Life Cycle Cost Estimating for System of Systems

Kishore Gagrani
Product Manager
PRICE Systems

Manmeet Grover
Principal Systems Engineer
Whole Life Engineering Directorate
Raytheon Missile Defense Center

Yousuf Mohammed
PhD Candidate,
Mechanical Engineering Dept.
Old Dominion University

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.

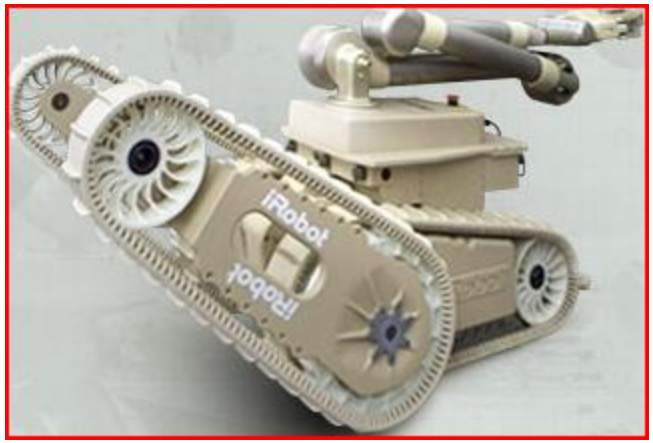
Department of Defense, *Joint Capabilities Integration and Development System*, CJCSI 3170.01E, May 11, 2005.

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

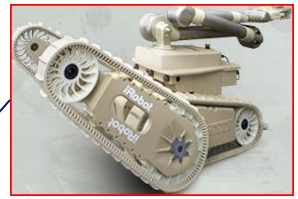
Unmanned Battlefield Reconnaissance (UBR)

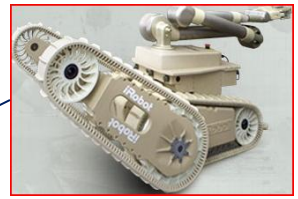
Unmanned Areal Vehicle System

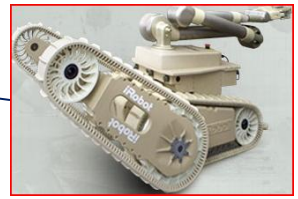
BOM

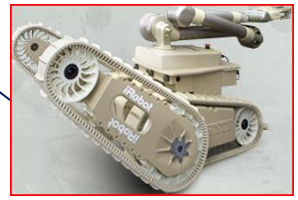
1		Unmanned Battlefield Reconnaissance (UBR)	Qty 150
2		Unmanned Aerial Vehicle System (UAV)	Qty 600
33		Unmanned Ground Vehicle (UGV)	Qty 600
53		Ground Control Station (GCS)	Qty 150

Ground Control Station System









Unmanned Ground Vehicle System

Problem Definition of SoS Life Cycle Cost Estimation

Problem:

- **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

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.

Operation Cost

- 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

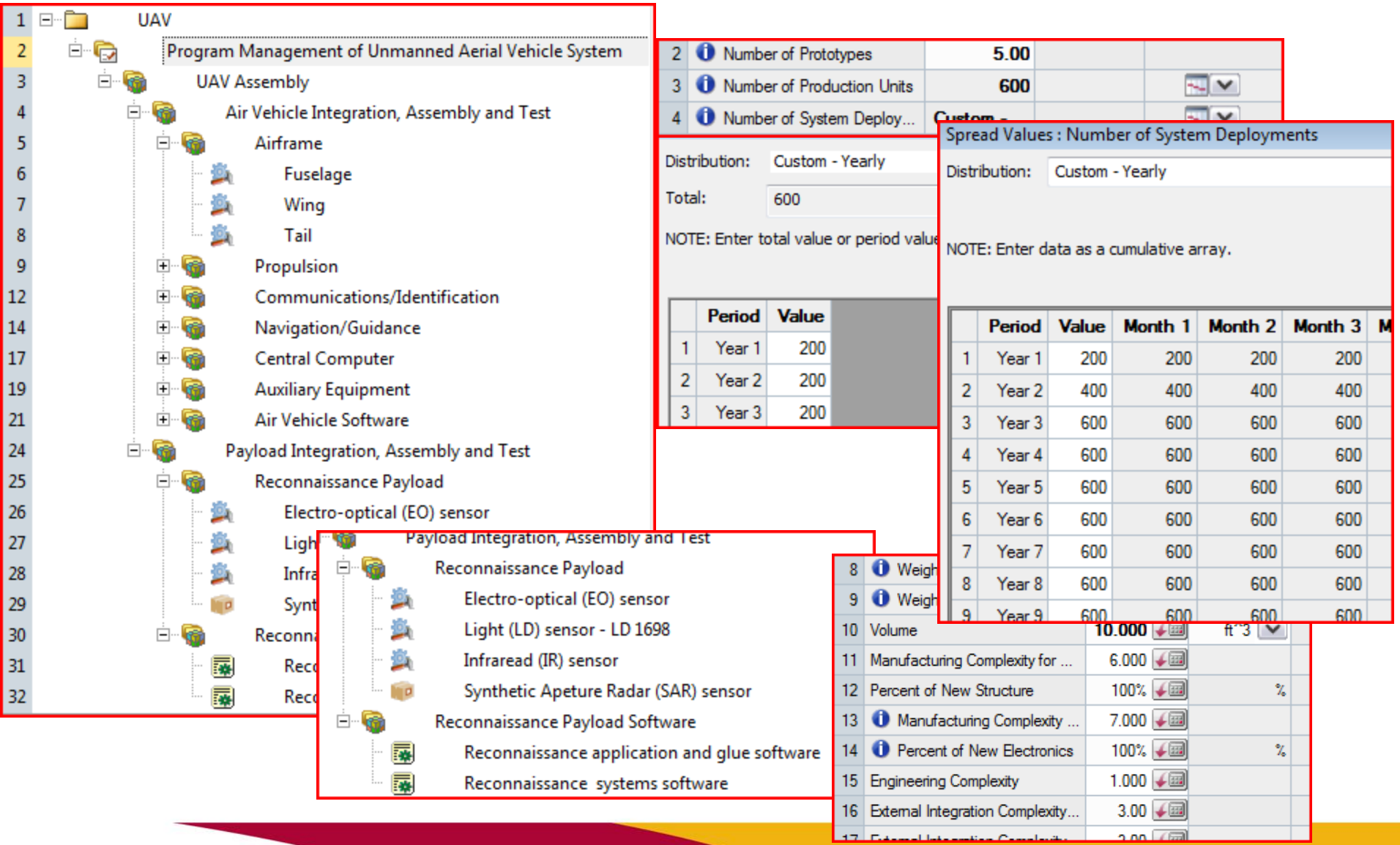
- In an individual system the cost of down time is a function of productivity of that system but in system of systems cost of down time should take into account the cost down-time of all the constitutive systems in that system of system.

- This again depends on the dependence of the system of systems on the system which is under repair or maintenance.

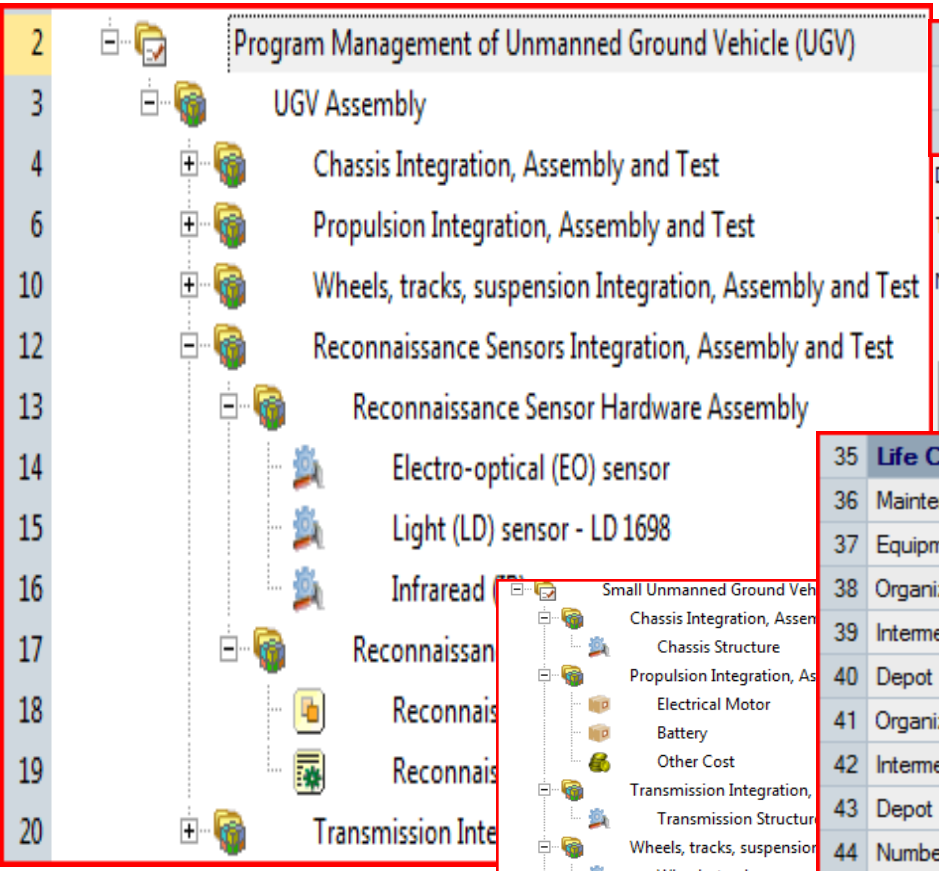
Retirement & Reuse

- 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.

Unmanned Areal Vehicle System



Unmanned Ground Vehicle System



2	Number of Prototypes	5.00		
3	Number of Production Units	600		
4	Number of System Deploy...	Custom - ...		

Distribution: Custom - Yearly

Total: 600

NOTE: Er

Spread Values : Number of System Deployments

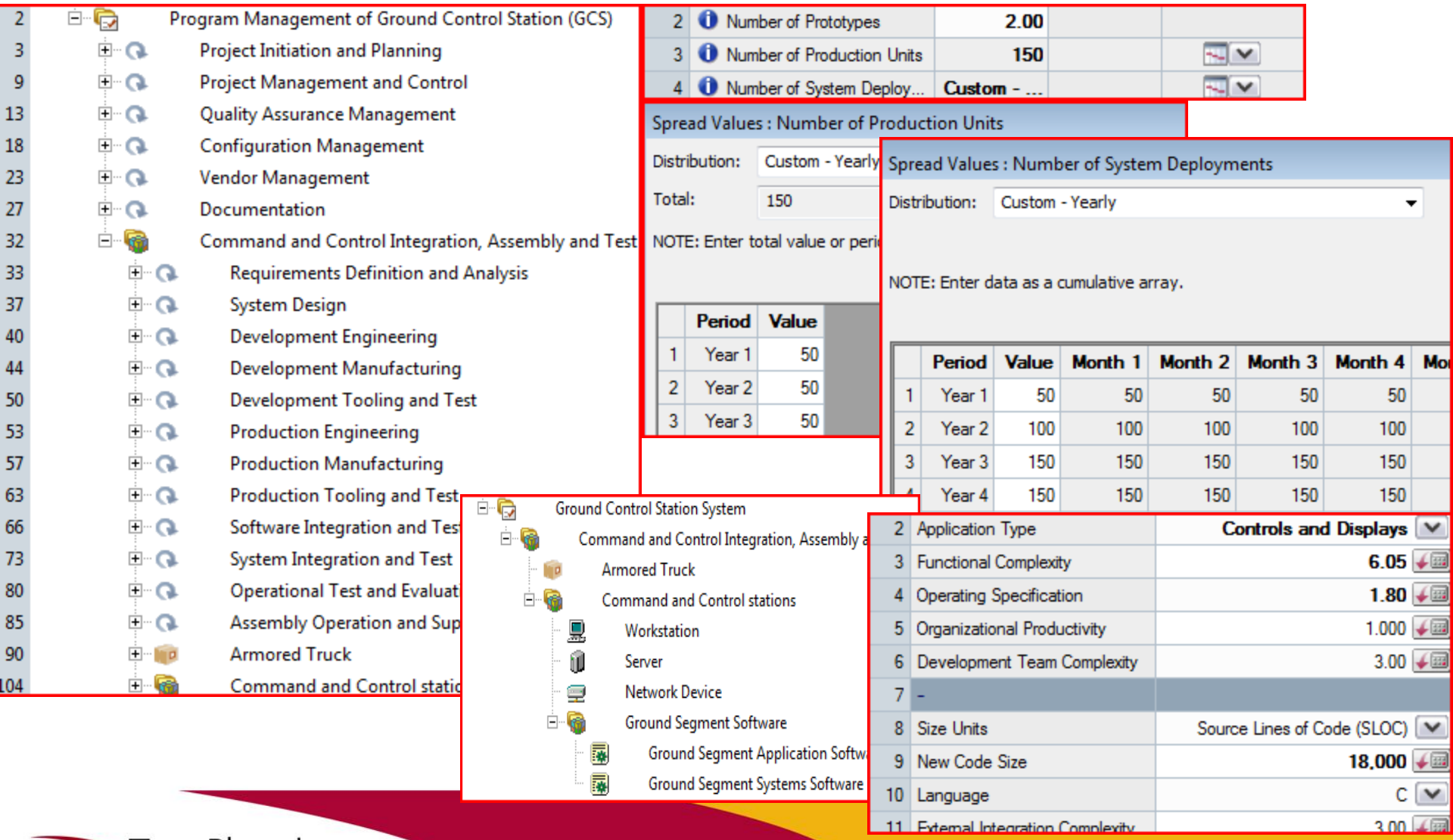
Distribution: Custom - Yearly

Pe

NOTE: Enter data as a cumulative array

35	**Life Cycle Deployment User Input**		
36	Maintenance Concept	16.Replace mods at EQP.Rep...	
37	Equipment Supply Points	1	
38	Organization Supply Points	0	
39	Intermediate Supply Points	0	
40	Depot Supply Points	0	
41	Organization Maintenance Points	0	
42	Intermediate Maintenance Points	0	
43	Depot Maintenance Points	1	
44	Number of Operational Hours	Custom - Yearly	
45	**Hardware Life Cycle User Input**		
46	Mean Time Between Failures	100.00	
47	Number Of Part Types	0.00	
48	Number Of Module Types	1.00	
49	Units Per Equipment Location	1.0	
50	Units Permitted To Be Out Of Service	0.00	
51	Contractor Unit Repair Cost	0.00	$ in
52	Contractor Module Repair Cost	0.00	$ in
53	Unit Checkout Test Set Cost	0.00	$ in
54	Unit Checkout Time At Organization	0.00	

Unmanned Ground Control Station System



TruePlanning® by PRICE® Systems

Constituent Systems cost by phase

	Costs : Program Management of Unmanned Aerial Vehicle System (UAV) Currency in USD ($) (as spent)	Total	Development	Production	Operation & Support
1	Program Management of Unmanned Aerial Vehicle System (UAV)	66,020,475	23,300,480	42,719,995	
2	UAV Assembl				
3	Air Vehicle Int				
4	Airframe				
5	Fuselage				
6	Wing				
7	Tail				
8	Propulsion				
9	Engine				
10	Fuel System				
11	Communicatic				
12	Comms and I				
13	Navigation/G				
14	GPS				
15	Guidance				
32	Total				

X_{uav}

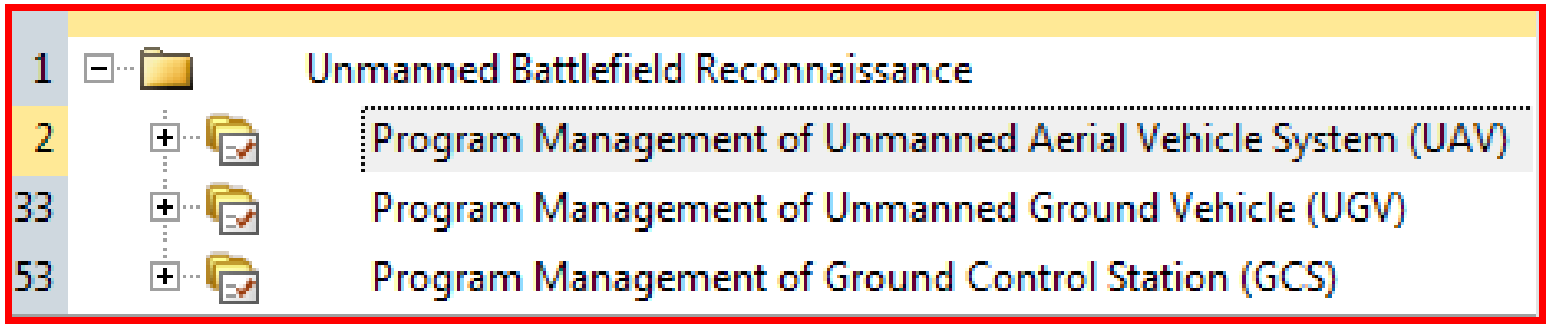
	Costs : Program Management of Unmanned Ground Vehicle (UGV) Currency in USD ($) (as spent)	Total	Development	Production	Operation & Support
1	Program Management of Unmanned Ground Vehicle (UGV)	136,510,489	94,615,973		41,894,515
2	UGV Assembly	53,260,451	3,981,694	169,393	49,109,364
3	Chassis Integration, Assembly and Test	5,391,130	60,202	240,152	5,090,776
4	Chassis Structure	36,392,337	311,019	3,475,158	32,606,160
5	Propulsion Integration, Assembly and Test	15,740	15,740	0	0
6	Electrical Motor	3,240,686	47,802	1,683,898	1,508,987
7	Battery				
8	Other Cost				
9	Wheels, tra				
10	Wheels, tra				
11	Reconnais				
12	Reconnais				
13	Electro-opt				
14	Light (LD) s				
21	Total				

X_{ugv}

	Costs : Program Management of Ground Control Station (GCS) - [S Currency in USD ($) (as spent)	Total	Development	Production	Operation & Support
1	Program Management of Ground Control Station (GCS)	8,853,095	4,083,645	4,769,450	
2	Command and Control Integration, Assembly and Test	4,850,659	555,269	0	4,295,390
3	Armored Truck	115,835,376	1,459,653	20,208,567	94,167,156
4	Command and Control stations	7,159,131	777,825	0	6,381,305
5	Workstation	36,417,866		2,107,364	34,310,503
6	Server	22,926,484		1,690,938	21,235,545
7	Network Device	3,770,574		219,770	3,550,804
8	Ground Segment Software	1,234,365	994,574	0	239,791
9	Ground Segment Application Software	3,247,186	2,780,148	185,944	281,093
10	Ground Segment Systems Software	3,480,657	2,561,631	190,605	728,422
11	**Total**	**207,775,392**	**13,212,744**	**29,372,639**	**165,190,009**

X_{gcs}

System of Systems life cycle cost



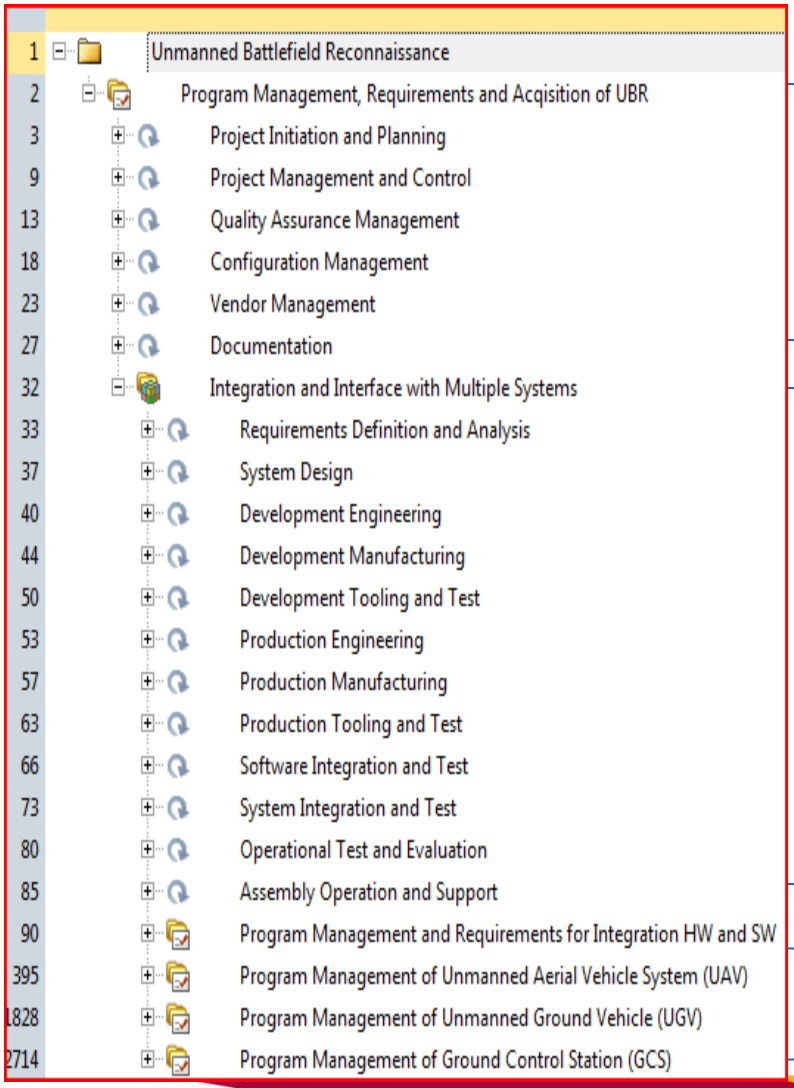
32	Total	662,644,139	51,143,431	114,627,424	496,873,284
21	Total	1,073,568,675	400,196,778	259,765,966	413,605,931
32	Total	662,644,139	51,143,431	114,627,424	496,873,284
63	Total	1,943,988,206	475,877,211	434,336,286	1,033,774,709

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

And what about “It depends” ?

Cost Estimation of SoS

Cost Components of UBR

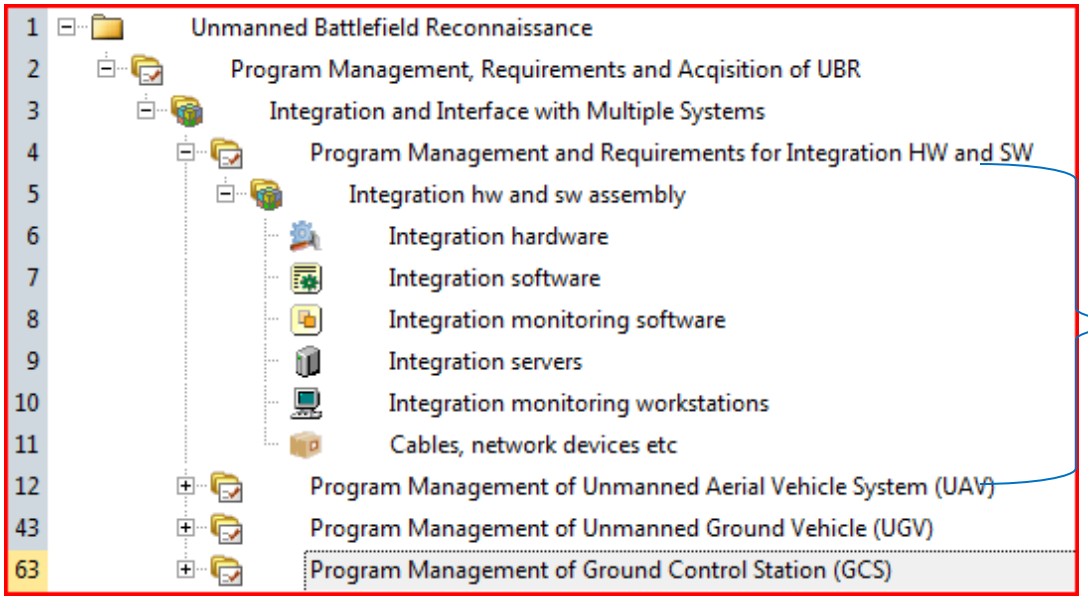


Cost of SoS Program Management and Requirements

Cost for interlinking and interfacing multiple constituent systems

Fraction or whole of constituent system cost

Cont.. Cost component of UBR



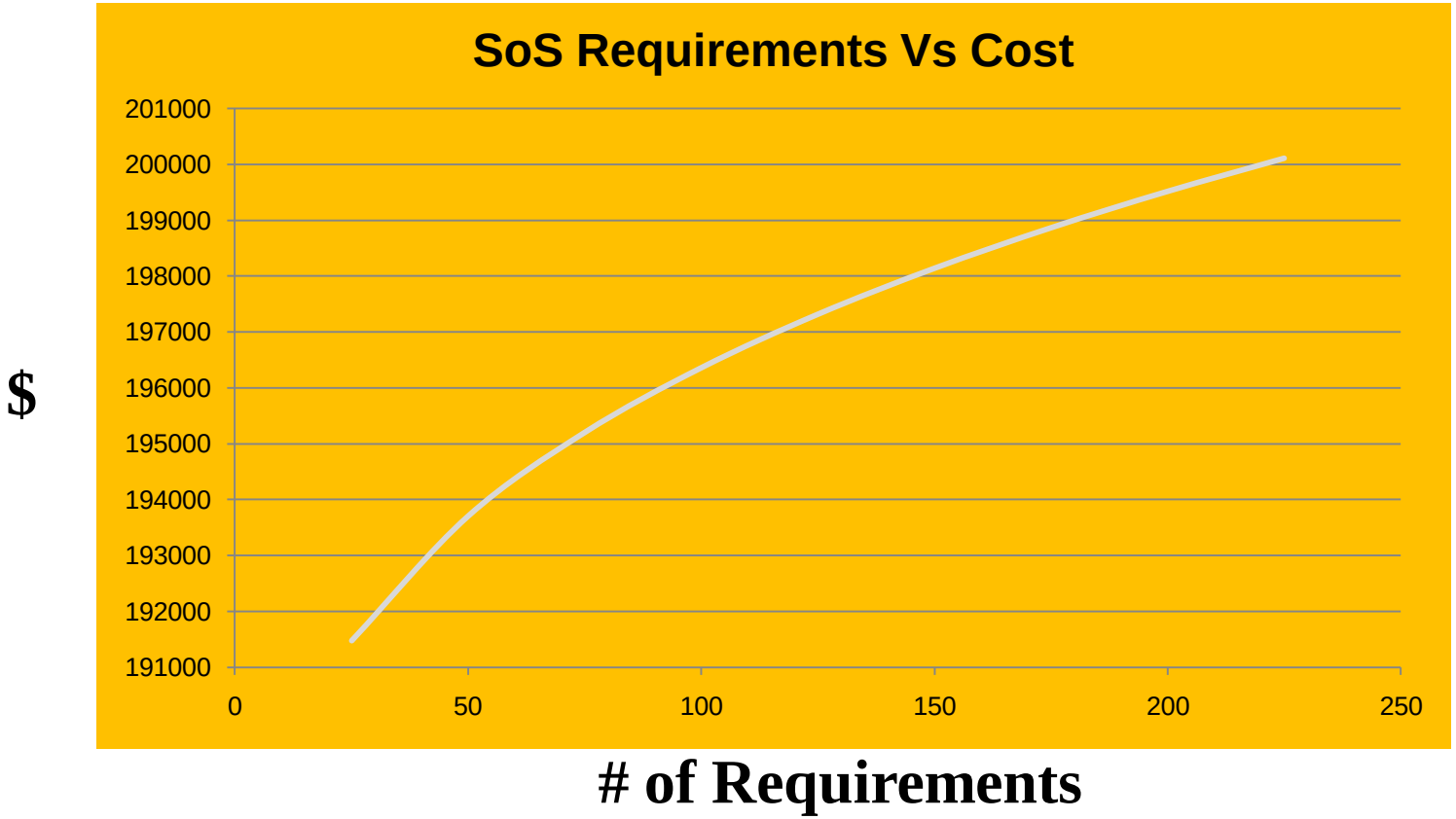
Cost for development, production and maintenance of Integration equipment

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

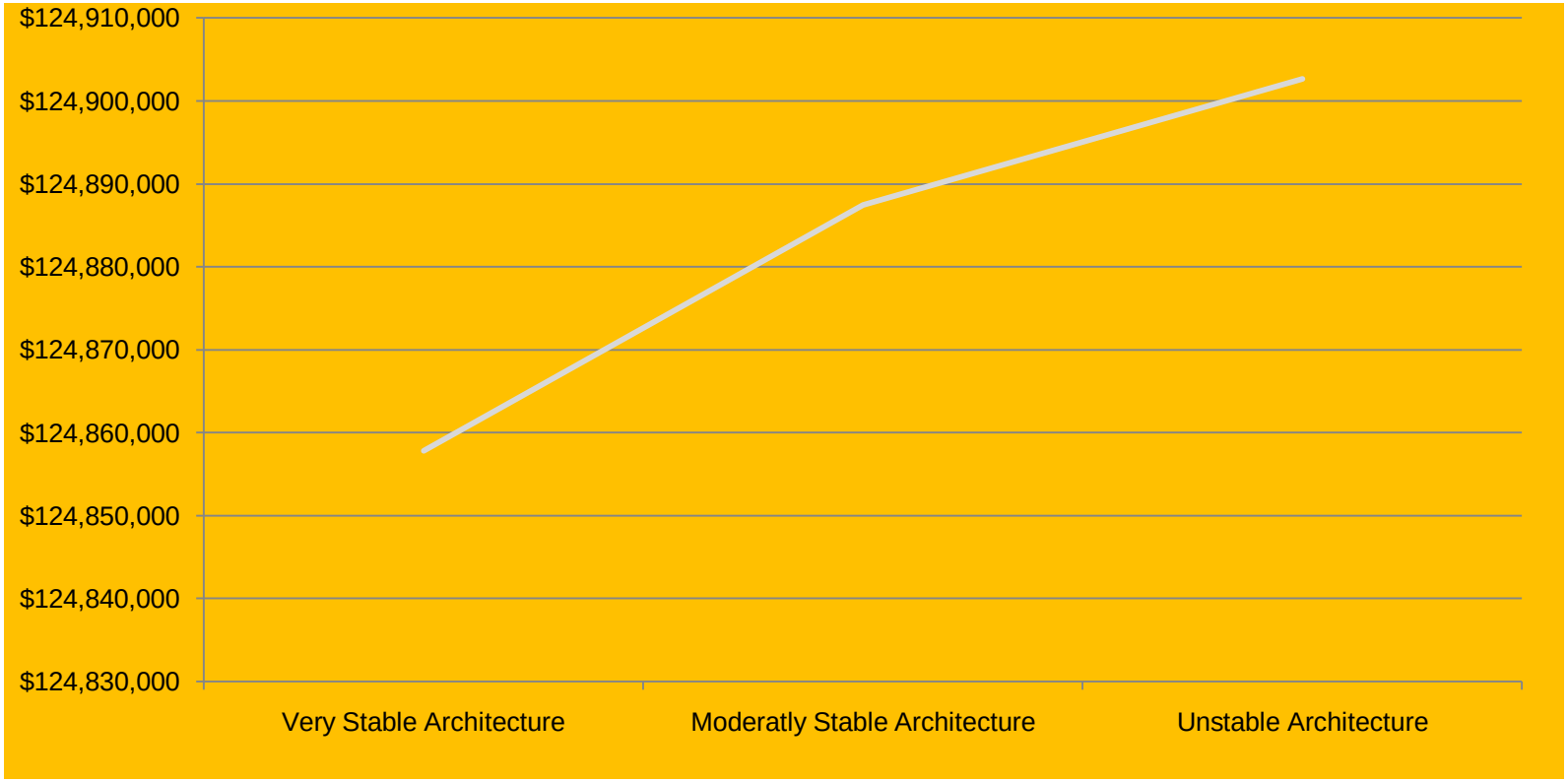


Estimating Cost of Interfacing and Interlinking constituent systems

- 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**

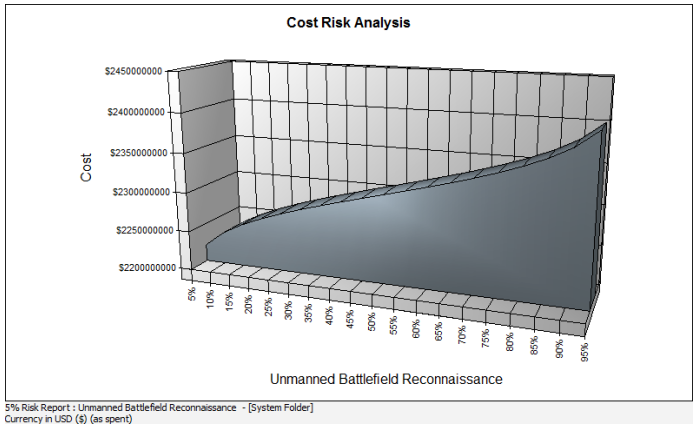
X_{SoS}

$$X_{SoS} > \text{Or} < X_{uav} + X_{ugv} + X_{gcs}$$

5% Risk report of UBR

5% Risk Report : Unmanned Battlefield Reconnaissance - [System Folder]
Currency in USD ($) (as spent)

	Confidence	Cost
5	25%	2,275,363,201
6	30%	2,283,719,749
7	35%	2,291,495,724
8	40%	2,298,888,810
9	45%	2,306,069,735
10	50%	2,313,158,397
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
17	85%	2,372,462,128
18	90%	2,386,708,584
19	95%	2,407,981,214



80% Confidence Level

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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- Estimating System-of-Systems Development Effort- Jo Ann Lane
- SoS FAQ- www.acq.osd.mil/dpap/Docs/FAQs%20--%20SoS%20&%20FoS.doc

Q & A

Kishore Gagrani
Product Manager
PRICE Systems
Kishore.Gagrani@PRICESystems.com
Phone: 856-608-7220

Manmeet Grover
Principal Systems Engineer
Whole Life Engineering Directorate
Raytheon Missile Defense Center

Yousuf Mohammed
PhD Candidate
Mechanical Engineering Dept.
Old Dominion University
Yousufshaker@gmail.com
Phone: 757-581-0579