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A Method for Estimating the Cost of Advanced Radar Systems at the Subsystem and Component Level

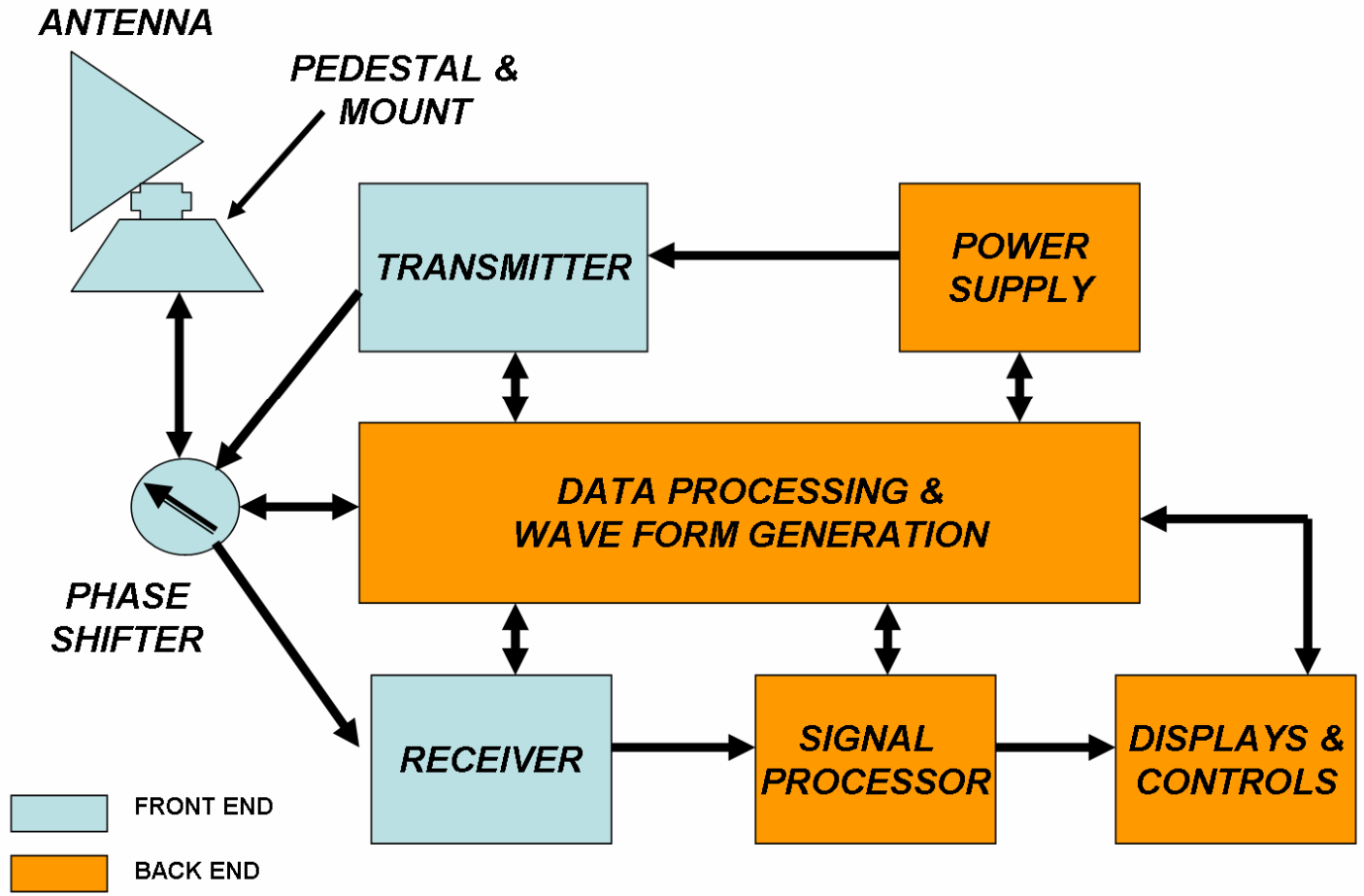
Paul Grim
Deputy Director
MDA/DOE
paul.grim@mda.mil

Dave Stamm & Greg Bell
MCR Federal LLC
dstamm@mcri.com
gbell@mcri.com

AGENDA

- ***PROBLEM & MODEL ORIGINS***
- ***RADAR COST MODELING***
  - ***DEVELOPMENT (SDD) PHASE***
  - ***PRODUCTION PHASE***
  - ***BTL and SUPPORT INVESTMENTS***
- ***MDA/DOBE RADAR MODEL - CONCLUSIONS***

Radar System – Basic Elements

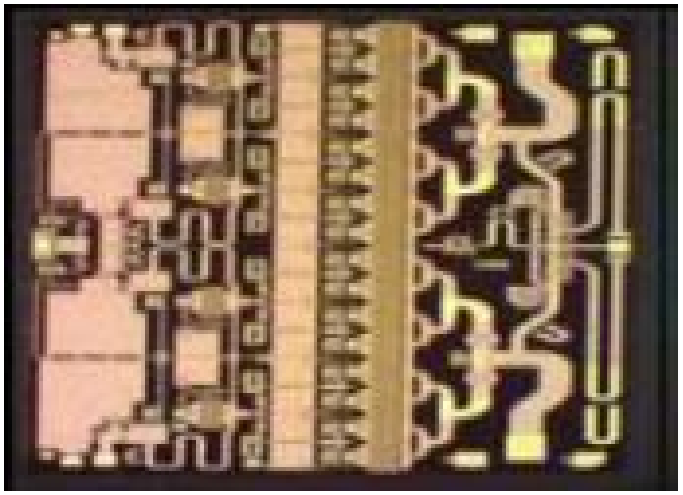


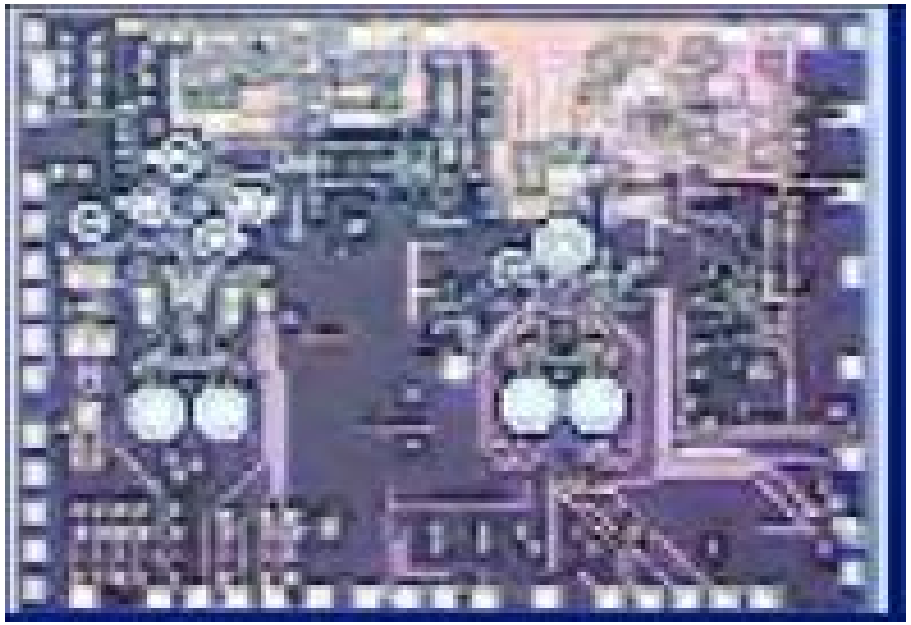
Radar Missions & Applications

- *Surveillance & Reconnaissance*
  - *Search & Detection*
  - *Track Development and Management*
  - *Clutter Rejection*
  - *Target Identification & Moving Target Indication*
  - *Discrimination*
- *Fire Control*
  - *Track Development and Management*
  - *Target Illumination*
  - *Target Identification*
  - *Discrimination*
- *Navigation*
  - *Doppler Measurement*
  - *Scene Matching*
  - *Terrain & Obstacle Avoidance*
  - *Weather*
- *Others*

New Component Technologies

NEW SUBSTRATE MATERIALS (GaN and Others) OFFER AFFORDABLE PERFORMANCE IMPROVEMENTS





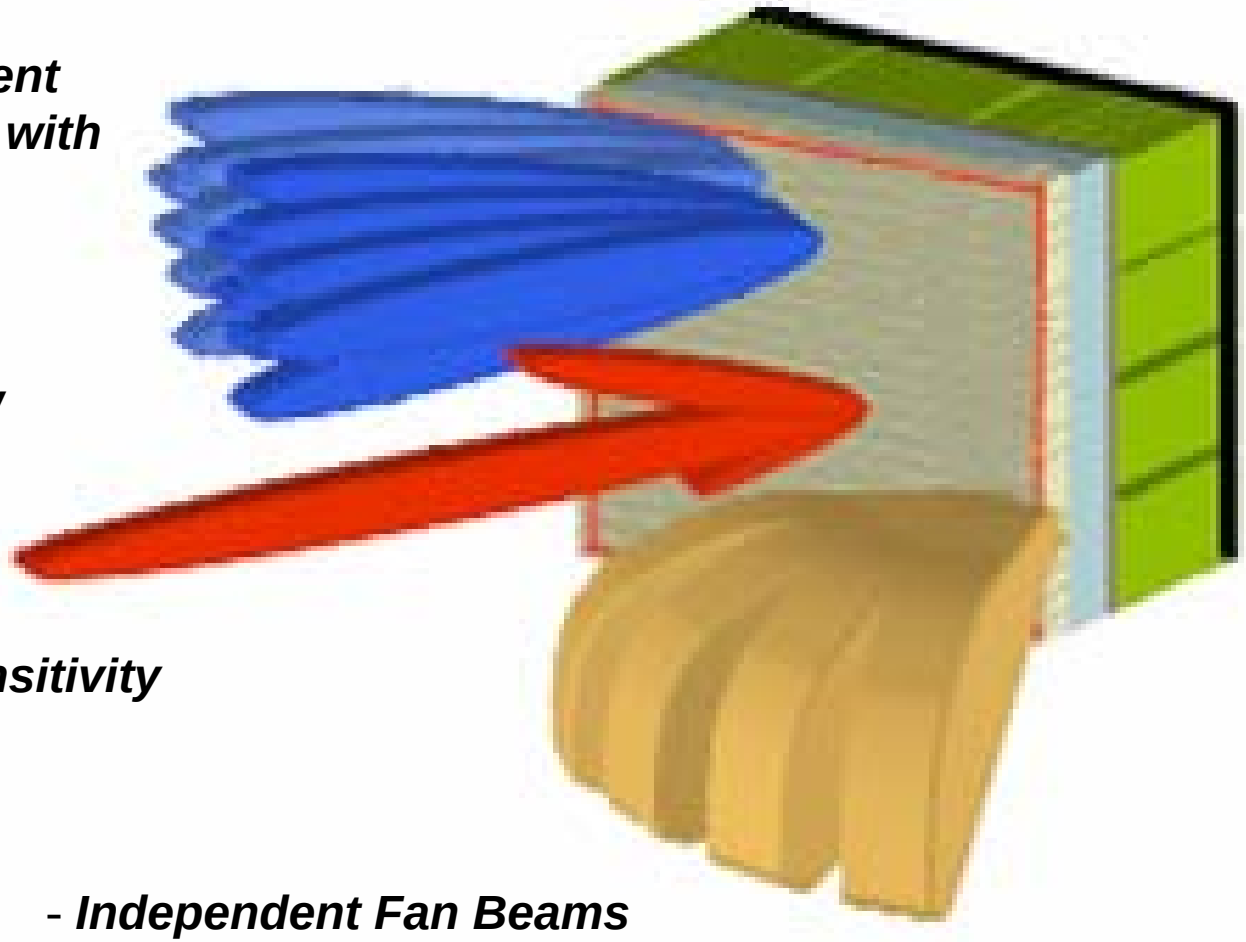
Enhanced Radar Front End Performance

PHASED ARRAY AGILITY & SENSITIVITY

- *Multiple Independent Beams (Steerable, with Frequency Agility)*

- *Wide Field of View*

- *Adaptive High Sensitivity Radar Beams*

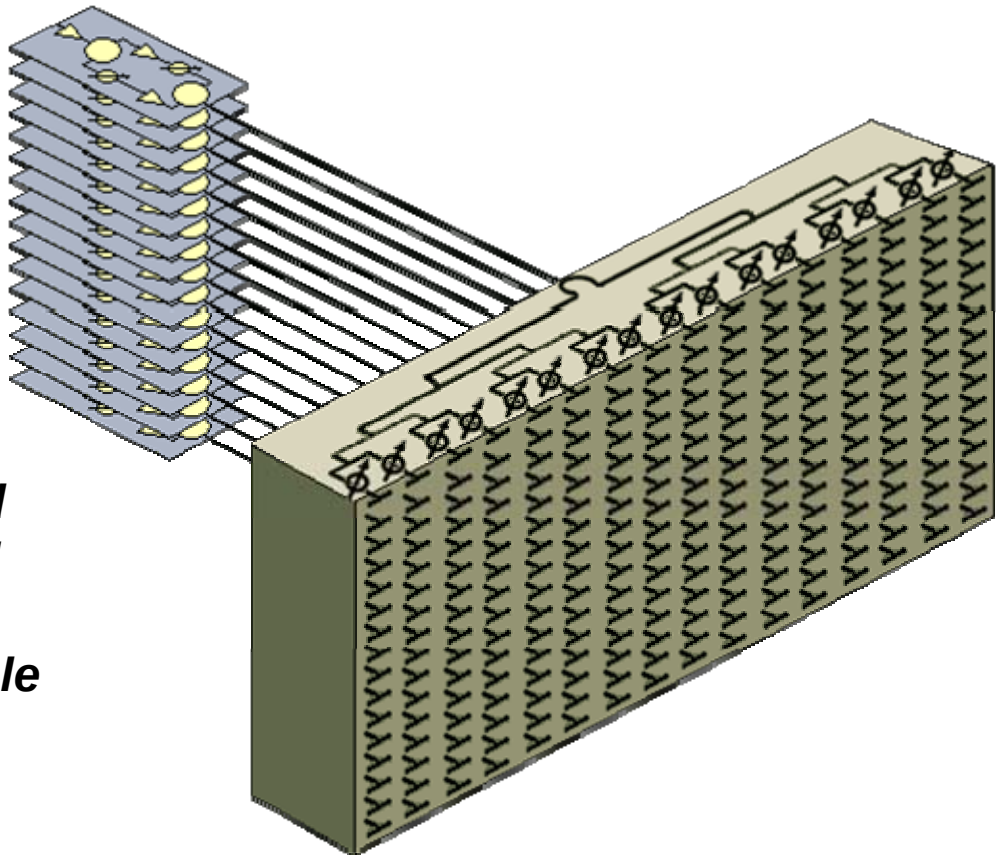


- *Independent Fan Beams for HPOI Horizon Search*

Enhanced Radar Front End Performance

IMPROVING PHASED ARRAY GAIN AND AGILITY

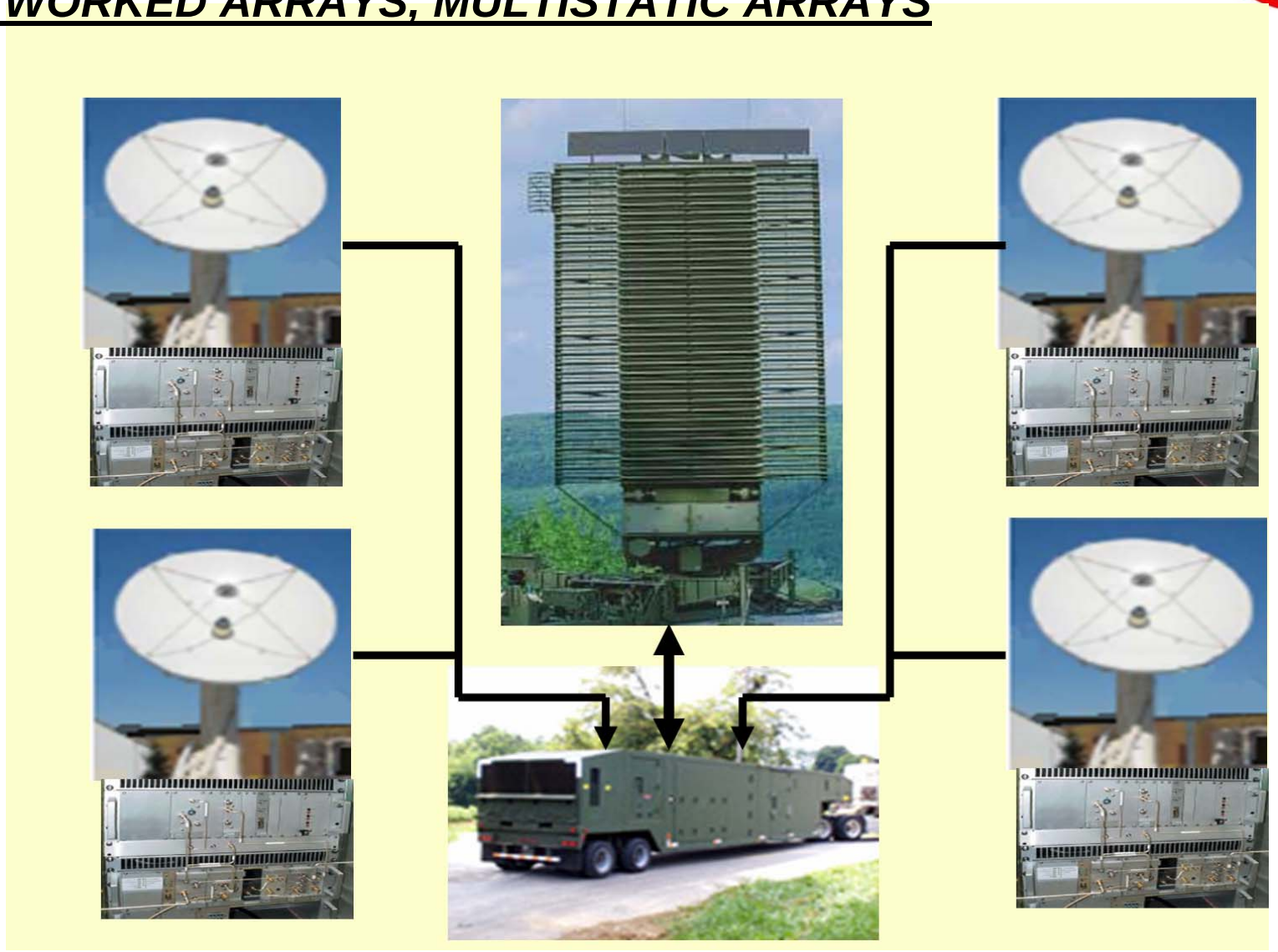
- *Increased Radar Power through use of High Value GaN Based T/R modules.*



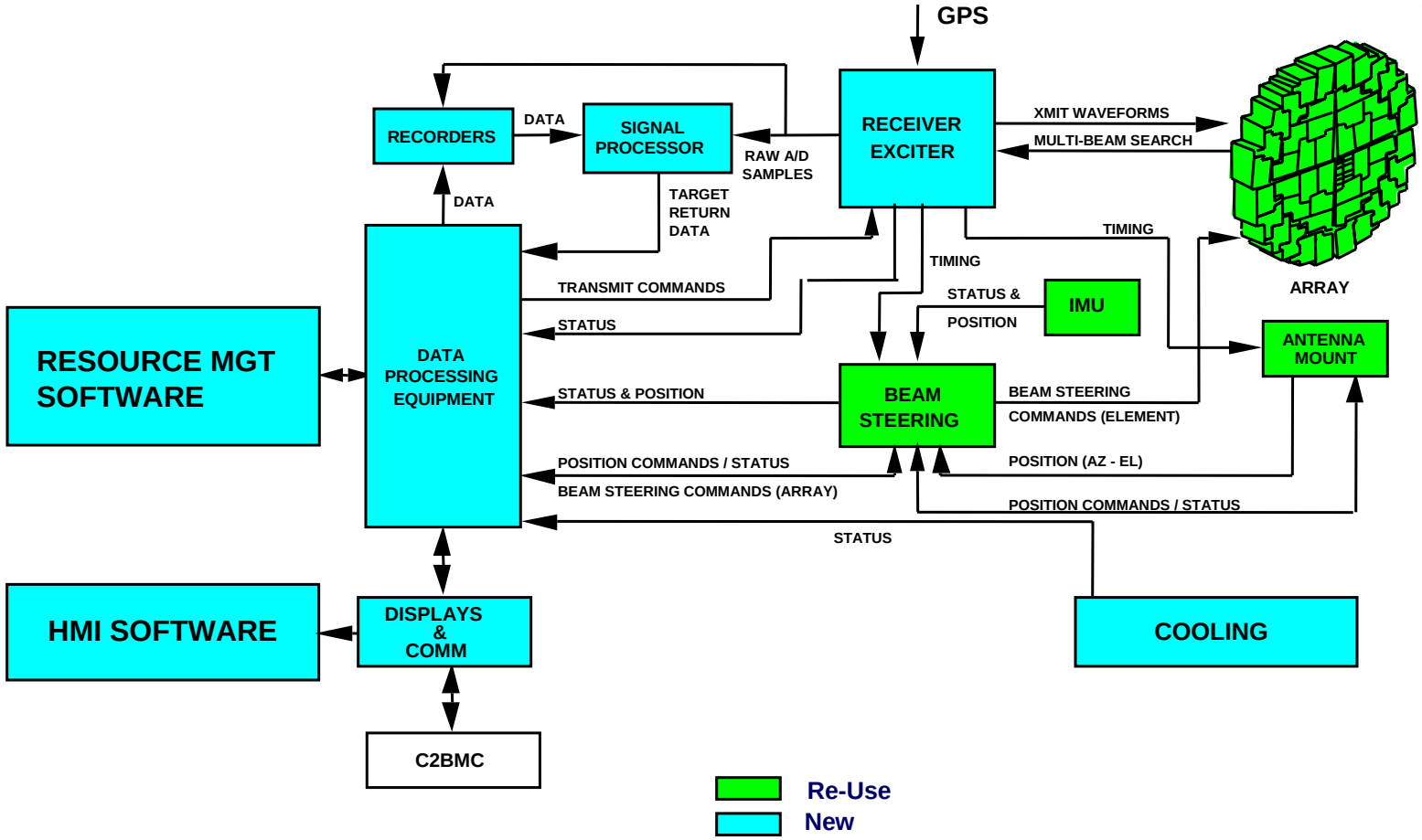
- *Transmitted and Received RF Signals are distributed to and from the array via large numbers of affordable (low cost) components:*
  - *o face elements*
  - *o splitter assemblies*
  - *o phase shifters*

Enhanced Radar Front End Performance

NETWORKED ARRAYS, MULTISTATIC ARRAYS



Radar Cost Analysis Challenge – Design Reuse and Upgrades



Re-Use "Front End", Replace "Back End"

Radar Parametric Cost Model

- ***DEVELOPED BY G. BELL AND PAUL GRIM IN 2007 AND 2008 FOR USE ON SPECIAL RADAR CONCEPT STUDIES & PROGRAMS.***
- ***THE MODEL IS NEW AND IS CURRENTLY BEING REFINED. THREE VERSIONS EXIST:***
  - ***Modular Radars***
  - ***Dish and Corporate Feed Array Radars***
  - ***Fighter Radars***
- ***THE MODEL IS A <u>PARAMETRIC</u> MODEL WITH CERS, FACTORS, AND DEFAULT VALUES THAT ARE USED TO ESTIMATE LCC ELEMENTS, INCLUDING DEVELOPMENT, PRODUCTION, SUPPORT, AND O&S COSTS.***
- ***<u>PARAMETRIC METHODS (Examples):</u>***

COST1 = f(Peak Power)

COST2 = f(ESLOC)

COST3 = f(Qty Modules/Elements)

COST4 = f(Aperture SQM)

COST5 = f(Power Density)

COST6 = f(Frequency GHz)

and Others

<u>Simple</u> Set of Technical Cost Drivers – We know these basic values on the front end

Radar Cost Model – Notional WBS

11/17/2008

		MODULAR	DISH	FIGHTER
	PRIME MISSION EQUIPMENT			
1.1	Modular Pedestal, Mount, Gimbal	X		
1.2	Dish & Planar Antenna & Mount		X	X
1.3	Radome	X	X	
1.4	T/R Modules	X		
1.5	Transmitter		X	X
1.6	Receiver & Receiver/Exciter	X		
1.7	Signal Processor	X	X	X
1.8	Data Processor	X	X	X
1.9	Displays & Controls	X	X	X
1.10	Power & Cooling Systems	X	X	X
1.11	Misc Systems & Provisions	X	X	X
1.12	Software	X	X	X
1.13	Integration, Assy, Chkout	X	X	X
	RADAR COMMON ELEMENTS			
2.1	System Engineering	X	X	X
2.2	Program Management	X	X	X
2.3	System Test & Evaluation	X	X	X
2.4	Support Equipment	X	X	X
2.5	Training	X	X	X
2.6	Data	X	X	X
2.7	Spares	X	X	X
2.8	Other System Level	X	X	X
2.9	Construction	X	X	

Cost Model Description

- ***Populated with historical data from over 21 DoD radar programs***
- ***Prime Mission Equipment (PME) CERs provide development and production cost dollars for radar system components, based on K-SLOC, physical and performance drivers.***
- ***Below the Line (BTL) Costs: A series of factors are used to provide system integration (SEPM. IACO, ST&E) and logistics commodities as a function of PME dollars.***
- ***Analyst inputs: Complexity adjustment factors are provided, allowing the analyst to capture percent new design, number of units previously built, logistic concept adjustments, and other sensitivities.***
- ***Model generates constant dollar cost for development and production at the component and systems level and integrates them into a parametric cost estimate.***
- ***Over 60 CERs are available in RPCM.***

Some Model Sources

- ***"TR-00-01B-01, Ship and Ground Based Radar Model," Technomics, Inc., Horak and Harder, 2002.***

- ***"CR964, T/R Module Cost Estimating Model, Tecolote Research, Inc., Thomas, Arnold, Schaefer, 1998.***

- ***"CR536, Updated T/R Module Cost Estimating Formulae, Tecolote Research, Inc., Higdon and Arnold, 1996.***

- ***"Radar Hardware Cost Estimating Relationships Database - Production," SAIC, Maksimowski, Roberts, Shelton, 1995.***

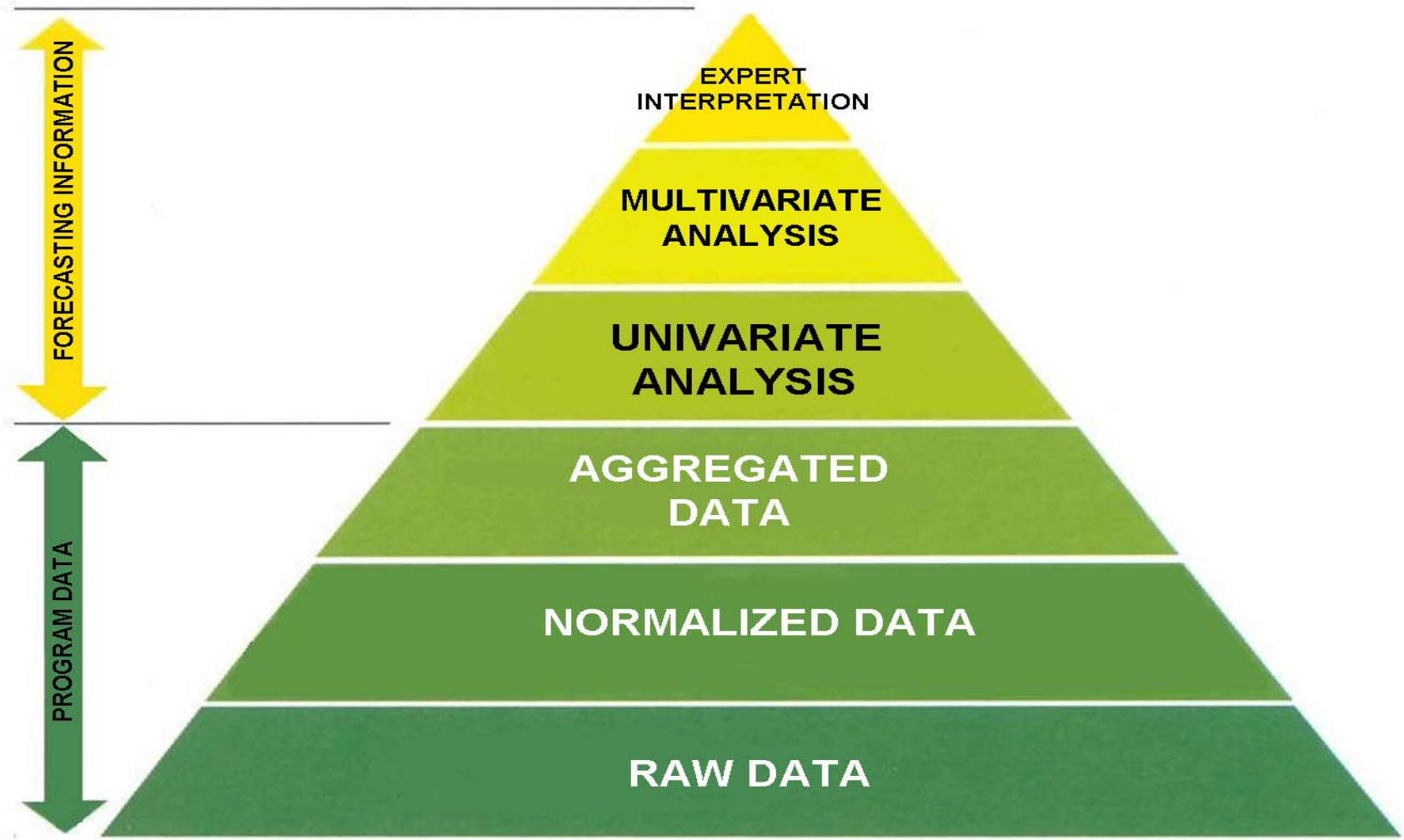
- ***"TM-180, Radar Cost – Development," Tecolote Research, Inc., Dwyer, Frederick, Kielpinski, Sjovold, and Van Hoomissen, 1985.***

- ***"TM-228, Radar Cost Book – Production," Tecolote Research, Inc., Frederick, Horak, Waller, 1984.***

- ***Cost Performance Reports (CPRs) for numerous MDA and DoD radars.***

And Many Others …

Radar Cost Model Development



Research Procedure – Raw Data

RADAR X	COSTS IN CONSTANT FY88 M$			
Total Cost	58260.3		AAABN Receiver/Exciter	4634.0
AAA Radar	44861.5			
AAAA Antenna	28306.8		Signal Processor	7549.0
AAABA Elements	1348.6		AAABM Signal Proc	7424.5
AAABJ Module P/S	1774.6		AAABL RCL Mod	124.5
AAABB Tx Beam Frmg	1061.8		Radar Control	4371.8
AAABC Rc Beam Frmg	1643.5		AAAAB Synchronizer	57.4
AAABD RF Monitor	372.0		AAABR Cooling Monitor	0.0
AAABE Array Gap Drv	462.1		AAABO Freq Time Stds	168.8
AAABF Sub Array Drv	429.3		AAABP Intercnnections	412.9
AAABH Array Wiring	801.3		AAFA Displays Hdw	2300.6
AAABG Array Mech	3113.3		AAFB Displays SW	1432.1
AAABI Solid S Module	16782.5		Data Processor	13398.8
AAABK Beam Steering	517.8		AADBA CDC Data Proc	12140.4
			AADBD Computer Mods	1258.4
AAABM Tx (see SS Mod)	0.0		External Communications	0.0
			Platform Stabilization	0.0

Raw Cost Data Set

Radar Y

Operating Frequency, GHz		5.5
No. Stabilization Dimensions in Pedestal		1
Frontal Area of Antenna, ft ²	4.8 M^2	52
Average Radiated Power, in Kw		10
Peak Radiated Power, in Kw		540
No. Parallel Signal Channels in Receiver		8
Max Pulse Compression Ratio in Sig Proc		775
No. Phase Shifters		5400
Average Power per PhaseShifter, in watts		2

Raw Technical Data Set

Raw data was organized in accordance with customer and contractor policies in place at the time of performance.

Research Procedure – Normalized Data

Raw Cost Data Set

DEVELOPMENT - Contractor Cost Level		FY 80 $ in M	DEVELOPMENT FY 01 $ in M
1.1.1	Development Engineering	$52.870	$108.624
1.1.2	PEP	$0.000	$0.000
1.1.3	Tooling	$17.520	$35.996
1.1.4	Prototype Manufacturing (6 ea)	$55.740	
1.1.5	Data	$2.400	$4.931
1.1.6	Sys Test & Evaluation	$8.400	$17.258
1.1.7	Sys Engr/Project Mgmt	$35.290	$72.505
1.1.8	Training	$0.400	$0.822
1.1.9	Facilities	$0.000	$0.000
1.1.10	Software	$5.680	$11.670
1.1.11	Disposal	$0.000	$0.000
1.1.12	Other	$0.000	$0.000
Total		$178.300	$251.805

PME

BTL

COST (LESS FEE)	DEVELOPMENT COST FY01 M$
Radar	
Antenna	$31.501
Transmitter	$12.383
Receiver	$9.559
Exciter	$10.319
Signal Processor	$8.907
Data Processor	$7.332
Radar Controller	$2.444
Software Development	$11.670
Other	$26.178
Summed Total PME	$120.294
Systems Engineering	$47.128
Program Management	$25.377
Systems Test & Evaluation	$17.258
GSE	$35.996
Training	$0.822
Data	$4.931
Spares	$0.000
Other	$0.000
System Wraps Sum	$131.511
Program Total	$251.805

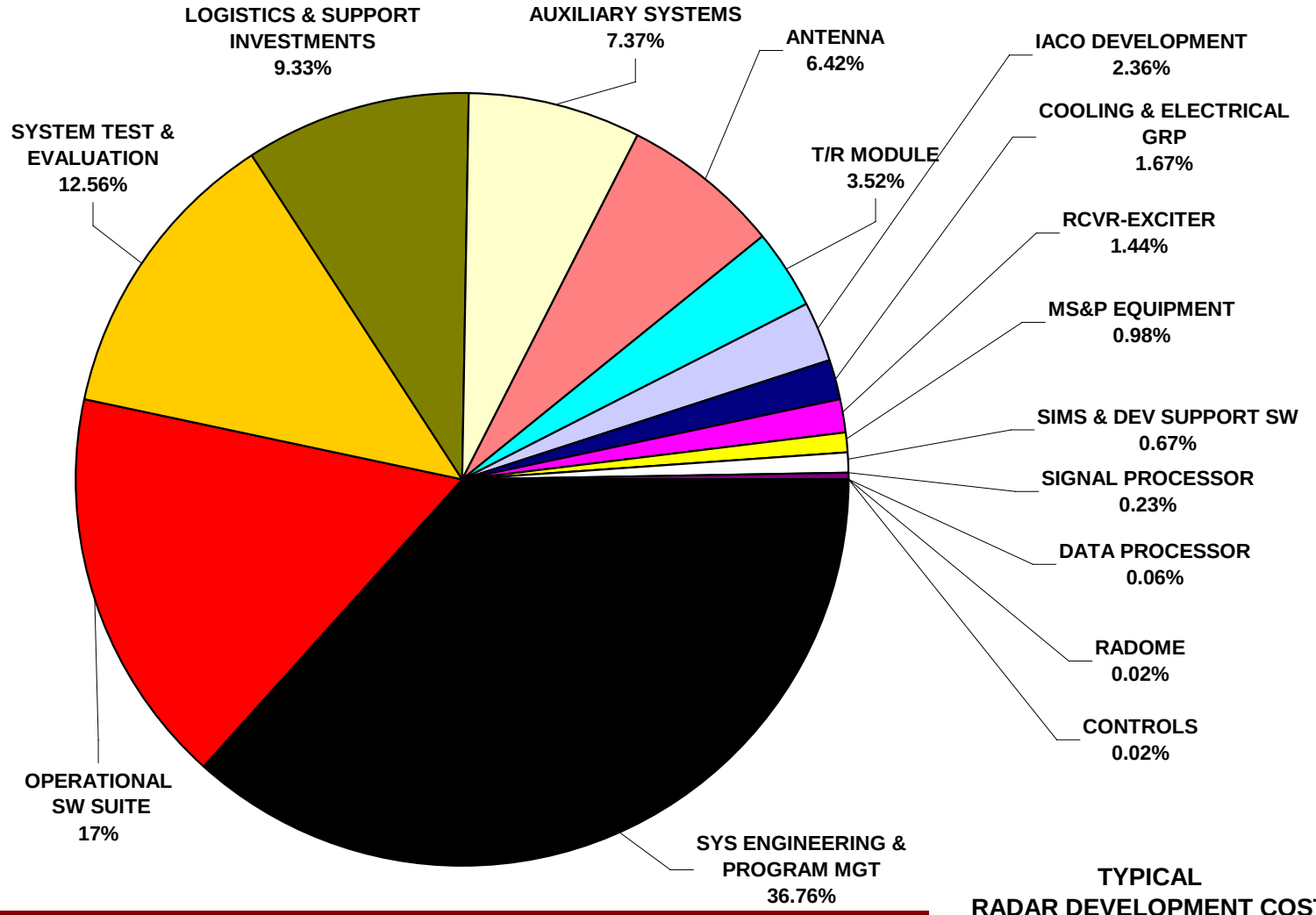
Normalization of Radar data requires three steps:

1) *organizing (as far as possible) the raw data to conform to the desired WBS.*
2) *parsing the data to overcome missing details using analogies and expert opinion.*
3) *adjustment of cost to a constant dollar framework using inflation factors.*

Raytheon

And others…

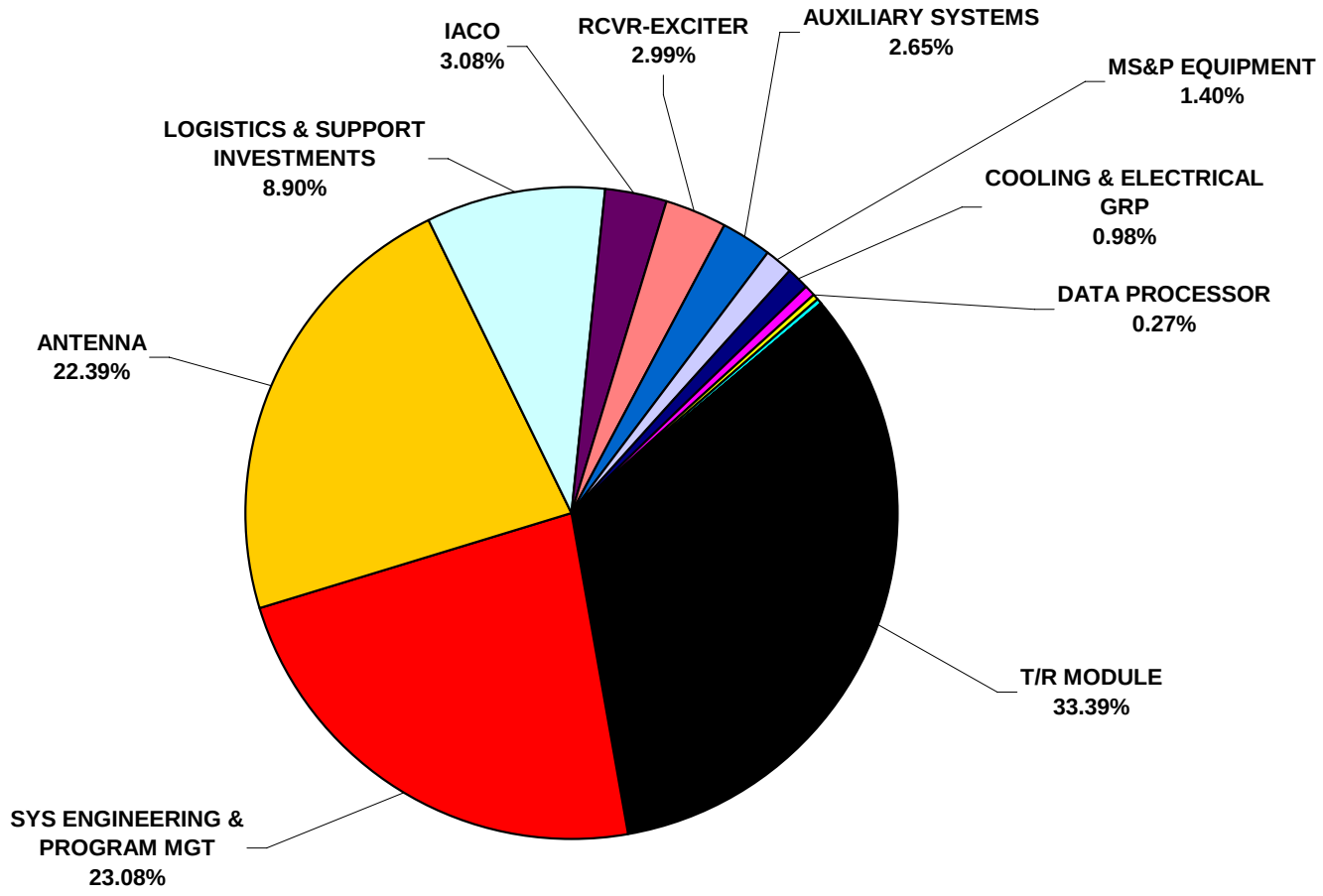
Analogies: Normalized Development Cost Data



TYPICAL RADAR DEVELOPMENT COST

Typical Modular Radar Development Cost Data Set

Analogies: Normalized Production Cost Data



Typical Modular Radar TFU Production Cost Data Set

Expert Opinion: Normalized Cost Data

Using an expert panel to parse cost data into lower WBS elements is a dangerous strategy, but sometimes it is the only way forward. No matter how experienced the panel is, be prepared to encounter and deal with outliers and anomalies.

Research Procedure – Aggregated Data

Technical Characteristics	ABRDR_1	ABRDR_2	ABRDR_3	ABRDR_4	ABRDR_5	ABRDR_6	ABRDR_7
Type	Area	Surveillance,	Early Warning	Fire Control &	Fire Control &	Fire Control &	Fire Control &
Platform	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft
No. of Faces	1	1	1	1	1	1	1
Antenna Type	Yagi Array	Planar Array	SWG Array	Dish	Dish	Dish	Dish
No. of Elements	42	400	1,820	----------	----------	----------	----------
Aperture	5.57 m^2	27.31 m^2	12.54 m^2	0.65 m^2	0.65 m^2	0.36 m^2	0.30 m^2
Frequency	.43 GHz	9.5 GHz	3.3 GHz	9.4 GHz	9.4 GHz	9.4 GHz	9.4 GHz
Band	UHF Band	X Band	S Band	X Band	X Band	X Band	X Band
Peak Power	500.00 KW	500.00 KW	1000.00 KW	10.00 KW	3.50 KW	1.50 KW	15.40 KW
Avg Power							
Duty Cycle							
Effective Range	300 NM	250 NM	300 NM	300 NM	300 NM	300 NM	300 NM
Weight Data	ABRDR_1	ABRDR_2	ABRDR_3	ABRDR_4	ABRDR_5	ABRDR_6	ABRDR_7
Total Weight (LBS)	11636 lbs	23454 lbs	22121 lbs	974 lbs	687 lbs	483 lbs	377 lbs
Antenna (W Beam Steering)	580 lbs	2768 lbs		184 lbs	110 lbs	81 lbs	61 lbs
Transmitter	1476 lbs	1056 lbs		134 lbs	175 lbs	113 lbs	69 lbs
Receiver/Exciter	1170 lbs	807 lbs		181 lbs	57 lbs	46 lbs	63 lbs
Signal Processor				98 lbs	68 lbs	54 lbs	21 lbs
Data Processor	747 lbs	3929 lbs	2382 lbs	69 lbs	43 lbs	44 lbs	63 lbs
Control Unit	1286 lbs	5967 lbs	3230 lbs	65 lbs	20 lbs	20 lbs	2 lbs
Power Supply Group	528 lbs	2010 lbs		80 lbs	36 lbs	0 lbs	
Cooling Group	520 lbs	334 lbs					
Communication Nav Ident Group	1611 lbs	2858 lbs	6595 lbs				
Radar Test & Maint PNL Group	192 lbs	249 lbs	249 lbs				
IFF Group			1061 lbs				
Surveillance Radar			8604 lbs				
Other	3527 lbs	3475 lbs					
SLOC	175,000	200,300	60,000	65,000	18,000	110,000	30,000

Typical Radar Technical Data Set

Research Procedure – Aggregated Data

Development Cost FY01 M$ - W/O Fee	SBRDR_1	SBRDR_2	SBRDR_3	SBRDR_4	SBRDR_5	SBRDR_6	SBRDR_7
RADAR PME							
ANTENNA	$12.979	$2.788	$29.947	$48.215	$5.987	$8.878	$14.735
TR MODULE GROUP	$0.000	$0.000	$5.285	$0.000	$0.000	$0.000	$0.000
TRANSMITTER	$3.401	$1.979	$0.000	$51.357	$2.354	$3.490	$5.792
RECEIVER	$1.214	$1.303	$0.000	$4.860	$1.817	$2.694	$4.471
EXCITER	$0.304	$0.326	$0.627	$3.508	$1.961	$2.908	$4.827
SIGNAL PROCESSOR	$1.735	$1.171	$1.256	$6.431	$1.693	$2.510	$4.166
DATA PROCESSOR	$6.478	$2.841	$1.116	$0.000	$1.486	$2.204	$3.658
CONTROLS	$1.099	$1.588	$0.419	$0.000	$0.372	$0.551	$0.915
SOFTWARE DEVELOPMENT	$16.413	$3.420	$57.697	$21.778	$4.617	$2.055	$6.164
COOLING & ELECTRICAL	$0.000	$0.000	$0.000	$0.000	$2.189	$3.246	$5.388
GRP A PROVISIONS	$0.000	$0.000	$0.000	$0.911	$1.652	$2.449	$4.065
OTHER (COMMS)	$0.907	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
OTHER (PLATFORM)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
INTEGRATION ASSY CHKOUT	$0.000	$1.481	$44.399	$29.641	$5.115	$7.584	$12.588
PME COST TOTAL	$44.529	$16.897	$140.745	$166.700	$29.243	$38.569	$66.769
NON-PME GROUP							
SYSTEMS ENGINEERING	$3.078	$2.564	$100.829	$55.688	$7.511	$10.417	$13.835
PROGRAM MANAGEMENT	$3.015	$1.121	$76.894	$29.986	$4.045	$5.609	$7.450
TEST & EVALUATION	$13.197	$4.982	$53.658	$45.015	$14.246	$9.862	$7.437
SUPPORT EQUIPMENT	$0.000	$0.000	$2.906	$3.088	$4.580	$2.671	$0.000
TRAINING	$0.939	$0.480	$0.000	$0.822	$0.660	$0.616	$0.452
DATA	$0.496	$0.494	$0.000	$17.669	$1.020	$6.369	$5.198
INITIAL SPARES	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
OTHER	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
NON-PME COST TOTAL	$20.726	$9.640	$234.287	$152.269	$32.061	$35.544	$34.373
TOTAL DEVELOPMENT COST	$65.255	$26.537	$375.032	$318.969	$61.304	$74.113	$101.141

Typical Radar Development Cost Data Set

Research Procedure – Aggregated Data

TFU PRODUCTION COST FY01 M$ - W/O Fee	GRNDRDR_1	GRNDRDR_2	GRNDRDR_3	GRNDRDR_4	GRNDRDR_5	GRNDRDR_6	GRNDRDR_7
RADAR PME							
ANTENNA	$29.672	$61.802	$46.410	$36.093	$0.632	$3.755	$7.998
TR MODULE GROUP	$0.000	$142.885	$0.000	$55.980	$0.000	$0.000	$2.526
TRANSMITTER	$13.877	$0.000	$13.444	$0.000	$0.607	$1.590	$0.000
RECEIVER	$2.825	$10.538	$27.942	$0.000	$0.200	$0.822	$0.000
EXCITER	$1.521	$0.000	$18.628	$5.329	$0.133	$0.548	$0.252
SIGNAL PROCESSOR	$1.476	$12.273	$12.544	$1.431	$0.776	$0.531	$1.551
DATA PROCESSOR	$6.930	$10.026	$3.446	$1.252	$0.480	$0.118	$1.701
CONTROLS	$1.222	$2.254	$1.600	$0.894	$0.220	$0.154	$1.157
SOFTWARE DEVELOPMENT	$0.000	$0.119	$0.000	$0.000	$0.000	$0.000	$0.000
COOLING & ELECTRICAL	$0.000	$0.000	$0.000	$2.133	$0.000	$0.000	$0.000
GRP A PROVISIONS	$0.000	$2.916	$5.018	$3.839	$0.000	$0.000	$0.000
OTHER (COMMS)	$0.595	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
OTHER (SHELTERS)	$0.000	$10.357	$0.000	$3.054	$0.000	$0.000	$0.000
INTEGRATION ASSY CHKOUT	$25.088	$0.000	$0.000	$1.767	$0.000	$0.000	$0.000
PME COST TOTAL	$83.206	$253.170	$129.032	$111.772	$3.049	$7.518	$15.185
NON-PME GROUP							
SYSTEMS ENGINEERING	$0.958	$7.877	$0.000	$1.415	$0.000	$0.000	$0.000
PROGRAM MANAGEMENT	$1.210	$5.753	$0.000	$1.158	$0.000	$0.000	$0.000
TEST & EVALUATION	$0.000	$10.991	$0.000	$0.000	$0.000	$0.000	$0.000
SUPPORT EQUIPMENT	$0.000	$2.965	$0.000	$0.000	$0.000	$0.000	$0.000
TRAINING	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
DATA	$0.000	$1.302	$0.000	$0.000	$0.000	$0.000	$0.000
INITIAL SPARES	$0.097	$4.561	$0.000	$0.000	$0.000	$0.000	$0.000
OTHER	$6.272	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
NON-PME COST TOTAL	$8.537	$33.449	$0.000	$2.573	$0.000	$0.000	$0.000
TOTAL TFU PRODUCTION COST	$91.743	$286.619	$129.032	$114.345	$3.049	$7.518	$15.185

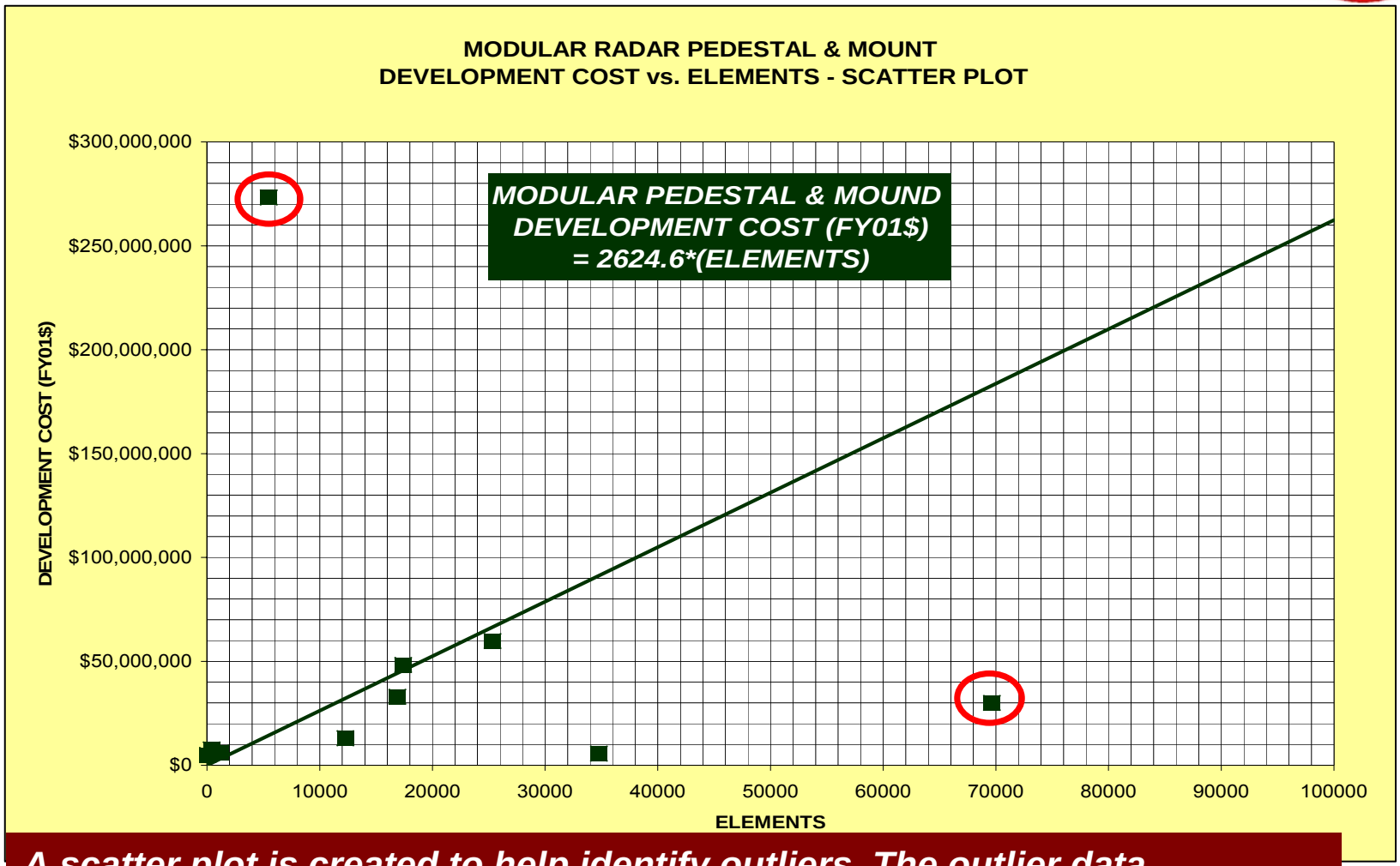
Typical Radar TFU Production Cost Data Set

Research Procedure – Univariate Analysis

ANTENNA STRUCTURE WITH GIMBAL/PEDESTAL	ELEMENTS	APERTURE (SQM)	DEVEL COST FY01 M$	PRODUCTION TFU COST FY01 M$
MODULAR ARRAY RADARS				
SBRDR_1	12288	36.95	$12.979	$9.398
SBRDR_3	69632	384.80	$29.947	$114.421
SBRDR_4	17400	56.00	$48.215	$21.082
GRNDRDR_1	34768	651.50	$5.618	$29.672
GRNDRDR_2	16896	105.00	$32.958	$61.802
GRNDRDR_3	5468	4.40	$273.307	$46.410
GRNDRDR_4	25344	9.20	$59.803	$36.093
GRNDRDR_5	64	2.42	$4.968	$0.632
GRNDRDR_6	408	8.64	$7.643	$3.755
GRNDRDR_7	1200	44.40	$6.090	$7.998

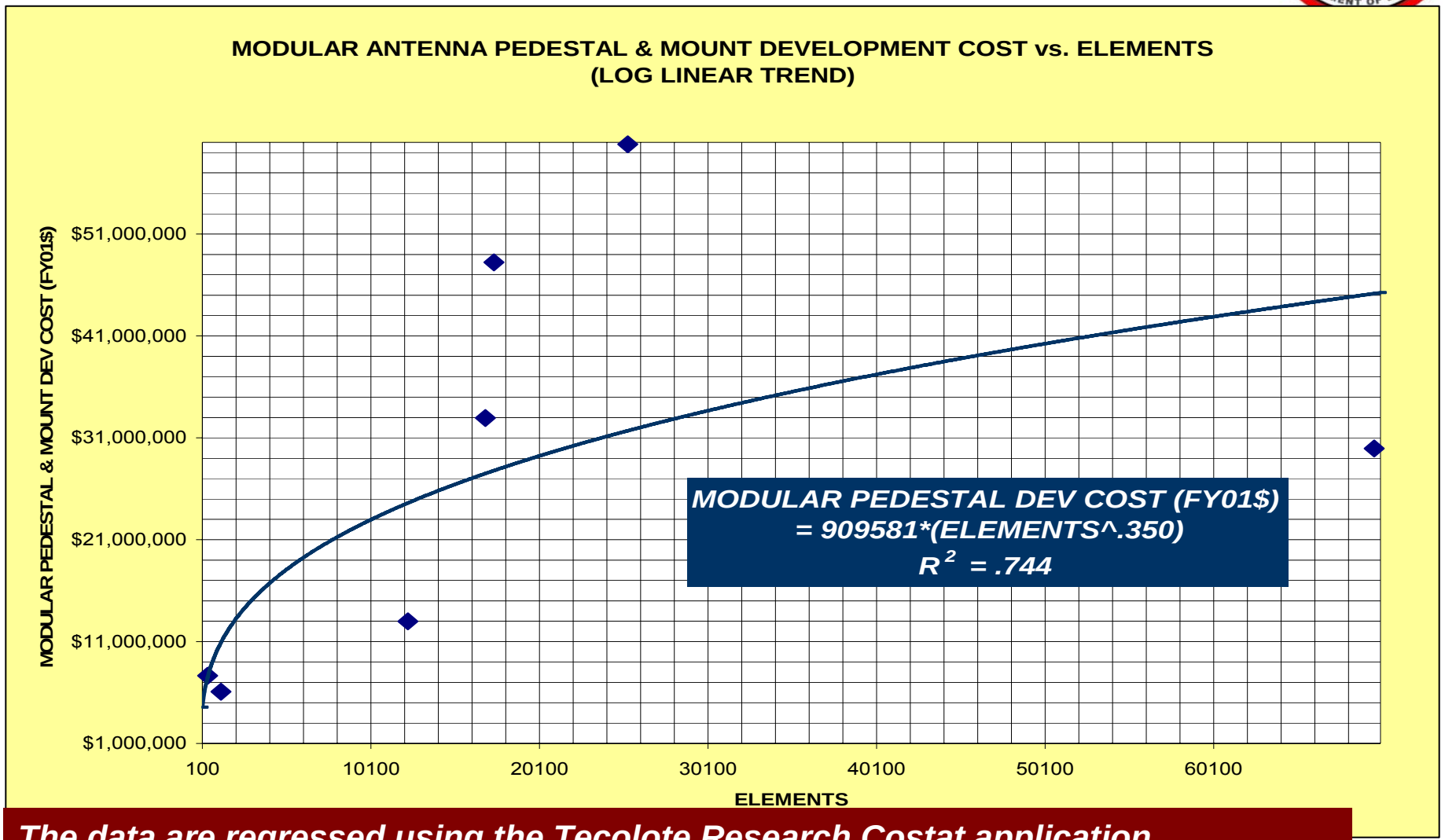
Aggregated data is arrayed to support regression analyses.

Research Procedure – Univariate Analysis



A scatter plot is created to help identify outliers. The outlier data is preserved for further study, and may be useful in other situations.

Research Procedure – Univariate Analysis



The data are regressed using the Tecolote Research Costat application.
The preferred CERs will have a coefficient of determination (R^2) greater than .70.

Research Procedure – Univariate Analysis

Base Year FY01 $

PME DEVELOPMENT CERS	Coeff	Exponent	R^2	
ANTENNA & MOUNT (MODULAR) DEV	909581	0.35	0.744	ANT_MODULAR DEV $ = A*(ELEMENTS^B)
ANTENNA & MOUNT (DISH & PLANAR) DEV	7012740	0.64	0.983	ANT_DISH_PLANAR DEV $ = A*(AP-SQM^B)
RADOME DEVELOPMENT	8745.6	0.52	0.710	RADOME DEV $ = A*(AP-SQFT^B)
T/R MODULE DEVELOPMENT	6737647	0.42	0.700	T/R MODULE DEV $ = A*(FREQ-GHZ^B)
TRANSMITTER (MODULAR) DEV	2064	1.00	0.720	TRNX_MODULAR DEV $ = A*(ELEMENTS^B)
RCVR-EXCITER (MODULAR) DEV	280.3	1.00	0.650	RCVREX_MODULAR DEV $ = A*(ELEMENTS^B)
SIG PROC (MODULAR) DEV	123627	1.00	0.510	SIG PROC_MODULAR DEV $ = A*(AP-SQM^B)
DATA PROC (MODULAR) DEV	122908	1.00	0.720	DATA PROC_MODULAR DEV $ = A*(AP-SQM^B)
CONTROLS (MODULAR) DEV	33718	1.00	0.700	CONTROLS_MODULAR DEV $ = A*(AP-SQM^B)
COOLING & ELECTRICAL AUX EQ DEV	21487	1.00	0.633	COOL_ELECT DEV $ = A*(PWR KW^B)
MISC SYSTEMS & PROVISIONS DEV	0.073	1.00	0.899	MS&P DEV $ = A*(SUBTOTAL PME COST^B)
SOFTWARE DEV (GROUND SYSTEM)	159.4	1.00	1.000	SW (GROUND) DEV $ = A*(ESLOC^B)
SOFTWARE DEV (MOBILE SYSTEM)	222.6	1.00	1.000	SW (MOBILE) DEV $ = A*(ESLOC^B)
SOFTWARE DEV (AIRBORNE SYSTEM)	278.4	1.00	1.000	SW (AIRBORNE) DEV $ = A*(ESLOC^B)
HARDWARE IACO DEV	0.165	1.00	0.707	IACO DEV $ = A*(PME COMPONENT TOTAL $^B)

The CERs are assembled into a typical model architecture. The CERs shown here cover development of radar Prime Mission Equipment (PME).

Research Procedure – Univariate Analysis

Base Year FY01 $

PME PRODUCTION TFU CERS	Coeff	Exponent	R^2	
ANTENNA & MOUNT (MODULAR) TFU	1567	1.00	0.840	ANT_MODULAR DEV $ = A*(ELEMENTS^B)
ANTENNA & MOUNT (DISH_PLANAR) TFU	432643	1.00	0.868	ANT_DISH_PLANAR DEV $ = A*(AP-SQM^B)
RADOME TFU	51860	0.49	0.730	RADOME TFU $ = A*(AP-SQFT^B)
T/R MODULE TFU	8391	-0.27	0.580	T/R MODULE TFU $ = A*(FREQ-GHZ^B)
TRANSMITTER (MODULAR) TFU	80700	0.50	0.720	TRNX_MODULAR TFU $ = A*(ELEMENTS^B)
RCVR-EXCITER (MODULAR) TFU	209.2	1.00	0.650	RCVREX_MODULAR TFU $ = A*(ELEMENTS^B)
SIG PROC (MODULAR) TFU	90366	1.00	0.810	SIG PROC_MODULAR TFU $ = A*(AP-SQM^B)
DATA PROC (MODULAR) TFU	52932	1.00	0.490	DATA PROC_MODULAR TFU $ = A*(AP-SQM^B)
CONTROLS (MODULAR) TFU	21375	1.00	0.920	CONTROLS_MODULAR TFU $ = A*(AP-SQM^B)
COOLING & ELECTRICAL AUX EQ TFU	4565	1.00	0.612	COOL_ELECT TFU $ = A*(PWR KW^B)
MISC SYSTEMS & PROVISIONS TFU	0.051	1.00	0.944	MS&P TFU $ = A*(SUBTOTAL PME COST^B)
HARDWARE IACO TFU	0.107	1.00	0.845	IACO TFU $ = A*(PME COMPONENT TOTAL $^B)

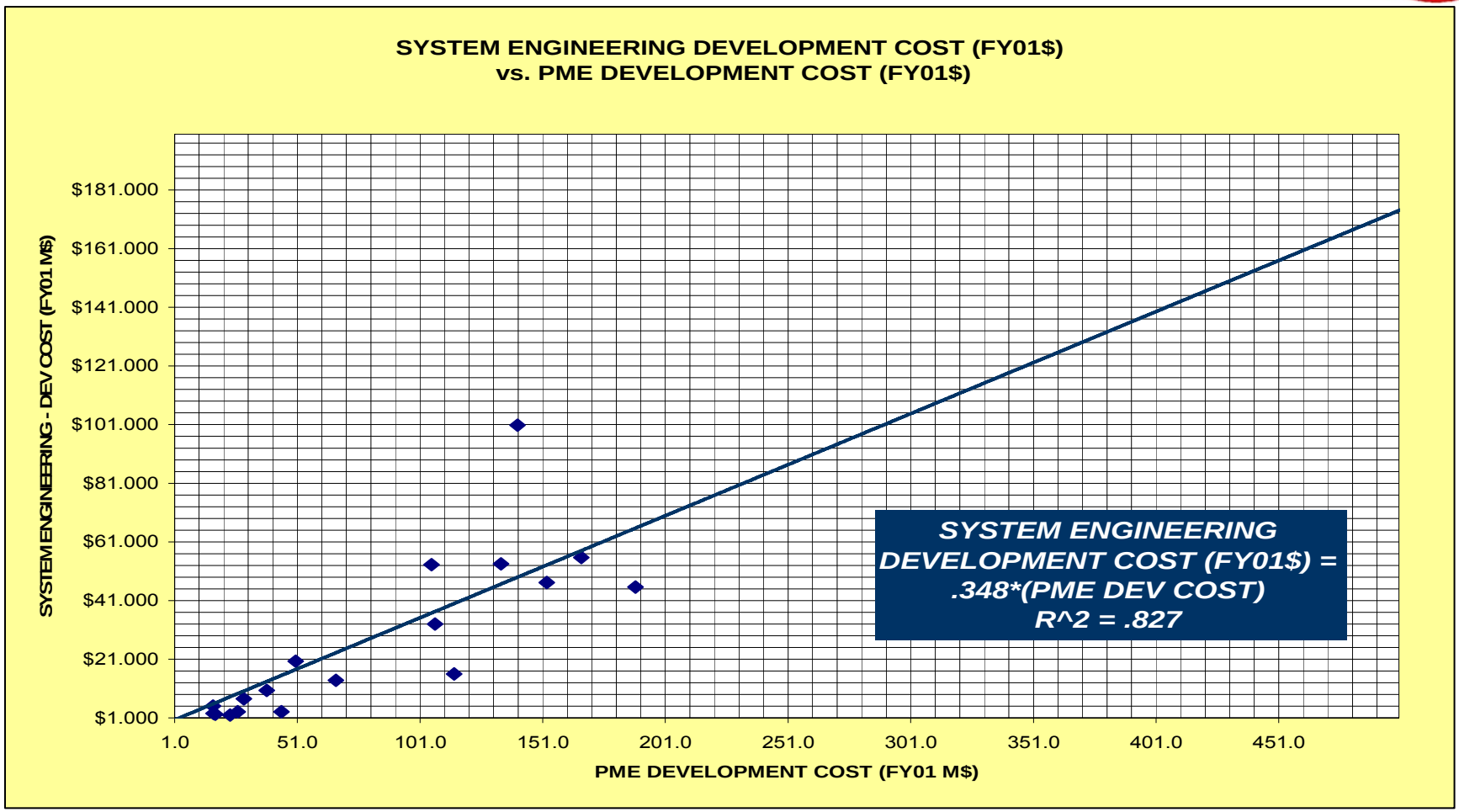
The CERs are assembled into a typical model architecture. The CERs shown here cover production theoretical first unit (TFU) for Prime Mission Equipment (PME).

Research Procedure – Univariate Analysis

RADAR SYSTEM LEVEL COST			
SYS ENG (DEV)	0.3480	1.00	SYS ENG $ = A*(DEV PME HDW$^B)
PROG MGT (DEV)	0.1896	1.00	PROG MGT $ = A*(DEV PME HDW$^B)
TEST & EVAL (DEV)	0.1837	1.00	T&E $ = A*(DEV PME HDW$^B)
SYS ENG (TFU)	0.0270	1.00	SYS ENG $ = A*(PRD PME HDW$^B)
PROG MGT (TFU)	0.0240	1.00	PROG MGT $ = A*(PRD PME HDW$^B)
TEST & EVAL (PRD)	0.0685	1.00	T&E $ = A*(PRD PME HDW$^B)
PEP (PRD)	0.0000	1.00	PEP $ = A*(PRD PME HDW$^B)
RADAR LOGISTICS COSTS			
Ground Support Equip (DEV)	0.0225	1.00	GSE $ = A*(DEV PME HDW$^B)
Training (DEV)	0.0150	1.00	TRNG $ = A*(DEV PME HDW$^B)
Data (DEV)	0.0490	1.00	DATA $ = A*(DEV PME HDW$^B)
Other Logistics CERS	0.0000	1.00	DEP VAR $ = A*(INDVAR$^B)
Ground Support Equip (PROD)	0.0880	1.00	GSE $ = A*(PRD PME HDW$^B)
Training (PRD)	0.0000	1.00	TRNG $ = A*(PRD PME HDW$^B)
Data (PRD)	0.0000	1.00	DATA $ = A*(PRD PME HDW$^B)
Spares (PRD)	0.0390	1.00	SPARES $ = A*(PRD PME HDW$^B)
Other Logistics CERS	0.0000	1.00	DEP VAR $ = A*(INDVAR$^B)

The CERs are assembled into a typical model architecture. The CERs shown here cover Below the Line (BTL) or systems level and logistics costs.

Research Procedure – Univariate Analysis



The CER shown (Systems Engineering for Development Phase) is an example of an important Below the Line (BTL) or systems level cost.

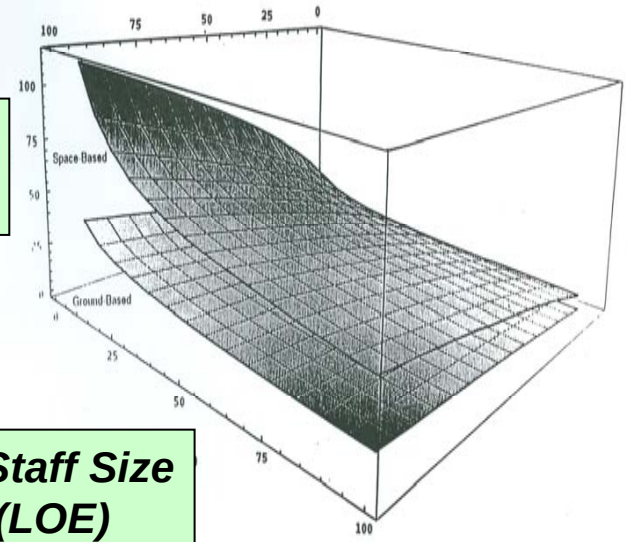
Research Procedure – Multivariate Analysis

SOFTWARE DEVELOPMENT DURATION

IDA

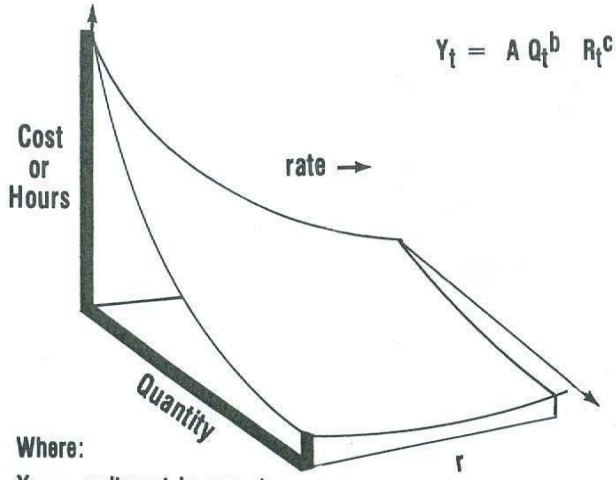
SLOC

SPAN TIME (MOS)



Staff Size (LOE)

Mfg Hrs vs. Qty vs. Rate



Where:

Y_t = unit cost in year t
A = prime or first unit cost
Q_t = cumulative quantity
+b = quantity exponent for describing the slope as log (progress rate)/log (2)
R_t = quantity effected by the present rate structure
+c = the exponent describing the slope of the rate/cost curve and which represents the economy of scale cost impacts for the items produced at the present rate

In cost analysis, we sometimes wish to see how cost relates to two independent variables. In a perfect world, we should be able to create carpet plots for cost.

Research Procedure – Multivariate Analysis

But in cost analysis, we often have just a few data points to work with, and they may be highly correlated among themselves. This phenomenon is called multicollinearity.

Where multicollinearity is present, the resulting coefficient values of the independent variables do not reflect the true contribution of that variable to the regressed solution.

The test for multicollinearity uses the pairwise correlation matrix.
Where |R| > .70, the CER should be rejected for multicollinear influence.

Example of Multicollinearity

T/R Module Case Study

T/R MODULE TFU PRODUCTION COST (FY01 $)

HISTORICAL ITEM	FREQUENCY GHz	TFU COST 95% CIC (FY01 $)	BAND	POWER (W) PER MODULE	WEIGHT (LBS)
RADAR 76	.35-.65	$12,524	UHF	322.0	3.00
RADAR 89	.35-.65	$7,905	UHF	322.0	3.00
USN BM SYS	5.8-6.25	$8,732	C	6.0	1.20
RDR_2	8-10	$3,256	X	CLASSIFIED	0.40
RDR_4	8-10	$4,328	X	CLASSIFIED	0.40

Example of Multicollinearity

T/R Module Case Study

Model Form: Unweighted Log-Linear model
Number of Observations Used: 5
Equation in Unit Space: TFU_COST_FY01$ = 108098 * FREQUENCY_GHz ^ (-0.9075) * PWR_(W) ^ (-0.5376)

Fit Measures (in Fit Space)

Coefficient Statistics Summary

Variable	Coefficient	Std Dev of Coef	Beta Value	T-Statistic (Coef/SD)	Prob Not Zero
Intercept	11.5908	1.6357		7.0860	0.9807
FREQUENCY_GHz	-0.9075	0.4241	-2.6486	-2.1396	0.8343
PWR_(W)	-0.5376	0.3420	-1.9460	-1.5720	0.7435

Goodness-of-Fit Statistics

Std Error (SE)	R-Squared	R-Squared (Adj)	Pearson's Corr Coef
0.3347	81.31%	62.61%	0.9017

Example of Multicollinearity

T/R Module Case Study

Pairwise Correlation Matrix

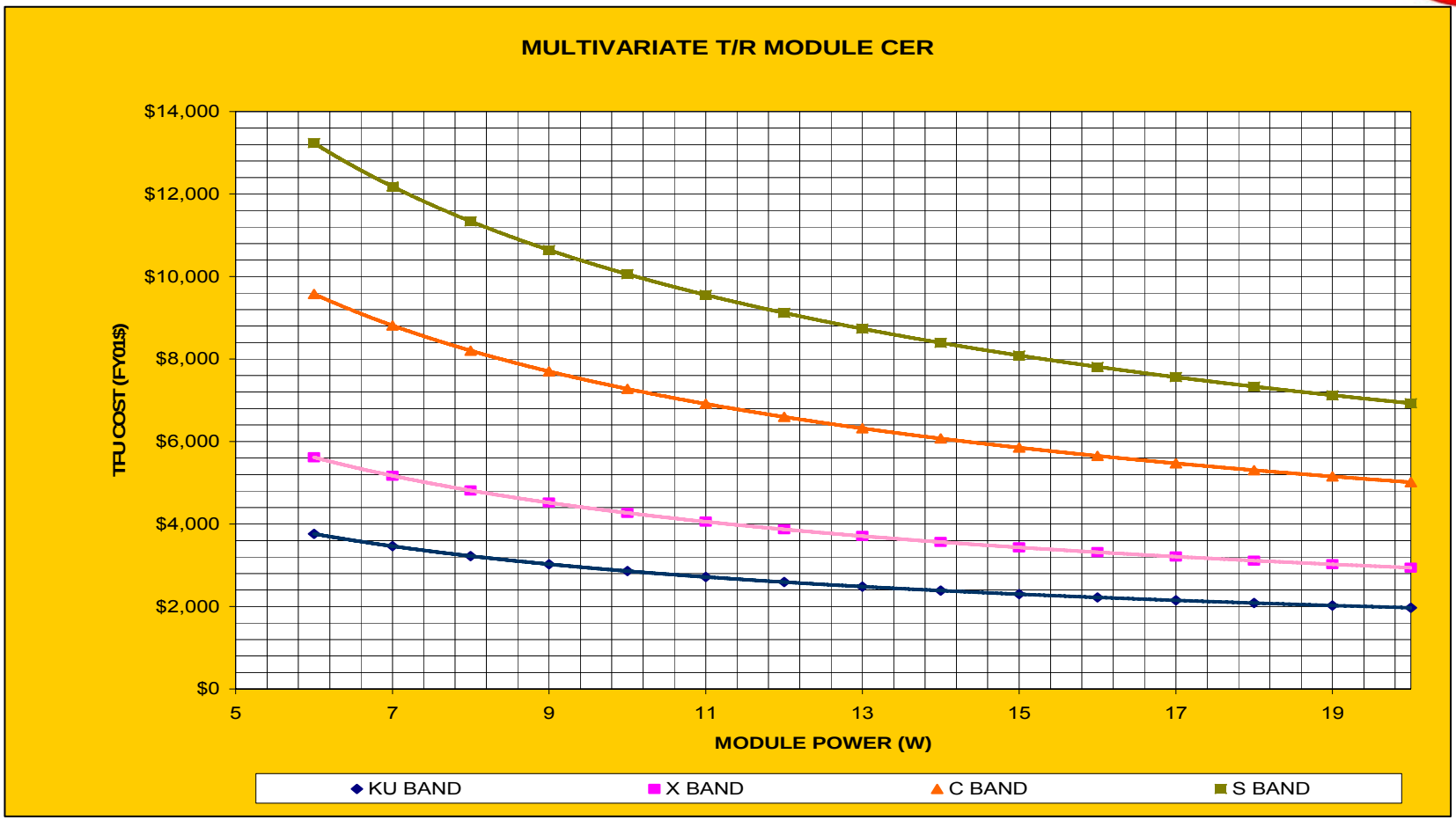
Variables	TFU_COST_FY01$	FREQUENCY_GHz	PWR_(W)
TFU_COST_FY01$	1.0000	-0.7629	0.6206
FREQUENCY_GHz	-0.7629	1.0000	-0.9690
PWR_(W)	0.6206	-0.9690	1.0000

Multicollinearity Analysis

Indep Variables	Indiv R-Sqr (%)	F-Stats	Prob Related to Other Vars	Indiv R-Sqr/Model R-Sqr	Flags
FREQUENCY_GHz	93.90%	46.1839	0.9935	1.1549	X
PWR_(W)	93.90%	46.1839	0.9935	1.1549	X

X = The indicated independent variable could be harmfully correlated to the other independent variables, i.e., it has a nearly better fit using the remaining independent variables than the dependent variable.

Research Procedure – Multivariate Analysis



But aside from the multicollinearity problem, the relationship must make engineering sense. In this instance, cost is said to decrease as module power increases, and this violates our engineering judgment and expectations.

Typical Production Cost Build-Up

RADAR W

				COST CURVE		UNITS	SLOPE B	1 + B	
	TFU - PRODUCTION			95.0%		1 - 250	-0.0740	0.926	
NOMENCLATURE	MAT COST		5	95.0%		250 - UP	-0.0740	0.926	
	(FY07 M$)	START	END	CURVE	(CT-END)-(CT-START)		TOTALS	UNIT COST	
PRODUCTION									
ANTENNA	$48.425	1	5	95.0%	$226.010	$0.000	$226.010	$45.202	
RADOME	$0.970	1	5	95.0%	$4.527	$0.000	$4.527	$0.905	
T/R MODULE	$0.003	90001	180000	95.0%	$233.489	$122.888	$110.600	$22.120	
TRANSMITTER	$0.000	1	5	95.0%	$0.000	$0.000	$0.000	$0.000	
RCVR-EXCITER	$0.000	1	5	95.0%	$0.000	$0.000	$0.000	$0.000	
SIGNAL PROCESSOR	$1.639	1	5	95.0%	$7.649	$0.000	$7.649	$1.530	
DATA PROCESSOR	$7.097	1	5	95.0%	$33.122	$0.000	$33.122	$6.624	
CONTROLS	$1.433	1	5	95.0%	$6.687	$0.000	$6.687	$1.337	
COOLING & ELECTRICAL GRP	$1.780	1	5	95.0%	$8.306	$0.000	$8.306	$1.661	
OTHER EQUIPMENT GRP	$0.000	1	5	95.0%	$0.000	$0.000	$0.000	$0.000	
CEU COST	$2.406	1	5	95.0%	$11.231	$0.000	$11.231	$2.246	
PPU COST	$3.584	1	5	95.0%	$16.729	$0.000	$16.729	$3.346	
EEU COST	$3.446	1	5	95.0%	$16.081	$0.000	$16.081	$3.216	
E&S INT & TEST COST	$0.746	1	5	95.0%	$3.481	$0.000	$3.481	$0.696	
OTHER MECHANICAL PROV	$0.000	1	5	95.0%	$0.000	$0.000	$0.000	$0.000	
PRE-FAB SHELTER COST	$0.000	1	5	95.0%	$0.000	$0.000	$0.000	$0.000	
CONSTRUCTION COST	$0.000	1	5	95.0%	$0.000	$0.000	$0.000	$0.000	
				TOTAL PRODUCTION RADAR PME COST		(FY07 M$)	$444.422	$88.884	

Integrated Acquisition Cost Estimate
(Development, Production, Support Investment)

RADAR Z

	COST	FEE	COM	MDA SET-ASIDE	TOTAL
RADAR SYSTEM POINT ESTIMATE					
PME HARDWARE DEVELOPMENT	$61.491	$7.379	$0.492	$3.689	$73.051
SOFTWARE DEVELOPMENT	$16.085	$1.930	$0.129	$0.965	$19.109
PME HARDWARE PROTOTYPE	$0.000	$0.000	$0.000	$0.000	$0.000
INTEGRATION & CHECKOUT	$0.000	$0.000	$0.000	$0.000	$0.000
SYSTEM ENG/PROGRAM MGT	$41.658	$4.999	$0.333	$2.499	$49.490
SYSTEM TEST & EVAL	$21.799	$2.616	$0.174	$1.308	$25.897
TOOLING & TEST EQUIPMENT	$13.498	$1.620	$0.108	$0.810	$16.036
PEP	$0.000	$0.000	$0.000	$0.000	$0.000
PECULIAR GSE	$1.253	$0.150	$0.010	$0.075	$1.488
DATA	$0.834	$0.100	$0.007	$0.050	$0.991
TRAINING	$0.252	$0.030	$0.002	$0.015	$0.300
SPARES	$1.255	$0.151	$0.010	$0.075	$1.491
ENG CHANGE ORDERS	$3.879	$0.465	$0.031	$0.233	$4.608
SUBTOTAL RADAR DEVELOPMENT	$162.003	$19.440	$1.296	$9.720	$192.460
HARDWARE PRODUCTION UNITS	$94.385	$14.158	$0.755	$5.663	$114.961
INTEGRATION & CHECKOUT	$8.872	$1.331	$0.071	$0.532	$10.806
SYSTEM ENG/PROGRAM MGT	$10.233	$1.535	$0.082	$0.614	$12.464
SYSTEM TEST & EVAL	$7.073	$1.061	$0.057	$0.424	$8.615
TOOLING & TEST EQUIPMENT	$8.705	$1.306	$0.070	$0.522	$10.602
PEP	$8.932	$1.340	$0.071	$0.536	$10.879
PECULIAR GSE	$1.668	$0.250	$0.013	$0.100	$2.031
DATA	$1.239	$0.186	$0.010	$0.074	$1.509
TRAINING	$0.568	$0.085	$0.005	$0.034	$0.692
SPARES	$1.670	$0.251	$0.013	$0.100	$2.034
ENG CHANGE ORDERS	$5.163	$0.774	$0.041	$0.310	$6.288
SUBTOTAL PRODUCTION	$148.507	$22.276	$1.188	$8.910	$180.882
RADAR SYSTEM TOTAL OUTLAY	$310.511	$41.716	$2.484	$18.631	$373.342

Research Procedure – Expert Interpretation

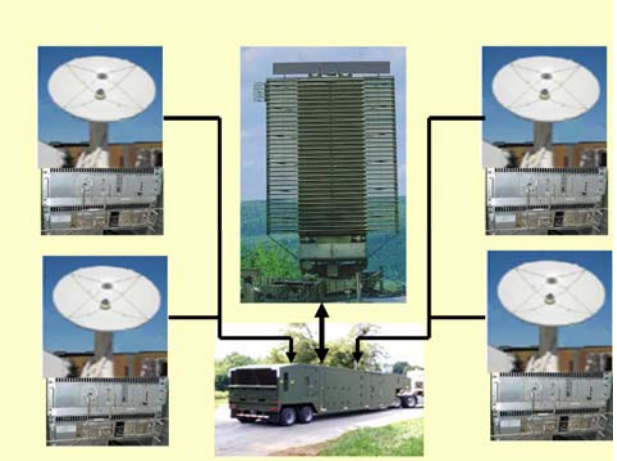
In cost analysis, expert interpretation is the art of using the tools we have to solve new problems outside our well understood technical data base.

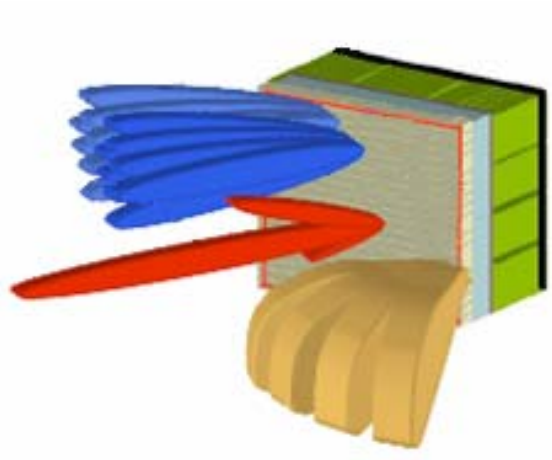
- ***This can involve treating existing methods with complexity adjustments.***

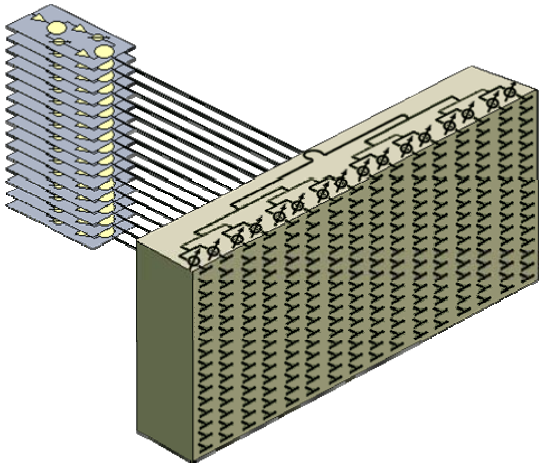
- ***This can involve additional historical investigation resulting in expansion of the models and methods to incorporate new content.***

- ***This can involve consultation with technical SMEs, to gather their assessments and harmonize expected cost effects and impacts.***

Research Procedure – Expert Interpretation







Radar Parametric Cost Model - Conclusions

Radar Cost Analyses Incorporating Component Sensitivity:

- ***The model facilitates estimates of derivative Radars and modification or upgrade programs for existing radars.***
- ***The model is sensitive to software content and new technology insertion.***
- ***The model suite includes provisions for cost spreads and escalations, and MILCON costs, including buildings, roads, substations, and other construction requirements.***