Business Case Analysis with a Modeled Enterprise (BeCAME)

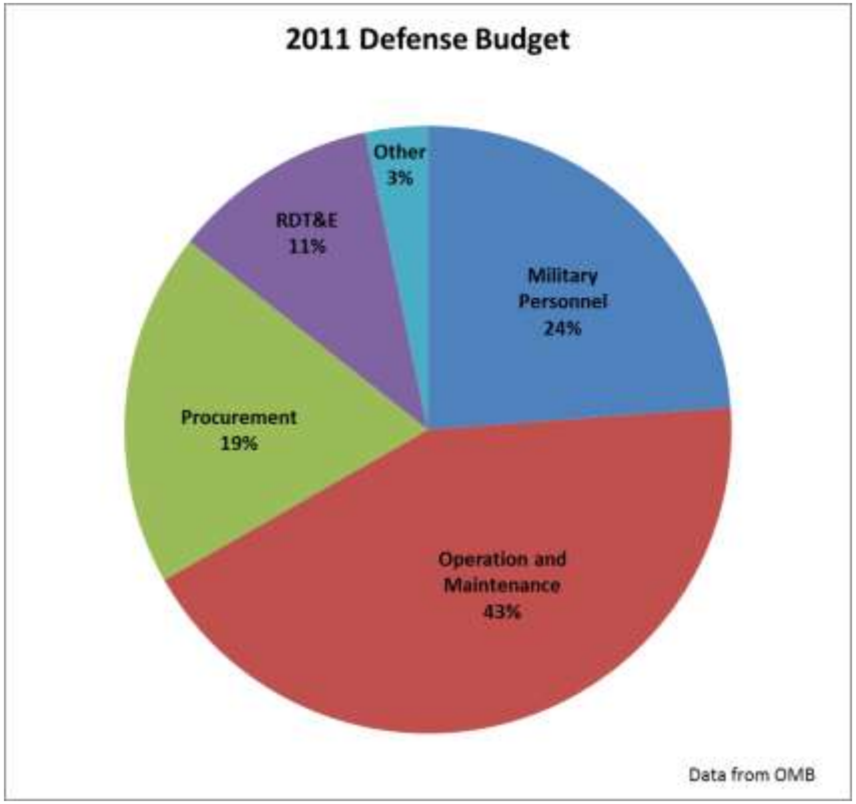
Elliott Reitz, 31 October 2013

Topics

- Introduction – Where is $ spent?
- Research analysis
- Business Case Assessment
- Use Cases
- Intelligent Asset Visibility
- Results
- Conclusions

Soldiers protected from Improvised Explosive Devices (IEDs) via Counter Remote Control IED (RCIED) Electronic Warfare (CREW) systems

Where is Defense Money Spent?



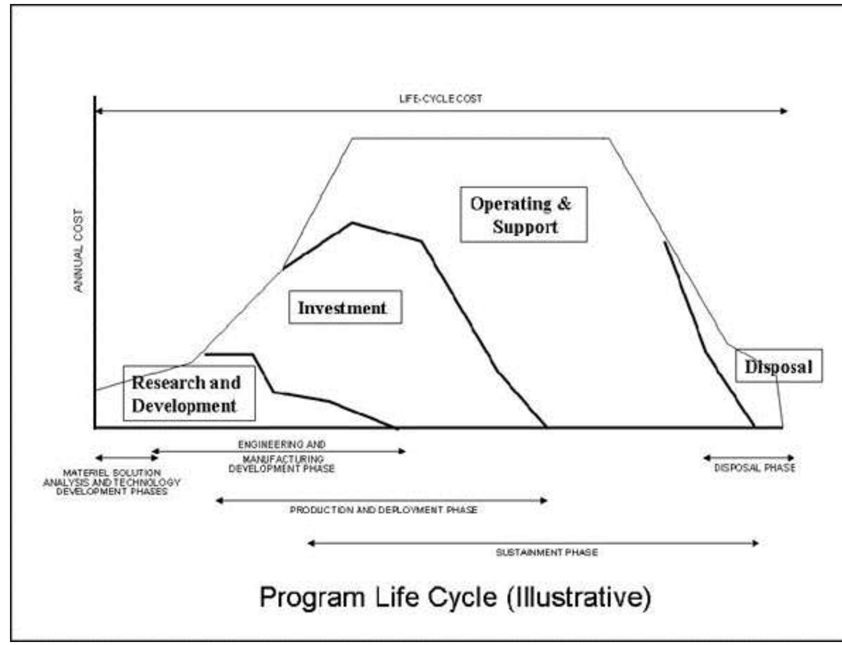


Figure from DAU

Operation & Maintenance costs are the largest part of both the Defense Department Budget and lifecycle costs within a single program.

Past Scientific Analysis

- Dempster Laird and Rubin used Kalman filtering in 1976
- Reitz applied Box-Jenkins and Kalman filtering in 1991
- In 2003, Murray Huges and Delgado applied Rank Sum feature selection and Support Vector Machines to predict failures of hard disk drives
- In 2007 Leon Lopez continued the application of pattern recognition methods with the application of Bayesian Neural Networks to prognostics
- Bringing us to the current state:
  - In 2007 a SBIR contract was awarded to Evigia and later with AAC, Metron, and NAVSEA to develop a Prognostic Sensor System (data logger of T,H,S).

References

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2. Introduction to Random Signal Analysis and Kalman Filtering, Robert Grovedr, © 1983, John Wiley & Sons Inc. ISBN 0-471-08732-7
3. Fault Prediction With Regression Models, E. Reitz, 1991 Thesis Project. http://edans.org/predict/predict.HTM
4. Advanced Electronic Prognostics Through System Telemetry and Pattern Recognition Methods, Leon Lopez, RAS Computer Analysis Laboratory, Sun Microsystems, San Diego, CA, United States, 2007. www.sciencedirect.com 47 (2007) 1865–1873.
5. Prognostic Sensor Microsystem – SBIR Phase 1 Contract Awarded to Evigia Systems Inc. https://sbirsource.com/sbir/awards/56490-prognostic-sensor-microsystem#
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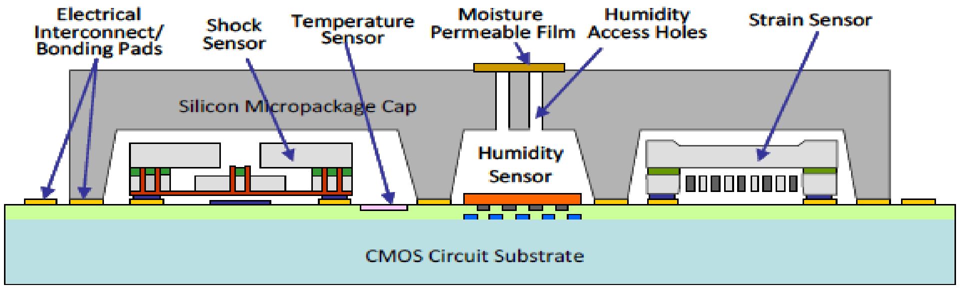
7. Hard Drive Failure Prediction using Non-Parametric Statistical Methods. Joseph F. Murray, Gordon F. Hughes and Kenneth Kreutz-Delgado. Proc. ICANN/ICONIP 2003, Istanbul, Turkey
8. The US Defense Budget. http://www.comw.org/qdr/fulltext/100223williams.pdf

PHM Applications Motives

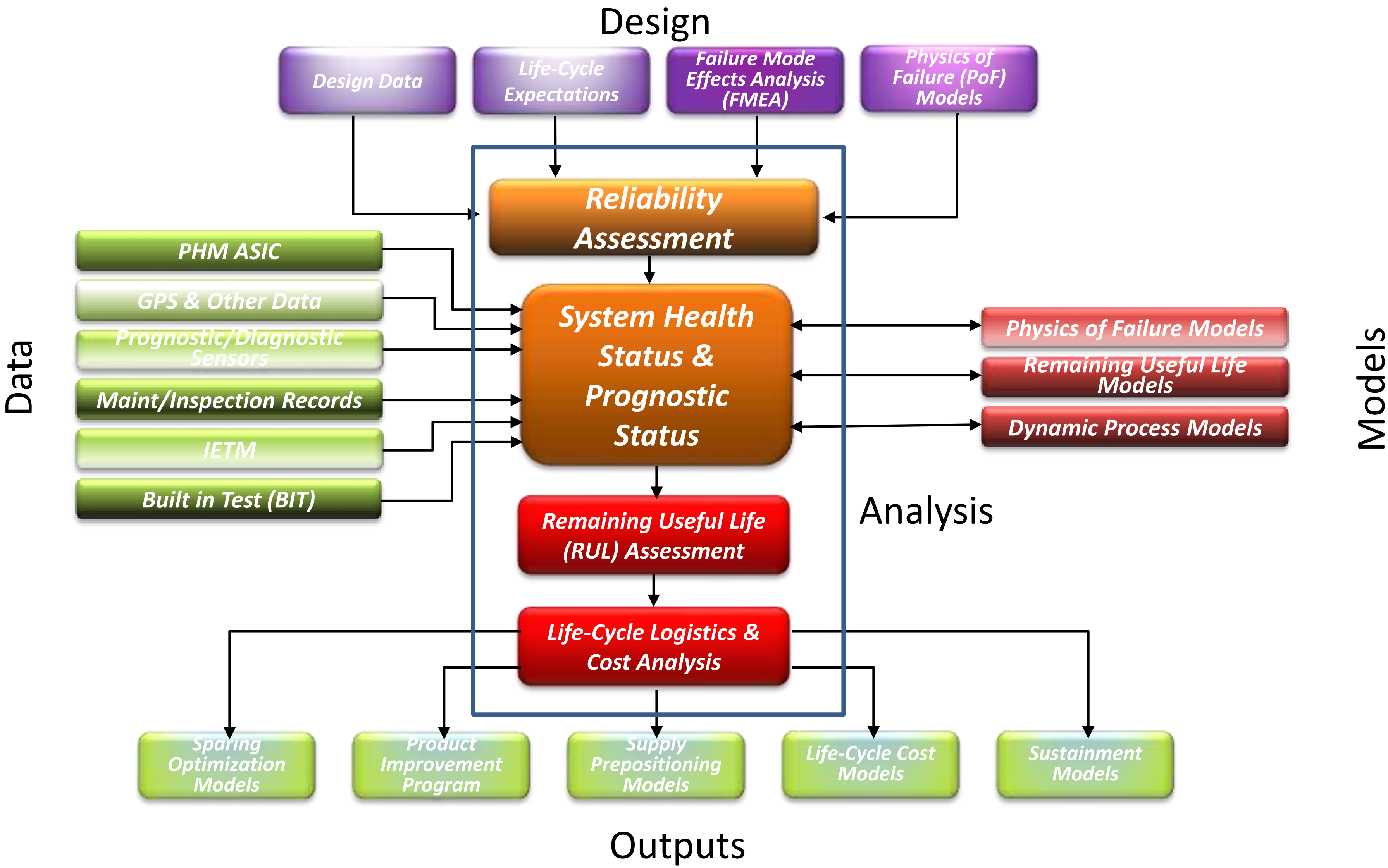
Reconsidering the motives and what's possible with an environmental data logger (rather than just prognostics), its wider benefits are:

- Forensics
  - Correlate failures to exposure
- Diagnostics
  - Improve failure isolation
- Prognostics
  - Determine when systems are near failure
  - Predictive analysis based on observations



PHM Data Logger

Basic PHM Methodology

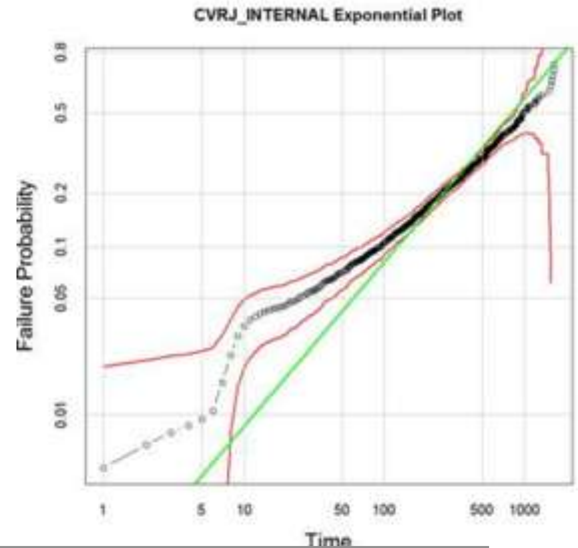


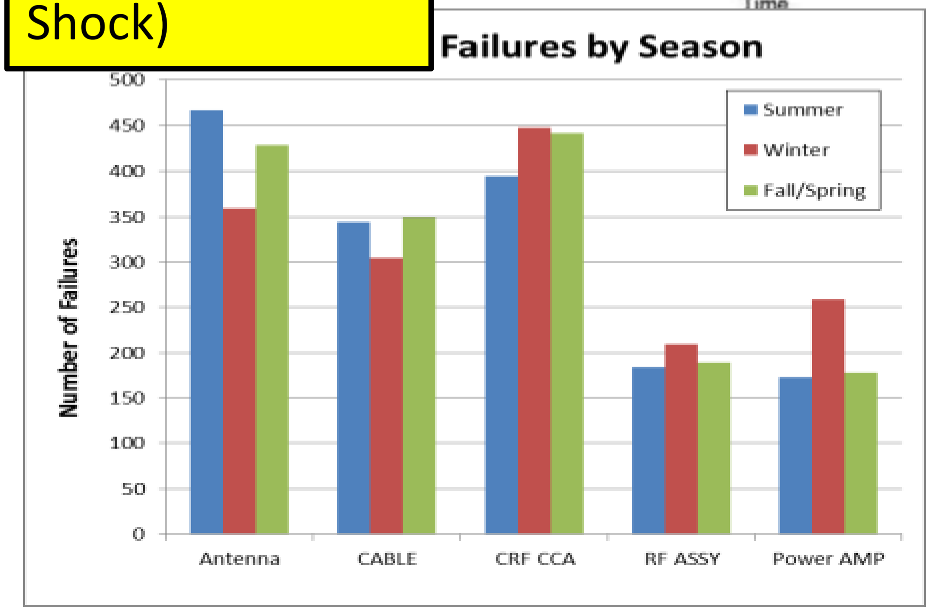
System Development

Data Analysis - Environmental Impact

- Winter stands out from Summer, and Fall/Spring
- Less usage (e.g. Antenna) but more electronics failures (e.g. CRF CCA)
  - Roughly 50% increase in internal component failures during winter when scaled for usage
  - This does not suggest Temperature as the cause
  - It may suggest moisture

Seasonal variation is evidence of environmentally sensitive failure modes (Temperature, Humidity, or Shock)

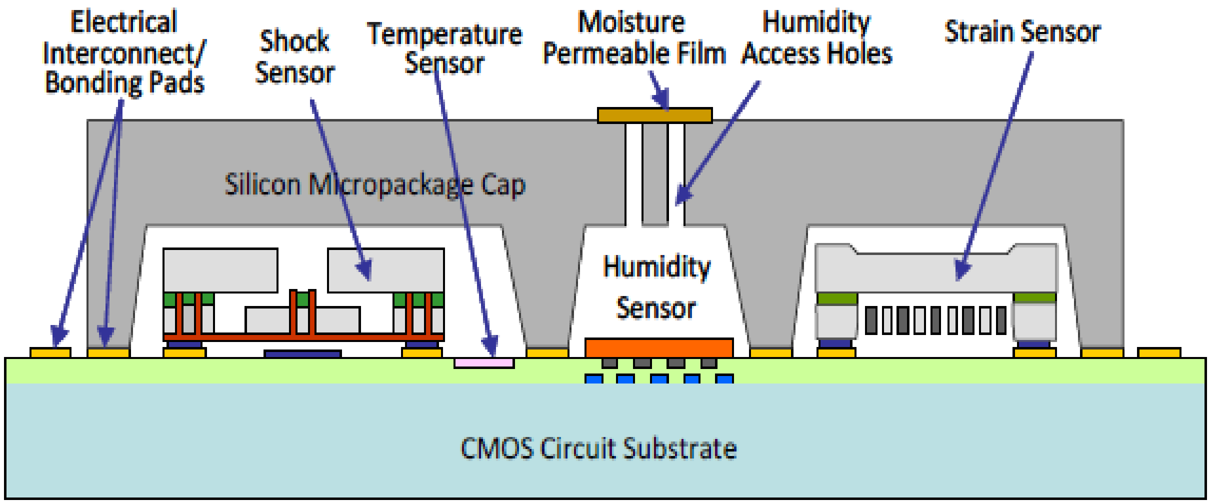




Initial Business Case Analysis

Initial Assessment via Modeling

- CVRJ failure rate is significant
- Environmentally induced Failure Modes Exist
- Preemptive repair should improve Ao using Data Logger
- Preemptive repair should reduce overall maintenance costs

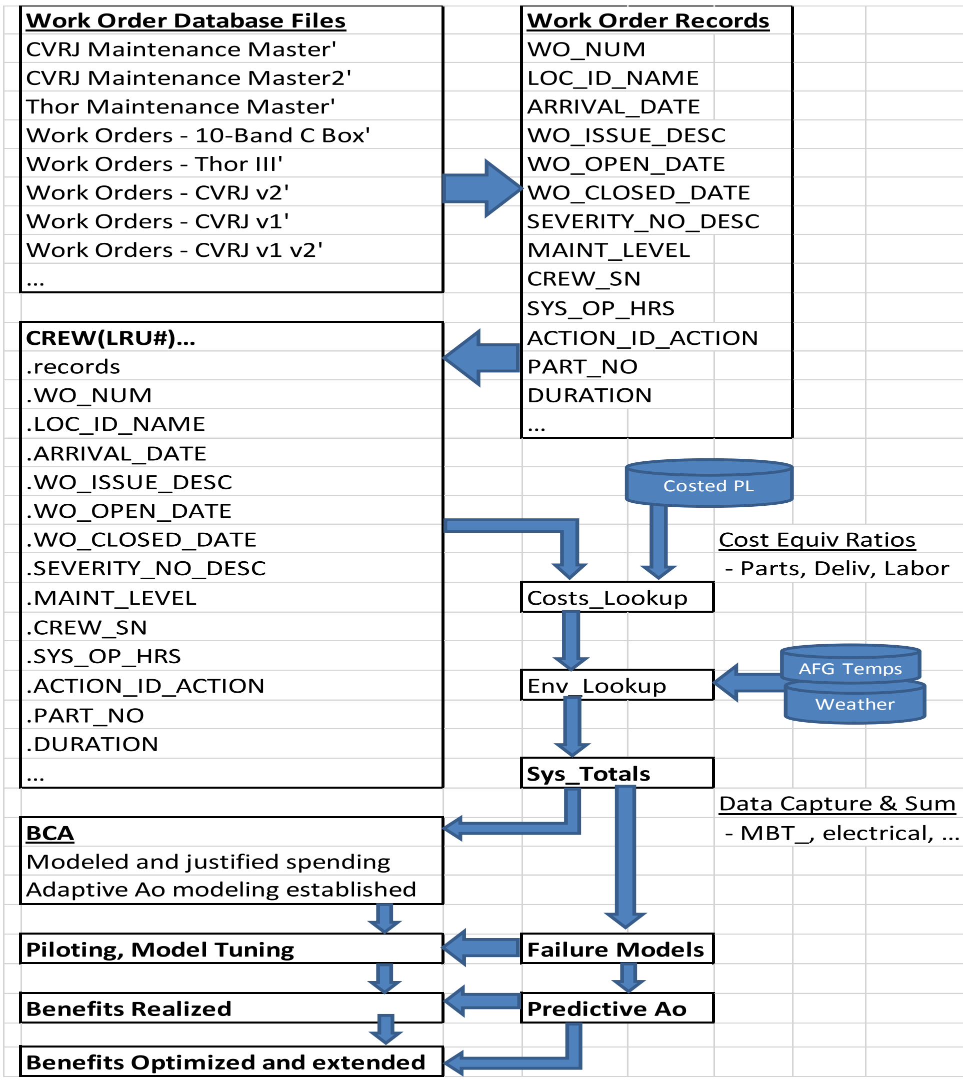


The PHM ASIC Detects Exposure to Environmental Conditions

Modeling Progression

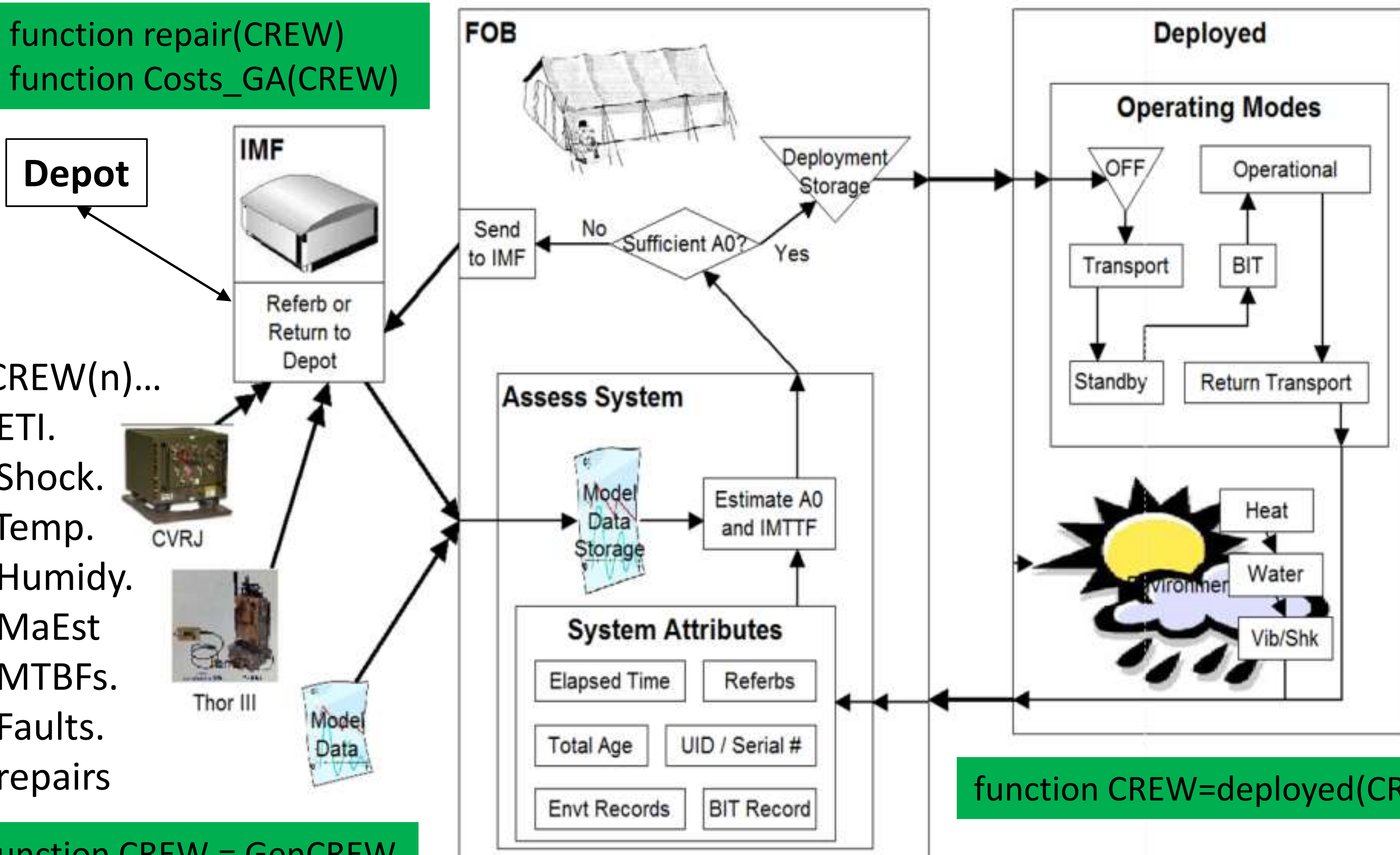
Work Order Database

- Provided MTBFs
- Parts Cost per NSN
- Consolidated raw data into CREW LRU data structures
- Used assumptions to estimate FOB/IMF overhead
- CREW.ETI and CREW.MTBFs support ERA™ analysis of the alternatives (scenarios)



Activity Diagram of Deployed Systems and Model Description

function repair(CREW)
function Costs_GA(CREW)



CREW(n)…
.ETI.
.Shock.
.Temp.
.Humidy.
.MaEst
.MTBFs.
.Faults.
.repairs

function CREW = GenCREW

function CREW=MaEst(CREW)

function CREW=deployed(CREW)

script Expeditions_Ma_Costs

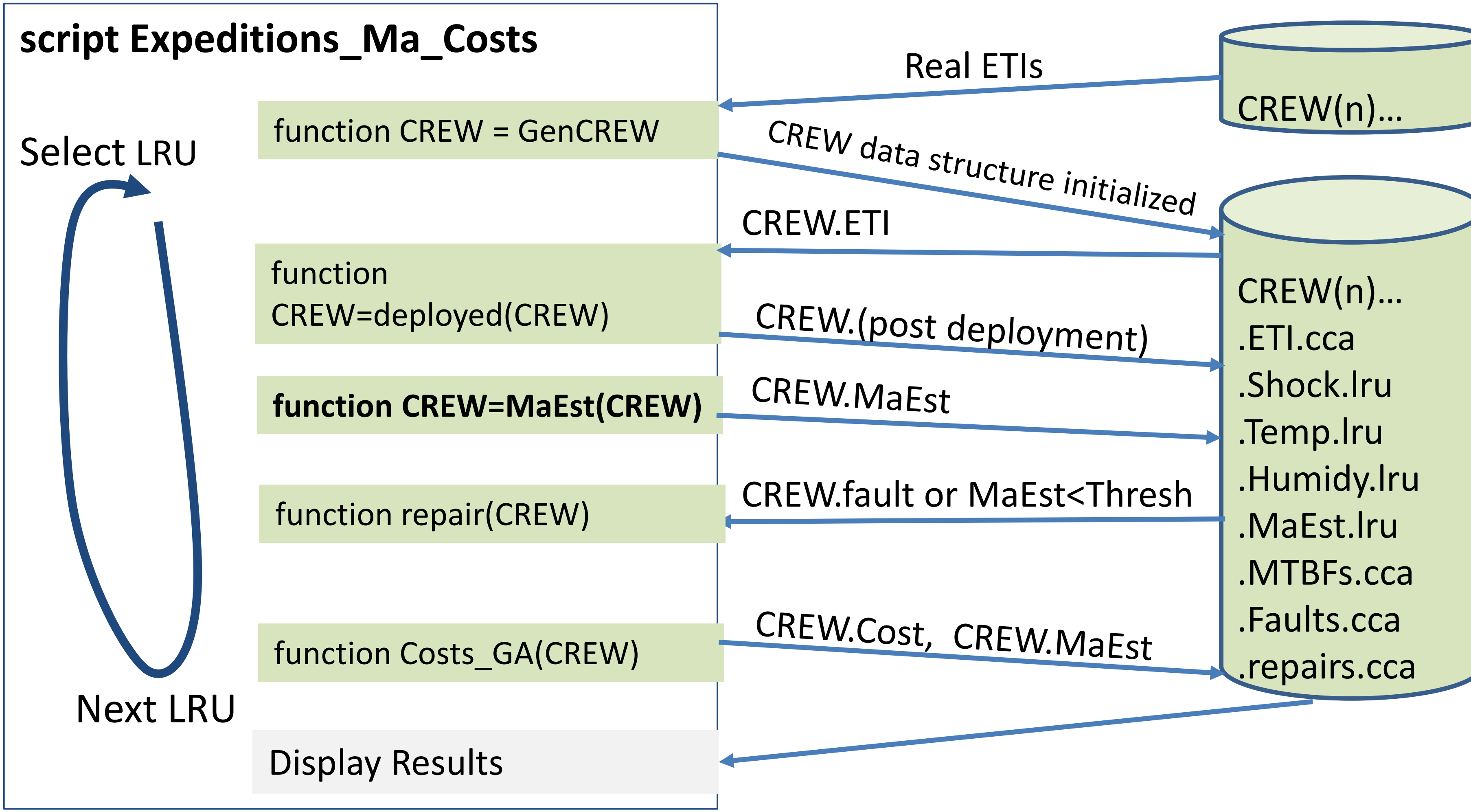
The "PHM Capability" provides the ability to achieve better Ma, Am, Ao at lower cost!

Model Description

ProcessModel™ and Matlab™ models mirror.
The .m files are:

- script Expeditions_Ma_Costs
  - Generate Scenarios, Run/average iterations, Present results
- function CREW=deployed(CREW):
  - Simulates changes to the LRU's parameters during a deployment
    - Exposure to shock, humidity, temp
    - Generates statistical failures per Weibull PDF (MTBF, K, Op_Hrs)
    - Degrades LRU's estimated MTBF according to exposure conditions (with assumptions)
- function CREW=MaEst(CREW):
  - Estimates Ma based upon exposure
- function repair(CREW):
  - Updates LRU's parameters per a repair
- function Costs_GA(CREW):
  - Tallies Costs of repaired components
- function CREW = GenCREW:
  - Initializes the LRU ETIs with real data

Use Case Model Description



LRU Data Objects Simulate the “Use” of real equipment in the scenario “case”

Use Case Analysis

Modeling Impact of Logistics on Operational Availability

- 3 Basic Scenarios – assume local conflict missions
- A: 30 day mission, no resupply
  - All equipment deploys with operational unit
- B: 60 day mission, resupply available
  - Equipment replacement provided once
  - All maintenance done at Depot
- C: 90+ day mission, resupply available
  - True “logistics tail” established
  - All maintenance at IMF or Depot

30 day missions shown, 60 and 90 also run

ario 2: USAF (790 CVRJs)

02	116	121	201	202	203	214	216	301	302	310	314	316	321
B	FOB	FOB	IMF	IMF	IMF	IMF	IMF	DEP	DEP	DEP	DEP	DEP	DEP
10	15.3	15.5	13.7	10.1	12.8	13.2	13.3	8.25	10.1	9.11	8.88	8.78	8.56
0	1.55	1.64	1.84	0	1.22	1.5	1.56	1.88	0	1.37	1.51	1.56	1.65
0	0.33	0.36	0.43	0	0.26	0.32	0.34	0.43	0	0.29	0.33	0.33	0.36
0	0.2	0.22	0.27	0	0.16	0.19	0.2	0.27	0	0.18	0.2	0.2	0.22
0	0.25	0.27	0.33	0	0.19	0.24	0.25	0.33	0	0.22	0.24	0.25	0.27
0	0.12	0.13	0.16	0	0.09	0.12	0.12	0.16	0	0.11	0.12	0.12	0.13
0	0.14	0.14	0.18	0	0.1	0.13	0.13	0.18	0	0.12	0.13	0.13	0.14
0	0.25	0.27	0.33	0	0.2	0.24	0.26	0.34	0	0.22	0.25	0.26	0.27
0	0.12	0.12	0.15	0	0.09	0.11	0.11	0.15	0	0.1	0.11	0.11	0.12
10	1.07	0.53	0	10	3.22	1.37	1.06	0	10	2.25	1.37	1.06	0.53
1	0.7	0.1	0	1	0.94	0.8	0.7	0	1	0.9	0.8	0.7	0.1
1	0.91	0.8	0.6	1	0.98	0.94	0.91	0.6	1	0.97	0.94	0.91	0.8
92	0.6	0.29		0.92	0.84	0.7	0.6		0.92	0.81	0.7	0.6	0.29
02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
01	0.02	0.06	0.1	0.01	0.01	0.02	0.02	0.1	0.01	0.01	0.02	0.02	0.06
05	0.01	0	0	0.05	0.02	0.01	0	0	0.05	0.01	0.01	0.01	0
0	0.01	0.01	0.02	0	0	0.01	0.01	0.02	0	0.01	0.01	0.01	0.01
0	0	0	0.07	0	0	0	0	0.07	0	0	0	0	0

ion: Depot only with MaThreshold = 0.7

repair_f_rem_ext	2.54	0	0.81	1.37	0	0	0.82	1.24	2.51	0	1.25	1.34	1.41	1.46
repair_f_rem_int	1.14	0	0.35	0.58	0	0	0.36	0.55	1.14	0	0.54	0.59	0.61	0.63
refurbs	0	30	15.6	5.79	30	30	15.6	7.82	0	30	7.83	5.83	4.54	4.32
MaThreshold	0	1	0.9	0.5	1	0.94	0.9	0.7	0	1	0.7	0.5	0.2	0.1
Ma_Mean	0.78	1	0.98	0.91	1	1	0.98	0.94	0.79	1	0.94	0.91	0.87	0.86
MaRefurbMean		0.85	0.77	0.58	0.85	0.85	0.77	0.64		0.85	0.64	0.58	0.58	0.59
MaLoss_mtbf	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
MaLoss_Temps	0.1	0.03	0.03	0.06	0.03	0.03	0.03	0.05	0.1	0.03	0.05	0.06	0.07	0.07
MaLoss_Humid	0	0.04	0.02	0.01	0.04	0.04	0.02	0.01	0	0.04	0.01	0.01	0.01	0.01
MaLoss_Shock1	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02
MaLoss_Shock2	0.06	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.06	0.01	0.01	0.02	0.02	0.02

Indicated Options: Depot only with MaThreshold = either 1.0 or 0.5

io 4: USMC (~6000 CVRJs)

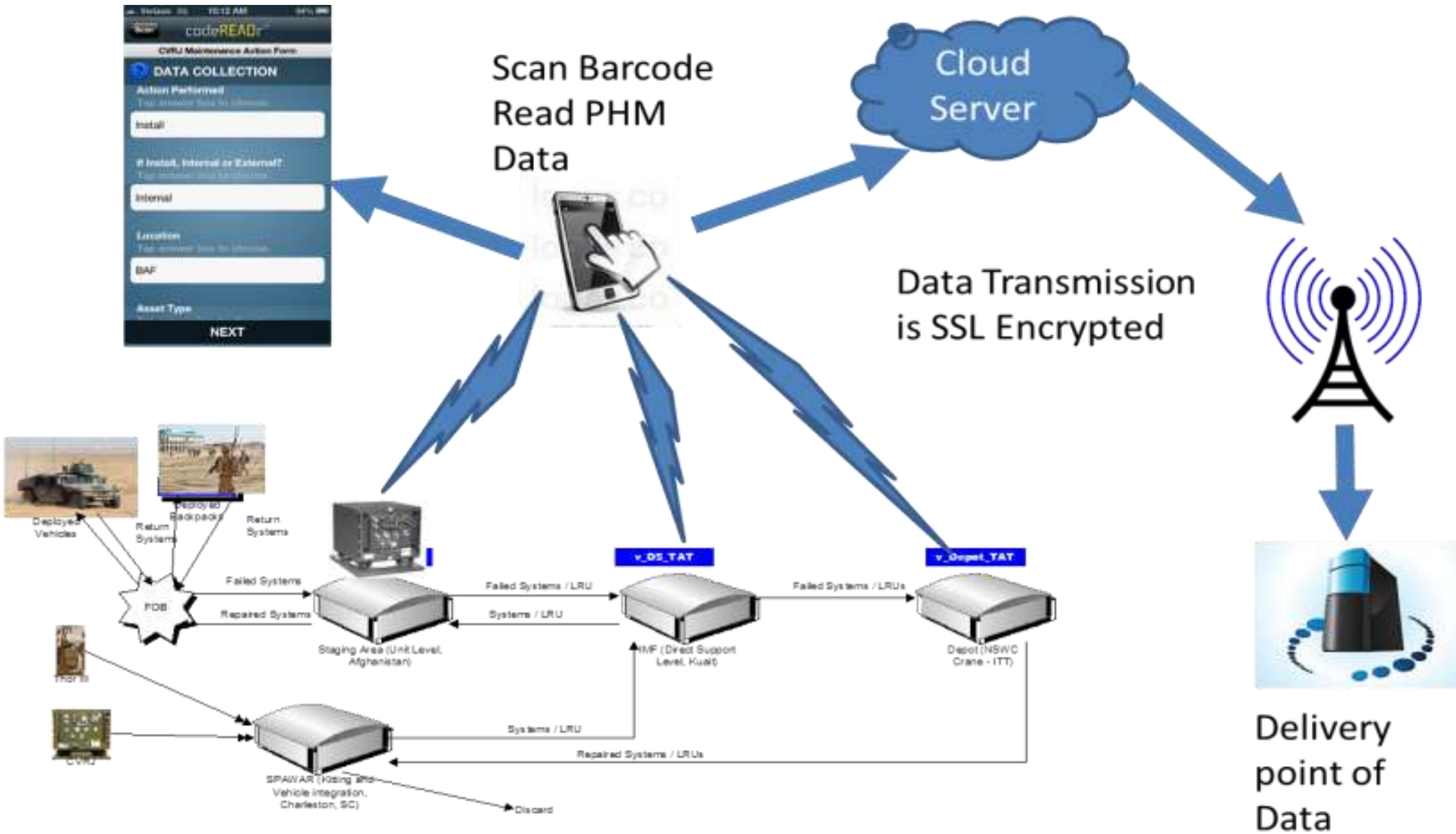
		2	110	114	116	201	202	210	214	301	302	310	314	316	318	319	320	321
			FOB	FOB	FOB	IMF	IMF	IMF	IMF	DEP	DEP	DEP	DEP	DEP	DEP	DEP	DEP	DEP
		6	91.4	94.7	97.6	108	89.5	90.5	92.3	66	89.6	88.7	87.2	86	83.8	83.2	81.5	80.9
		1	1	0.99	0.97	0.41	1	1	0.99	0.45	1	1	0.99	0.97	0.94	0.92	0.88	0.86
		0	23.3	67.3	107	503	0	23.3	67.3	546	0	23.5	67.2	107	168	192	230	244
		0	5.18	14.8	23.2	132	0	5.09	14.9	132	0	5.18	14.8	23.2	36.1	41	48.6	51.4
		0	2.81	7.94	12.4	87.7	0	2.79	8.04	87.7	0	2.78	8.05	12.4	19.4	22.2	26.6	28.3
		0	2.99	8.53	13.6	92.9	0	3.01	8.46	93.1	0	3.07	8.45	13.5	21.2	24.2	28.7	30.9
		0	1.69	4.98	7.74	56.7	0	1.71	4.89	56.4	0	1.67	4.91	7.73	12	13.8	16.4	17.3
repair_f_rf_assy	59.5	0	1.78	5.19	8.14	59.1	0	1.77	5.18	59.8	0	1.81	5.15	8.09	12.7	14.6	17.3	18.5
repair_f_rem_ext	99.5	0	3.29	9.35	14.8	99.8	0	3.31	9.31	99.4	0	3.3	9.26	14.9	23.1	26.5	31.6	33.5
repair_f_rem_int	45.2	0	1.35	3.8	5.98	45.1	0	1.35	3.81	45.6	0	1.36	3.81	6.11	9.38	10.9	13.1	13.9
refurbs	0	1180	1121	1013	917	0	1180	1122	1013	0	1180	1121	1013	917	770	713	623	587
MaThreshold	0	1	0.9	0.8	0.7	0	1	0.9	0.8	0	1	0.9	0.8	0.7	0.5	0.4	0.2	0.1
MaRefurbMean		0.43	0.41	0.35	0.29		0.43	0.41	0.35		0.43	0.41	0.35	0.3	0.19	0.15	0.1	0.09
MaLoss_mtbf	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
MaLoss_Temps	0.16	0.04	0.04	0.04	0.04	0.16	0.04	0.04	0.04	0.16	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.06
MaLoss_Humid	0	0.05	0.04	0.04	0.04	0	0.04	0.04	0.04	0	0.05	0.04	0.04	0.04	0.03	0.03	0.02	0.02
MaLoss_Shock1	0.29	0.07	0.07	0.08	0.08	0.29	0.07	0.07	0.08	0.29	0.07	0.07	0.08	0.08	0.1	0.1	0.11	0.11
MaLoss_Shock2	1.69	0.39	0.39	0.39	0.4	1.69	0.39	0.39	0.39	1.69	0.39	0.39	0.39	0.4	0.42	0.44	0.48	0.5

Indicated Option: Depot only with MaThreshold = 0.4

Each “Use Case” describes expected usage and exposure statistics.
Models apply the statistics with statistical noise and iterate the see the response.

Intelligent Asset Visibility

The PHM Support Concept



How to Achieve
Intelligent Asset Visibility

- Portable IUID Reader (handheld, tablet, etc.) available – TAV info, already being fielded
- Online application to transmit and store data
- Coordinate with COLTS database - FRACAS
- Centralized Analysis – to correlate failures to environmental exposure conditions
- Use of failure mode models to govern preemptive repairs

Move from **Total Asset Visibility**
to **Intelligent Asset Visibility**

Conclusions

- Failure modes (root causes) are hard to isolate
  - Heat, Shock, Humidity may couple to these modes.
  - Prediction of failure to affect preemptive repair depends upon the validity of these relationships.
  - Aggregate exposure effects may exist, model validation is needed to determine if these expectations are real.
- Pre-emptive repair can achieve a reduction in Life Cycle Cost
  - Rather than prediction of a failure time (Kalman, etc)…
  - Its easier to calculate a "Remaining Life Estimate" (RLE) based upon the exposure events and how they couple to the failure modes.
  - Due to multiple simultaneous failure modes the RLE actually makes better sense than the trend analysis projection that would be more applicable for something like a rotating part subject to accumulative physical wear.
- Adding equipment condition to TAV enables use of pre-emptive repair to achieve desired estimated Ma and RLE.

PHM Data Logger

Temp, Hum, Shock Enable

- Forensics
- Diagnostics
- Prognostics

Intelligent Asset Visibility, IAV

Backups

Forensics – Why Did It Fail?

LCMR = Perfect Example

- Antenna Columns are expensive field replaceable maintenance items.
- The Antenna Columns are sensitive to shock, especially while operating.
- Shock events have multiple causes that may not be detected or reported.
- Undetected shock exposure reduces system performance and increases costs.

The Opportunity

- A simple PHM shock sensor attached to each Antenna Column records the environmental exposure of the device including temperature, humidity, and in this case especially shock events.
- Shock exposure contractually shifts the responsibility for paying for the spares.
- Simple addition of a PHM device on new spare parts is easy to accomplish/deploy.

Diagnostics – What’s Wrong?

- Diagnostics = Fault Isolation
- Automotive Applications provide Perfect Examples
  - Bearing problems (what wheel, sure it’s the bearing?)
  - CV - Universal Joints (which one?)
  - Engine components (what component?)
- The Opportunity
  - A simple PHM vibration and temperature sensor with magnetic mounting and wireless communication to a smart-phone app.
    - Easier to use than a stethoscope;
    - Can be used without putting a car onto a lift so wheels can spin;
    - Improves accuracy with weight of vehicle and load conditions intact.

Automotive Stethoscope

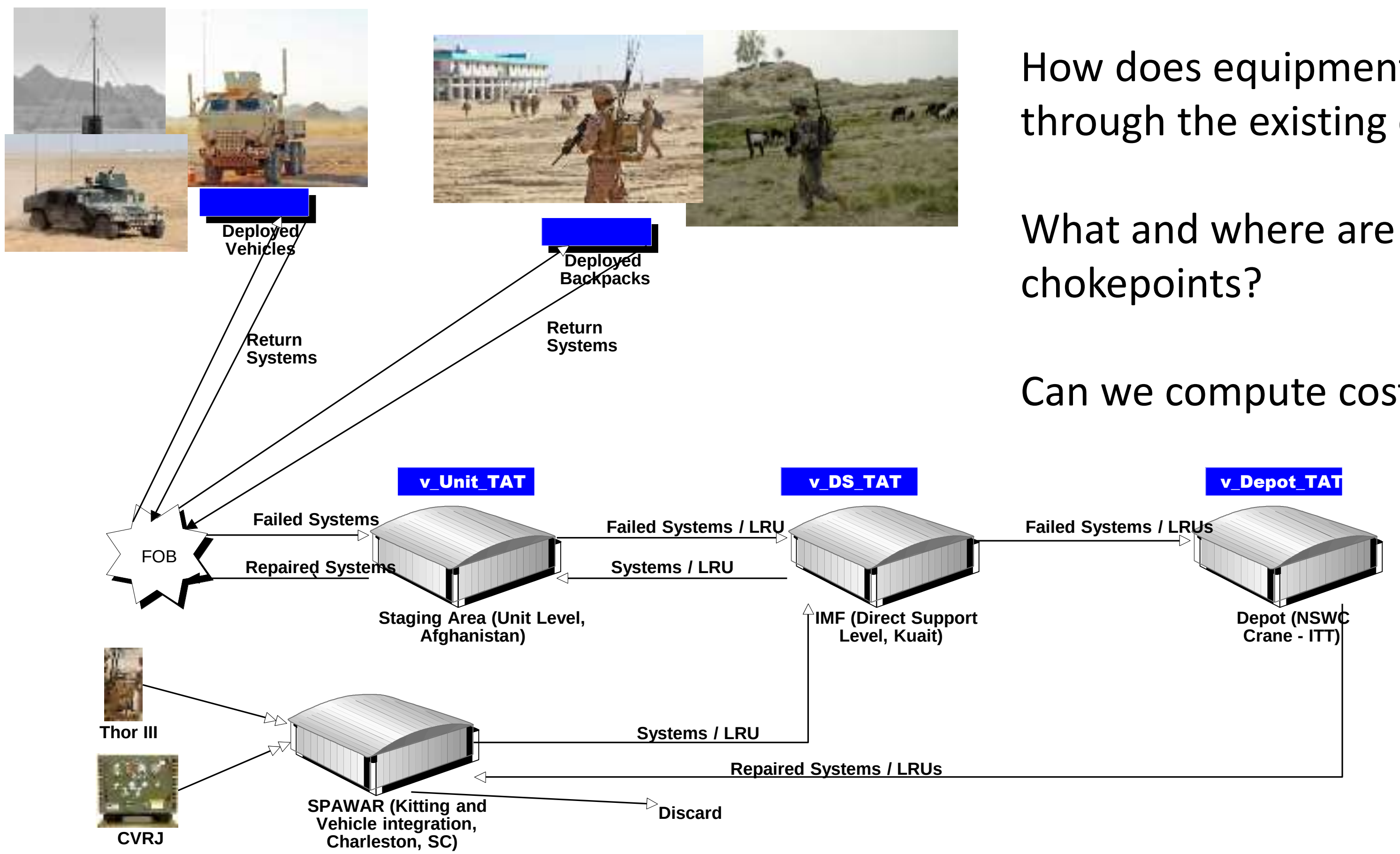
Prognostics – Will it still work?

- CREW Systems = Perfect Example
  - Counter RF Electronic Warfare is used to keep men alive
  - System availability is paramount
  - Thermal, Shock, and Humidity events have multiple causes that may not be detected or reported
- The Opportunity
  - A simple PHM shock sensor attached to each CREW system records the environmental exposure of the device including temperature, humidity, and shock events
  - Availability is predicted based upon exposure and use
  - Availability predictions are used as a system deployment criteria
  - Cost reduction via Pre-emptive maintenance can be achieved WITH improved availability

Soldiers protected from Improvised Explosive Devices (IEDs) via Counter Remote Control IED (RCIED) Electronic Warfare (CREW) systems

Existing Logistics

Model and Analysis



How does equipment flow through the existing chain?

What and where are the chokepoints?

Can we compute costs?