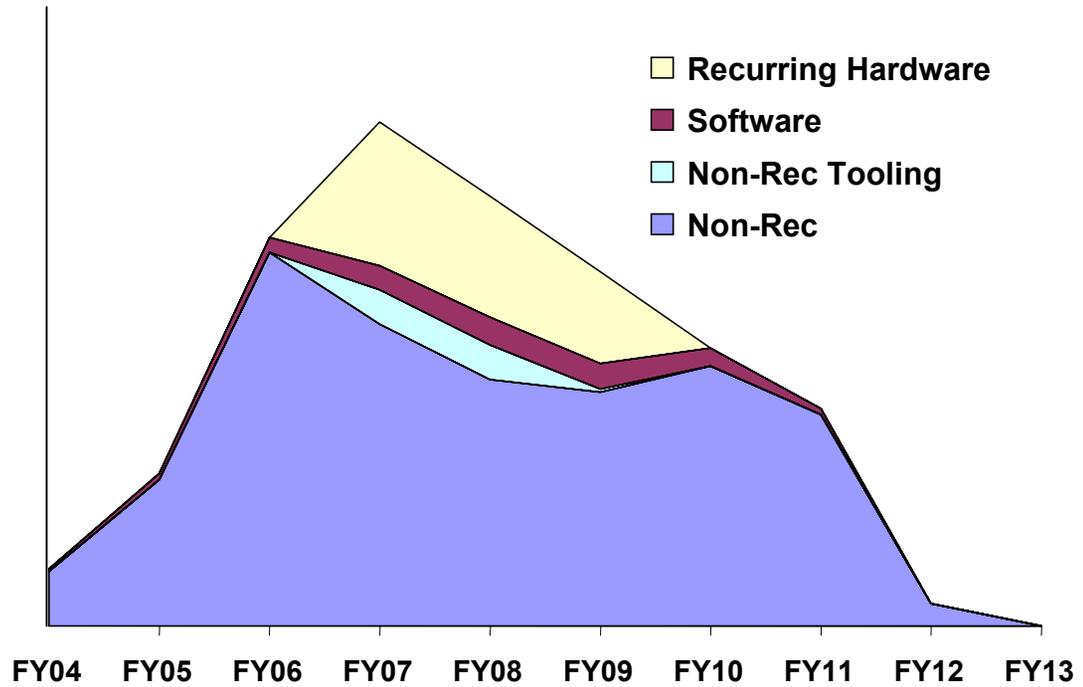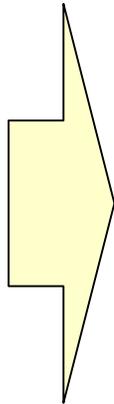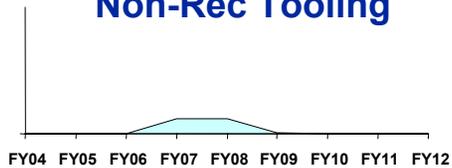
KEI Estimate Summary
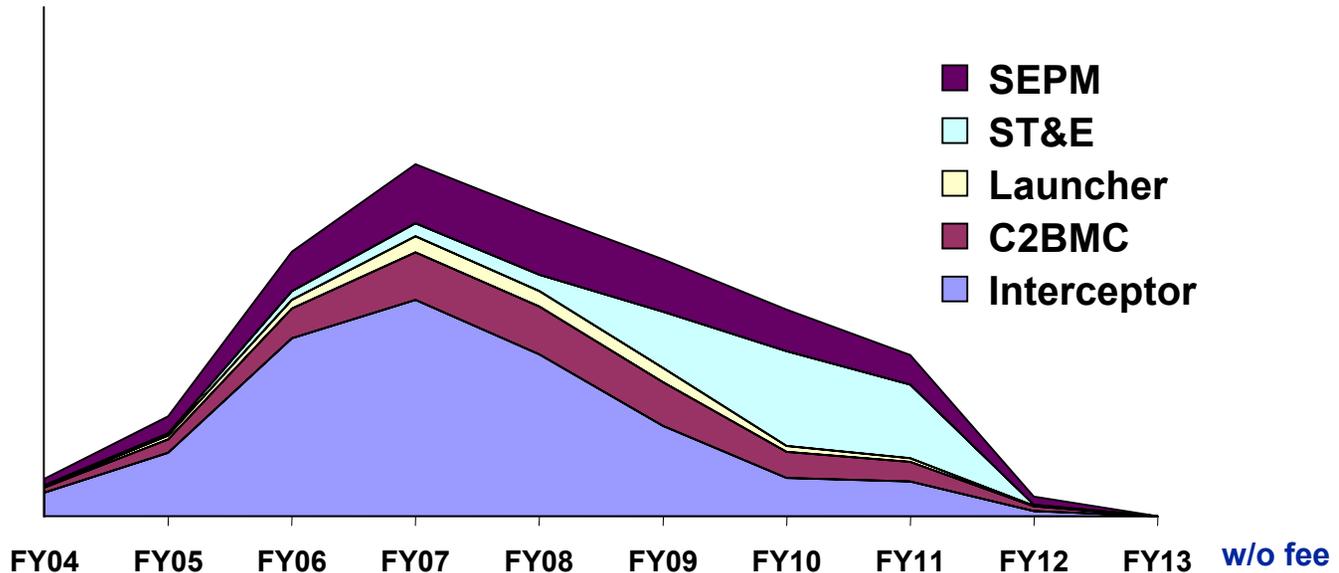## Notional Example

KE Interceptors

- **Burn Rate Summary**
  - **Internal accounting**
  - **Less Radar**
  - **Scoped from Program X to KEI**
  - **PDRR to EMD burn rate**
  - **Applied KEI schedule**

- **Added in:**
  - **Recurring hardware**
  - **Software**
  - **Non-Recurring tooling**
  - **Fees**

Legend:
- **SEPM**
- **ST&E**
- **Launcher**
- **C2BMC**
- **Interceptor**

FY04 FY05 FY06 FY07 FY08 FY09 FY10 FY11 FY12 FY13 **w/o fee**

KE Interceptors

"Work-to" & "Normalized" Results

"What to do with it"

"Work-To" vs. "Normalized" Schedules
Notional Example

KE Interceptors

Mapped Normalized Land contract schedule to the key events

Key Events	Work-To Months	Adj.	Normalized Months
Award to DR-1 (IDR+)	28		28
DR-1 to DR-2 (FDR+)	16	7	23
DR-2 to 1st Flight	7		7
1st Flight to Last Test + 4 mos	24	7	41
Total D&T Months	75	14	89

– Notional Example only

– Used more "windows" than actually indicated as well as different durations
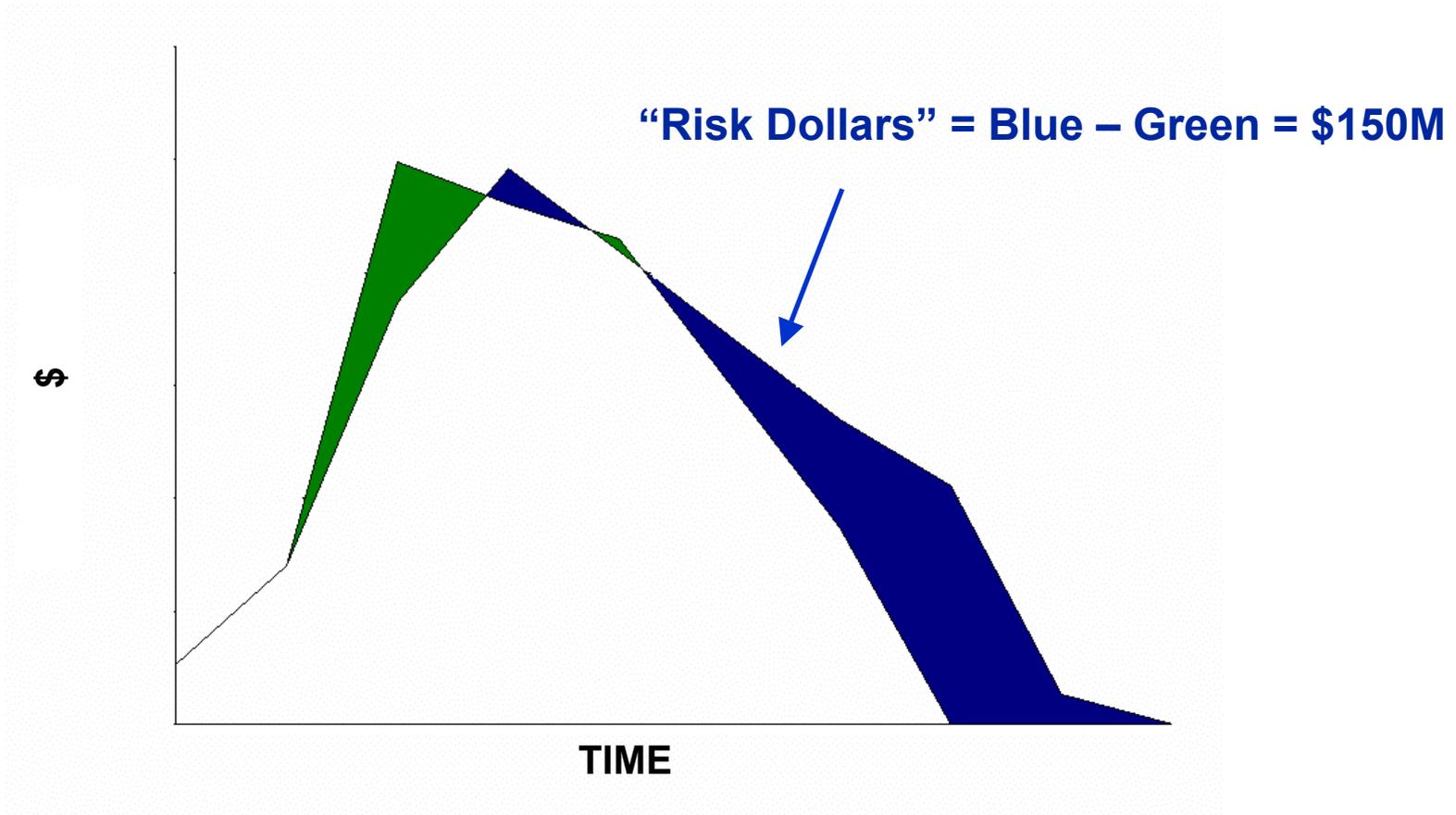
"Work-To" vs. "Normalized" Estimates Notional Example

KE Interceptors

"Risk Dollars" = Blue – Green = $150M

TIME

$ (vertical axis)

"Work-To" Estimate = White + Green ($1,000M example)

"Normalized" Estimate = White + Blue ($1,150M for example)

Summary

- **Schedule normalization is a good way to address program risk**
  - **Technical risk factors empirically drive longer schedules**
  - **Longer schedules drive the cost risk estimate**
  - **The risk estimate can then be added to the budget, put on contract, and the contractor is incentivized to meet a work-to schedule**

- **Schedule-based estimating provides a tool for converting technical risk into a cost estimate for that risk**
  - **Allows the impacts of schedule delays (for any reason) to be modeled while the program is executing**
  - **Easy to relate the cost impact of technical/schedule problems to senior management**

KE Interceptors