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Reliability Roadmap Using Quality Function Deployment (QFD)

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Agenda

- **Project Background**
- **Review of Results from each step**
- **Overall QFD Findings**
- **Reliability Roadmap**
- **Next Steps**

Situation Summary

- **Traditional handbook reliability methods are inadequate for rapidly changing new technologies**
- **Customers are seeking new reliability methods that use physics of failure and support Design for Reliability**
- **DoD, industry and academia are partnering to revise or create new reliability handbooks and standards that address these needs**

AVSI

- **Aerospace Vehicle Systems Institute (AVSI)**
  - **Chartered to conduct research to benefit aerospace industry**
  - **Research Consortium, based at Texas A&M University**
  - **Member companies include:**
    - Department of Defense
    - FAA
    - Boeing
    - Honeywell
    - Rockwell Collins
    - BAE Systems
    - Goodrich ECS
    - Etc.
  - **Funding for research is based on shared contributions from companies sponsoring the research**

AVSI Research Projects

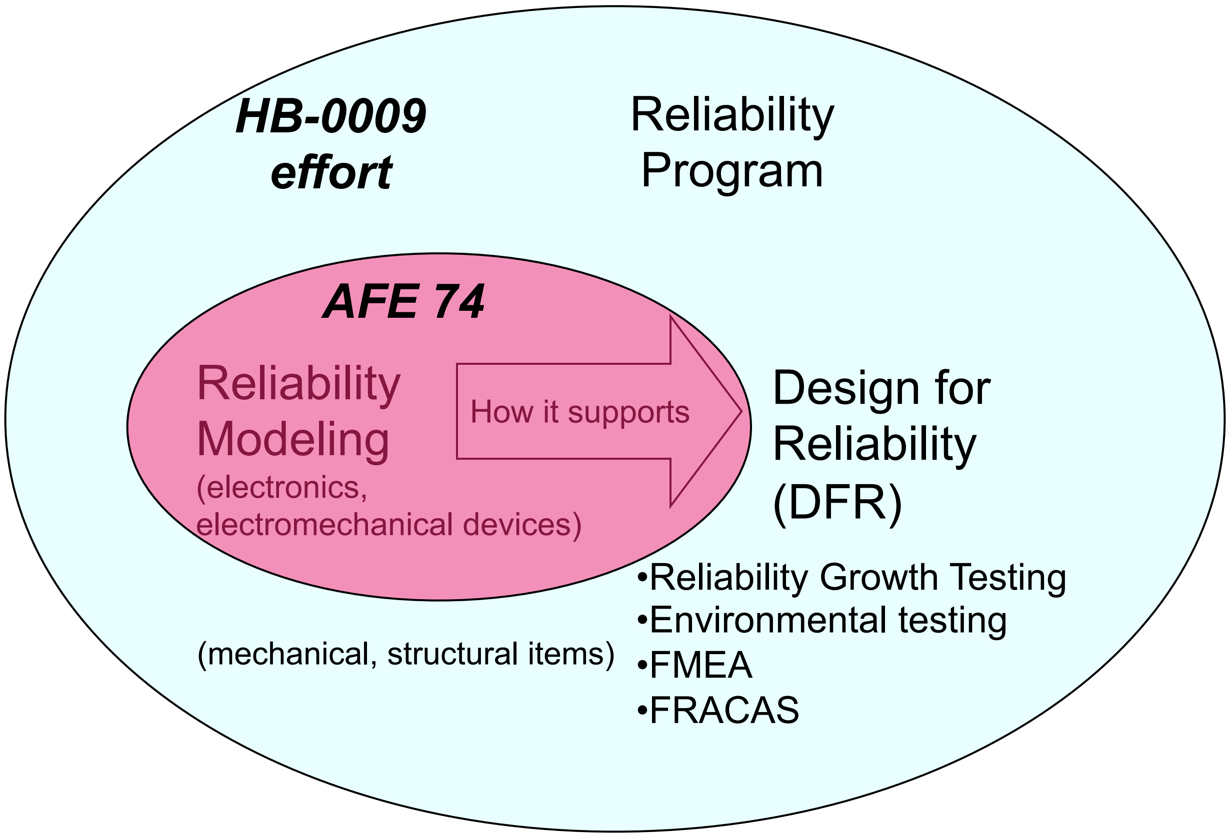
- **AFE 17, 71 – Semiconductor Wearout**
  - **Have developed and validated physics of failure models for small scale feature semiconductor wearout effects**
  - **Developing software tools to streamline development and use of physics of failure models**
- **AFE 16, 72 – Atmospheric Radiation Effects on Semiconductors**
  - **Have characterized the damaging effects of atmospheric radiation for semiconductors**
  - **Developed testing protocols for determining SEE susceptibility**
- **AFE 74 – Reliability Prediction Framework**
  - **Developing roadmap and framework for utilizing AVSI research results in context of a reliability prediction**
  - **Providing information to MIL-HDBK-217 revision team**

Objectives – AFE 74

- **Chart the future of reliability research**
- **Integrate the wisdom and experience of a large number of industry reliability experts**
- **Focus the discussions around the common goal to improve electronics reliability assessment practices**
- **Critically analyze findings, and organize analysis process using the Quality Function Deployment (QFD)**
- **Develop a reliability roadmap with broad support**

Within the scope of AFE 74's charter to investigate electronic and electromechanical failure rate modeling

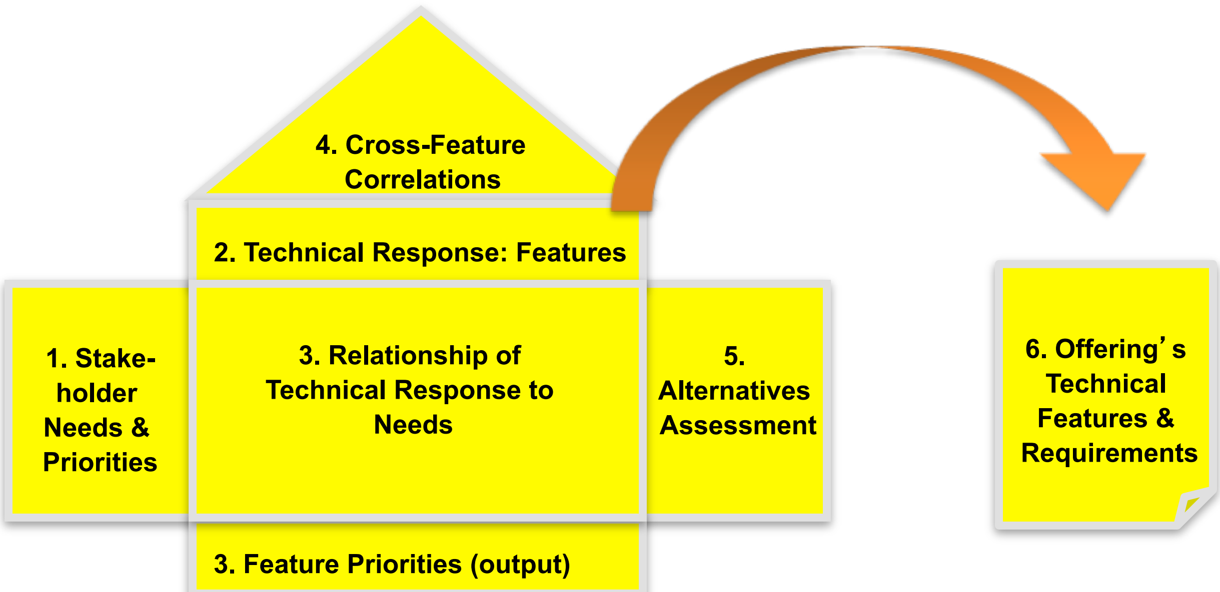
Scope of this study and other efforts



Reliability modeling provides information for the DFR process, but is not the only activity in the reliability program

Roadmap approach - QFD

- **Quality Function Deployment (QFD) tool selected:**
  - **Recognized industry decision making tool**
  - **Organizes a quantified team consensus evaluation**
  - **Maps prioritized needs with design features**
  - **Results in framework for new capability and identifies gaps for future developmental work**
  - **Honeywell expertise in its use – Six Sigma Black Belts**



QFD Process of Engagement

- **QFD conducted in a series of questionnaires, each followed by telecon discussions**
- **Data reduction done by AFE 74 core project team**
- **Consensus where possible, Delphi process for resolution of polarized issues, segmentation or adaptation where necessary, continue moving forward**

Participation by Business Segment

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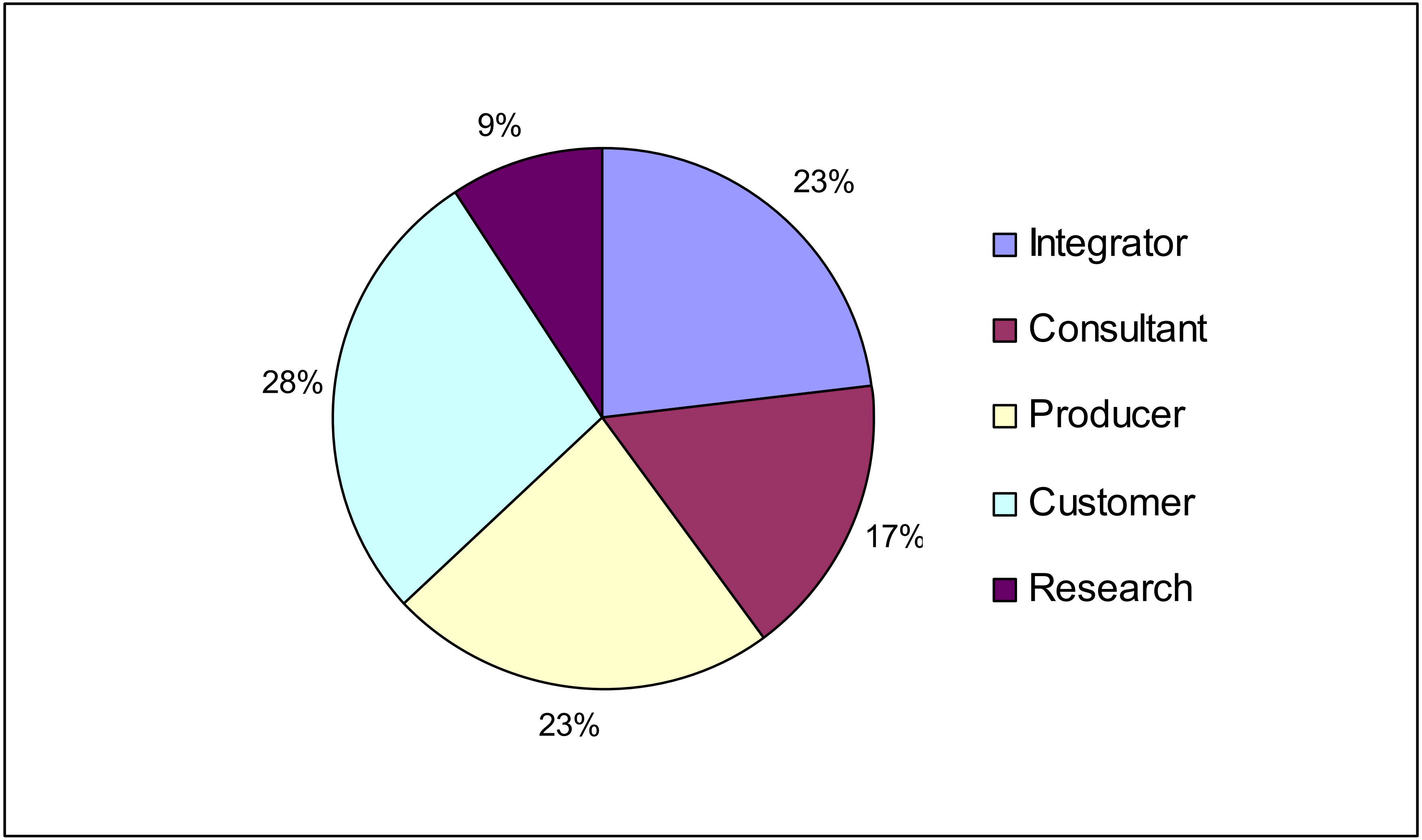
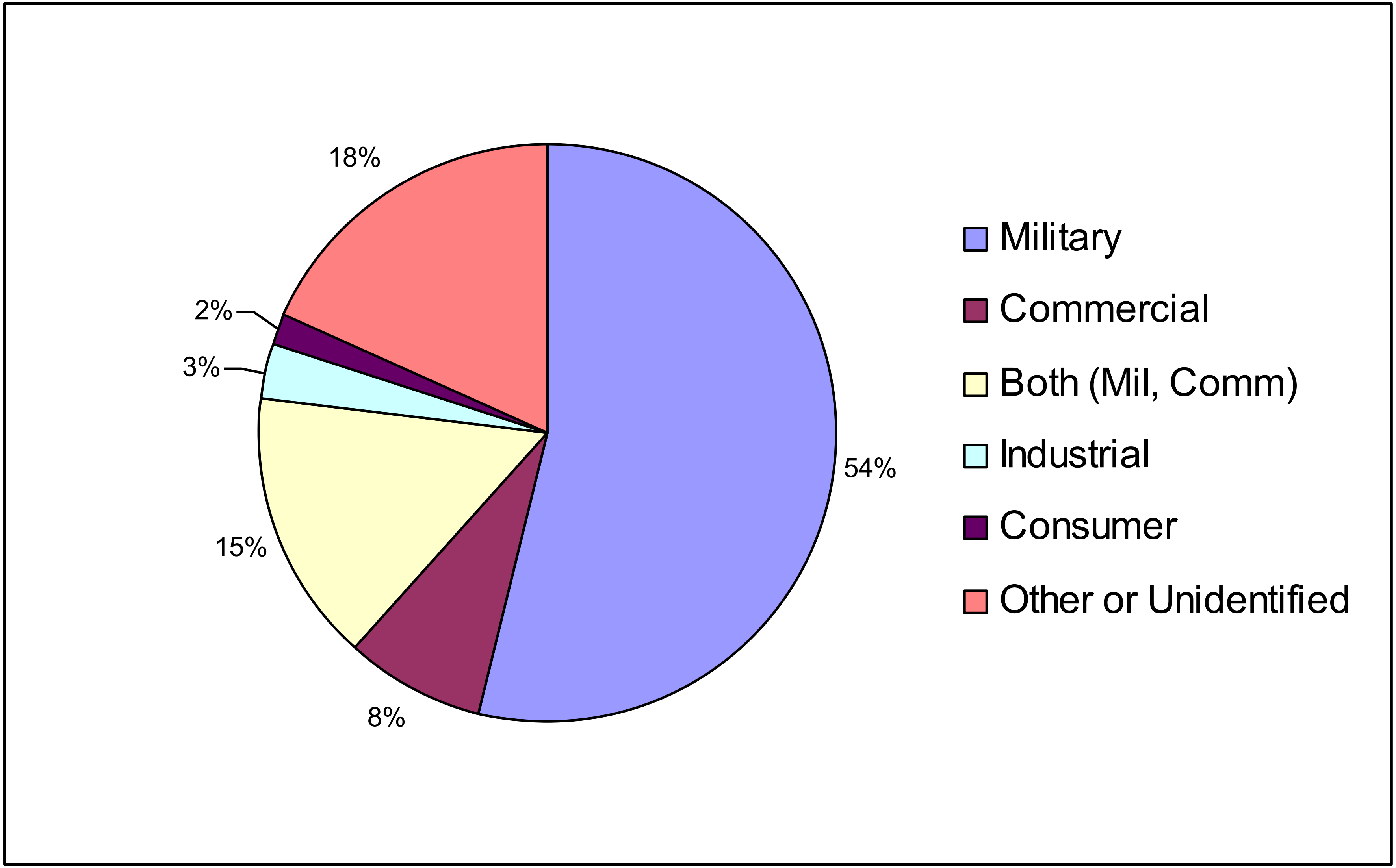


Participation by Market Segment



Step 1 – Needs

- **Identify and prioritize stakeholder needs (requirements)**
- **Questionnaire 1 provided a starting list (seed values) of needs – participants asked to modify list and suggest additions**
- **Questionnaire 1.1 – Recirculation of Q1 for reactions to changes**
- **Questionnaire 2 – Need priorities and Features**

Needs

Stakeholder Needs / Requirements	Priority Weight	ID	Elaboration
Coverage of Legacy, contemporary and near future technologies	9	1	Models include legacy, contemporary and near future technologies and their influential factors as understood by state of the practice.
Coverage of comprehensive range of electronic and electromechanical devices. and relevant packaging elements.	9	2	Reliability models cover a comprehensive range of electronic / electrical device types / functions used in a variety of applications and environmental stress levels. Includes parts implementing mixed technologies.
Assessments of physical failure mechanisms	9	3	Models include detailed assessments of physical failure mechanisms, providing results that can be incorporated into the overall reliability assessment and can be used for design or process improvement. These methods and tools also provide explanations and identification of specific failure mechanisms (i.e. why things break and/or age) Models include wearout impact due to feature size
Transient and cumulative effects due to atmospheric radiation	4	4	Models account for the impact of transient and possible cumulative damage mechanisms due to atmospheric radiation, such as those that may be covered under the umbrella of Single Event Effects.
Solder joint integrity including effects of lead-free materials	7	5	Models account for the impact of solder joint fatigue, including the effects of lead-free solders and/or device termination finishes. This includes mixed technology (PbSn solder with lead free finishes)
Impact of lead-free solder/finishes tin whisker risk	7	6	Models include impact of tin whisker risk due to use of lead-free solder or solder finishes, with consideration of the benefit of preventative measures.
Software/firmware reliability	4	7	If applicable, software/firmware reliability issues are considered. This can be an important issue for system reliability modeling.
No Fault Found removal rate	1	8	If there's an observed issue with NFF's, models include no fault found "removal rate" This is not applicable if contracting language limits countable failures to confirmed primary failures.
Results support a design for reliability program	8	9	Results provide timely and useful information to the design process, and support a broader reliability improvement program.
Consistent methods to aggregate results	7	10	Consistent methodology for aggregating detailed results from different statistical distributions in a system level reliability or availability model
Time dependent results & constant, fixed rate	5	11	Models include time dependent results as well as constant, fixed point, rate estimates
Non-operating (storage), operating and mixed results	7	12	Models are included for non-operating (storage) and operating conditions and for the combinations of these based on pre-defined (or explicit) operational profile input. (Otherwise models normally provide results on an operating hour basis) (Serves a couple of purposes: Dormant models and ability to mix a dormant and operating model together)
Estimates of statistical confidence or other uncertainty measures.	5	13	Reliability estimates include mean and expected variation or uncertainty. If feasible, variation may be modeled by use of statistical confidence (e.g. confidence or prediction intervals) and / or estimated by a measure of risk associated with particular results. Estimates of uncertainty and risk are aggregated along with mean, single point values.

Needs

Stakeholder Needs / Requirements	Priority Weight	ID	Elaboration
Results are reproducible	9	14	Given the same assumptions, defined level of refinement, and version of model, results are reproducible across analysts, organizations, implementation vehicle (tool), and time, (implies all factors, their range of values, and prerequisite assumptions are explicitly defined, constrained and quantified through appropriate tables, functions or algorithms. Variation due to implicit assumptions, open-ended model elements, or subjective assessment is minimized.)
Models are validated	9	15	Models and/or model parameters have been validated, or are traceable or have a documented foundation, or provide a methodology of validation with data and model outputs are representative of in-service performance
Progressive refinement from ROM to high fidelity	5	16	Models allow for cost-effective progressive refinement from rough order of magnitude to high fidelity reliability assessments for application throughout the development lifecycle. (e.g. parts count vs. stress)
Mil-aero environments and operating loads	8	17	Reliability models apply to a wide range of detailed environments and operating loads, including military and aeronautic applications
Models account for design for environment	7	18	Modeled environmental effects should recognize the applicability of a design to the environment (a full Mil cable vs. an "office cable" in an outside application. Mil/avionic connector on an avionic environment.
Adjustment based on data such as test and/or in-service results	7	19	Reliability models allow for adjustment based on data such as quantified test and/or in-service results including experience with specific parts, manufacturers and system level effects when this data is available. Similarity determination method defined within the model.
Widely accepted / used in aerospace / Hi Rel	7	20	Use of reliability models and methods that are widely accepted / used in aerospace
Widely accepted / used in general industry	4	21	Use of reliability models and methods that are widely accepted / used in general industry
Easy to use and implement with limited data	5	22	Model assumptions, limitations, and trade-offs are easy to understand and model can be applied correctly by the experienced or lightly experienced analyst. Also can be used without excessive cost, research or equipment.
Support widely and readily available	5	23	Support is widely and readily (public domain?) available, including comprehensive documentation and training.
Literature elaborating bases of the models available	7	24	Technical literature is readily available elaborating the basis and derivation of the models developed, including traceability to validated sources
Readily implemented through software	5	25	Models can be implemented through software (either purchase price of canned/proprietary tools or implementation cost through common off-the-shelf tools.).

Step 2 – Identified Technical Response (Features)

- **Questionnaire 2 and 2.1 – Established list of 65 design features**
- **Continued the discussion of need priorities**
- **Utilized "Delphi" method to bring together polarized results**

Features

	Features	Elaboration
1	Results include confidence intervals	Model produces results that include measure of statistical confidence, if based on empirical data
2	Result includes estimate's risk or maturity level	The level of maturity or conversly the risk in the reliability estimate is defined and applied to each component and aggregated to the system level by some well defined means. Where reliability and/or safety are less critical a lower maturity estimate may be acceptable. Conversely for safety critical or space applications one could foresee using the highest maturity (lowest risk) estimates. Guidelines for maturity levels can be defined by factors such as the leve of detail of the analysis, quality of assumptions, the degree of testing and validation, etc. these factors may map directly to a DFR program. The maturity level could potentially be a requirement, providing a basis for the level of effort in the reliability program.
3	Component model provides failure distribution parameters, e.g. Weibull, where not constant	Failure rate output is a time-dependent curve from which fixed point estimates may be taken. Component model provides failure distribution parameters, e.g. Weibull 2 or more parameters, where they deviate from constant failure rate assumption
4	Result includes estimate of useful system life	Methodology to estimate useful life based on life estimates of individual components and interconnects.
5	Provides explicit conversion method from time-dependent failure rate to constant failure rate	Provides explicit conversion method from time-dependent failure rate, e.g. Weibull, to estimated equivalent fixed rate for expected life of system
6	Allow for combined probability distributions (pdf and cdf)	Determine methods to combine multiple distribution types into single equations, no matter how complex that may be. Go beyond the SR-332 methods 1, 2 and 3 and beyond Bayesian Combinations
7	Model results in failure rates directly in a specific cyclic measure, e.g. operating hour	Model results in failure rates in a specific cyclic measure e.g. time (op hours), distance (miles), cycles (revolutions, operations), etc. Knowing the failure rate in multiple cyclic measures e.g. operating time (hours), calendar time (hours), distance (miles), cycles (revolutions, operations), etc. the model provides means to determine failure rate in a standard measure, e.g. calendar hours.
8	Method for adjusting failure rates to a single measure	Results can be adjusted to failures in a specific cyclic measure e.g. time (hours), distance (miles), cycles (revolutions, operations), etc. Knowing the failure rate in multiple cyclic measures e.g. operating time (hours), calendar time (hours), distance (miles), cycles (revolutions, operations), etc. the model provides means to determine failure rate in a standard measure, e.g. calendar hours.
9	Model includes assessment of individual failure modes and mechanisms	In addition to an overall failure rate, the models include a breakout by failure mode, and assessments of the impact of dominant failure mechanisms. Assessment of individual failure mechanisms provides detailed information for mitigation of those mechanisms during design and supports FMEA's, FTA's, RGT and ESS design.
10	Allows for easy "what if" analyses	Models can be easily manipulated to test "what if" scenarios, such as providing better environmental controls: Testing "what if" scenarios can be used to estimate the effectiveness of mitigation measures on fatigue life, such as controling the thermal or vibration environments. When combined with cost information, a conscious decision can be made to use or not use the mitigation measure. The ability to perform "what if" CAE simulation scenarios to evaluate reliability performance while operating in various environmental factors, geographic locations among different usage conditions.
11	Models include combined environmental effects	Models can be used to assess the fatigue life based on combined factors, such as thermal/vibration or thermal/humidity. This can be used for creating designed experiments during the reliability growth testing phase.

Features

	Features	Elaboration
12	Results seamlessly compatible with other reliability tools	Output of reliability estimate a form that can directly link to tools such as FMEA/FMECA, FTAs, RBDs, ... without "post processing" the reliability estimates (outside the tool). E.g. the numbers "add up", appropriate time domain basis, failure rates for all relevant failure modes, ... model could include failure mode distribution, i.e. how the part may fail given that physics of failure are understood.
13	Systems are modelled as integrated elements of hardware, software and human interaction producing an overall system reliability predictor	Systems consist of electronics, electromechanical, human and software elements at a minimum. System reliability predictors must assess the interaction and effect of how these different elements operate together.
14	Supports Simulated Guided Testing	Enables virtual test to field correlation analysis capabilities such as Simulated Guided Testing (SGT) the ability to optimize an accelerated life test profile for specific devices base on their design, components & architecture.
15	Supports Simulated Aided Testing	Enables virtual test to field correlation analysis capabilities such as Simulated Aided Testing (SAT) the ability to interpret/translate life test results into accurate field life estimates.
16	Model considers the SW and all of the environment layers as appropriate	Model utilises a layered approach to consider the SW and all of the environment layers (SW environment: operating system, intermediate IO layer, application layer, ...) as appropriate, eg SW language, operating system, HW drivers.
17	Coverage of comprehensive range of software issues and characteristics	Operational failures are chargeable to software. Reliability predictors must consider all chargeable categories.
18	Coverage of comprehensive range of human reliability issues	Operational failures are chargeable to operators, training and technical documentation. Reliability predictors must consider all chargeable categories.
19	Models include a component for SW FR	Models include a model based on software assessment, software quality practices, or empirical data. It may be time dependent/growth model or not
20	Includes comprehensive semiconductor PoF models	Include key physics of failure models for semiconductor failure rates and acceleration factors, including, EM (Electro Migration), TDDB (Time dependent Dielectric Breakdown), NBTI (Negative Bias Temperature Instability), HCI (Hot Carrier injection).
21	Comprehensive suite of models for parts in common use.	Instead of listing each part type seperately, e.g. passive and active components, capacitors, resitors, microcircuits, etc. this feature is written. Model coverage for parts and part technologies are expanded beyond those available in current reliability analysis tools and handbooks, Fill gaps driven by new technology devices, new materials (e.g. electrolytic caps, high power LEDs, displays,...), mixed technologies (e.g. power and logic, analog and digital, ...), higher degrees of integration, etc. The "part space" for aerospace/hi-rel applications to be effectively covered. This may require surveys of part utilization, gap analyses, and follow-on research integrated with the modeling methodology defined by this effort.
22	Connector Models	Model includes the connector failures due to corrosion, vibration fatigue, thermal cycling.
23	Electrolytic capacitor life model	operating and storage (shelf) life models for electrolytic capacitors where applicable. Means defined to integrate into overall system reliability, life or failure rate estimates.
24	Reliability, durability & life models for electrochemical cells	cells used in aero/high rel environments are covered by models addressing their special considerations. Means defined to integrate into overall system reliability, life or failure rate estimates.

Features

	Features	Elaboration
25	Photonics	Model includes photonics, LED's, fiber optic cables, fiber switches, etc.
26	Predict SW impact on HW architecture	with regard to thermal loads, memory usage, processor demands, and other HW capacity limited characteristics to predict system generated processing delays.
27	Provide SW errors per single lines of code.	SW errors can be separated into SW specific failure mode features. Show regression rate drop predictors of SW with reliability growth tracking for successive version releases. Consider speed of self boot error handling directions at component level and impact on signal processing. Consider programmable components stability and retention of program. Consider organizational practices and maturity for SW development.
28	Programmable device data retention/wearout modeled	Model includes programmable device data retention/wearout term
29	Model considers human in the loop in individual capability and response.	Model predict errors in the cognitive informaiton processing with regard to knowledge based errors, skill based errors, mistakes, slips, lapses. Consider the effects of stressors such as time pressure on working memory, attention, performance expectation. Note that depending on structure / writing objectives these human errors can be readily reworked into an overivew statement for general system failure mode, and then break out the elaboration statement into human specific failure modes as has been done for semi-conductors in rows 25-35
30	Model considers human in the loop in the operating environment.	Predict errors relating to human system interface with regard to physical operator station ergonomics, signal processing, workload intensity/complexity/quantity, emergency (rare event) response, fatigue, vigilance, circadian rhythm, comfort levels, degree of automation. Consider the effects of noise, vibration, light, heat, time of day, frequency of activity, sleep factors, personal motivation and others on performance.
31	Model consider human in the loop in the organizational context.	Model consider effects of team interaction, and allows for scenarios of under manning, and under skilled operators. Consider leadership, organization goals, responsibility, communication,
32	Conformal Coat Model	Model includes consideration of conformal coatings, both in terms of the benefit of moisture protection and the cost in terms of potential exacerbated thermal cycling fatigue. Different materials will have different effects, and the model should be capable of comparing different options.
33	Tin whisker models, including stress-dependent failure mechanisms for SnPb and Pb-free solder	Tin whisker model includes model parameters for Pb-free solder alloys for PWB level. (in addition to standard SnPb solder)
34	Includes time-dependent radiation failure modes	Time dependent radiation failure modes and rates. Failure modes that result in permanent cumulative change in device characteristics to the point of failure.
35	Includes SEE upset models for SEU, MBU, & SEL	Atmospheric radiation environment factor relationships SEU, MBU, SEL and guidance for driving factors (e.g. altitude, latitude), with defaults for applications (for example cross-section vs technologies and feature sizes).
36	Solder joint models, including temperature-dependent failure mechanisms for Pb-free solder	Solder joint FR fatigue model includes fatigue ductility coefficient for Pb-free solder alloys for each component and possibly PWB level. (in addition to standard SnPb solder)
37	Provides Package model, e.g.config & complexity factors	Provides a comprehensive package model that addresses legacy and new package technologies (i.e. BGA, CGA, SOIC, etc), perhaps a physics of failure model.. Includes provision for package configuration factors, e.g. differentiating full BGAs vs perimeter BGAs. Model to include package related failure mechanisms (i.e. loss of hermiticity, corrosion, etc).

Features

	Features	Elaboration
38	Includes models for <130nm IC technology	Includes models for <130 nanometer IC technologies
39	Model accounts for die complexity	Models include terms for die complexity
40	Include storage / dormant environment models	Models include Storage / dormant environment model
41	Provides temperature cycling fatigue model at hot/cold extremes	Models include temperature cycling fatigue between extreme cold and hot conditions that are typical for Mil-Aero environments (and ramp rates).
42	Includes method to quantify transient/intermittent failures	Model includes method to quantify removal rate - includes NFF (transient effects (SEE), weak bit, tolerance stackup, …)
43	Provides coverage for hot/cold extreme temperature effects	Acceleration factors for at least -55 to 125°C
44	Provides shock/vibration (high-cycle) fatigue effects	Models include shock and vibration effects at levels typical for mil-aero environments
45	Provides a humidity factor	Models include a humidity factor including humidity cycling profiles.
46	Provides tailorable environments defined by application	Model includes environment defined by application - e.g. AIF, AUC, and choice to tailor specific environmental factors for custom applications: altitude, location in platform, and modification of defaults of temperature, vibration, etc.
47	Provides for electrical operating load/stress	Basic electrical operating load/stress relationships - includes operating frequency (Oscillator frequency, clock frequency, signal switching, etc)
48	Provides ability to account for device operating duty cycle	Explicit method to adjust results based on duty cycle (ontime/(on-time and off-time))
49	Takes into account power cycling rate	Model takes into account power cycle rate
50	Facilitates risk identification	The ability to rank and prioritize reliability risks identified in CAE simulations in terms of time to first failure, failure rate, mean life . . . etc.
51	Models include a simplified version (e.g. parts count method)	Models include a simplified version (e.g. support for parts count model) for early assessments
52	Context driven defaults are provided for factors	Defaults are provided for factors for early assessments. Knowing the application, environment and part characteristics - provide the ability to use default values for factors that may be unknown.
53	Addresses variability in design, development and manufacturing processes	Predicted or estimated subassembly, assembly and system failure rates (based on the sum of component failure rates) are positively or negatively impacted by the relative level of robustness used in the design, development and manufacturing processes. As these processes become progressively more robust, achieved field reliability can be expected to approach maximum projected reliability potential. As these processes become progressively less robust, achieved field reliability will not realize or approach full projected reliability potential.
54	Addresses variability in materials properties	Outputs from models that treat materials properties as constants or static variables will not reflect the reliability impact that can occur as a result of variability in materials properties during the component manufacturing and assembly processes.
55	Addresses impact of complexities in the "natural" environment	Outputs from component models that address only a subset of the expected field failure mechanisms (specific failure mechanisms are not modeled), that do so statically (mechanisms are treated as constants or fixed variables, not statistically-distributed variables), or that do not consider the impact of combined environments (e.g., variability in material property responses over combined temperature/vibration/humidity ranges) can be misinterpreted or lead to erroneous results.

Features

	Features	Elaboration
56	Model allows for adjustment based on test/in-service results	Method allows for adjustment of parameters by specificying the data required, method of adjustment, and limitations to adjustment.
57	Provides capability to incorporate field experience reliability data.	Field experience reliability data can be combined with the initial empirical or deterministic model, using techniques such as Bayesian, to improve model results to include data based on the complex "natural" environment.
58	Model includes similarity methodology (definition & adjustment)	Model includes similarity methodolgy. Includes definition of what the similarity determinants (power, complexity, etc.) are and how to adjust for differences.
59	Models account for design for environment	Modeled environmental effects should recognize the appliability of a design to the enviroment (a full Mil cable vs an "office cable" in an outside application. Mil/avionic connector on an avionic environment.
60	Models are self-contained	Models are self-contained – Factors are explicitly defined, constrained and quantified through appropriate tables, functions or algorithms
61	Mechanism for review and update of models	Models provide broad coverage of common IC technologies: CMOS; bipolar, GaAs, digital, analog, NAND Flash as the industry changes. Other component types are updated periodically or as required.
62	Models are substantiated	Models include substantiation - bases for models elaborated. References in the model to available papers, publications.
63	Validated by test	Models have been validated through test
64	Validated by industry accepted models / tools	Correlation with simulation & analytical tools used in industry such as CALCE solder joint models; proposed FaRBS; etc.
65	Validated by field performance	Correlation with in-service experience

Step 3: Needs/Features Correlations

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Relationships between Customer Needs and Design Parameters (Features)

Determine relationships to see how well the design variables predict the customer needs

Relationship Scoring:
9 = Direct and Strong Effect
3 = Moderate Effect
1 = Remote Effect
0 = No Effect
blank = default to seed score

Stakeholder Requirements	**Framework Design Features** / Stakeholder Priority	Results include confidence intervals	Result includes estimate's risk or maturity level	Component model provides failure distribution parameters, e.g. Weibull, where not constant	Result includes estimate of useful system life	Provides explicit conversion method from time-dependent failure rate to constant failure rate	Allow for combined probability distributions (pdf and cdf)	Model results in failure rates directly in a specific cyclic measure, e.g. operating hour
Coverage of Legacy, contemporary and near fut	9	0	0	1	1	1	1	0
	Score->							
Coverage of comprehensive range of electronic	9	0	0	0	0	0	0	0
	Score->							
Assessments of physical failure mechanisms	8	0	0	1	1	3	3	0
	Score->							
Transient and cumulative effects due to atmosp	4	0	0	0	0	0	0	9
	Score->							
Solder joint fatigue including effects of lead-free	7	0	0	3	3	3	3	3
	Score->							
Impact of lead-free solder/finishes tin whisker ris	7	0	0	0	3	0	0	0
	Score->							
Software/firmware reliability	3	0	0	0	0	0	0	9
	Score->							

…

⋮

Initial values provided as starting point or "seed" score

Input requested in space below

Features Prioritized

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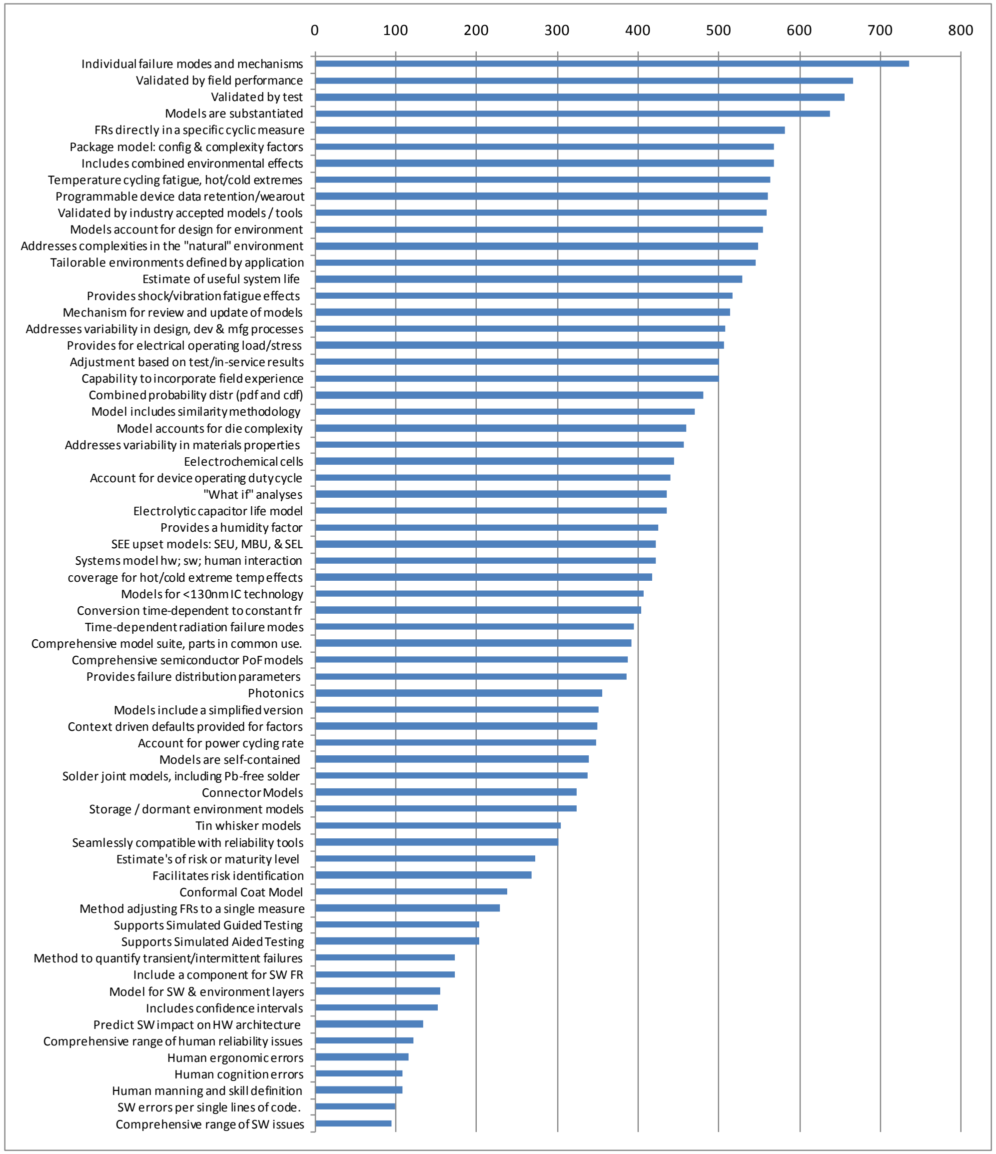

Prioritized Needs, Coverage by Features

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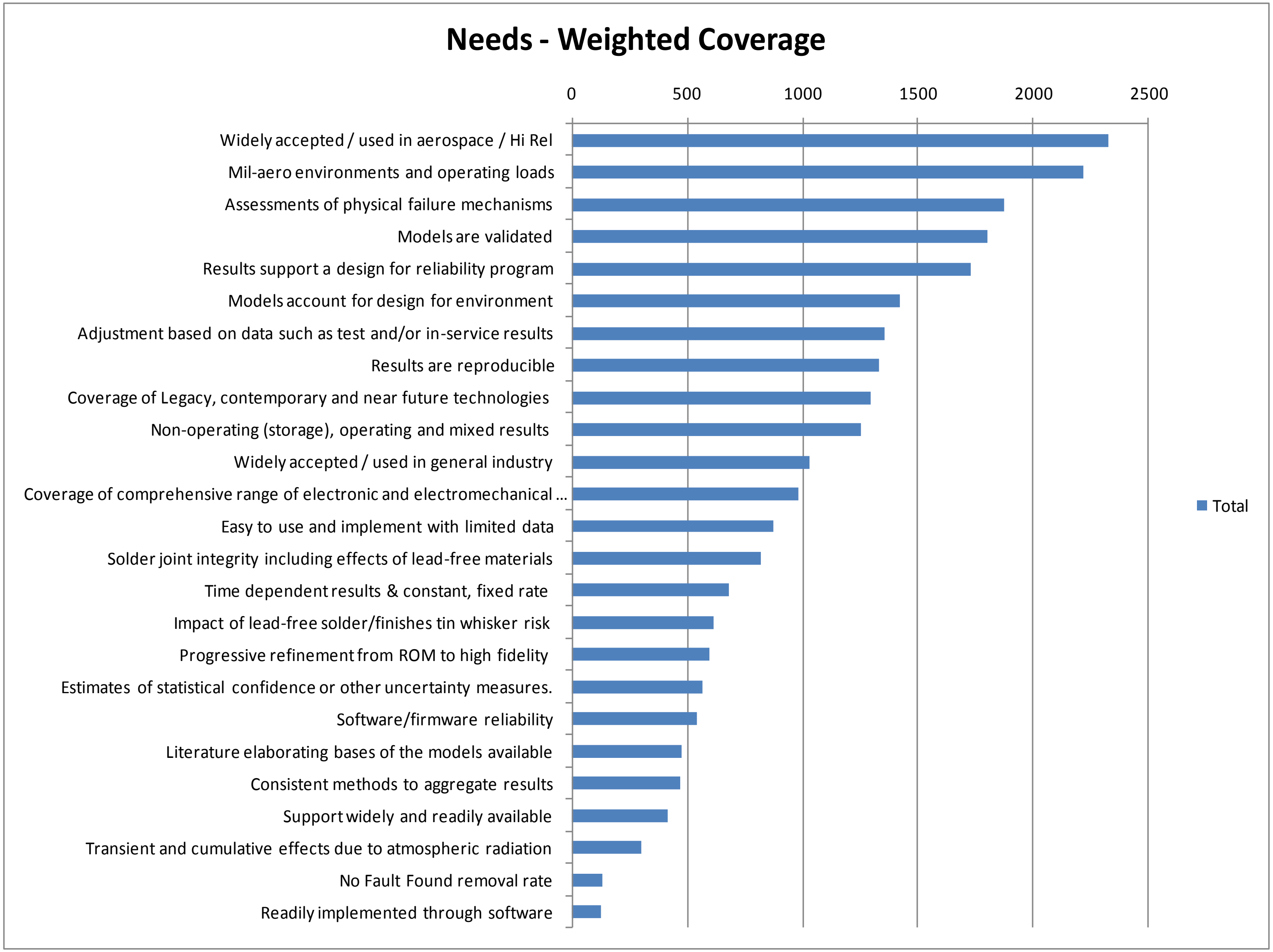


Step 4 – Feature Correlations

- **Questionnaire 4 – Feature/Feature correlations**
  - **Discussed in Telecon August 4**
- **Purpose: Identify conflicts and design trade-offs – *Does implementing this feature help or hinder implementing the other feature?***
- **Feature to feature scoring:**

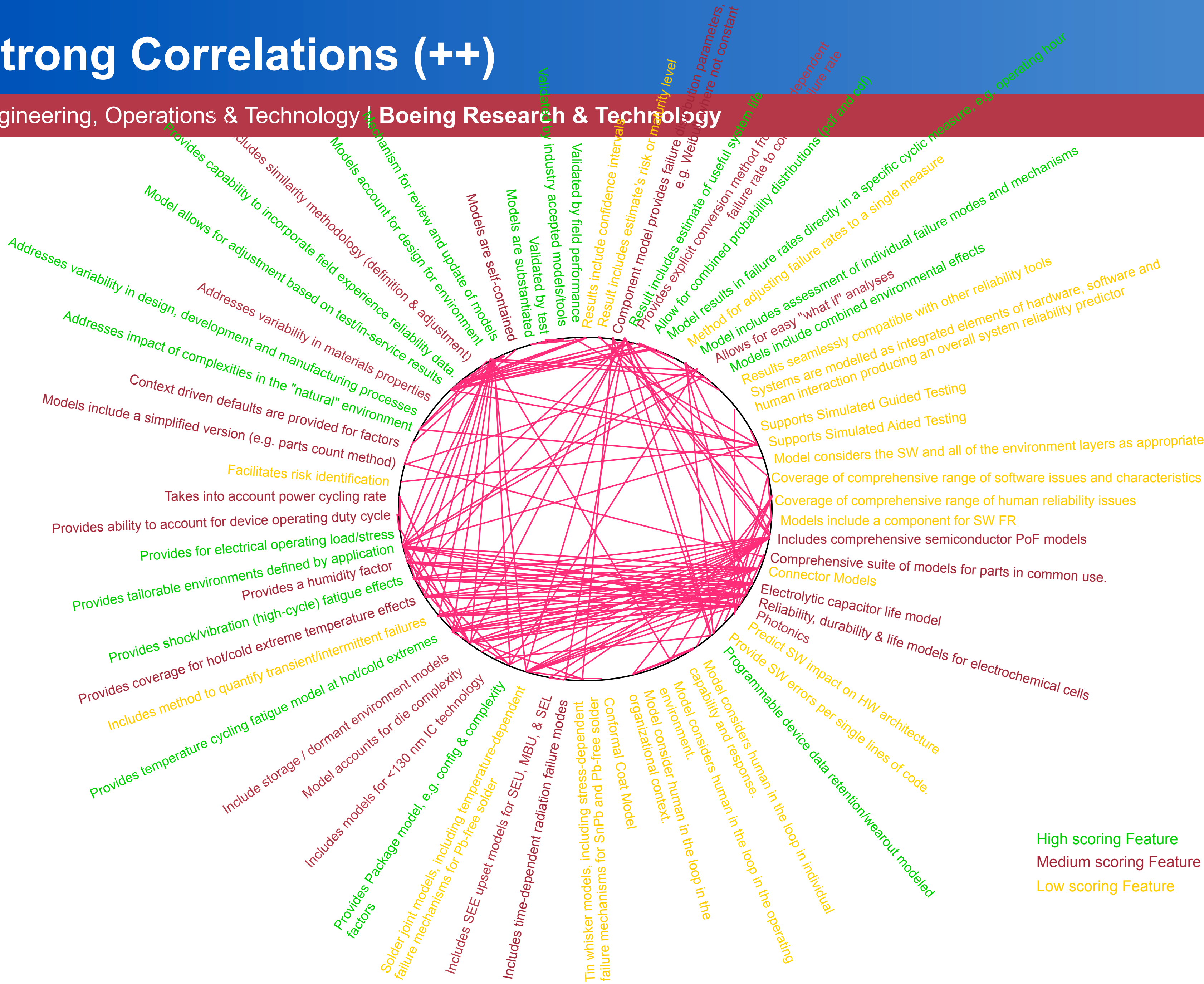
Scoring	
++	Strong correlation
+	Minor correlation
(blank)	Neutral
-	Minor conflict
--	Strong conflict

- **Seed scores provided, respondents provided recommended changes and comments**

Questionnaire 4 – Summary of Results

- **Strong correlation provides potential for joint implementation, for taking advantage of synergy**
- **Features that are strongly correlated are candidates for joint development - a consideration for the reliability roadmap**
- **Strong correlation (++) examples:**
  - **"Provides capability to incorporate field experience reliability data" strongly correlates with:**
    - **Results include confidence intervals**
    - **Result includes estimate of useful system life**
    - **Supports Simulated Aided Testing**
    - **Provides tailorable environments defined by application**
    - **Model allows for adjustment based on test/in-service results**
    - **Mechanism for review and update of models**
    - **Validated by field performance**

Strong Correlations (++)



Step 5 – Offerings Assessment

- **Existing Reliability Prediction tools and methodologies**
- **How well they meet Needs established in Step 1**

- **Initial evaluation of each tool/methodology by developers/owners**
- **Questionnaire 5 distributed**
- **Demos of Offerings**
- **Discussions, comparative assessments, clarifications of capabilities**
- **Results, wrap-up**

Offerings Assessments

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Stakeholder Needs / Requirements	Stakeholder Priority	Alternative Products & Planning										
		217Plus (P)	VITA 51.2 (V)	Telcordia (T)	FIDES (E)	MIL-HDBK-217F N2 (F)	MIL-HDBK-217G (G)	CALCE SARA (S)	Sherlock & PoF IC Calc (D)	Gaps	Best Coverage	Count of >5
Coverage of Legacy, contemporary and near future technologies	9	6	7	6	6	4	5	8	8		**S,D**	6
Coverage of comprehensive range of electronic and electromechanical d	9	7	5	7	7	5	6	8	6		**S**	6
Assessments of physical failure mechanisms	9	6	8	0	6	1	1	8	8		**V,S,D**	5
Results are reproducible	9	7	3	1	1	8	8	5	5		**F,G**	3
Models are validated	9	6	6	1	1	3	5	6	6		**P,V,S,D**	4
Results support a design for reliability program	8	5	8	0	3	5	5	9	8		**S**	3
Mil-aero environments and operating loads	8	5	7	0	5	5	5	7	8		**D**	3
Solder joint integrity including effects of lead-free materials	7	6	6	0	3	1	1	8	9		**D**	4
Impact of lead-free solder/finishes tin whisker risk	7	0	1	0	1	0	0	5	0	X		0
Consistent methods to aggregate results	7	2	3	0	3	0	0	5	5	X		0
Non-operating (storage), operating and mixed results	7	5	0	0	5	0	0	8	5	X		1
Models account for design for environment	7	4	5	0	4	1	1	5	5	X		0
Adjustment based on data such as test and/or in-service results	7	8	3	9	1	0	0	7	8		**T**	4
Widely accepted / used in aerospace / Hi Rel	7	6	4	1	3	7	7	6	5		**F,G**	4
Literature elaborating bases of the models available	7	7	7	5	1	7	6	5	5		**P,V,F**	4
Time dependent results & constant, fixed rate	5	3	3	0	0	1	1	5	3	X		0
Estimates of statistical confidence or other uncertainty measures.	5	5	0	9	0	0	0	7	4		**T**	2
Progressive refinement from ROM to high fidelity	5	8	0	9	0	8	8	3	0		**T**	4
Easy to use and implement with limited data	5	9	1	6	3	9	9	3	3		**P,F,G**	4
Support widely and readily available	5	6	0	6	1	9	9	6	6		**F,G**	6
Readily implemented through software	5	9	9	9	9	9	9	9	9		**all**	8
Transient and cumulative effects due to atmospheric radiation	4	1	4	0	0	0	0	0	0	X		0
Software/firmware reliability	4	7	0	0	0	0	0	0	0	X		1
Widely accepted / used in general industry	4	7	4	6	1	5	5	6	5		**P**	3
No Fault Found removal rate	1	4	0	0	0	0	0	1	0	X		0

(GAP is any need that has less than 2 scores >5 (green))

	Score 0 or 1
	Score >5

Questionnaire 6 – Features Effort

- **For each Feature, rate how difficult it would be, relatively speaking, to implement the feature in a reliability prediction methodology or tool.**
- **This assessment is on a scale of 1 to 3.**
- **65 Features, defined during QFD Step 2**
- **Initial "seed scores" were provided by the core team**
- **Results reviewed in Telecon on Dec. 1**

Relative level of Effort	
3	High
2.5	Med-High
2	Med
1.5	Low-Med
1	Low

effort, resources, time; high, many, long
3 = have no clue how to begin
2.5 = have some idea, but incomplete information to do it

Matrix of Features

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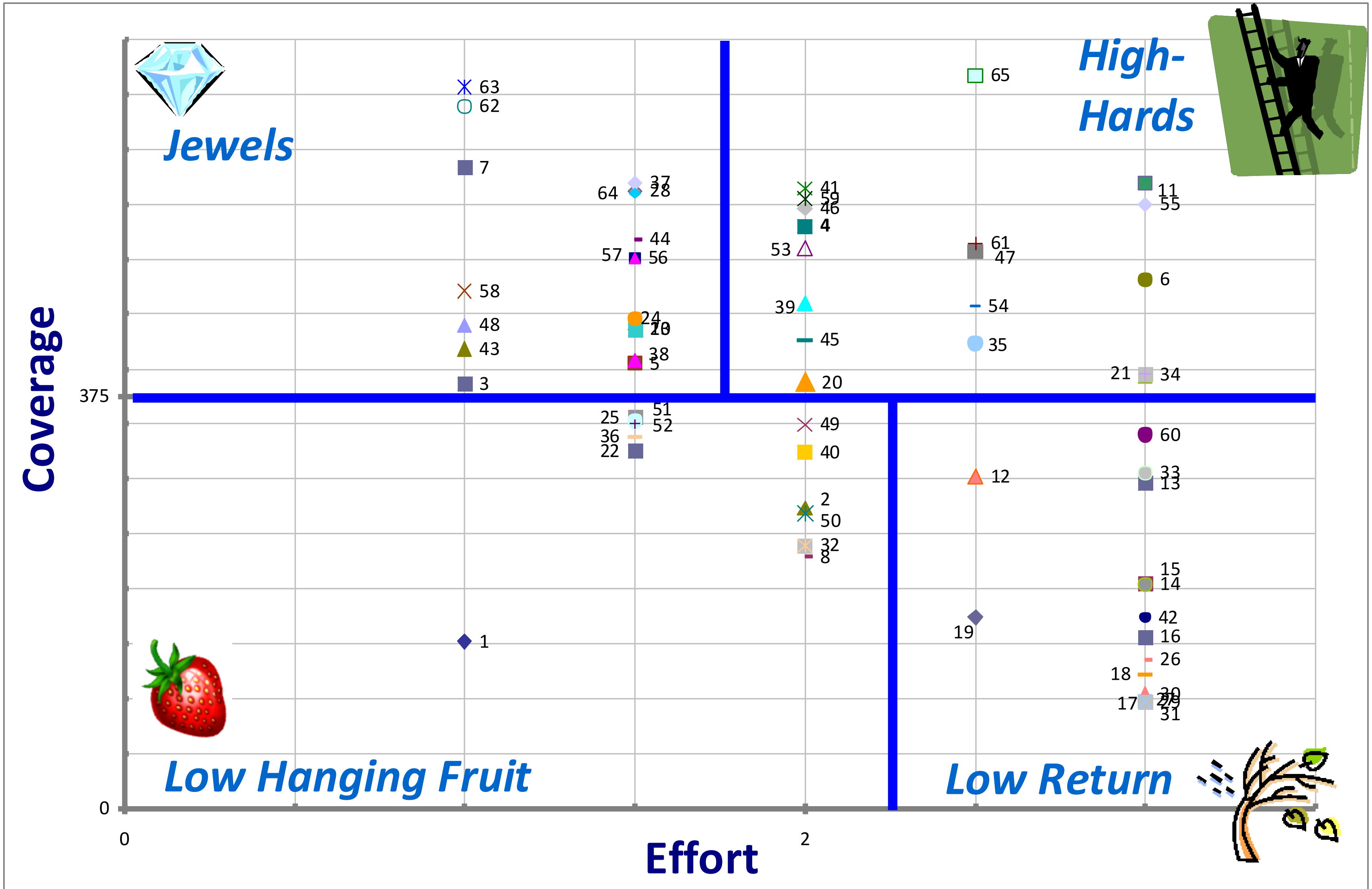


Definitions

- ***Jewels:*** **High Coverage and Low Effort**
  - **Good candidate for small scale projects**
  - **Good for initial projects in roadmap, rapidly address needs**
- ***Low Hanging Fruit:*** **Low Coverage and Low Effort**
  - **May address only one need, limited usefulness**
  - **Good for combining with other higher coverage efforts**
- ***High-Hards:*** **High Coverage and High Effort**
  - **Requires time, resources, effort but will provide good return**
  - **Good candidates for funded efforts, multi-year projects**
- ***Low Return:*** **Low Coverage and High Effort**
  - ***May be higher priority needs as considered by a small number of participants***
  - ***Needs scored as lower priority for the larger group***
  - ***Are included in roadmap as exploratory studies, or combined with other features***

Features Coverage versus Effort

ID	Feature	Feature Score	Effort	Labeled as:
1	Results include confidence intervals	152	1	Low Hanging Fruit
2	Result includes estimate's risk or maturity level	273	2	Low Hanging Fruit
3	Component model provides failure distribution parameters, e.g. Weibull, where not constant	386	1	Jewel
4	Result includes estimate of useful system life	530	2	High Hard
5	Provides explicit conversion method from time-dependent failure rate to constant failure rate	405	1.5	Jewel
6	Allow for combined probability distributions (pdf and cdf)	481	3	High Hard
7	Model results in failure rates directly in a specific cyclic measure, e.g. operating hour	583	1	Jewel
8	Method for adjusting failure rates to a single measure	229	2	Low Hanging Fruit
9	Model includes assessment of individual failure modes and mechanisms	736	2.5	High Hard
10	Allows for easy "what if" analyses	436	1.5	Jewel
11	Models include combined environmental effects	569	3	High Hard
12	Results seamlessly compatible with other reliability tools	302	2.5	Low Return
13	Systems are modelled as integrated elements of hardware, software and human interaction producing an overall system reliability predictor	296	3	Low Return
14	Supports Simulated Guided Testing	204	3	Low Return
15	Supports Simulated Aided Testing	204	3	Low Return
16	Model considers the SW and all of the environment layers as appropriate	156	3	Low Return
17	Coverage of comprehensive range of software issues and characteristics	95	3	Low Return
18	Coverage of comprehensive range of human reliability issues	122	3	Low Return
19	Models include a component for SW FR	174	2.5	Low Return
20	Includes comprehensive semiconductor PoF models	388	2	High Hard
21	Comprehensive suite of models for parts in common use.	393	3	High Hard
22	Connector Models	325	1.5	Low Hanging Fruit

Features Coverage versus Effort

ID	Feature	Feature Score	Effort	Labeled as:
23	Electrolytic capacitor life model	436	1.5	Jewel
24	Reliability, durability & life models for electrochemical cells	446	1.5	Jewel
25	Photonics	356	1.5	Low Hanging Fruit
26	Predict SW impact on HW architecture	135	3	Low Return
27	Provide SW errors per single lines of code.	99	3	Low Return
28	Programmable device data retention/wearout modeled	562	1.5	Jewel
29	Model considers human in the loop in individual capability and response.	97	3	Low Return
30	Model considers human in the loop in the operating environment.	104	3	Low Return
31	Model consider human in the loop in the organizational context.	97	3	Low Return
32	Conformal Coat Model	239	2	Low Hanging Fruit
33	Tin whisker models, including stress-dependent failure mechanisms for SnPb and Pb-free solder	305	3	Low Return
34	Includes time-dependent radiation failure modes	395	3	High Hard
35	Includes SEE upset models for SEU, MBU, & SEL	423	2.5	High Hard
36	Solder joint models, including temperature-dependent failure mechanisms for Pb-free solder	338	1.5	Low Hanging Fruit
37	Provides Package model, e.g.config & complexity factors	569	1.5	Jewel
38	Includes models for <130nm IC technology	408	1.5	Jewel
39	Model accounts for die complexity	460	2	High Hard
40	Include storage / dormant environment models	324	2	Low Hanging Fruit
41	Provides temperature cycling fatigue model at hot/cold extremes	564	2	High Hard
42	Includes method to quantify transient/intermittent failures	174	3	Low Return
43	Provides coverage for hot/cold extreme temperature effects	418	1	Jewel
44	Provides shock/vibration (high-cycle) fatigue effects	518	1.5	Jewel

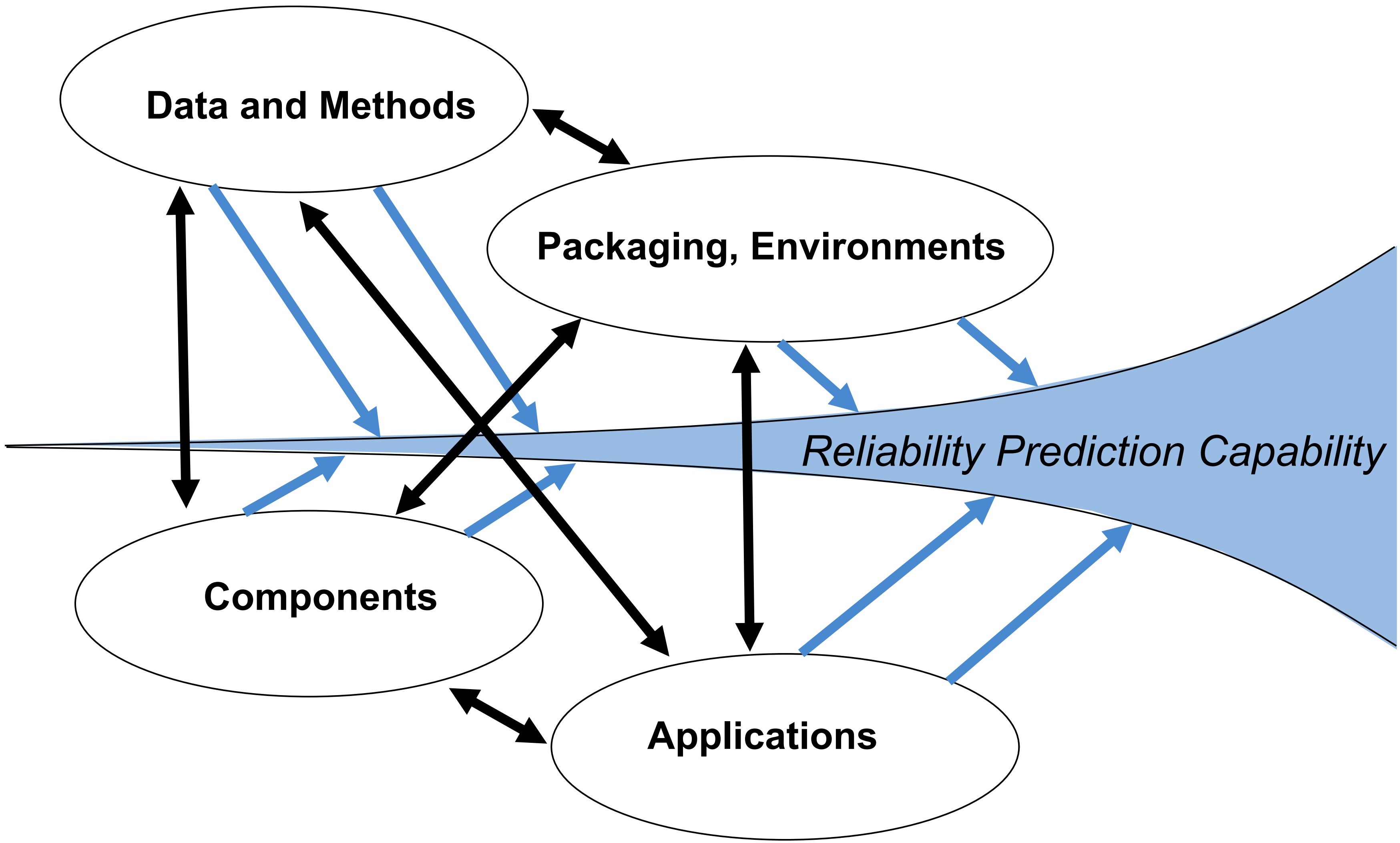
Features Coverage versus Effort

ID	Feature	Feature Score	Effort	Labeled as:
45	Provides a humidity factor	426	2	High Hard
46	Provides tailorable environments defined by application	546	2	High Hard
47	Provides for electrical operating load/stress	507	2.5	High Hard
48	Provides ability to account for device operating duty cycle	440	1	Jewel
49	Takes into account power cycling rate	349	2	Low Hanging Fruit
50	Facilitates risk identification	269	2	Low Hanging Fruit
51	Models include a simplified version (e.g. parts count method)	352	1.5	Low Hanging Fruit
52	Context driven defaults are provided for factors	350	1.5	Low Hanging Fruit
53	Addresses variability in design, development and manufacturing processes	510	2	High Hard
54	Addresses variability in materials properties	457	2.5	High Hard
55	Addresses impact of complexities in the "natural" environment	550	3	High Hard
56	Model allows for adjustment based on test/in-service results	501	1.5	Jewel
57	Provides capability to incorporate field experience reliability data.	501	1.5	Jewel
58	Model includes similarity methodology (definition & adjustment)	471	1	Jewel
59	Models account for design for environment	555	2	High Hard
60	Models are self-contained	340	3	Low Return
61	Mechanism for review and update of models	514	2.5	High Hard
62	Models are substantiated	639	1	Jewel
63	Validated by test	657	1	Jewel
64	Validated by industry accepted models / tools	560	1.5	Jewel
65	Validated by field performance	667	2.5	High Hard

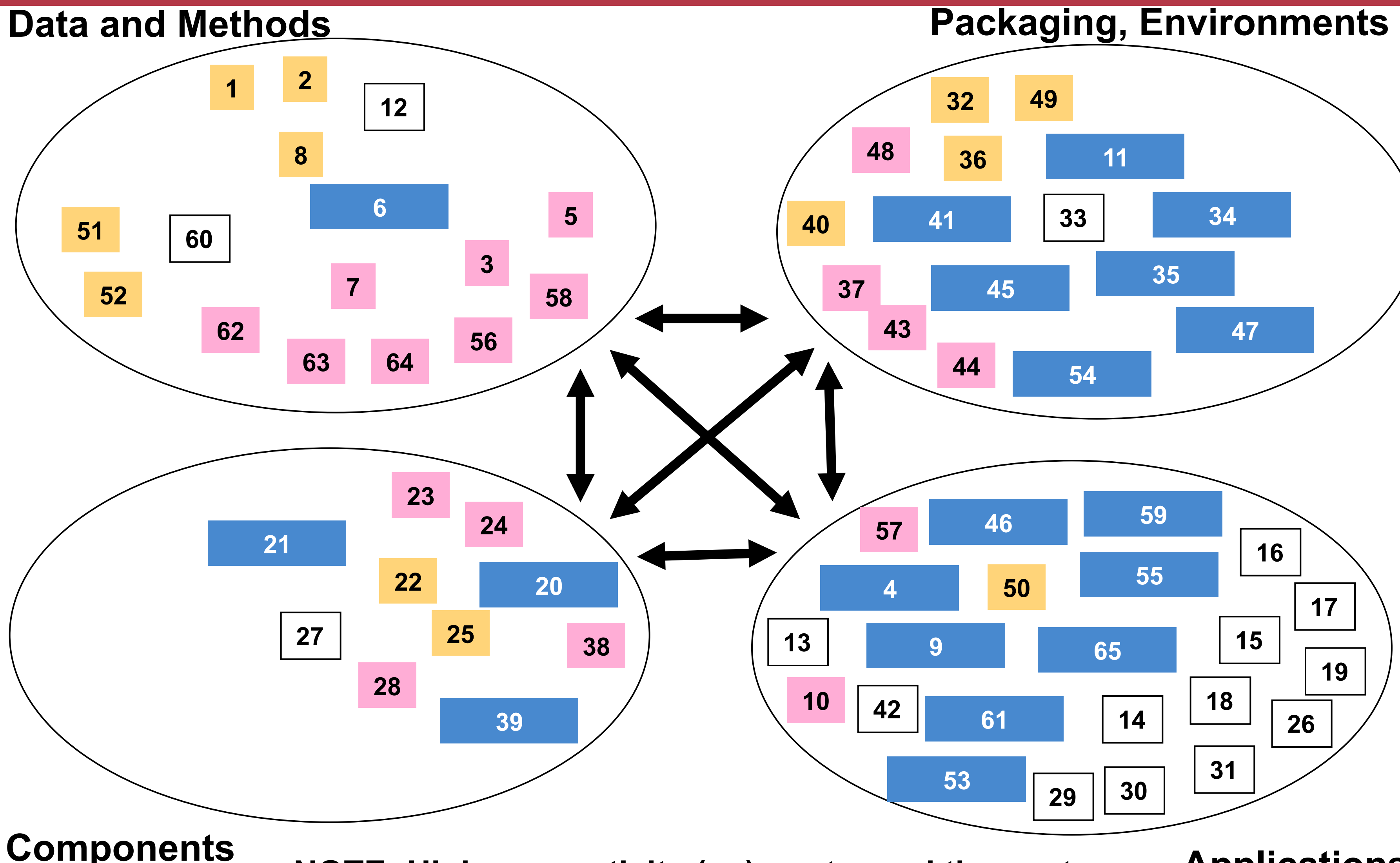
Reliability Roadmap – Focus Areas

- **Data and Methods**
  - **e.g. Confidence intervals, Weibull distribution, combined distributions, conversions from cycles to hours, models self-contained, substantiated, validated by test, validated by industry accepted models**
- **Applications**
  - **e.g. Supports DfR process, assessment of system failure modes and mechanisms, easy "what if" analyses, integrated systems, software failures, human in the loop considerations, facilitates risk identification, design for environment, validated by field experience**
- **Components**
  - **Comprehensive suite of models for parts in common use, connectors, electrolytic capacitors, electrochemical cells, photonics, Semiconductor PoF models**
- **Packaging, Environments**
  - **Solder joint fatigue (incl. Pb-free), packaging, storage/dormant, temperature cycling, humidity, tailorable environments, combined environments, electrical operating load/stress, duty cycle, variability of material properties, design for environment**

Reliability Roadmap – High level



Reliability Roadmap – Mid-level



NOTE: High connectivity (++) are toward the center of page, "Timeline" goes from center outward.

Data and Methods

YEAR 1	YEAR 2	YEAR 3	YEAR 4

58 Similarity Method

6 Combined probability distributions pdf and cdf

56 Adjust based on test/in-service results

1 Confidence Intervals

2 Risk/Maturity Level

62 Substantiated

64 Validated by Models

12 Feasibility study: Results seamlessly compatible with other reliability tools

3 Weibull Parameters

5 Convert Non-CFR to CFR

8 Adjust failure rates to single measure

63 Validated by Test

51 Simplified Version

52 Context driven defaults

60 Self-contained

Components

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YEAR 1 **YEAR 2** **YEAR 3** **YEAR 4**

20 Comprehensive semiconductor PoF models

38 Models <130nm

39 Die complexity

24 Electrochemical Cells

21 Suite of models for parts in common use

23 Electrolytic Cap Life

28 Program Dev data retention/wearout

25 Photonics

22 Connectors

27 Feasibility Study: SW errors per SLOC

Packaging, Environments

YEAR 1 | **YEAR 2** | **YEAR 3** | **YEAR 4**

- 41 Temp cycling at hot/cold extremes
- 11 Combined environmental effects
- 35 Includes SEE upset models for SEU, MBU & SEL
- 43 Hot/cold temp extremes
- 34 Includes time-dependent radiation models
- 40 Storage/dormant models
- 45 Humidity factor
- 47 Electrical Operating Loads & Stress
- 54 Variability in material properties
- 49 Power Cycling
- 44 Shock/vibe fatigue
- 32 Conformal Coat model
- 48 Device duty cycle
- 36 Solder joint, incl Pb-free
- 33 Feasibility study: Tin whiskers including stress-dependent failure mechanisms for SnPb and Pb-free solder
- 37 Packaging, config & complexity

Applications

YEAR 1 **YEAR 2** **YEAR 3** **YEAR 4**

57 Incorp. Field Experience Reli data

65 Validated by field performance

10 Allows easy what-if analysis

46 Tailorable environments defined by application

4 Est. of useful system life

59 Models account for Design for Environment

9 Assessment of indiv. Failure modes and mechanisms

55 Addresses complexities in Natural Environment

61 Mechanism for review and update

53 Addresses variability in design, development and manufacturing processes

50 Facilitates Risk Identification

13 Feasibility Study:
Systems modeled as Integrated elements of hw, sw, human interaction

(Note: Order, timing and scope of "Feasibility Studies" will depend on interest and funding)

Feasibility Studies: 14, 29, 30

42 Feasibility Study: Transient/ intermittent failures

Feasibility Studies: 15, 16, 17, 18, 19, 26, 31

Next Steps

- **Development of Reliability Prediction capability envisioned by the participants in the QFD**
  - **Final Report delivered to AFE 74 management committee sponsors**
  - **Roadmap provided to NSWC Crane**
  - **Follow on projects proposed**
  - **People who helped the QFD are invited to support future follow on projects**

Questions?