Estimating Software Maintenance Costs: The O&M Phase

17 September 2014

CRITICAL THINKING.
SOLUTIONS DELIVERED.

G. C. Bell – MCR LLC
(202) 284 1291
gbell@mcri.com

Modeling Software Maintenance Costs in the O&M Phase

Presentation Agenda

Modeling Software Maintenance Costs in the O&M Phase

Purpose & Scope

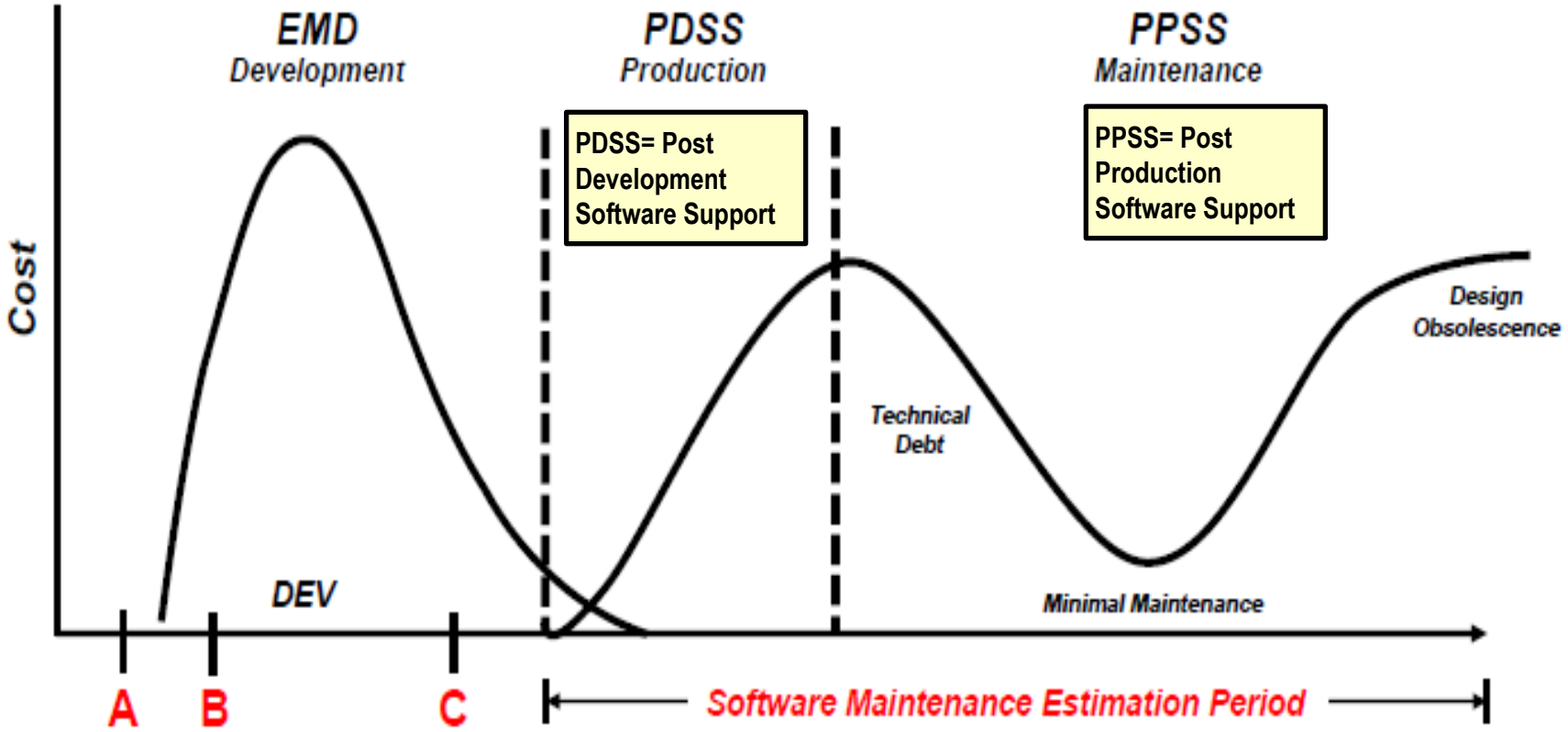
- ***The software legacy of RDT&E Programs:*** ***Many RDT&E programs create a large body of software codes. Much of this code could be described as "OFP" or operational weapons system codes, but there are also considerable amounts of support software that are not installed in the weapons but are used to maintain the weapons, plan missions, or train personnel. Finally there are simulation codes that play an important role in the continued evolution of the weapons system over time.***

- ***All of these codes require maintenance during the O&M phase. Aggregate DoD outlays for software maintenance amount to many billions of dollars every year.***

- ***Despite this, historical cost data collection and methods for estimating the O&M cost of software maintenance are not well developed. A large body of research material and investigation has not produced a definitive method or a public database that can be used to develop robust or defendable methods.***

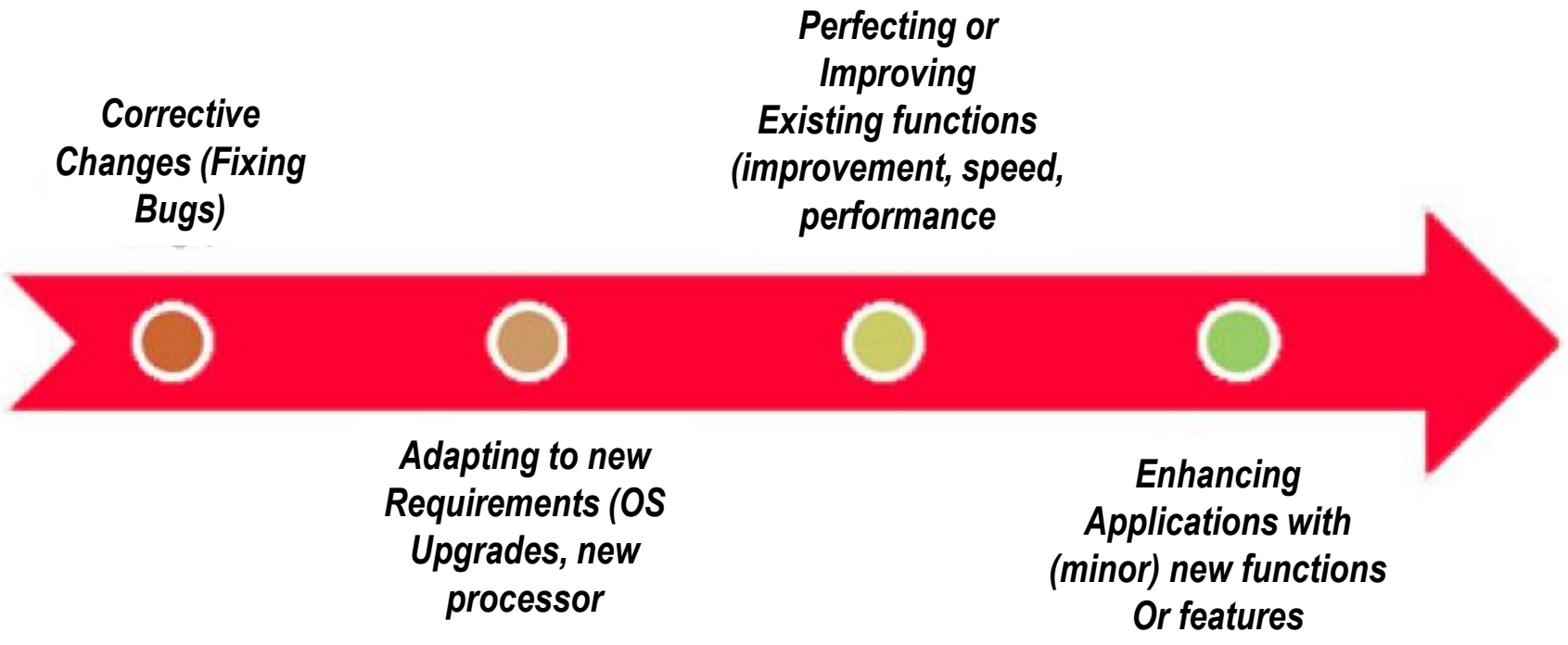
The Software Life Cycle

How Long is the PDSS/PPSS (O&M) Interval?



Ref: Clark, C. and Miller, C., PSMUG Conference Workshop #7, - Software Maintenance Cost Estimating Relationships, ODASA-CE, 2012

Software Maintenance Missions

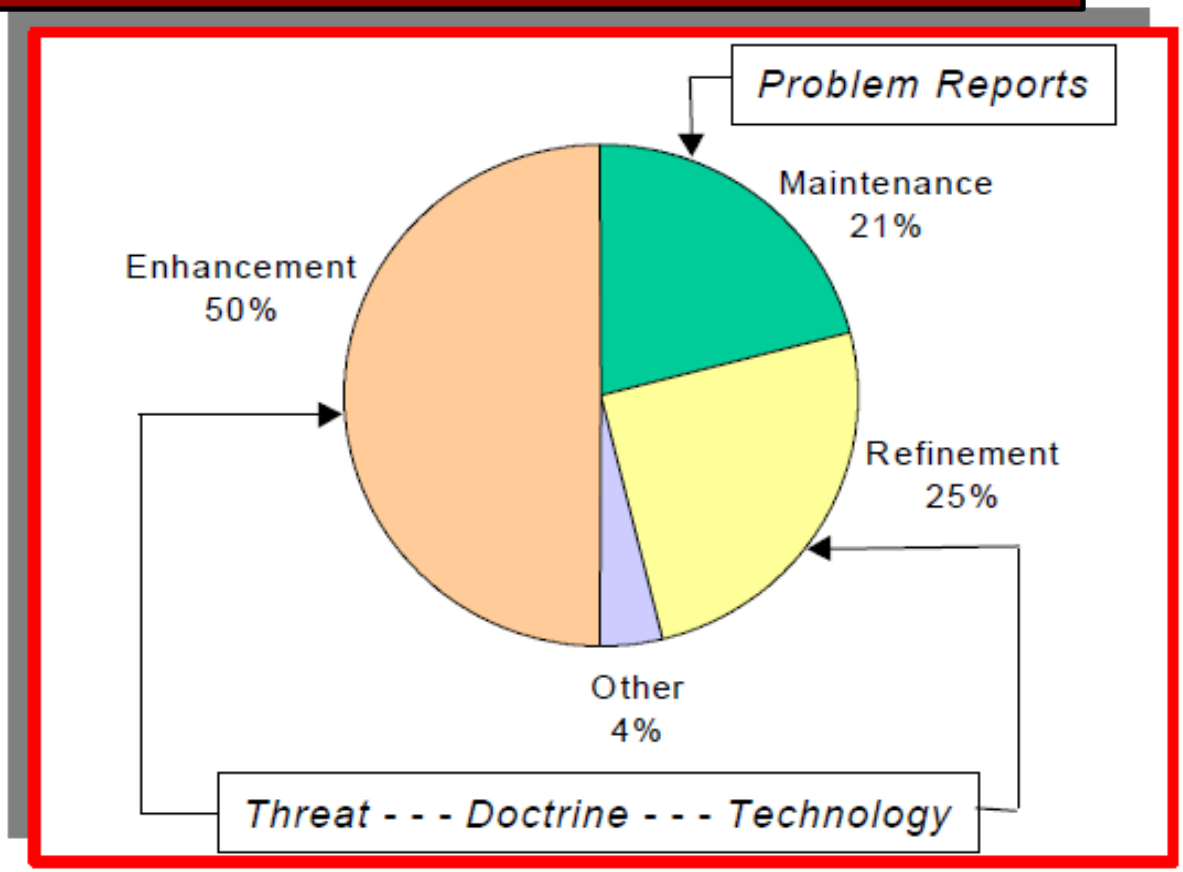


In the absence of historical data, breaking software maintenance costs down at this level is no more than an academic theory.

Ref: Galorath, D.D., Software Total Ownership Costs: Development is Only Job 1, SEER, Inc., 2011

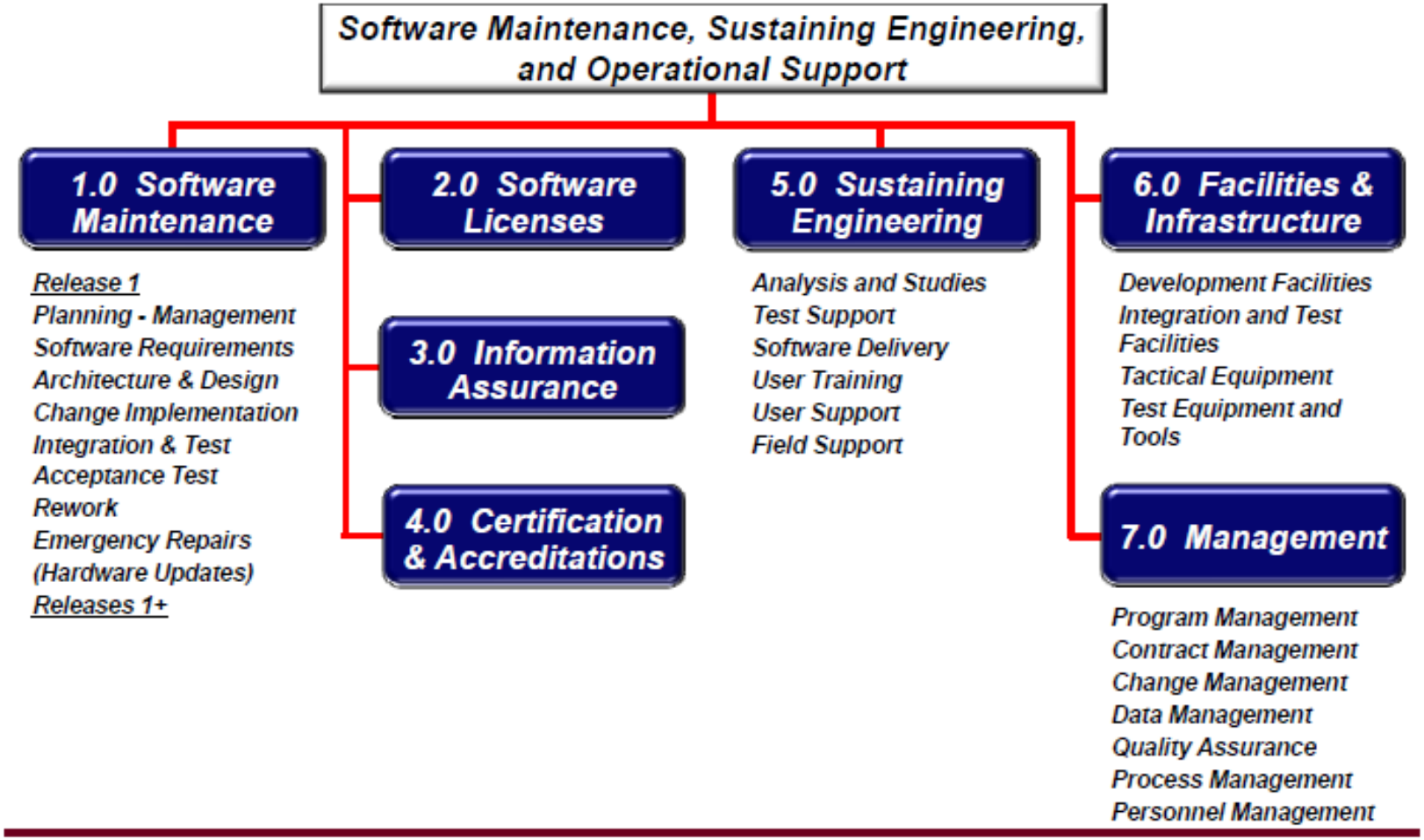
Software Maintenance Missions

In the absence of historical data, breaking software maintenance costs down at this level is no more than an academic theory.



Ref: ***Guidelines for Successful Acquisition and Management of Software Intensive Systems, (GSAM, Version 3, Chapter 12)****, USAF AFIT, 1997*

WBS for Software Maintenance Projects – ODASA-CE - 2012



Ref: Clark, C. and Miller, C., PSMUG Conference Workshop #7, - Software Maintenance Cost Estimating Relationships, ODASA-CE, 2012

WBS for Software Maintenance Projects – ODASA-CE - 2012

1.0 Software Maintenance - products and activities associated with modifying an operational software product or system

2.0 Software Licenses - products and activities associated with the procurement and renewal of software licenses for operational software

3.0 Information Assurance - products and activities associated with ensuring that the software is compliant with externally defined information assurance requirements

4.0 Certifications and Accreditations - products and activities associated with verifying a software system against externally defined domain performance criteria

5.0 Sustaining Engineering - products and activities associated with supporting a deployed software product or system in its operational environment

6.0 Facilities & Infrastructure - products and activities associated with establishing and operating the facilities and processes required to modify, integrate, and test operational software products or systems

7.0 Management - products and activities associated with planning, organizing, funding, and controlling the resources required to support operational software products or systems

Ref: Clark, C. and Miller, C., PSMUG Conference Workshop #7, - Software Maintenance Cost Estimating Relationships, ODASA-CE, 2012

Current Army Methods – Estimating Software Maintenance Costs

- **Number of lines of code per software engineer**
  - Each engineer can maintain 20K-25K LOC/ESLOC
  - Does not reflect the impact of software reuse or COTS

DoD Method

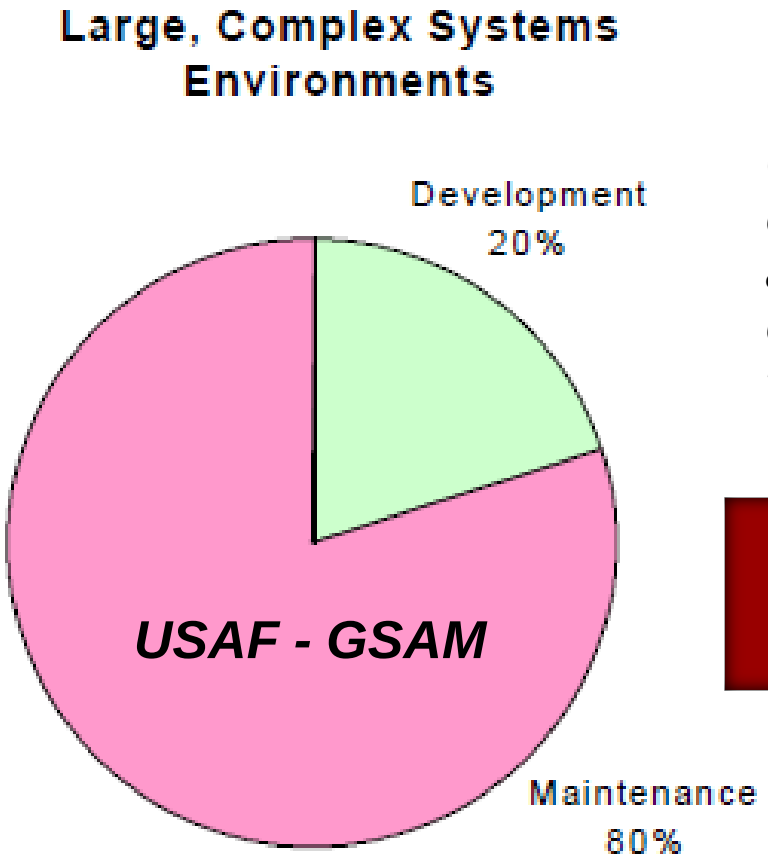
- **Software maintenance estimated as a percentage of development costs**
  - Rule(s) of thumb - development based:
    - S/W maintenance costs - 2/3 of total S/W life cycle costs
    - S/W maintenance costs - 60% to 75% of total S/W life cycle costs
    - Annual S/W maintenance costs - 5% to 10% of total S/W life cycle costs
  - Ignores total system life cycle software growth and maintenance requirements/strategy/tasks

Cost Factor Method Common Throughout Government & Industry

No data publicly available.

Ref: Clark, C. and Miller, C., PSMUG Conference Workshop #7, - Software Maintenance Cost Estimating Relationships, ODASA-CE, 2012

Are SW Maintenance Costs Related to SW Development Costs?

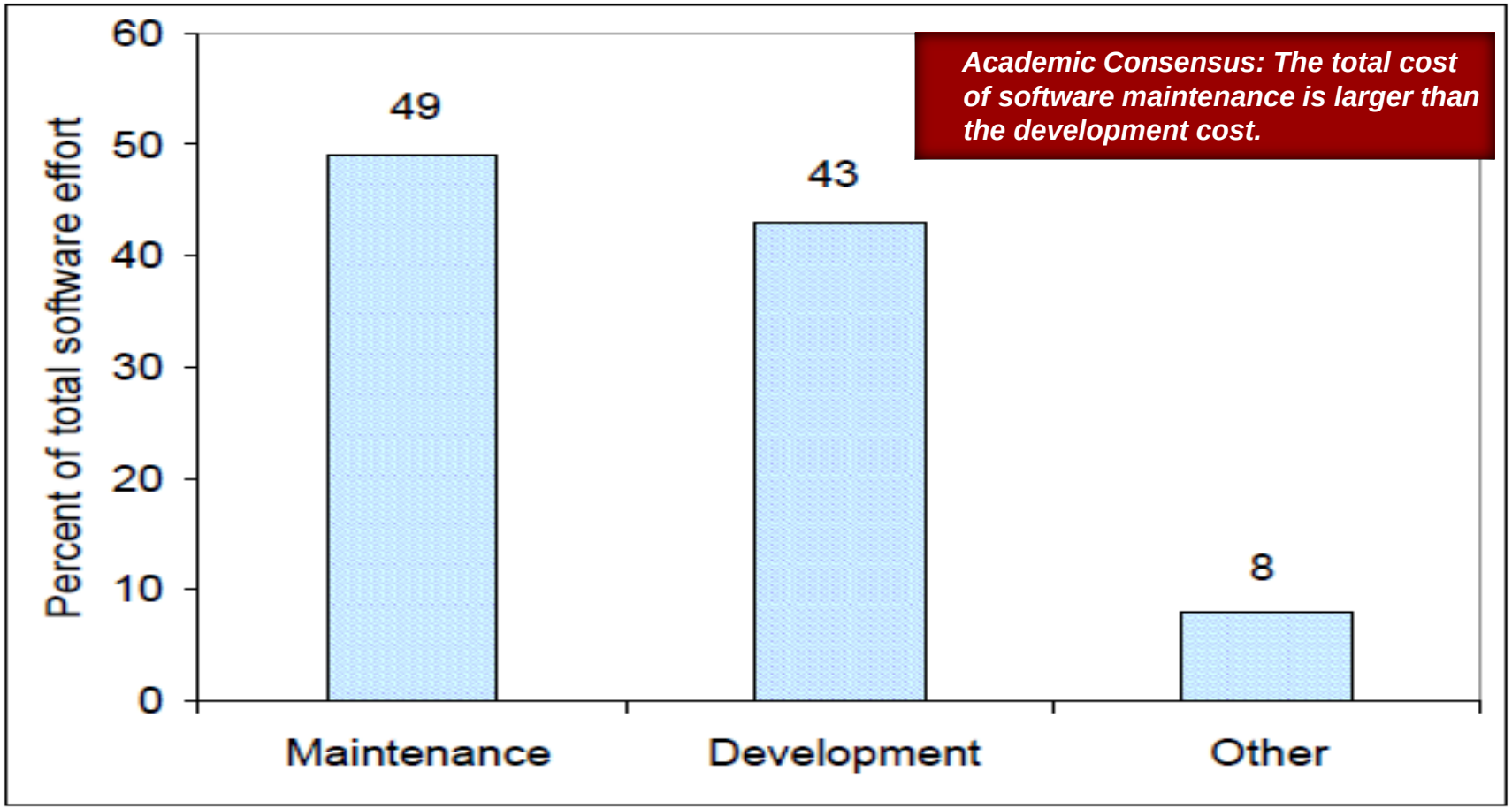


The cost factor method posits that software O&M costs can be predicted as a function of development costs. Generally, this is a percentage of the total SW development cost per year times the number of years in the O&M phase.

Academic Consensus: The total cost of software maintenance is larger than the development cost.

Ref: ***Guidelines for Successful Acquisition and Management of Software Intensive Systems, (GSAM, Version 3, Chapter 12), USAF AFIT, 1997***

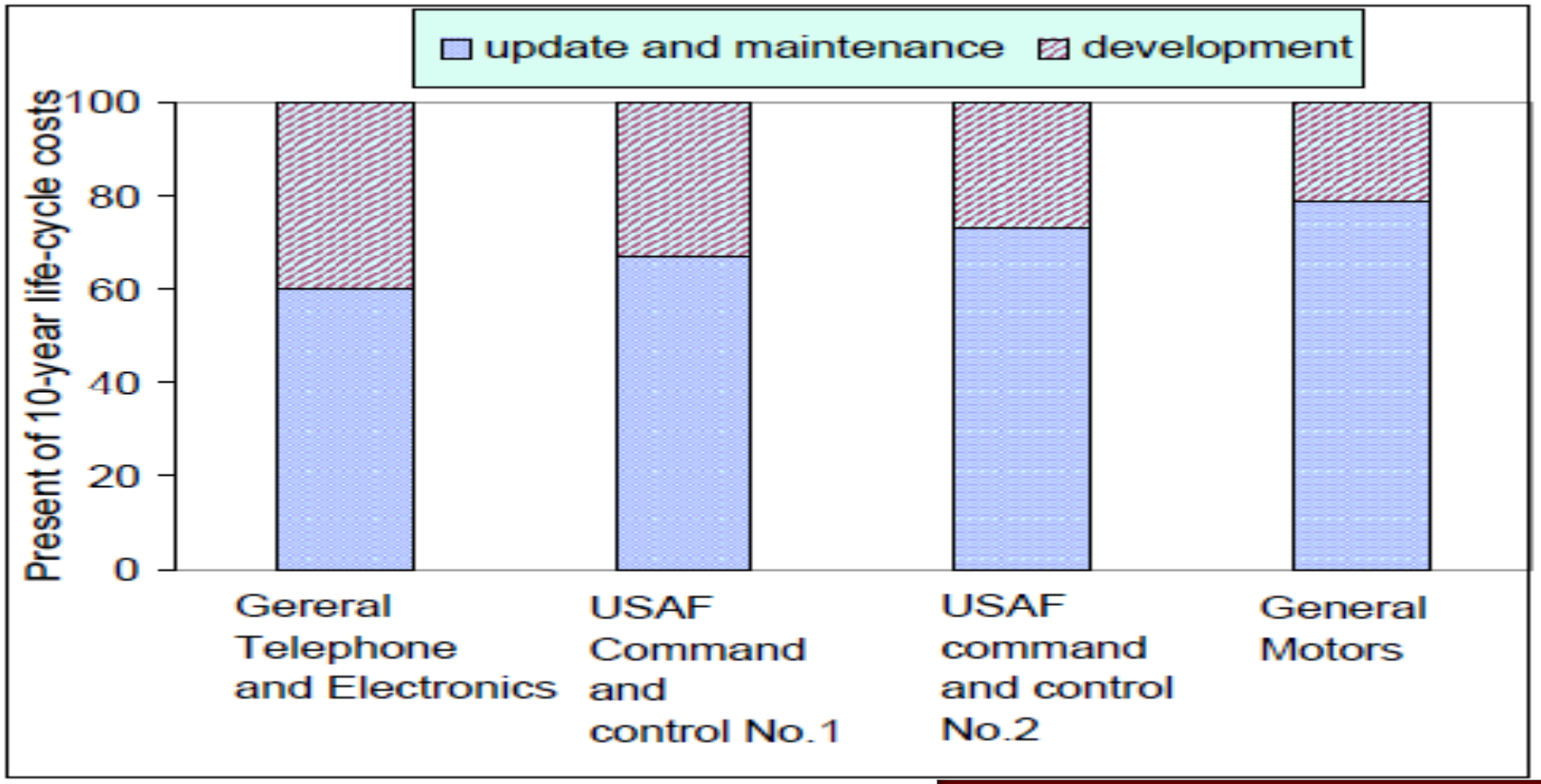
Are SW Maintenance Costs Related to SW Development Costs?



From Boehm Study, 1981, 487 Business Organizations

Ref: Mukhija, A., Estimating Software Maintenance, University of Zurich, 2003

Are SW Maintenance Costs Related to SW Development Costs?



From Boehm Studies, 1981

Academic Consensus: The total cost of software maintenance is larger than the development cost.

Ref: Mukhija, A., Estimating Software Maintenance, University of Zurich, 2003

Are SW Maintenance Costs Related to SW Development Costs?

Consolidated Sample (Boehm – 487 Organizations)

20 YEAR SERVICE LIFE - DEVELOPMENT - MAINTENANCE COMPARISON	DEVELOPMENT COST	MAINTENANCE COST	LIFE CYCLE COST	MAIN/DEV RATIO	LEVEL LOADED % PER YEAR
BOEHM - 487 ORGANIZATIONS	46.7%	53.3%	100.0%	114.1%	5.7%

Stratified Sample based on Levels of Software Complexity

Diminishing *Complexity* ↓

20 YEAR SERVICE LIFE - DEVELOPMENT - MAINTENANCE COMPARISON	DEVELOPMENT COST	MAINTENANCE COST	LIFE CYCLE COST	MAIN/DEV RATIO	LEVEL LOADED % PER YEAR
COMPLEX OFP SOFTWARE	30.0%	70.0%	100.0%	233.3%	11.7%
NON COMPLEX OFP SOFTWARE	35.0%	65.0%	100.0%	185.7%	9.3%
COMPLEX SUPPORT SOFTWARE	40.0%	60.0%	100.0%	150.0%	7.5%
NON COMPLEX SUPPORT SOFTWARE	45.0%	55.0%	100.0%	122.2%	6.1%
COMPLEX AIS SOFTWARE	50.0%	50.0%	100.0%	100.0%	5.0%
NON COMPLEX AIS SOFTWARE	55.0%	45.0%	100.0%	81.8%	4.1%

How are SW Maintenance Costs Distributed Over Time?

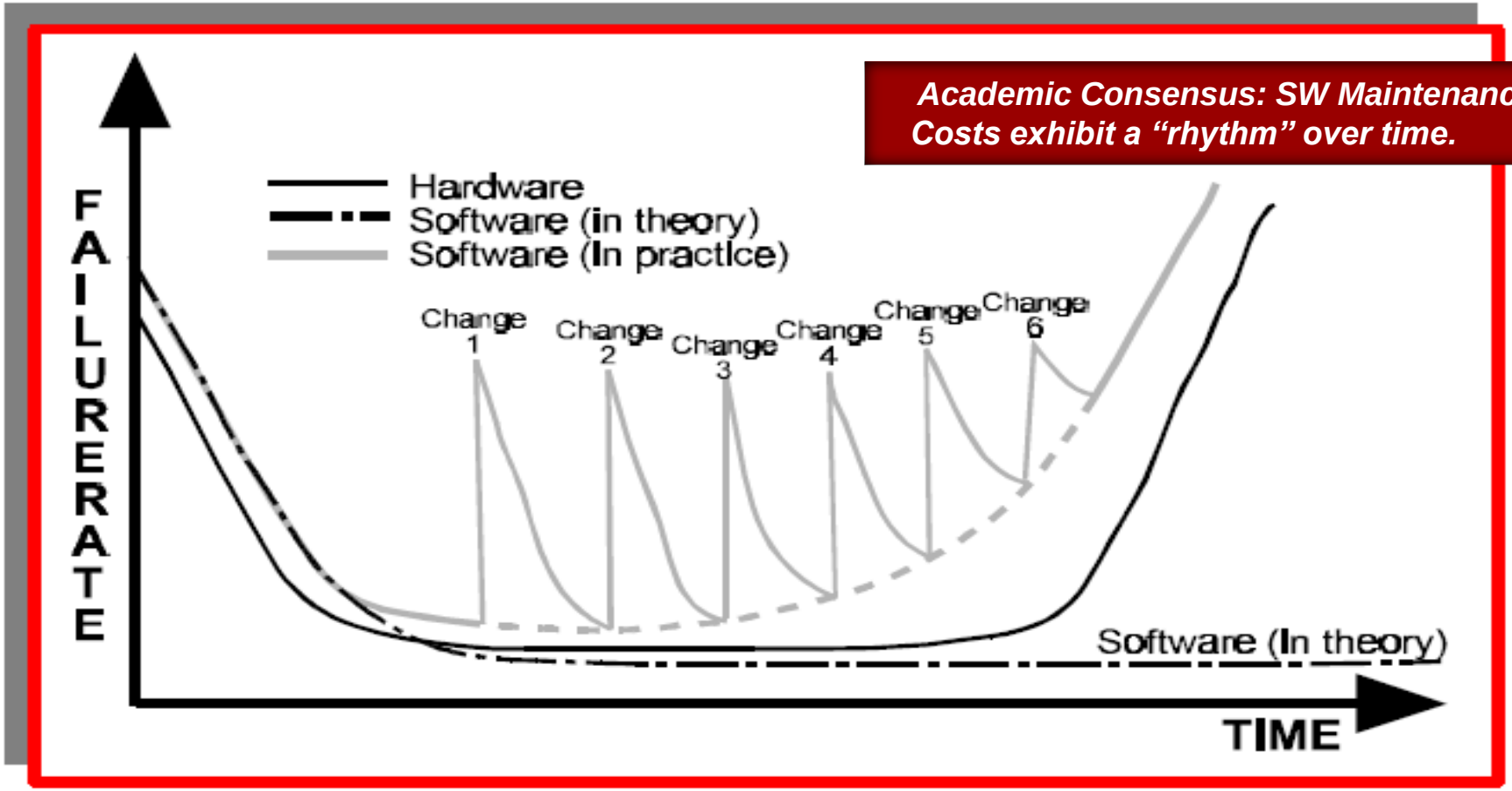
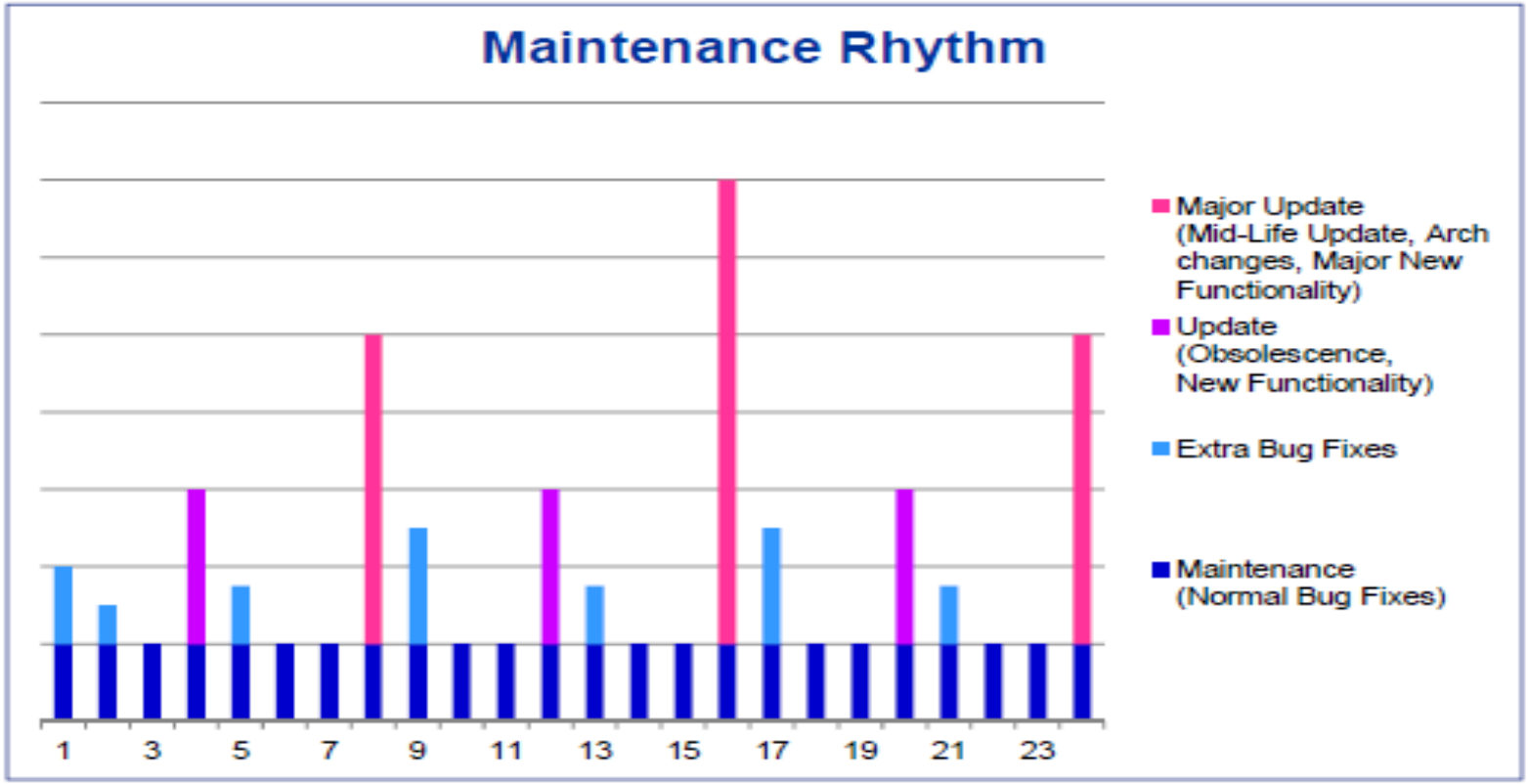


Figure 12-5. Bathtub Curves for Hardware and Software

Ref: ***Guidelines for Successful Acquisition and Management of Software Intensive Systems, (GSAM, Version 3, Chapter 12), USAF AFIT, 1997***

How are SW Maintenance Costs Distributed Over Time?



Academic Consensus: SW Maintenance Costs exhibit a "rhythm" over time.

Ref: *Software Maintenance Cost Estimating Relationships: One Size Does Not Fit All, ODASA-CE, 2013*

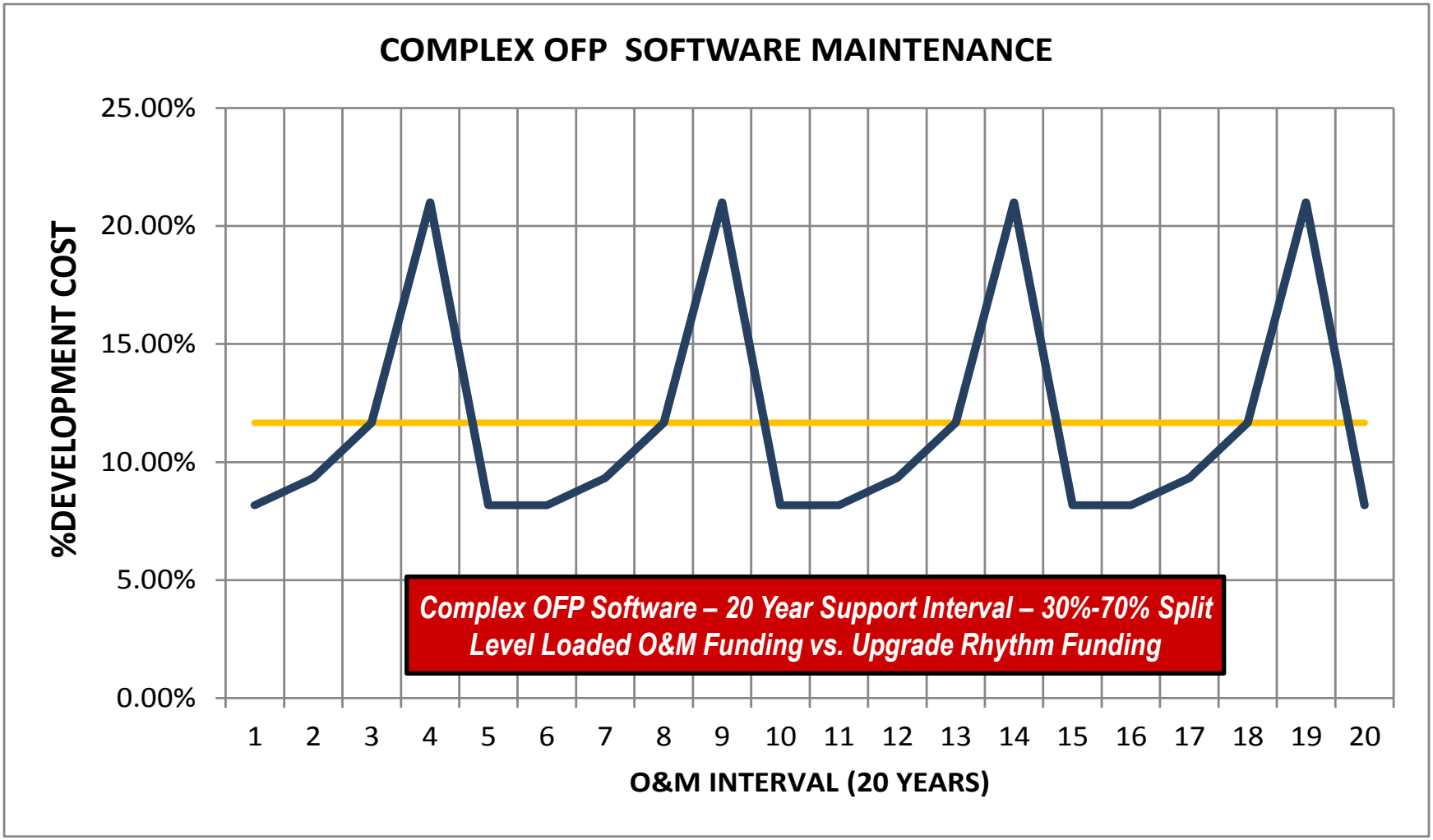
How are SW Maintenance Costs Distributed Over Time?

20 YEAR SERVICE LIFE - DEVELOPMENT - MAINTENANCE COMPARISON	DEVELOPMENT COST	MAINTENANCE COST	LIFE CYCLE COST	MAIN/DEV RATIO
COMPLEX OFP SOFTWARE	30.0%	70.0%	100.0%	233.3%

LEVEL LOAD % OF DEV COST PER YEAR	PDSS-PPSS YEAR	PHASED SUPPORT FRACTION	MAINT EFFORT % DEV COST	
11.67%	1	0.70	8.17%	
11.67%	2	0.80	9.33%	
11.67%	3	1.00	11.67%	
11.67%	4	1.80	21.00%	
11.67%	5	0.70	8.17%	58.33%
11.67%	6	0.70	8.17%	
11.67%	7	0.80	9.33%	
11.67%	8	1.00	11.67%	
11.67%	9	1.80	21.00%	
11.67%	10	0.70	8.17%	58.33%
11.67%	11	0.70	8.17%	
11.67%	12	0.80	9.33%	
11.67%	13	1.00	11.67%	
11.67%	14	1.80	21.00%	
11.67%	15	0.70	8.17%	58.33%
11.67%	16	0.70	8.17%	
11.67%	17	0.80	9.33%	
11.67%	18	1.00	11.67%	
11.67%	19	1.80	21.00%	
11.67%	20	0.70	8.17%	58.33%
			233.33%	233.33%

Complex OFP Software – 20 Year Support Interval – 30%-70% Split

How are SW Maintenance Costs Distributed Over Time?



Case Study: Software Maintenance Cost for APG-77 Radar

Case Study – Estimating Software O&M Costs

Case Study

- *Our intent is to shown the differences between use of the DoD method and the Cost Factor method for estimating software O&M cost. The APG-77 radar was developed by the Northrop Grumman/Raytheon team to equip the F-22 fighter. The software codes here are treated as entirely new. Code sizes shown below were obtained from several sources and adjusted for changes during the extended development program.*

SOFTWARE SLOC SUMMARY	NEW SLOC	REUSED SLOC	TOTAL SLOC
OPERATIONAL FLIGHT SW	300000	0	300000
TEST LABORATORY SOFTWARE	35000	0	35000
SIMULATIONS & MODELS	56500	0	56500
SUPPORT SOFTWARE	41500	0	41500
TOTAL SYSTEM SLOC	433000	0	433000

Ref: Stem, D., Dryden, J. et. al., A Cost, Technical, and Industrial-Base Review of Select Airborne Radars, RAND National Defense Research Institute, 2008

Case Study – APG-77 Software Development Cost (FY14 M$)

SOFTWARE DEVELOPMENT - COST SUMMARY (FY14 M$) UNCLASSIFIED
APG-77 SOFTWARE SUITE

ACQUISITION COST ELEMENT	CFE SUITE (FY14 M$)	GFE SUITE (FY14 M$)	TOTAL ACQUISION OUTLAY (FY14 M$)	PERCENTAGE OF DEVELOPMENT COST
o ENG & MFG DEVELOPMENT				
SW ENGINEERING (NEW CODE)	$128.052	$0.000	$128.052	39.34%
SW ENGINEERING (REUSED CODE)	$0.000	$0.000	$0.000	
TEST & DEVELOPMENT	$7.315	$0.000	$7.315	2.25%
SUPPLIER NONRECURRING	$0.000	$0.000	$0.000	
COTS SOFTWARE LICENSES	$0.000	$0.000	$0.000	
ILS REQUIREMENTS ANALYSIS	$8.813	$0.000	$8.813	2.71%
QUALITY ASSURANCE ANALYSIS	$3.742	$0.000	$3.742	1.15%
SYSTEM ENG & PROGRAM MANAGEMENT	$160.599	$0.000	$160.599	49.34%
SUBTOTAL SOFTWARE DEVELOPMENT	$308.521	$0.000	$308.521	
o SUPPORT INVESTMENT				
GROUND SUPPORT EQUIPMENT	$0.000	$0.000	$0.000	
TRAINING EQUIPMENT & SERVICES	$9.256	$0.000	$9.256	2.84%
ENGINEERING & SUPPORT DATA	$7.713	$0.000	$7.713	2.37%
INITIAL SPARES	$0.000	$0.000	$0.000	
SITE ACTIVATION/ICS	$0.000	$0.000	$0.000	
SUBTOTAL SUPPORT INVESTMENT	$16.969	$0.000	$16.969	
o ACQUISITION PRICE TOTAL GOVERNMENT OUTLAY $	$325.490	$0.000	$325.490	100.00%
	(FY14 M$)	(FY14 M$)	(FY14 M$)	

UNCLASSIFIED

Case Study – APG-77 Software Development Cost (FY14 M$)

Total Software Effort (Percentages) used to allocate O&M costs to lower level WBS elements

	DEV COST	PERCENT DEV	PERCENT OF SW CHNGS
SOFTWARE CHANGES	$128.052	39.34%	
SOFTWARE LICENSES	$0.000	0.00%	0
INFORMATION ASSURANCE	$11.057	3.40%	8.64%
CERTIFICATION & ACCREDITATIONS	$7.713	2.37%	6.02%
SUSTAINING ENGINEERING	$121.23	37.25%	94.67%
FACILITIES & INFRASTRUCTURE	$9.256	2.84%	7.23%
PROGRAM MANAGEMENT	$48.180	14.80%	37.63%
	$325.490	100.00%	154.19%
		USED IN COST FACTOR METHOD	USED IN DoD METHOD

Case Study – APG-77 SW O&M Cost (FY14 M$) – DoD Method

The DoD Method

- **Number of lines of code per software engineer**
  - Each engineer can maintain 20K-25K LOC/ESLOC
  - Does not reflect the impact of software reuse or COTS

TOTAL SLOC DELIVERED	SLOC	SLOC PER FTE YEAR	SOFTWARE FTE MAINTENANCE	
OPERATIONAL FLIGHT SW	300000	20000	15.00	
TEST LABORATORY SOFTWARE	35000	20000	1.75	
SIMULATIONS & MODELS	56500	20000	2.83	
SUPPORT SOFTWARE	41500	20000	2.08	
		TOTAL SW MAINT FTE	21.65	
		ENG MHRS PER YEAR	41568	
		WRAP RATE	$181.38	FY14 $, PRICE
		ANNUAL SW MAINT COST	$7.540	(FY14 M$)
		OTHER SUPPORT COSTS	$11.626	SEPM, QA, TEST (154.2%)
		TOTAL ANNUAL SW MAINT COST	$19.165	(FY14 M$)
		LIFE CYCLE O&M COST (20 YRS)	$383.307	(FY14 M$)
	LIFE CYCLE O&M FRACTION OF DEV COST		117.76%	

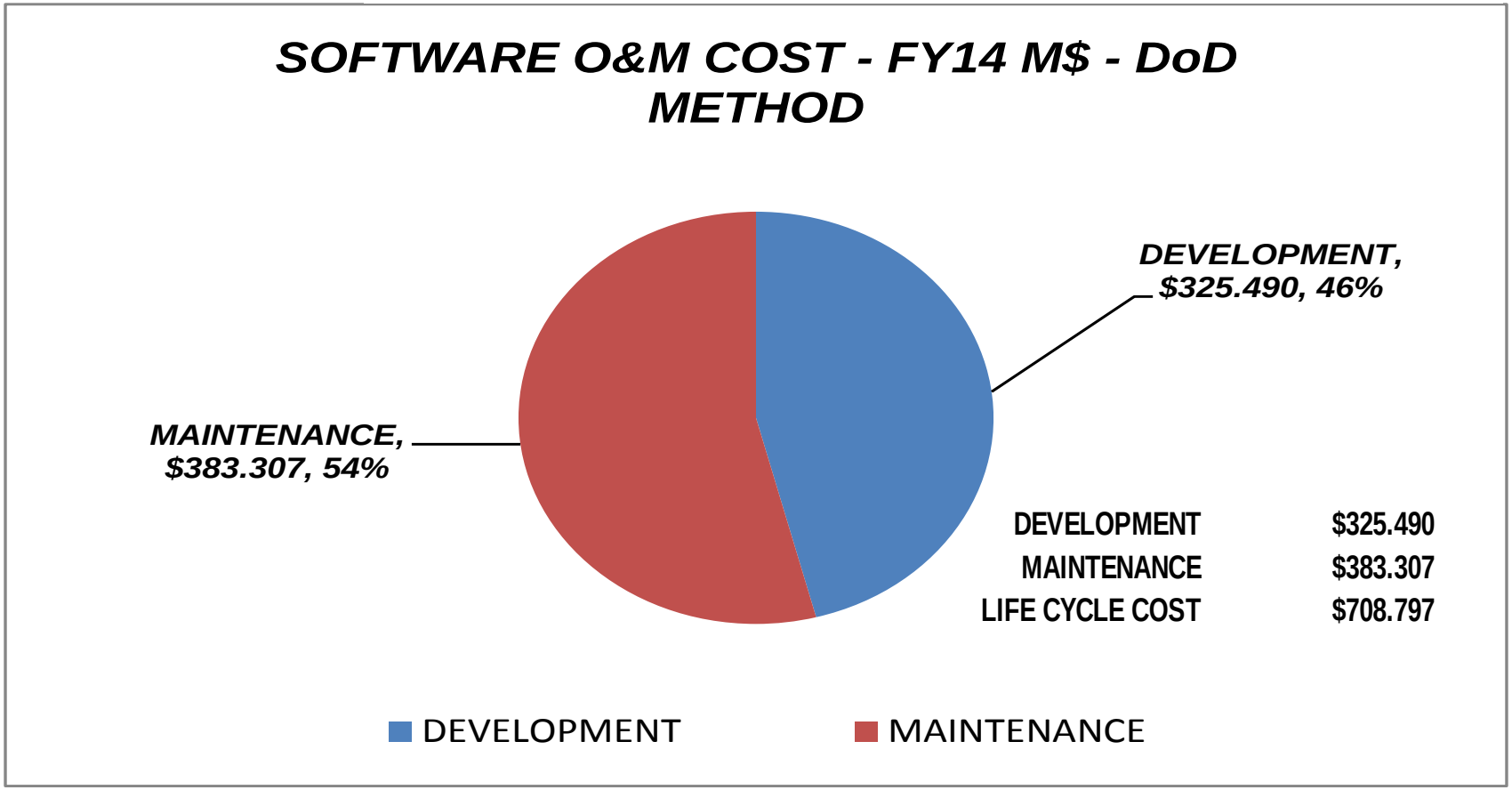
INDEPENDENT VARIABLE

INDEPENDENT VARIABLE

Case Study – APG-77 Software O&M Cost (FY14 M$) - DoD

The DoD Method

- Number of lines of code per software engineer
  - Each engineer can maintain 20K-25K LOC/ESLOC
  - Does not reflect the impact of software reuse or COTS



Case Study – APG-77 Software O&M Cost (FY14 M$) – DoD Method – Level Load Details IAW O&M WBS

The DoD Method

SOFTWARE DEVELOPMENT COST (FY14 M$)	$325.490		
ANNUAL SOFTWARE O&M COST (FY14 M$)	$19.165	LEVEL LOADED O&M COST PER YEAR	$383.307 20 YEAR O&M COST
SOFTWARE O&M COST ELEMENTS	PERCENTAGE		
SOFTWARE CHANGES		$7.540	$150.795
SOFTWARE LICENSES	0.00%	$0.000	$0.000
INFORMATION ASSURANCE	8.64%	$0.651	$13.021
CERTIFICATION & ACCREDITATIONS	6.02%	$0.454	$9.083
SUSTAINING ENGINEERING	94.67%	$7.138	$142.765
FACILITIES & INFRASTRUCTURE	7.23%	$0.545	$10.900
PROGRAM MANAGEMENT	37.63%	$2.837	$56.737
	154.19%	$19.165	$383.302

Case Study – APG-77 Software O&M Cost (FY14 M$) – DoD Method – Rhythm Load Details IAW O&M WBS

The DoD Method- Time Phasing "Rhythm"

DOD METHOD - O&M COST ALLOCATIONS	0.7000 YEAR 1	0.8000 YEAR 2	1.0000 YEAR 3	1.8000 YEAR 4	0.7000 YEAR 5	0.7000 YEAR 6	0.8000 YEAR 7	1.0000 YEAR 8	1.8000 YEAR 9	0.7000 YEAR 10
SOFTWARE CHANGES	$5.278	$6.032	$7.540	$13.572	$5.278	$5.278	$6.032	$7.540	$13.572	$5.278
SOFTWARE LICENSES	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
INFORMATION ASSURANCE	$0.456	$0.521	$0.651	$1.172	$0.456	$0.456	$0.521	$0.651	$1.172	$0.456
CERTIFICATION & ACCREDITATIONS	$0.318	$0.363	$0.454	$0.817	$0.318	$0.318	$0.363	$0.454	$0.817	$0.318
SUSTAINING ENGINEERING	$4.997	$5.711	$7.138	$12.849	$4.997	$4.997	$5.711	$7.138	$12.849	$4.997
FACILITIES & INFRASTRUCTURE	$0.381	$0.436	$0.545	$0.981	$0.381	$0.381	$0.436	$0.545	$0.981	$0.381
PROGRAM MANAGEMENT	$1.986	$2.269	$2.837	$5.106	$1.986	$1.986	$2.269	$2.837	$5.106	$1.986
	$13.416	$15.332	$19.165	$34.497	$13.416	$13.416	$15.332	$19.165	$34.497	$13.416
	0.7000 YEAR 11	0.8000 YEAR 12	1.0000 YEAR 13	1.8000 YEAR 14	0.7000 YEAR 15	0.7000 YEAR 16	0.8000 YEAR 17	1.0000 YEAR 18	1.8000 YEAR 19	0.7000 YEAR 20
SOFTWARE CHANGES	$5.278	$6.032	$7.540	$13.572	$5.278	$5.278	$6.032	$7.540	$13.572	$5.278
SOFTWARE LICENSES	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
INFORMATION ASSURANCE	$0.456	$0.521	$0.651	$1.172	$0.456	$0.456	$0.521	$0.651	$1.172	$0.456
CERTIFICATION & ACCREDITATIONS	$0.318	$0.363	$0.454	$0.817	$0.318	$0.318	$0.363	$0.454	$0.817	$0.318
SUSTAINING ENGINEERING	$4.997	$5.711	$7.138	$12.849	$4.997	$4.997	$5.711	$7.138	$12.849	$4.997
FACILITIES & INFRASTRUCTURE	$0.381	$0.436	$0.545	$0.981	$0.381	$0.381	$0.436	$0.545	$0.981	$0.381
PROGRAM MANAGEMENT	$1.986	$2.269	$2.837	$5.106	$1.986	$1.986	$2.269	$2.837	$5.106	$1.986
	$13.416	$15.332	$19.165	$34.497	$13.416	$13.416	$15.332	$19.165	$34.497	$13.416
TOTAL O&M COST - 20 YEARS	$383.302									

Case Study – APG-77 Software O&M Cost (FY14 M$) – Cost Factor Method

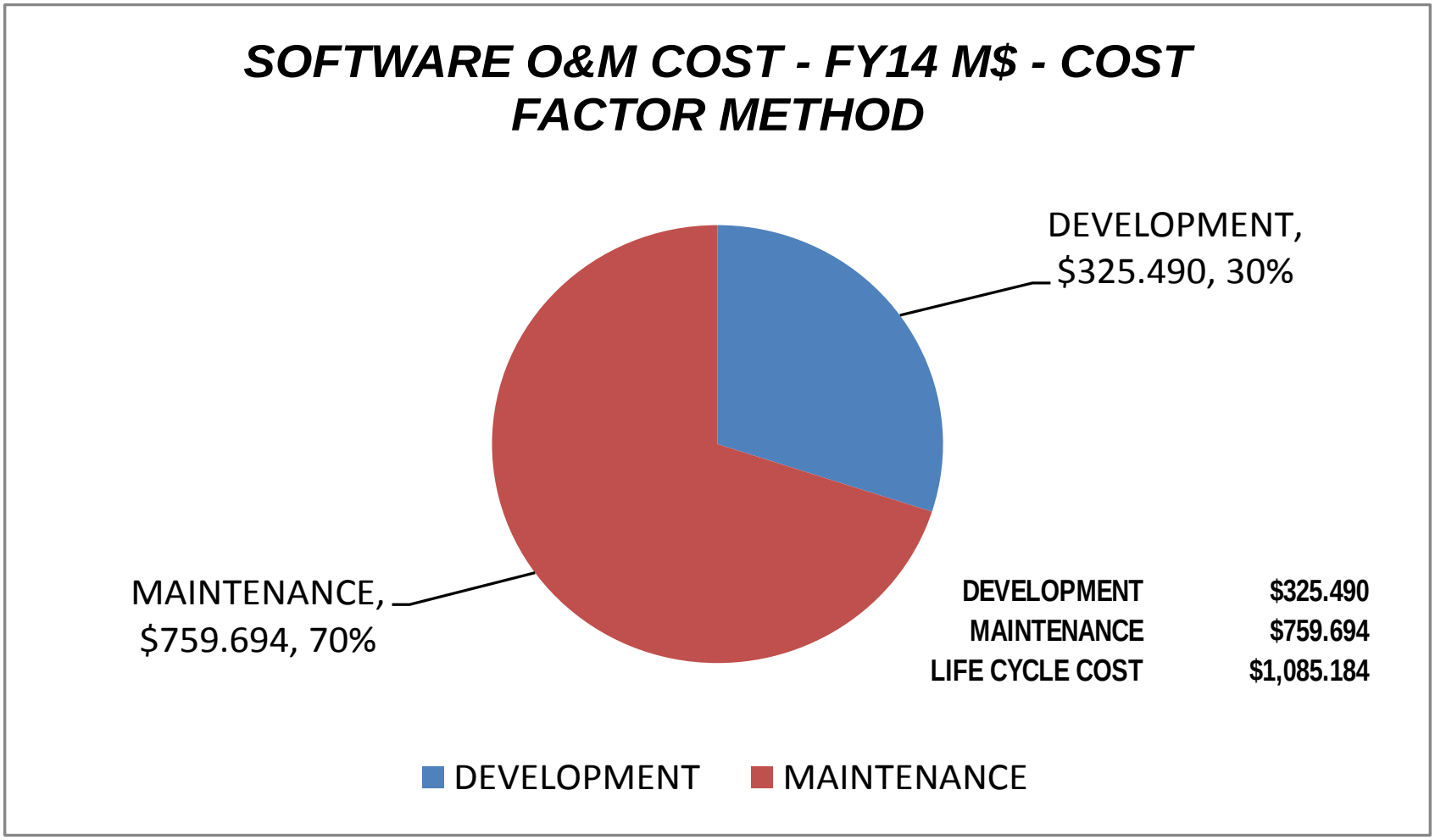
The Cost Factor Method

- Software maintenance estimated as a percentage of development costs
  - Rule(s) of thumb - development based:
    - S/W maintenance costs - 2/3 of total S/W life cycle costs
    - S/W maintenance costs - 60% to 75% of total S/W life cycle costs
    - Annual S/W maintenance costs - 5% to 10% of total S/W life cycle costs
  - Ignores total system life cycle software growth and maintenance requirements/strategy/tasks

TOTAL SW DEVELOPMENT COST	$325.490	(FY14 M$)
O&M COST FACTOR PER YEAR	11.67%	
ANNUAL SW MAINT COST	$37.985	(FY14 M$)
LIFE CYCLE O&M COST (20 YRS)	$759.694	(FY14 M$)
LIFE CYCLE O&M FRACTION OF DEV COST	233.40%	

Case Study – APG-77 Software O&M Cost (FY14 M$) – Cost Factor Method

The Cost Factor Method



Case Study – APG-77 Software O&M Cost (FY14 M$) – Cost Factor Method – Level Load Details IAW O&M WBS

The Cost Factor Method

SOFTWARE DEVELOPMENT COST (FY14 M$)	$325.490		
ANNUAL SOFTWARE O&M COST (FY14 M$)	$37.985	LEVEL LOADED O&M COST	20 YEAR
SOFTWARE O&M COST ELEMENTS	PERCENTAGE	PER YEAR	O&M COST
SOFTWARE CHANGES	39.34%	$14.943	$298.863
SOFTWARE LICENSES	0.00%	$0.000	$0.000
INFORMATION ASSURANCE	3.86%	$1.466	$29.324
CERTIFICATION & ACCREDITATIONS	2.25%	$0.855	$17.093
SUSTAINING ENGINEERING	34.54%	$13.119	$262.383
FACILITIES & INFRASTRUCTURE	5.21%	$1.979	$39.580
PROGRAM MANAGEMENT	14.80%	$5.622	$112.450
	100.00%	$37.985	$759.694

Case Study – APG-77 Software O&M Cost (FY14 M$) – Cost Factor Method – Rhythm Load Details IAW O&M WBS

	0.0817	0.0933	0.1167	0.2101	0.0817	0.0817	0.0933	0.1167	0.2101	0.0817
COST FACTOR METHOD - O&M COST ALLOCATIONS	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
SOFTWARE CHANGES	$10.458	$11.951	$14.939	$26.902	$10.458	$10.458	$11.951	$14.939	$26.902	$10.458
SOFTWARE LICENSES	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
INFORMATION ASSURANCE	$0.903	$1.032	$1.290	$2.323	$0.903	$0.903	$1.032	$1.290	$2.323	$0.903
CERTIFICATION & ACCREDITATIONS	$0.630	$0.720	$0.900	$1.620	$0.630	$0.630	$0.720	$0.900	$1.620	$0.630
SUSTAINING ENGINEERING	$9.901	$11.315	$14.144	$25.470	$9.901	$9.901	$11.315	$14.144	$25.470	$9.901
FACILITIES & INFRASTRUCTURE	$0.756	$0.864	$1.080	$1.945	$0.756	$0.756	$0.864	$1.080	$1.945	$0.756
PROGRAM MANAGEMENT	$3.935	$4.497	$5.621	$10.122	$3.935	$3.935	$4.497	$5.621	$10.122	$3.935
	$26.582	$30.379	$37.974	$68.382	$26.582	$26.582	$30.379	$37.974	$68.382	$26.582
	0.0817	0.0933	0.1167	0.2101	0.0817	0.0817	0.0933	0.1167	0.2101	0.0817
	YEAR 11	YEAR 12	YEAR 13	YEAR 14	YEAR 15	YEAR 16	YEAR 17	YEAR 18	YEAR 19	YEAR 20
SOFTWARE CHANGES	$10.458	$11.951	$14.939	$26.902	$10.458	$10.458	$11.951	$14.939	$26.902	$10.458
SOFTWARE LICENSES	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
INFORMATION ASSURANCE	$0.903	$1.032	$1.290	$2.323	$0.903	$0.903	$1.032	$1.290	$2.323	$0.903
CERTIFICATION & ACCREDITATIONS	$0.630	$0.720	$0.900	$1.620	$0.630	$0.630	$0.720	$0.900	$1.620	$0.630
SUSTAINING ENGINEERING	$9.901	$11.315	$14.144	$25.470	$9.901	$9.901	$11.315	$14.144	$25.470	$9.901
FACILITIES & INFRASTRUCTURE	$0.756	$0.864	$1.080	$1.945	$0.756	$0.756	$0.864	$1.080	$1.945	$0.756
PROGRAM MANAGEMENT	$3.935	$4.497	$5.621	$10.122	$3.935	$3.935	$4.497	$5.621	$10.122	$3.935
	$26.582	$30.379	$37.974	$68.382	$26.582	$26.582	$30.379	$37.974	$68.382	$26.582
TOTAL O&M COST - 20 YEARS	$759.594									

Modeling Software Maintenance Costs in the O&M Phase

Conclusions

- *A lack of historical data has resulted in poor forecasting, poor budgeting, and poor understanding of software O&M costs. A few general concepts appear in the literature and seem to have wide support:*

  - Software O&M outlays probably exceed SW Development outlays, but there is no consensus for how much larger they should be. The DoD modeling method appears to generate lower O&M cost estimates than the cost factor method.

  - A standard Software O&M service life is currently undefined in Mil-Std-881C.

  - The scope of O&M outlays is probably related to total SLOC size, type or platform, and software complexity.

  - Software O&M budgets are usually level loaded by year, but reality probably requires incorporation a kind of rhythm distribution, to reflect quiet periods and peaks of update activity

Modeling Software Maintenance Costs in the O&M Phase

Conclusions

- Changes in software technology (auto-coding, new generation programming languages, etc.) could impact the scope of O&M outlays.

- Lower level Software O&M Work Breakdown Structures or "Maintenance Missions" can help us to understand the work being accomplished. Without data, however, our ability to estimate costs for these elements, or create models that operate in these areas is primitive, or limited at best.

Software Maintenance Costs – Research Bibliography

Collected Documents:

1) Estimating Software Maintenance Costs for U.S. Army Systems, ODASA-CE, 2013

2) Software Maintenance Cost Estimating Relationships: One Size Does Not Fit All, ODASA-CE, 2013

3) Clark, C. and Miller, C., PSMUG Conference Workshop #7, - Software Maintenance Cost Estimating Relationships, ODASA-CE, 2012

4) Michaluk, S., Software Maintenance in the Department of Defense, OSD Interest Areas and Perspectives 2012, DoD Maintenance Symposium, 2012

5) Reifer, D., Army Software Operations, Maintenance, and Sustainment Study Overview: What Life Cycle Software Centers Do, ODASA-CE, 2011

6) Buchmann, I., et. al., Towards an Estimation Model for Software Maintenance Cost, Technishe Universitat Darmstadt, FGR, 2011

7) Galorath, D.D., Software Total Ownership Costs: Development is Only Job 1, SEER, Inc., 2011

8) Jones, T.C., The Economics of Software Maintenance in the 21st Century, Software Productivity Research, Inc., 2006

Software Maintenance Costs – Research Bibliography

Collected Documents:

9) Lehman, D. Software Maintenance Refactoring, North Carolina State University, 2006

10) Hayes, J.H., et. al., A Metrics Based Software Maintenance Effort Model, University of Kentucky, 2004

11) Koskinen, J., et. al., Software Cost Estimation and Modernization Support, Information Technology Research Institute, University of Kyvaskyla, 2003

12) Mukhija, A., Estimating Software Maintenance, University of Zurich, 2003

13) Mukhija, A., Estimating Software Maintenance, IFI , 2002

14) Pigoski, T., Software Maintenance, Techsoft, Inc. 2001

15) Granja-Alvarez, J.C., et. al., A Method for Estimating Maintenance Cost in a Software Project: A Case Study , Software Maintenance Research and Practice, Volume 9, 161 – 175, 1997

16) Guidelines for Successful Acquisition and Management of Software Intensive Systems, (GSAM, Version 3, Chapter 12), USAF AFIT, 1997

Software Maintenance Costs – Research Bibliography

Collected Documents:

17) Bailey, E.K., et. al., Maintenance of Department of Defense Mission Critical and Mission Support Software; A Preliminary Characterization, LMI, 1997

18) Banker, R. et. Al., Software Complexity and Software Maintenance Costs, ACM Communications, 1993

19) Foster, J.R., Cost Factors in Software Maintenance, University of Durham, 1993

20) Banker, R.D., et. al., Software Complexity and Software Maintenance Costs, MIT, Sloan School of Management, 1992

21) NeSmith, R.E., A Study of Software Maintenance Costs of Air Force Large Scale Computer Systems, USAF, AFIT GSM, 1986

CRITICAL THINKING.
SOLUTIONS DELIVERED.