A Systems Engineering Expert System Performance Capability, Cost and Schedule for Pre-Milestone A Decisions

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This presentation is based upon the book-

Cost Engineering System *for Aerospace and Military Programs* (CES)

“Systems Engineering-Performance/Cost/Schedule Tool” (SE-PCST)

In this document the process and simulations shall be referred to as **SE-PCST**

The Systems Engineering Challenge

There are no Systems Engineering (SE) processes/tools that provide credible **Performance Capability**, **Cost** and **Schedule** information for Defense Acquisition at the Pre-Milestone A phase of a program.

The Systems Engineering Challenge

A preconceived perception exists that it is nearly impossible to formulate links between **Performance Capability**, **Cost**, and **Schedule** at Pre-Milestone A.

At Pre-Milestone A 70-75% of the Life-Cycle Cost (LCC) decisions have been made.

At Pre-Milestone B 85% of the Life-Cycle Cost (LCC) decisions have been made

SOURCE –

Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition (2008)

Existing cost estimating methodologies do not provide realistic, credible, consistent, and timely cost estimates.

Current cost estimating methodologies are not dependent upon technically relevant and available information to support trade-studies at Pre-Milestone A and only on occasion at Pre-Milestone B.

The Solution

Systems Engineering – Performance/Cost/Schedule Tool (SE-PCST) is a revolutionary architecture that is based upon *Algorithms*, *Boundaries* and *Rules*.

To be used from Pre-Milestone A through Initial Operational Capability (IOC) for major DoD programs.

SE-PCST is for a “Point Design” where considerable engineering effort has been expended to establish the configuration by analysis, engineering computer simulations, trade-studies and other available engineering tools.

Performance Capability, **Development Cost**, **Production Cost** and **Schedule** are determined at the **Total Program Level**.

Algorithms, *Boundaries* and *Rules* are developed from past programs to simultaneously determine a **Performance Capability**, **Cost** and **Schedule**.

Individual modules interface with each other in a dynamic manner with respect to **Performance Capability**, **Cost** and **Schedule**.

Additional information that depicts the interfaces have been included within the Supplemental File.

All *Algorithms*, *Boundaries* and *Rules* are formulated in a sequential manner from previous programs to establish a **Performance Capability** and have been forced to be within ± 5% of the actual values.

Foreign programs are included when the required information is available.

All *Algorithms*, *Boundaries* and *Rules* used to estimate **Cost** and **Schedule** are determined in a sequential manner from previous programs and have been forced to be within ± 10% of the actual values.

Foreign programs are included when the required information is available.

Three simulations have been developed –

Air-Superiority Fighter (ASFS)

Air Transport

Naval Surface Combatant and Submarines

Air-Superiority Fighter (ASFS)

- This was the first simulation to be developed.
- Very large amount of information from “Public Domain”
- Initial Performance Capability obtained from International Defense Review, May 1989.
- Includes US, European, Asian, Russian/USSR aircraft where sufficient information was available to formulate *Algorithms*, *Boundaries* and *Rules* for **Performance Capability**, **Cost** and **Schedule**.
- Required simulation inputs are included in the Supplemental Information File.

Air Transport

- The second simulation to be developed
- An intensely modified Air-Superiority Fighter Simulation which a member of the ***Set of Aircraft***
- Demonstrated the ability to utilize previous efforts that could be applied for a new manned/unmanned bomber or unmanned aerial vehicle (UAV)
- Six months were required to create the Air Transport Simulation.

Surface Combatant and Submarines

- The third simulation that was developed
- The first non-aerospace **SE-PCST** simulation
- Demonstrated that **SE-PCST** has universal application.
- List of Ships and Submarines and the sequence that they were included to develop *Algorithms*, *Boundaries* and *Rules* for the simulation are included in the Supplemental Information File.

Four important characteristics of all **SE-PCST** simulations include-

1. Intrinsic and Extrinsic Elements

2. Boundary Performance Groupings

3. Simulation Generation

4. Multiple Attributes

1. Intrinsic Elements

A performance parameter or design configuration where there are multiple simultaneous changes when one parameter is altered from a “Point Design”. **Intrinsic Elements** can only be modified by using data from engineering simulations or analysis.

Examples include: Thrust/Weight Ratio, G Loading, Maximum Range and Maximum MACH Number for an Air-Superiority Fighter.

The user shall be informed of all **Key Performance Parameters (KPP)** that are required for a particular **SE-PCST** simulation to be executed.

All KPPs values shall be provided from the engineering “Point Design” that will evolve as the design matures.

Extrinsic Elements

A performance parameter, design configuration or sub-system where there is an individual change when one parameter is altered from a point design. **Extrinsic Elements** can be added or deleted independently in conducting trade-offs.

Examples include: AESA Radar, GPS Navigation, Data Link 16 and Advanced Air-to-Air Missile for an Air-Superiority Fighter.

2. Boundary Performance Groupings

Performance parameters, design configurations and sub-systems will be included within one of the following groupings for any type of Aerospace or Military Program.

1. Endurance
2. Lethality or Payload
3. Maneuverability
4. Situational Awareness
5. Speed
6. Survival

Each **SE-PCST** simulation is unique and an example for the **ENDURANCE** Grouping is shown below:

First Generation Air Superiority Fighter	Range (Nautical Miles)
Second Generation Air Superiority Fighter	Range (Nautical Miles) Specific Fuel Consumption (SFC) Internal Fuel (Gallons)
First Generation Preliminary List for Satellites	Total of Forty (40) to Date Angle of Inclination (Degrees) Latitude (Degrees) Design Life (Year) Beginning of Life Power (BOL) (Watts) Etc.

MANEUVERABILITY
Parameters in Air-Superiority Fighter:

Angle of Attack (Degrees)
Aspect Ratio
Basing (Carrier/Land)
Canards (Yes/No)
Ceiling (Feet)
Climb Rate (Feet/Second)
Fly-by-Wire (Yes/No)
G Loading
Thrust/Weight Aircraft
Thrust/Weight Engine
Thrust Vectoring-Axial
Thrust Vectoring-2D
Wing Area (SF)
Wing Configuration
Wing Loading (Lbs/SF)

MANEUVERABILITY
Relative Capability:

Aircraft	Value	Country
Su-30 MKI	2.22	Russia
Su-27P	2.15	Russia
F-22	2.03	US
Eurofighter-2000	1.77	European
F-15E	1.73	US
Rafael C	1.41	France
Mig-29	1.33	Russia
F-18 E/F	1.26	US
F-35A	1.17	US
Gripen JAS-39	1.00	Sweden

3. Simulation Generation

First Generation

The first three **SE-PCST** are *First Generation* simulations that provides **Performance Capability**, **Cost** (Development and Production) and **Schedule** that are accurate, consistent and complete**.**

A *First Generation* simulation provides a **Performance Capability Trade-Off Capability**.

Second Generation

A *Second Generation* simulation provides a **Design-to-Cost (DTC)** capability for at least one subsystem/capability along with a **Performance Capability Trade-Off Capability**.

The *First Generation* **ASFS** was first introduced in May 2007.

A *Second Generation* **ASFS** has been developed that permits the estimation of the number of software Lines of Code (LOC).

In the case of the Air-Superiority Fighter other **Design-to-Cost (DTC)** capabilities can be developed:

Active Electronically Scanned Array (AESA)
Air-to-Air Missiles
Gas Turbine Engines
Glass Cockpit
System of Systems (SOS)
Thrust-Vectoring (Axial or 2-D)

Systems Engineers at Pre-Milestone A shall be able to:

- Conduct **Performance Capability Trade-Offs** with *First Generation simulations*.
- Conduct **Performance Capability Trade-Offs** and **DTC Trade-Offs** with *Second Generation* simulations.
- Create Blocks/Spirals that are within desired budgets at acceptable **Performance Capability** with a likely **Schedule** by using *Second Generation* simulations.

SITUATIONAL AWARENESS GROUPING

Performance Capabilities were determined for fighter aircraft in conjunction with the following elements to estimate the Lines of Code (LOC) at the Initial Operating Capability (IOC) timeframe.

These same elements are used to determine the **Performance Capability** of the aircraft and in reality is an “Expert System” within an “Expert System”.

Elements: (Included on Aircraft - Yes/No)

Canards
Countermeasures
Data Link
DEWS Electronic Warfare System
Direct Voice Input (DVI)
Electronic – Digital
Electro-Optical Targeting (EOT)
Engine Nozzle –
Axial, 2-D, Convergent, Convergent-Divergent

Elements (Continued)

Full Authority Digital Engine Control (FADEC)
Fly-by-Wire
Glass Cockpit
Global Positioning Satellite (GPS)
Hands-Off Throttle (HOTAS)
Heads-Up Display (HUD)
Helmet Mounted Display (HMD)
Identification Friend or Foe (IFF)
Improved Data Modem

Elements (Continued)

Infrared-Search and Track (IRST)

Joint Tactical Radio (JTRS)

Multifunctional Display

Radar
Active Electronically Scanned Array (AESA)
Passive Electronically Scanned Array (PESA)
Phase Radar
Doppler Phase Radar

Situational Awareness (SAIRIST)

Lines of Code (LOC) – Millions

Aircraft	Estimate	Actual	Year
F-35 Program (1)	18.20	19.0	2006
F-35A	7.44	-	-
F-35B	10.71	-	-
F-35C	7.44	-	-
F-22	3.96	4.00	1997
F-15E (2)	3.56	3.40	2006
F-18E/F (2)	3.39	2.80	2008
F-15C (2)	2.53	Unknown	2000

Lines of Code (LOC) – Millions (Continued)

Aircraft	Estimate	Actual	Year
Eurofighter-2000	1.54	1.50	1996
Su-30MKI	1.48	Unknown	2000
Su-27	1.39	Unknown	1979
Gripen JAS 39	1.11	.50 (3)	1988
F-15E	1.07	Unknown	1986
F-18C	1.07	.90	1987
Rafael	.93	1.00	1991
F-18A	.77	.50	1978
Mig-29	.61	Unknown	1977
F-15A	.06 (4)	.06	1972

Notes –

1. Assumes a Reuse Factor of 41.0 % for F-35B and F-35C versions.

2. Includes upgrade of an AESA radar.

3. Sweden’s Gripen (JAS-39)Prototype crashed due to faulty software.

4. Analog electronics

Multiple Attributes

An Active Electronically Scanned Array (AESA) was identified as a possible candidate to develop a **Design-to-Cost (DTC)** capability for **ASFS**.

The *Algorithms*, *Boundaries* and *Rules* that would be developed could be modified for *First Generation* Early Warning Aircraft, Ground Radars, Naval Radars or Satellites simulations.

Multiple Attributes is applicable for Synthetic Aperture Radars (SAR) on Aircraft or Satellites.

Air Transport Simulation

After this simulation was developed it was used to perform a preliminary investigation for the *Joint Future Lift (JFTL) Concept*

Replacement aircraft for the –

C-130	USAF Transport
CH-47	US Army Helicopter
CH-53	US Marine Helicopter

To minimize Program Risk, Cost (Development**,** Production and O&M) and **Schedule** the analysis assumed the following:

a. C-17 is the Point of Departure.

b. For the C-130 replacement use the C-17 glass cockpit, landing gear, a straight wing and a shortened C-17 fuselage. The aircraft has two engines (F117-PW-100) which are the same as on the C-17.

c. For the CH-47 replacement the C-17 glass cockpit would be modified, a straight wing and a shortened C-17 fuselage would be required. Two or Four engines (F135-PW-600) would be mounted on the wings and another two engines would be included in the tail section. These engines are used for the F-35B fighter and permits a vertical take-off (VTOL) followed by a transition to horizontal flight.

d. For the CH-53 the previously identified replacement for the CH-47 would be reduced to two engines on the wing and possibly have the fuselage shortened depending upon detailed engineering design and analysis.

e. This preliminary information has been given to the in the cost community of the USAF and USN along with de-rated **Development** and **Production Cost Estimates**.

Naval Surface Combatants & Submarines

a. *Algorithms*, *Boundaries* and *Rules* were developed to create **Performance Capability** from pre-WW II ships to the present day.

b. A total of 174 Ships and Submarines have been used to develop this simulation.

c. A total of 294 ***Intrinsic*** and ***Extrinsic Elements*** were utilized to establish **Performance Capability** relationships with the vast majority being ***Extrinsic*** in nature.

Naval Surface Combatants & Submarines

d. The required simulation inputs to determine **Performance Capability** are included in the Supplemental Information File.

e. Sequence of developing Performance Capability elements by **Type-**

(1). Destroyers
(2). Frigates
(3). Cruisers
(4). Battleships
(5). Aircraft Carriers
(6). Amphibious Assault Ships (LHA & LPD)
(7). Attack Submarine
(8). Missile Ballistic Submarines

Validation of Simulations

1. Gripen JAS 39 Development Cost was validated by Aviation Week & Technology (AW&ST) article.

Cost published in May 2007
AW&ST article of October 2007

2. Naval Surface Combatant and Submarine Simulation estimated a Modernization Cost for the USS Missouri an Iowa Class Battleship to be within ± 10% of the actual.

3. Details for both of these **Validations** have been included in the Supplemental File

Inputs for Air-Superiority Fighter Simulation

	Maximum Number
Performance Capability *First Generation* (1)	40
Performance Capability *Second Generation*	74
Development Cost	16
Production Cost	26
Schedule	7

Note: Twenty-two (22) items are Key Performance Parameters (KPPs) that are included in *First Generation*

SE-PCST Development

Simulations are labor, knowledge and time intensive to develop but offers Systems Engineers, Cost Estimators, Design Engineers and Program Management an unprecedented opportunity to make the best possible Pre-Milestone A decisions.

Personnel:

Instructing individuals how to create **SE-PCST** simulations can only be made in principle. General and specific engineering knowledge is an absolute requirement to establish a **Performance Capability**.

A Principal Engineer, Sr. Engineer, Sr. Software Engineer and Data Technician comprise the core development group.

The number of **SE-PCST** simulations that can be developed simultaneously is probably no more than 2-3.

Making a significant increase in staff will not necessarily assure the creation of high-quality simulations at an accelerated pace.

The industry-wide organization, corporation, military service or DoD that first embraces **SE-PCST** will have a significant advantage over others since their priorities will be addressed first.

Time:

To develop a new SE-PCST simulation approximately 6-9 months is required. This assumes that all required information is readily available at the start of the effort. This also requires access to engineering expertise to clarify technical questions and concerns.

A additional 3-4 months would be required to develop the pseudo code and write/debug code in a Windows © Visual Basic 6 environment so that Systems Engineer could use the simulation.

Three paths of Future Simulation Development

1. Complete Stand-Alone Program Simulations

2. Stand-Alone Subsystem Simulation

3.A combination of a Program Simulation and Sub-System Simulation: *Second Generation*

1. *Complete Stand-Alone Program Simulations such as:*

a. Littoral Combat Ships (LCS)

b. Next Generation Bomber (Long Range Strike)

c.Supports Japan's effort to develop a replacement for its F-15s

d. Replacement for the cancelled USAF Transformational Satellite Communications System (TSAT)

e. Unmanned Aerial Combat Vehicles (UAVs)

2. *Stand-Alone Subsystem Simulations such as:*

a. Active Electronically Scanned Array (AESA)

b. Air-to-Air Missiles

c. Air-to-Ground Missiles

d. Gas Turbine Engines

e. Liquid Rocket Engines

f. Solid Rocket Engines

g. Surface-to-Air Missile

h. Synthetic Aperture Radar (SAR)

Client Options

1. An industry-wide effort of financial support to where all participants would have unlimited access to all developed simulations.

Priority of simulation development would be determined by an industry-wide Working Group.

2. Government funded support for development

3. Individual Corporation or Company provides funding for the development of its priority simulations.

Summary

This presentation is the initial opportunity to introduce a proven capability that includes **Performance Capability**, **Cost** and **Schedule** to the Systems Engineering (SE) Community that can be used for Pre-Milestone A decisions.

Fidelity of the simulation increases as the design matures and provides:

The *best available* **Cost** and **Schedule** estimate at any time-frame of the development process.

Systems Engineers and Cost Analysts shall be able to:

• Conduct **Performance Capability Trade-Offs** with *First Generation simulations*.

• Conduct **Performance Capability Trade-Offs** and **Design-to Cost Trade-Off** with *Second Generation* simulations.

• Establish Program Blocks/Spirals that will be within established budgets at acceptable **Performance Capability** at likely **Schedule** by using *Second Generation* simulations.

Program Management, Congress and the Executive Branch will have:

- A significant capability to execute programs in an affordable and timely manner that provides the required level of performance for a program.
- A heightened level of confidence in the success of programs that will ensure stable funding

Scope Assessment

An assessment must be made with potential clients to optimize their programs, products and potential new business.

This effort will identify priorities, schedules and costs to establish specific **SE-PCST** simulations.

Normally this work would be completed within a 30-45 day timeframe at an affordable cost.

Questions/Comments/Concerns

All questions, comments and concerns about **SE-PCST** theory and simulations are welcomed.

A summary with responses shall be prepared and posted on the blog by May 1st.

The book is available at –

http://costengineeringsystem.blogspot.com

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