Life Cycle Cost Estimating for System of Systems

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Agenda

- Define a System of Systems
- Define UBR, a hypothetical scenario for SoS
- Define problem of UBR life cycle cost estimation
- UBR Estimation workflow and persona
- Cost Estimation of UBR Constituent Systems
- Cost Estimation of UBR
- Summary, Conclusion and References
- Q&A



Defining a System of Systems



Defining System of Systems

- Very large system using a framework or architecture to integrate constituent systems
- Exhibits emergent behavior not otherwise achievable by constituent systems
- SoS constituent systems:
 - Independently developed and managed
 - New or existing systems in various stages
 - May include multiple COTS products
 - Have their own purpose
 - Can dynamically come and go from SoS
- Typical Domains
 - Business: Enterprise-wide and cross-enterprise integrations
 - Military/Crisis Response: Dynamic communications infrastructure

Based on Mark Maier's SoS definition [Maier, 1998]



Defining "System of Systems"

• Many definitions of the term "System of Systems" exist:

A set or arrangement of interdependent systems that are related or connected to provide a given capability.

The loss of any part of the system will significantly degrade the performance or capabilities of the whole.

The development of a SoS solution will involve trade space between the systems as well as within an individual system performance.

Department of Defense, *Joint Capabilities Integration and Development System*, CJCSI 3170.01E, May 11, 2005.



A hypothetical System of System Scenario



Scenario: Unmanned Battlefield Reconnaissance (UBR)

The three main Constituent Systems identified for UBR are::

Unmanned Ground Vehicle System

Unmanned Areal Vehicle System

Ground Control Station System





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Presented at the 2010 ISPA/SCEA Joint Annual Conference and Training Workshop - www.iceaaonline.com Unmanned Battlefield Reconnaissance (UBR)

Unmanned Areal Vehicle System



Problem Definition of SoS Life Cycle Cost Estimation



 Q: If Life Cycle Cost (LCC) of UAV System is \$X_{uav} (i.e. to develop, produce and maintain), LCC of UGV System is \$X_{ugv} and LCC of GCS System is \$X_{gcs}, what will be the LCC of UBR?

• A: It depends



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LCC of UBR depends upon:

- Lots of things, some examples include:
 - Development , production and O&S of Integration cost between systems
 - Organizational and programmatic relationships between the constituent systems
 - Operational environment, including usage patterns
 - Program management of SoS through its life cycle phases
 - SoS-specific characteristics (e.g., emergent behavior)

Hence:
$$X_{uav} + X_{ugv} + X_{gcs} = X_{SoS}$$
 Doesn't hold true



UBR Estimation Workflow & Persona



UBR Estimation workflow

- DoD needs to deploy 150 UBR over three years starting from year 2015
- The development and production of UBR needs to be completed by no later than 2013
- DoD intends to maintain the deployed UBR for next 10 years

DoD now wants to set the budget aside hence needs an estimate for life cycle cost of UBR



DoD Program Manager for UBR

- A Program Manager at DoD has been tasked to provide life cycle estimate for UBR.
 - PM Invites contractors to submit estimates on constituent systems of UBR
 - PM Mandates that estimates be submitted in three different phases:
 - Development
 - Production
 - O&S
 - PM Validates , Consolidates and Submits the estimates to program office



Estimators at Contractors

- Estimators at each contractor are tasked to prepare winning bids
 - Estimators analyze the requirements document from DoD PM
 - Estimators prepare the estimates
 - Estimators submit the estimates to DoD PM



UBR Personas

- DoD Program Manager
- Estimators at contractors:
 - A (UAV Estimate),
 - B (UGV Estimate) and
 - C (GCS Estimate)
- Estimator at contractor D (Prime contractor a.k.a. the Lead Systems Integrator (LSI) estimates the SoS integration cost)



Cost Characteristics of the Constituent Systems



SoS Cost Contributors

The cost of a system of systems can be classified as cost of each of the following

- R&D,
- Production/fabrication,
- Operations,
- Maintenance and finally
- Retirement.

This is very similar to the life cycle cost of a system. However, internally each of these items has in it an added cost when operating as part of system of systems rather than an individual system.



R&D Cost

- The added cost in R&D stage comes from extra effort spent in designing an interface for each of the systems to communicate and collaborate with others
- Also effort needs to be made to make each system as generalized as possible so that it remains compatible with other systems over a long period of time.
- The extra challenge comes from the fact that the innovations and changes in the technology of each of the systems are not synchronized.



Fabrication/Production Cost

- In fabrication stage the added cost comes from synchronizing the fabrication of each of the systems this makes production and scheduling more expensive.
- Added to this is the challenge of controlling the schedule of systems which might be manufactured in various locations across the globe.



Re-design and Re-fabrication

- Most of the times existing systems are chosen to form the components of a system of systems. In that case redesign efforts of an existing system might be needed to make it compatible with other systems.
- The same applies to fabrication. Modifications might have to be made for compatibility purpose.



Grouping Cost

 Since system of systems is very large by nature consisting of hundreds or thousands of lower level components. Sometimes it might be economical to redesign the parts in the initial stages so that similar parts can be grouped to facilitate manufacturing and cost reduction during repair and maintenance.



 The difference between the cost of operation in systems and system of systems is that system of systems the cost is a function of time and location of the component systems.



Maintenance & Repair

- In an individual system the cost of down time is a function of productivity of that system but in system of systems cost of down time should take into account the cost down-time of all the constitutive systems in that system of system.
- This again depends on the dependence of the system of systems on the system which is under repair or maintenance.



Retirement & Reuse

- In a SoS since the constituent systems can also be used as stand alone systems, the retirement of the SoS does not necessarily mean complete disposal of the systems. They can be salvaged.
- The disassembly of the constituent systems from SoS is not as costly as disassembly of a system.



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3	🗄 🎯 UAV Assembly	3	3 0	Numbe	er of Produ	uctio	n Units		600		-				
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Presented at the 2010 ISPA/SCEA Joint Annual Conference and Training Workshop - www.iceaaonline.com Unmanned Ground Vehicle System

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3	🗄 🖓 🎧 UGV Assembly		3 1 Number of Production Units 600
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15	Light (LD) sensor - LD 1698	36	Maintenance Concept 16.Replace mods at EQP.Rep
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19	Reconnais 6 Other Cost	42	Intermediate Maintenance Points 0
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	→ Wheels, tracks, suspension → 🌉 Wheels, tracks, suspension	44	Number of Operational Hours Custom - Yearly
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		52	Unit Checkout Test Set Cost
	by PRICE® Systems	54	Unit Checkout Time At Organization

Presented at the 2010 ISPA/SCEA Joint Annual Conference and Training Workshop - www.iceaaonline.com Unmanned Ground Control Station System

2	i 🕞	Program Management of Ground Co	ontrol Station (GCS)	2	🕕 Num	nber of Prototyp	bes			2.00					
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Constituent Systems cost by phase

		Costs : Progra Currency in U	am M SD	Managemen (\$) (as spen	nt)	Unmanned Aerial Vehicle System (Total	Developmer	nt Produ	uction	Operation & Support		
	1	Program Man	age	ment of Unr	Unmanned Aerial Vehicle System (UAV) 66.020.47		66,020,475	23,300,4	480 42	42,719,995			_
	2	UAV Assembl		Costs : Pro	ograi h U.S	m Management of Unmanned Grou SD (\$) (as spent)	ind Vehicle (UGV)	lotal	Develo	pment	Production	Operation & Support	
	3	Air Vehicle Int										copport	
	4	Airframe											
	5	Fuselage	1	Program M	lana	gement of Unmanned Ground Veh	icle (UGV)	136,510,48	39 94,	615,973	1	41,894,51	5
	6	Wing	2	UGV Asse	mbh			53,260,4	51 3.	981.694	169.3	93 49,109,36	4
	7	Tail	3	Chassis Int	tean	ation. Assembly and Test		5 391 1	30	60,202	240.1	52 5.090.77	6
	8	Propulsion	-	Chassie St	nuct			36 393 3	37	211 019	3 475 1	52 32 606 16	n
	10	Engine Fuel System	7	Desculation	Luci			15 7	40	15 740	3,473,1	0 32,000,10	0
	11	Communicatio	2	Propulsion	Inte	egration, Assembly and Test		15,74	40	15,740		0	U
	12	Comms and I	6	Electrical I	Moto	or		3,240,6	86	47,802	1,683,8	98 1,508,98	/
	13	Navigation/G	7	Battery		Currency in USD (\$) (as spent)	Ground Control Sta	tion (GCS) - [S	Iotai		Development	Production	Support
	14	GPS	8	Other Cost									
\mathbf{V}	15	Guidanaa	9	Wheels, tra	2								
Λ_{uav}	32	2 Total 10 Wheels, tra 1 Program Management of Ground Control Station (G						CS)	8,853	. <mark>09</mark> 5	4,083,645	4,769,450	
	11 Reconnais			Reconnais	2	Command and Control Integration, Assembly and Test			4,850,659		555,269	0	4,295,390
			12	Reconnais	3	Armored Truck			115,835	.376	1,459,653	20,208,567	94,167,156
			13	Electro-opt	4	Command and Control stations			7,159	.131	777,825	0	6,381,305
			14	Liaht (LD)	5	Workstation			36,417	.866		2,107,364	34,310,503
		V			6	Server			22,926	.484		1.690.938	21,235,545
		ugv	2	1 Total	7	Network Device			3.770	574		219.770	3.550.804
					8	Ground Segment Software			1 234	365	994 574	0	239 791
					0	Ground Segment Application Soft	ware		3 247	186	2 780 1/9	185 944	281 092
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				ges	11	TOLA			207,775	,552	13,212,744	23,372,639	100,100,009



System of Systems life cycle cost

1	— …	Unmanned Battlefield Reconnaissance
2	÷ 🕞	Program Management of Unmanned Aerial Vehicle System (UAV)
33	÷ 🕞	Program Management of Unmanned Ground Vehicle (UGV)
53	÷ 🕞	Program Management of Ground Control Station (GCS)

32	Total	662,644,139	51,143,431	114,627,424	496,873,284
21	Total	1,073,568,675	400,196,778	259,765,966	413,605,931
32	Total	662,644,139	51,143,431	114,627,424	496,873,284
63	Total	1,943,988,206	475,877,211	434,336,286	1,033,774,709

$$X_{SoS} = X_{uav} + X_{ugv} + X_{gcs}$$

And what about "It depends" ?



Cost Estimation of SoS



Cost Components of UBR

1	🖃 🛅 🛛 Unmar	ned Battlefield Reconnaissance	
2	🗄 🕞 🛛 Pro	gram Management, Requirements and Acqisition of UBR	0
3	÷. 😯	Project Initiation and Planning	C
9	Ð 🗄	Project Management and Control	a
13	Ð 🖸	Quality Assurance Management	
18	Ð 🖸	Configuration Management	
23	Ð - 🔁	Vendor Management	
27	Ð - 🔁	Documentation	
32	ė	Integration and Interface with Multiple Systems	
33	÷ 🚱	Requirements Definition and Analysis	
37	🕞	System Design	
40	🕞	Development Engineering	
44	🕞	Development Manufacturing	C
50	🕞	Development Tooling and Test	n
53	🕞	Production Engineering	11
57	🕞	Production Manufacturing	
63	🕞	Production Tooling and Test	
66	🕞	Software Integration and Test	
73	🕞	System Integration and Test	
80	🕞	Operational Test and Evaluation	
85	🕞	Assembly Operation and Support	
90	÷ 🕞	Program Management and Requirements for Integration HW and SW	F
395	÷ 🕞	Program Management of Unmanned Aerial Vehicle System (UAV)	S
828	÷ 🕞	Program Management of Unmanned Ground Vehicle (UGV)	У
2714	÷ 🕞	Program Management of Ground Control Station (GCS)	

Cost of SoS Program Management and Requirements

Cost for interlinking and interfacing multiple constituent systems

Fraction or whole of constituent system cost



Cont.. Cost component of UBR



Cost for development, production and maintenance of Integration equipment



Presented at the 2010 ISPA/SCEA Joint Annual Conference and Training Workshop - www.iceaaonline.com Estimating Cost of Program Management and Requirements

- Consider all major cost drivers:
 - How many SoS related requirements?
 - How many unique interface protocol?
 - What level of service will be required?
 - How much process maturity and capability Lead System Integrator (LSI) has?

Consider risk assessment on each of these cost drivers by applying risk methodology such as triangular risk



Example of SoS requirements cost driver



of Requirements



\$

Estimating Cost of Interfacing and Interlinking constituent systems

- Consider all major cost drivers:
 - How mature is SoS architecture?
 - How mature and stable are constituent systems?
 - How many unique interface protocol?
 - Are the constituent systems ready for development, production or deployment?
 - What are the life cycle cost estimates of constituent systems?
 - Are there specific maintenance concepts for constituent system?

Consider risk assessment on each of these cost drivers by applying risk methodology such as triangular risk



Example of SoS Architecture cost driver





Cost consideration for estimating O&S cost of SoS

- UNIT-LEVEL MANPOWER
- UNIT OPERATION
- MAINTENANCE
- SUSTAINING SUPPORT
- CONTINUING SYSTEM IMPROVEMENTS
- INDIRECT SUPPORT
- DEMILITARIZATION AND DISPOSAL



Estimating maintenance cost of SoS

For each constituent system:

- Deployment Period
- Maintenance concepts
- Operational Hours
- MTBF

For the SoS:

- Roll-up of each constituent system
- SoS mission objectives

Consider risk assessment on each of these cost drivers by applying risk methodology such as triangular risk



UBR's life cycle cost estimate

	Costs : Program Management, Requirements and Acqisition of UBF Currency in USD (\$) (as spent)	Total	Development	Production	Operation & Support
1	Program Management, Requirements and Acqisition of UBR	116,120,956	88,272,159	27,848,797	
2	Integration and Interface with Multiple Systems	32,323,796	2,703,272	9,753	29,610,771
3	Program Management and Requirements for Integration HW and	21,586,699	21,319,619	267,080	
4	Integration hw and sw assembly	33,266,683	30,538,315	5,928	2,722,440
5	Integration hardware	1,954,134	1,704,500	192,671	56,963
6	Integration software	2,483,203	2,112,307	53,876	317,020
7	Integration monitoring software	19,193,885	10,002,033	1,203,430	7,988,422
8	Integration servers	357,802		33,000	324,802
9	Integration monitoring workstations	408,186		35,555	372,631
10	Cables, network devices etc	476,420	367,414	55,140	53,866
11	Program Management of Unmanned Aerial Vehicle System (UAV)	66,020,475	41,367,885	24,652,590	
12	UAV Assembly	28,016,640	1,572,593	1,619,749	24,824,298
13	Air Vehicle Integration, Assembly and Test	33,383,241	1,415,025	2,213,817	29,754,399
14	Airframe	18,859,878	480,728	1,995,281	16,383,869
15	Fuselage	50,246,020	1,984,450	13,599,089	34,662,482
16	Wing	78,968,818	1,182,804	9,287,304	68,498,710
72	Total	2,172,159,972	669,495,656	427,442,691	1,075,221,624

X_{gcs}



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 $X_{SoS} > Or < X_{uav} + X_{ugv} +$

5% Risk report of UBR

		5% Risk Report : Unmanned Battlefield Reconnaissance - [System Folder] Currency in USD (\$) (as spent)		Cost Risk Analysis
		Confidence	Cost	52-0000000 52-35000000
	5	25%	2,275,363,201	S230000000
	6	30%	2,283,719,749	\$225000000
	7	35%	2,291,495,724	\$220000000
	8	40%	2,298,888,810	6 1900 1900 1900 1900 1900 1900 1900 190
	9	45%	2,306,069,735	ت السلمين المعالية ال Unmanned Battlefield Reconnaissance
	10	50%	2,313,158,397	5% Risk Report : Unmanned Battlefield Reconnaissance - [System Folder] Currency in USD (5) (as spent)
	11	55%	2,320,268,848	
	12	60%	2,327,516,557	
	13	65%	2,335,025,857	
	14	70%	2,342,976,528	
	15	75%	2,351,581,394	
	16	80%	2,361,200,379	80% Confidence Level
	17	85%	2,372,462,128	
	18	90%	2,386,708,584	
	19	95%	2,407,981,214	
- 1				



Defending SoS Estimates

- Credibility is important factor in defending
 - Do cross checks, if possible use multiple estimation methodology
 - Assemble backup documentation and be ready to refer to them
 - Conduct peer reviews before presenting to board
 - Be thorough by questioning everything
 - Validate your cost models
 - Explain basis of assumptions and scope of estimate
 - Know your SoS



Summary, Conclusion and References



Major cost drivers of SoS

- Interconnectivity between UAV, UGV and GCS
- Effects of technological or requirements changes for UAV, UGV and GCS while SoS is deployed in field
- Size and complexity of UBR
- Cost of constituent systems UAV, UGV and GCS



SoS Estimation Consideration

- Time phased deployment of UAV, UGV and GCS systems
- Be ready you will need to re-estimate and "quickly"
- You will need to stay engaged through out SoS mission: Estimation in SoS scenario is just NOT an upfront one time activity
- DoD 5000-02 requires evolutionary development of material solution: your estimates will need to be incremental, chances are you will be contacted post MS-C for next increment

Ratio of Program Management cost to total cost of UBR is 6%

Ratio of integration cost to total cost of UBR is 5%



References

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Q & A

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