PSM PRESENTATION

Engineering Process and Tools Organization (EP&TO)


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DEPLOYING COST EFFECTIVE SOFTWARE QUALITY METRICS USING DYNAMIC PROCESS MODELING: A METHODOLOGY & CASE HISTORY

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Process Modeling

POLICY
Measure & Control

POLICY
Analysis of Process

POLICY
Training

POLICY
EPO Group

Define Metrics

Collect Metrics

Analyze Metrics

Disseminate Metrics

Validate Metrics

- Process Input Data
- Benchmark Data
- Quality Attributes

- Process Capability
- Establish Goals
- Process Control Limits

- Process Performance
- Process Improvement
- Process Parameters
SOFTWARE METRICS

I. PROGRAMMATIC METRICS
1. SOFTWARE COST
2. SOFTWARE SCHEDULE
3. SOFTWARE EFFORT (PERSON-MONTHS)
4. SOFTWARE SIZE (EXECUTABLE LINES OF CODE)
5. SOFTWARE COMPLEXITY
6. SOFTWARE RISK (ECONOMIC & TECHNOLOGY)
7. STAFF (HEADCOUNT)

II. PERFORMANCE METRICS
1. SOFTWARE DEFECTS (SEVERITY LEVELS)
2. SOFTWARE DEFECT DENSITY (DEFECTS PER 1,000 SLOC)
3. SOFTWARE PRODUCTIVITY (SLOC / STAFF-MONTH)
4. SOFTWARE CPU & MEMORY
5. SOFTWARE SLOC GROWTH RATE
6. SOFTWARE STABILITY & VOLATILITY
7. SOFTWARE OPERATIONAL AVAILABILITY
**SOFTWARE METRICS**

**III. QUALITY METRICS**
1. SOFTWARE RELIABILITY
2. SOFTWARE MAINTAINABILITY
3. SOFTWARE DEPENDABILITY
4. SOFTWARE INTER-OPERABILITY
5. SOFTWARE SURVIVABILITY
6. SOFTWARE EXPANDABILITY
7. SOFTWARE PORTABILITY

**IV. COMPUTER SCIENCE METRICS**
1. NUMBER OF COMMON & UNIQUE OPERATORS
2. NUMBER OF COMMON & UNIQUE OPERANDS
3. SOFTWARE CYCLOMATIC COMPLEXITY
4. SOFTWARE VOLUME
5. SOFTWARE EFFICIENCY
6. OOA / OOD--DEPTH OF INHERITANCE TREE
7. OOA / OOD--LACK OF COHESION
"SEVEN (7) GOLDEN" METRICS

I. COST PERFORMANCE INDEX (CPI)
II. SCHEDULE PERFORMANCE INDEX (SPI)
III. DEFECTS (DEFECT DENSITY & CONTAINMENT)
IV. SOFTWARE PRODUCTIVITY
V. LEARNING
VI. RETENTION
VII. DIVERSITY
CPI & SPI METRICS

INPUT PARAMETERS:

A) BCWS: BUDGETED COST OF WORK SCHEDULE
B) BCWP: BUDGETED COST OF WORK PERFORMED
C) ACWP: ACTUAL COST OF WORK PERFORMED

CALCULATED VALUES:

SCHEDULE PERFORMANCE INDEX: SPI = BCWP/BCWS

COST PERFORMANCE INDEX: CPI = BCWP/ACWP

SCHEDULE VARIANCE: SV = (BCWP) - (BCWS)

COST VARIANCE: CV = (BCWP) - (ACWP)

PERCENT SCHEDULE VARIANCE: PCTSV = ((BCWP - BCWS)/BCWS) * 100.

PERCENT COST VARIANCE: PCTCV = ((BCWP - ACWP)/BCWP) * 100.
DR. AARON N. SILVER--PROCESS MODELING--DATA (AUG2000.STA)
REGRESSION ANALYSIS--FILE#:REGAUG00.STG--OCTOBER 2, 2001

COST PERFORMANCE INDEX (CPI)

SCHEDULE PERFORMANCE INDEX (SPI)

y = 11.102 - 18.637*x + 8.501*x^2 + \epsilon

DENVER DATA
DR. AARON N. SILVER--PROCESS MODELING--SPI DATA

X-BAR
Mean: 1.01281 (1.01281) Proc. sigma: 0.089011 (0.089011) n: 1
Specifications: LSL=0.926256 Nominal=1.01281 USL=1.09936

CONTROL CHART (MEAN)--FILE#: AUG00SPI--OCTOBER 2, 2000

DENVER PROGRAMS--AUGUST 2000--SPI DATA (AUG. 2000)

X-Bar chart: SPI--SCHEDULE PERFORMANCE INDEX

No of obs

Histogram of Means

0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4

PROG. #1 PROG. #2 PROG. #3 PROG. #4 PROG. #5 PROG. #6

1.27984
W: 1.1463
1.01281
W: 0.87929
0.745773
Dr. Aaron N. Silver--Process Modeling--CPI Data

X-Bar
Mean: 0.999615 (0.999615) Proc. sigma: 0.086826 (0.086826) n: 1

Specifications: LSL = 0.931020 Nominal = 0.999615 USL = 1.06821

CONTROL CHART (MEAN)--FILE#: AUG00CPI--OCTOBER 2, 2000

Histogram of Means

X-Bar chart: CPI--COST PERFORMANCE INDEX

No of obs

0.70 0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20 1.25 1.30

0 1 2 3

1.26009
W: 1.1299

0.999615
W: 0.86938

0.739138

DENVER PROGRAMS--AUGUST 2000--CPI DATA (AUG. 2000)
Process Modeling

Dr. Aaron N. Silver--Process Metrics--Prog. Data
Quadratic Prediction Model--File#: DCS3D15A.STG--June 9, 2001

\[ z = -8.721e5 + 1.501e6 \times x - 1.045e6 \times y + 8.333e5 \times x^2 - 1.865e6 \times x \times y + 1.444e6 \]

Total Cost Variance ($)

Total SPI

Total CPI
DR. AARON N. SILVER--PROCESS METRICS--PROG. DATA
QUADRATIC PREDICTION MODEL--FILE#:DCCS4D1A.STG--JUNE 9, 2001

TOTAL COST VARIANCE <= 0: OVER RUNS

TOTAL COST VARIANCE > 0: UNDER RUNS

TOTAL COST VARIANCE: <= 0
\[ z = -8.143e5 + 1.4216e6 \times x - 1.106e6 \times y + 1.108e6 \times x^2 - 2.258e6 \times x \times y + 1.63e6 \times y^2 \]

TOTAL COST VARIANCE: > 0
\[ z = -2.824e6 + 3.454e6 \times x + 2.845e5 \times y - 8.623e5 \times x^2 + 1.079e5 \times x \times y - 1.682e5 \times y^2 \]
Process Modeling

DR. AARON N. SILVER--PROCESS METRICS--DATA (TOTAL)
REGRESSION ANALYSIS--FILE#:DCCSLN01.STG (DCCS1)--JUNE 22, 2001

TOTAL COST PERFORMANCE INDEX (CPI)

TOTAL COST VARIANCE (DOLLARS)

JAN.-94
FEB.-94
MAR.-94
APR.-94
MAY -94
JUN.-94
JUL.-94
AUG.-94
SEP.-94
OCT.-94
JAN.-95
FEB.-95
MAR.-95
APR.-95
MAY- 95
JUN.-95
JUL.-95
AUG.-95
SEP.-95
OCT.-95
JAN.-96
FEB.-96
MAR.-96
APR.-96
MAY -96
JUN.-96
JUL.-96
AUG.-96
SEP.-96
OCT.-96
NOV.-96
JAN.-97
FEB.-97
MAR.-97
APR.-97
MAY -97
JUN.-97
JUL.-97
AUG.-97
SEP.-97
OCT.-97
NOV.-97
DEC.-97
JAN.-98
FEB.-98
MAR.-98
APR.-98
MAY -98

\[ y = -1.197e6 + 1.246e6 \times x + \epsilon \]
DR. AARON N. SILVER--PROCESS METRICS
FILE#:DCCSCHR2.STG (DCCS1)--JULY 7, 2001

CHERNOFF FACES--MANAGEMENT COMPONENT (DOLLAR DERIVED)

LEGEND: face/w = MGT. BCWS, ear/lev = MGT. BCWP, halfface/h = MGT. ACWP,
upface/ecc = MGT.SCH.VAR., loface/ecc = MGT.PCT.SCH.VAR., nose/l = MGT.PCT.COST VAR.,
mouth/cent = MGT. SPI, mouth/curv = MGT. COST VAR., mouth/l = MGT. CPI,
## Balanced Scorecard

### Financial
- **Strategic Objective**
  - Growth Orientation & Financial Strength
- **Measurement**
  - Negotiation metric
  - Cash
  - Revenue - 2004
  - Margin
  - Annual growth
  - ROIC

### Process
- **Strategic Objective**
  - Process Improvement
- **Measurement**
  - Defect Rate
  - ROI on Improvements
  - Productivity Improvement (O/H)
  - % Functional Groups in Plans
  - Performance to Plan

### Customer
- **Strategic Objective**
  - Meet Commitments, Expectations, Easy to do Business with
  - Protect, Expand, Diversify Customer Base
- **Measurement**
  - Gate 5 reviews
  - Composite award fee
  - SPI
  - CPI

### Learning
- **Strategic Objective**
  - Share Best Practices and Lessons Learned
  - Focused People Strategy
  - Skill Development
  - Investment - People, Assets, Technology
- **Measurement**
  - Build / Reuse Ratio
  - Gate II Completion
  - Strategic Job Coverage Ratio
  - # Successors / Critical Positions
  - Retention Rate
  - Critical Skill / Need Ratio
  - Skill Training Plan
  - Performance to Plan

### “Classic Balanced Scorecard”

<table>
<thead>
<tr>
<th>Lead</th>
<th>Lag</th>
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<tbody>
<tr>
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</table>
Process Modeling

DR. AARON N. SILVER--S/W MODELING--DATA (NPPTAB04.STA)
REGRESSION ANALYSIS--FILE#:NPPREG05.STG--DECEMBER 12, 2001

S/W DEVELOPMENT K-$ = 14.017 - 48.595x + 4.476x^2 - 0.095x^3 + 7.508e-4x^4 - 2.01e-6x^5 + \epsilon_s

S/W MAINTENANCE K-$ = 81.012 - 12.295x + 0.296x^2 + 6.339e-4x^3 - 3.998e-5x^4 + 1.744e-7x^5 + \epsilon_s
DR. AARON N. SILVER--RISK PROFILE--DATA (SASRSK.STA)
RISK ANALYSIS--FILE#: NPPSLOC1.STG--DECEMBER 4, 2001

SLOC RISK ESTIMATE
SLOC ESTIMATES
CSCI #1 (1.4.3.1.1) 10500
CSCI #2 (1.4.3.1.2) 50000
CSCI #3 (1.4.3.1.3) 33600
CSCI #4 (1.4.3.1.4) 12500
CSCI #5 (1.4.3.1.5) 16000
CSCI #6 (1.4.3.1.7) 1000

y=2.71828^((-0.5) ((x-123733.)/12373.3)^2)

NORMAL DISTRIBUTION
(LEFT SCALE)

CUMULATIVE PERCENT RISK
(RIGHT SCALE-CALCULATED)

SLOC VALUES
EXECUTABLE SOURCE LINES OF CODE (SLOC)
Process Modeling

DR. AARON N. SILVER--BENCHMARK METRICS (DATA:RAYPROD01.STA)

REGRESSION ANALYSIS--FILE#:RAYLIN04.STG--DECEMBER 4, 2001

SOFTWARE SIZE (EXECUTABLE SOURCE LINES OF CODE)

PRODUCTIVITY (SOURCE LINES OF CODE PER STAFF MONTH)

VARIABLE VALUES (EXECUTABLE SLOC)

y = 282.416 + 8.881e-5*x + ep

(PREDICTED--MODEL)
y = 235 + 75e-5*x

(BENCHMARK DATA)

y = 282.416 + 8.881e-5*x + ep

(BENCHMARK DATA)
NEURAL NETWORKS--DR. AARON N. SILVER--DATA (INDIA1.STA)

REGRESSION ANALYSIS--FILE#: NETREG01.STG--AUGUST 31, 2001

TOTAL DEFECTS IDENTIFIED (PREDICTED) = 5.42 + 0.011x - 1.285e-4x^2 + 2.761e-7x^3 + eps
TOTAL DEFECTS IDENTIFIED (DATA) = 8.497 + 0.084x - 9.238e-4x^2 + 1.923e-6x^3 + eps
Cluster Analysis--Unweighted pair-group average (euclidean Dist.)---1/23/02

VARIABLES
1. PERCENT (%) COMPLETE
2. CONTRACT VALUE (MILLIONS $
3. ESTIMATED COST AT COMPLETION (MILLIONS $
4. PROFIT (PERCENT)
5. BCWS (BUDGETED COST OF WORK SCHEDULED)
6. BCWP (BUDGETED COST OF WORK PERFORMED)
7. ACWP (ACTUAL COST OF WORK PERFORMED)
8. CPI (COST PERFORMANCE INDEX)
9. SPI (SCHEDULE PERFORMANCE INDEX)
10. ATTRITION (YEAR 2000 PROGRAMS)
DR. AARON N. SILVER--PROCESS MODELING--DATA (C3IDATA.STA)
NEURAL NETWORK/REGRESSION--FILE#:INDNET4A.STG--JANUARY 26, 2002

GENERALIZED PERFORMANCE INDEX (NORMALIZED EQUAMAX ROTATION DERIVED)

CPI = 0.971 + 0.004 * x - 7.513e-4 * x^2 + eps
SPI = 0.969 + 0.01 * x - 6.443e-4 * x^2 + eps

VARIABLES
1). PERCENT (%) COMPLETE
2). CONTRACT VALUE (MILLIONS $)
3). ESTIMATED COST AT COMPLETION (MILLIONS $)
4). PROFIT (PERCENT)
5). CPI (COST PERFORMANCE INDEX)
6). SPI (SCHEDULE PERFORMANCE INDEX)
7). ATTRITION (YEAR 2000-FOR PROGRAM)

(RADIAL BASIS FUNCTION NEURAL NETWORK)
(INDEX (INPUT))
(V1, V2, V3, V4, V5, V6, V7)
(V1-V7 (OUTPUTS))

(BACK PROPAGATION TRAINED)
Process Modeling

DR. AARON N. SILVER--PROCESS MODELING--DATA (C3IDATA.STA)
NEURAL NETWORK ANALYSIS--FILE#:NEUCON06.STG--JANUARY 29, 2002

MULTI-LAYER PERCEPTRON

INDEX (OUTPUT MAX)

% PROFIT

(CONTRACT TYPE:
- CPAF
- CPFF
- FFP
- CPIF
- FPIF
- CPIAF

OUTPUT VARIABLES:
1). PERCENT (%) COMPLETE
2). CONTRACT VALUE (MILLIONS $)
3). ESTIMATED COST AT COMPLETION (MILLIONS $)
4). PROFIT (PERCENT)
5). CPI (COST PERFORMANCE INDEX)
6). SPI (SCHEDULE PERFORMANCE INDEX)
7). ATTRITION (YEAR 2000-FOR PROGRAM)

BACK PROPAGATION TRAINED

PERCENT (%) PROFIT

ESTIMATED COST AT COMPLETION (MILLIONS $)
**Process Modeling**

- **X(N)** = STATES OF SYSTEM AT STAGE N
- **R(N)** = RETURN FROM STAGE N
- **D(N)** = DECISION AT STAGE N

**Bellman's Principle of Optimality**

"An optimal set of decisions to an n stage process has the property that no matter what the state of the input of the system is at stage n, and no matter what decision is made at stage n, the remaining decisions must be optimal with respect to the state resulting from the nth stage decision."

\[
Q_n(X_n, D_n) = R_n(X_n, D_n) + F_{n-1}(X_{n-1})
\]

and

\[
F_n(X_n) = \max_{d_n} \{ Q(X_n, D_n) \}
\]
**DR. AARON N. SILVER--PROCESS MODELING--DATA (SILTXT.STA)**
**DYNAMIC PROGRAMMING--FILE#:DYNDAT01.STG--FEBRUARY 5, 2001**

### REQUIREMENTS ANALYSIS

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<th>STAGE</th>
<th>STATE 0</th>
<th>STATE 1</th>
<th>STATE 2</th>
<th>STATE 3</th>
<th>STATE 4</th>
<th>STATE 5</th>
<th>STATE 6</th>
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<th>STATE 8</th>
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**STATE VARIABLES = PERCENT OF RESOURCES (REQUIREMENTS) DEPLOYED**

**STAGES (ALTERNATIVES) = PROPOSED REQUIREMENTS**

**MATRIX ENTRIES = PERCENT EFFECTIVENESS**

**OBJECTIVE:**

ALLOCATE REQUIREMENTS TO PERCENT (%) RESOURCES DEPLOYED TO "MAXIMIZE" OVERALL EFFECTIVENESS.
Dr. Aaron N. Silver -- Process Modeling -- Data: SILTSTXT.STA
Stage Diagram -- File#: SILTST6A.STG -- September 10, 2001

Percent Normalized Resource Effectiveness

Percent Resource Deployed:
- State 0 (0%)
- State 1 (10%)
- State 2 (20%)
- State 3 (30%)
- State 4 (40%)
- State 5 (50%)
- State 6 (60%)
- State 7 (70%)
- State 8 (80%)
- State 9 (90%)
- State 10 (100%)

Optimal Solution (Value = 270)

Upper Boundary States

Lower Boundary States
PROCESS MODELING--DR. AARON N. SILVER--DATA (SNNTST9X.STA)
REGRESSION ANALYSIS--FILE#:SNNTST01.STG--OCTOBER 6, 2001

STAGE #1--NORMALIZED PERCENT EFFECTIVENESS

STAGE #1 (TARGET)=-11.369+10.153*x-1.313*x^2+0.144*x^3-0.007*x^4+1.24e-4*x^5+eps
STAGE #1 (PREDICTED)=-12.945+11.147*x-1.442*x^2+0.153*x^3-0.007*x^4+1.339e-4*x^5+eps

MULTI-LAYER PERCEPTRON

STAGE #1 (OUTPUT) (BACK PROPAGATION TRAINED)