HALT In The Product Development Process

Adam Bahret
Apex Ridge Reliability
5/11/16

YOUR LEADER
IN RELIABILITY SOLUTIONS

APEX RIDGE
RELIABILITY

Apex Ridge Reliability provides tailored reliability solutions that advance our customer's products in the market.

Adam Bahret
is a reliability engineer with extensive experience in program strategy, reliability analysis, accelerated testing and HALT in the fields of robotics, medical devices, consumer electronics, and heavy equipment.

"The book presents practical examples of what an engineer should and shouldn't do to be successful in developing a reliable product. It is a must read for all engineers and managers who are involved with corporate-wide improvement efforts."
James McLinn, CRE, Fellow ASQ, Manager of Reliability, Beckman-Coulter

"Mike and Adam take you on a guided tour of Design for Reliability techniques, which are interwoven with many fascinating and useful case studies that demonstrate how this approach has already benefited many organizations. They have gifted you with the tools to help make your great products better."
Mark Turner, C.R.P., Six Sigma & DFSS Black Belt

"If most people who want reliable products would execute even half of what Mike and Adam are espousing, how great it would be for consumers. Instead of going into depth on each topic, this book stays at a higher level to give a perspective of reliability within the product development lifecycle."
Harry McLean, Author of *HALT, HASS, and HASA Explained: Accelerated Reliability Techniques*

Mike Silverman passed away on September 13, 2014. Throughout his twenty-five-year career, he maintained a singular focus on reliability. He was the founder and managing partner of Ops A La Carte, a reliability engineering consultancy that helps customers build end-to-end reliability into their products. Mike created HALT and HASS Labs, a reliability laboratory in Northern California. A Certified Reliability Engineer, he published over a dozen technical papers and was also a former president of the Silicon Valley IEEE Reliability Society.

Adam Bahret has over twenty years of industry experience as a Design, Analysis, and Reliability Engineer. He has developed major reliability programs in fields such as Semiconductor Ion Implantation, Medical Blood Analysis, Industrial Robotics, and Diesel Systems. Adam has specialized in combining reliability analytical and design tools into product development programs, as well as developing specialized testing programs for product development and qualification. He has a Bachelor's in Mechanical Engineering and a Master's in Systems Engineering. He is a member of ASQ and IEEE, as well as a Nationally Certified Reliability Engineer (CRE).

Mike and Adam worked together for many years on collaborative initiatives and advancing reliability practices in industry through education and mentoring. In addition to their professional relationship, they were close friends who greatly enjoyed exchanges on both the philosophical and practical aspects of engineering while mountain hiking or skiing. One can only conclude that they believed altitude was a catalyst for discovery.

DESIGN : PRODUCT : MANAGEMENT
& LEADERSHIP : QUALITY CONTROL

$44.95 US

SUPERSTAR press
http://superstarpress.com

How Reliable is your Product?

MIKE SILVERMAN
ADAM BAHRET

SECOND EDITION

How Reliable is Your Product?

50 WAYS TO IMPROVE PRODUCT RELIABILITY

MIKE SILVERMAN
ADAM BAHRET

Available June 2016

Definition of HALT

Highly Accelerated ~~Life~~ Limit Test

HALT: Performed to ruggedize the product and obtain large margins over the expected in-use conditions. Uses all stresses which can cause relevant failures. Stresses are not limited to field levels or stresses.

-"Accelerated Reliability Engineering: HALT and HASS", Gregg Hobbs

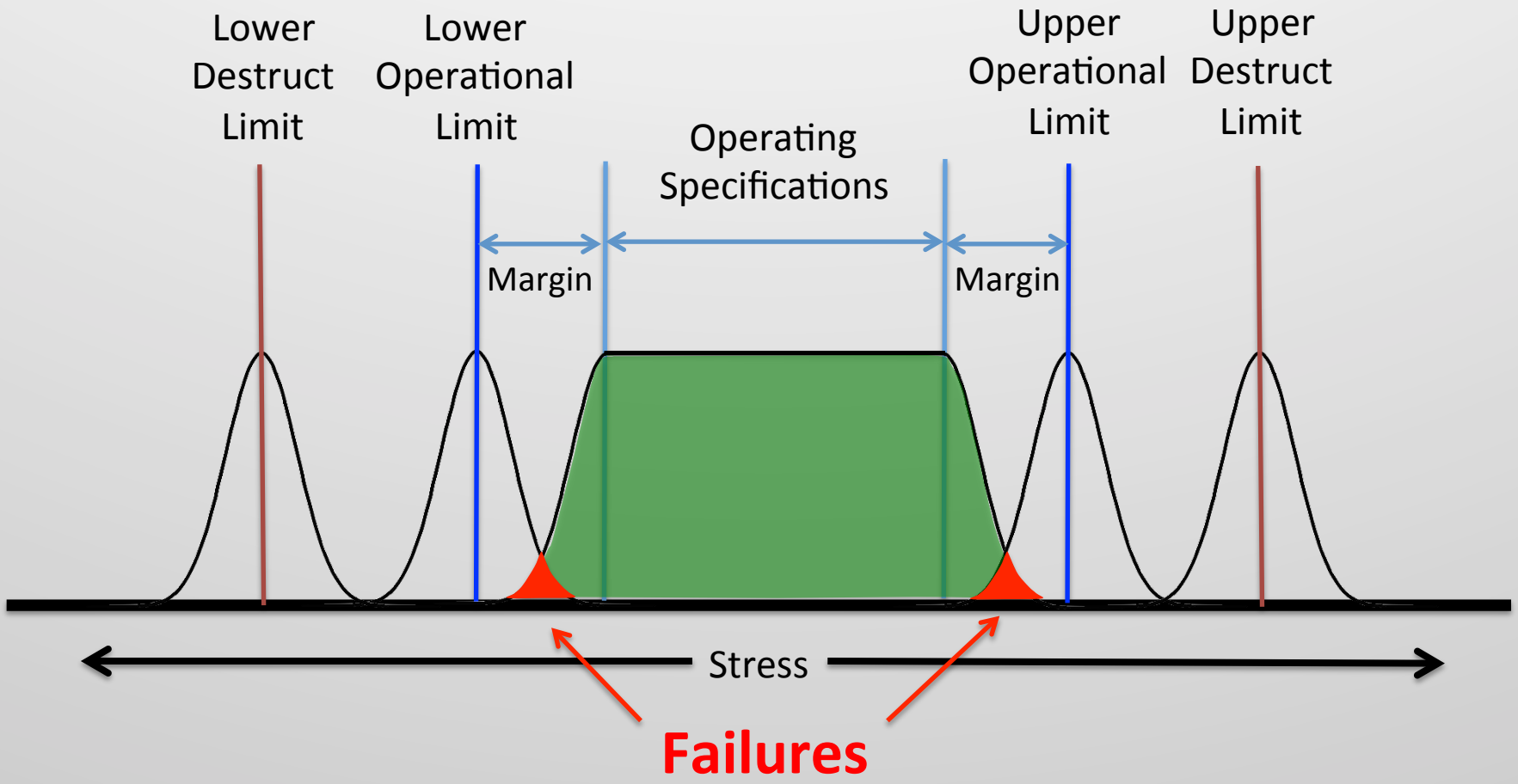
What does HALT do?

- Quickly discovers failure modes
- Evaluates design margins
- Supports release of a mature product
- Reduction in development time and cost

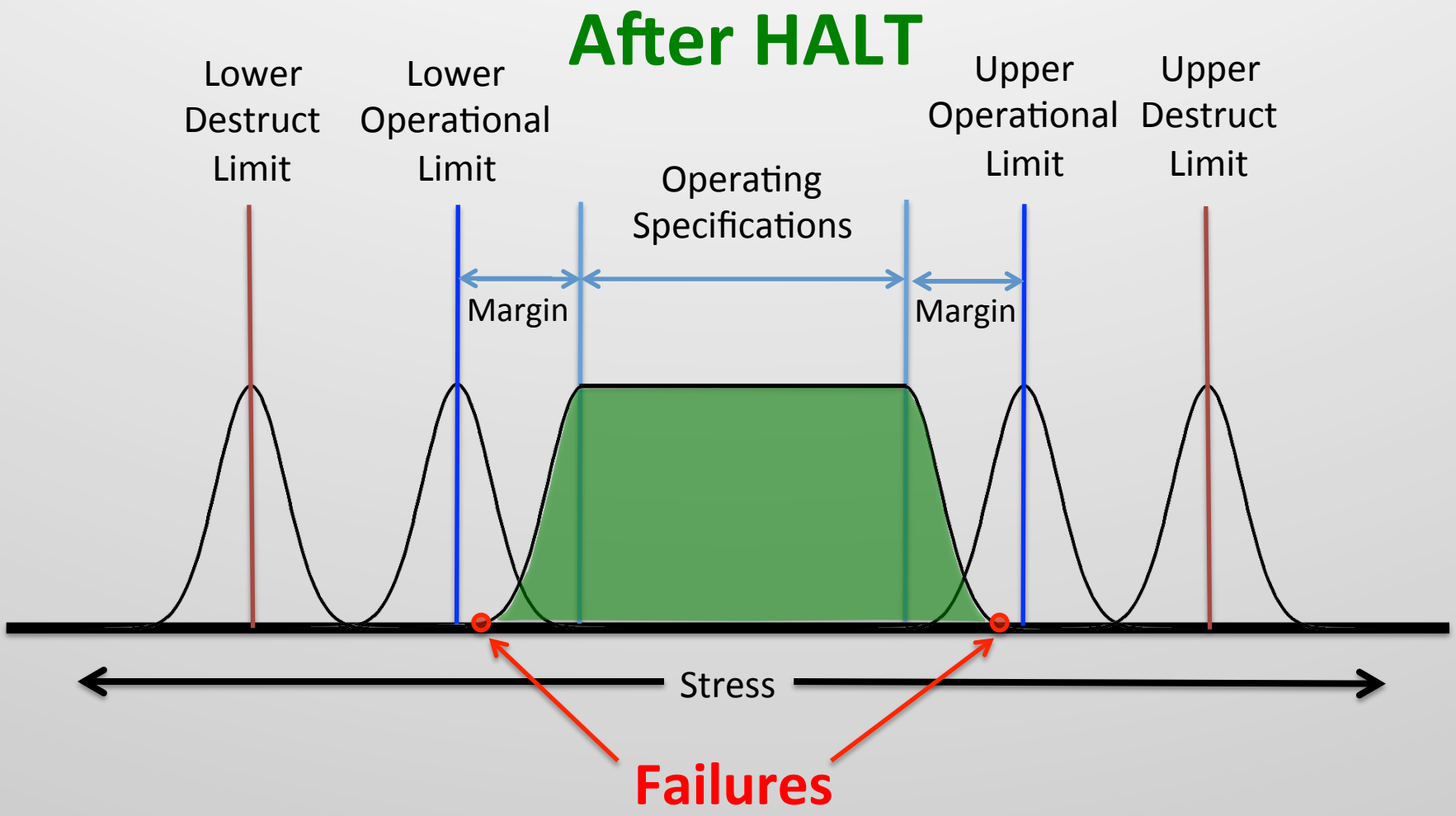
- HALT is not something you pass or fail
- HALT is a tool for discovery of design characteristics

APEX RIDGE
RELIABILITY

Stress Exposure and Limits



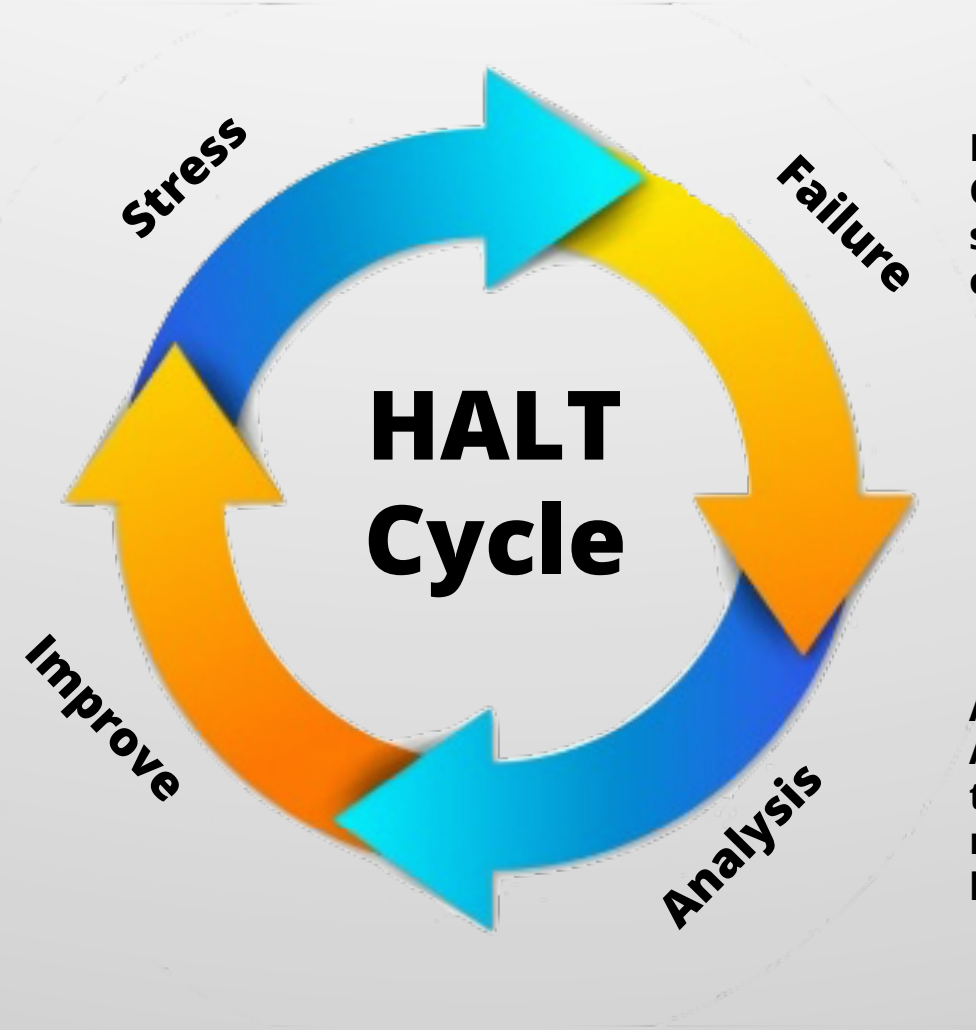
Stress Exposure and Limits



Adam Bahret

HALT Process

Stress:
Start low and step up the stress, testing the product during the stressing



Failure:
Gradually increase stress until a failure occurs

Improve:
Make temporary improvements or isolate stress from found failure mode and continue

Analyze:
Analyze the failure to root cause as much as possible in lab

System Engineering Qualitative Value

Reliability Integration-

“ The Process of seamlessly cohesively integrating reliability tools together to maximize reliability and at the lowest possible cost.”

APEX RIDGE
RELIABILITY

Product Development Process

Assess-ment	Goal Setting	Gap Analysis	Bench-mark	Metrics	Block Diagrams	CONCEPT PHASE
DFMEA	FTA	Component Selection	Thermal Analysis	Derating Analysis	HALT Sub-Assemby	DESIGN PHASE
DOE (Des Of Exprts)	Tolerance Analysis	Preventive Mainten.	HALT Assemby	Design Func Testing	Stress Strength Analysis	
Life Cycle Testing	HALT System	ALT (Accel Life Tst)	HALT-AFR Calculator	RCA (Root Cause Anlys)	CLCA (Cls Loop corctv Actn)	PROTO PHASE
Vendor Assessmt	HASS (high Acl strs scrn)	ORT (ongng Rel Test)	OOBA (out of box audit)	Warranty Strategy	Field Reporting	MANUF PHASE

Adam Bahret

APEX RIDGE RELIABILITY

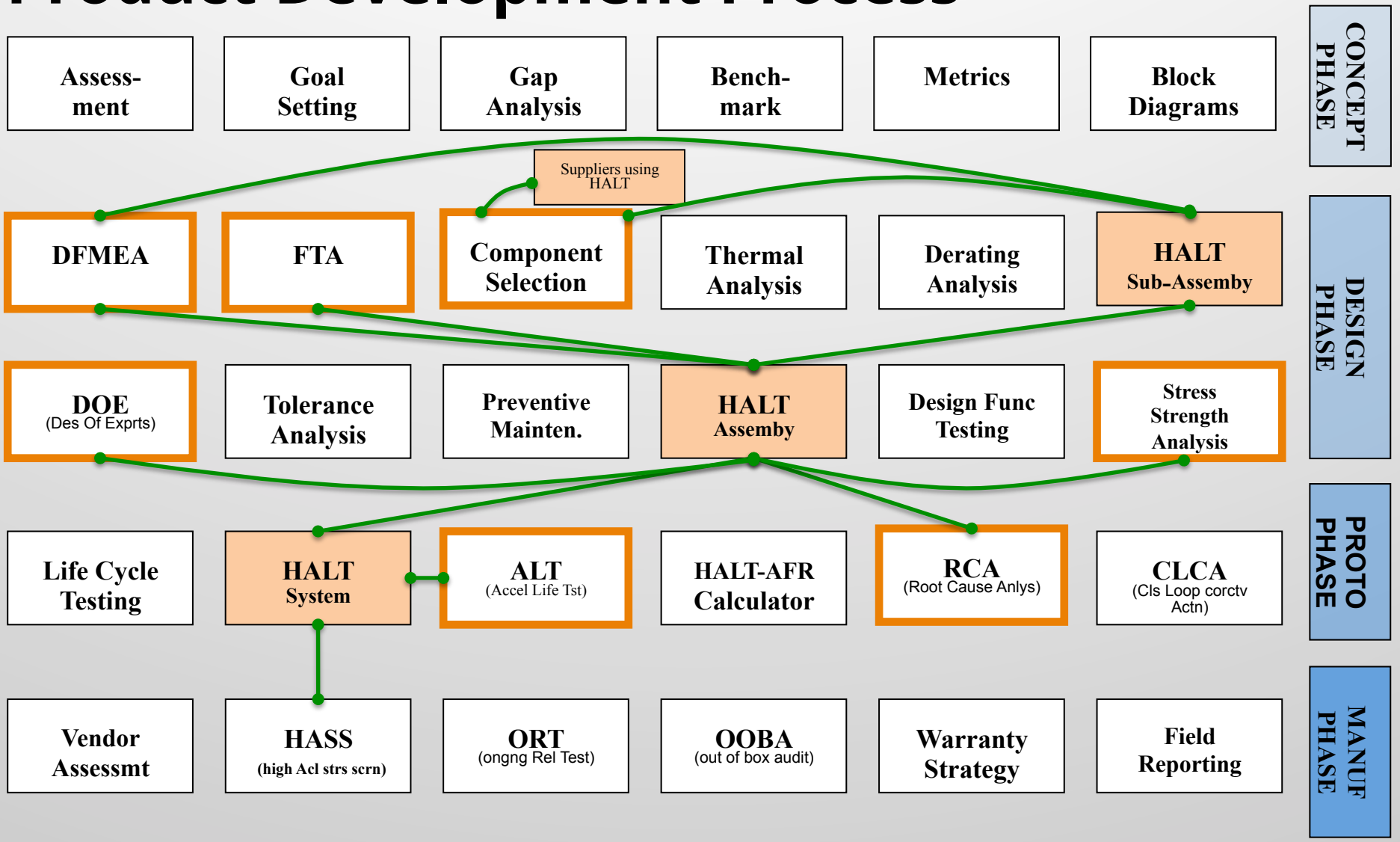
Product Development Process

Assess-ment	Goal Setting	Gap Analysis	Bench-mark	Metrics	Block Diagrams	CONCEPT PHASE
DFMEA	FTA	Component Selection	Thermal Analysis	Derating Analysis	HALT Sub-Assemby	DESIGN PHASE
DOE (Des Of Exprts)	Tolerance Analysis	Preventive Mainten.	HALT Assemby	Design Func Testing	Stress Strength Analysis	
Life Cycle Testing	HALT System	ALT (Accel Life Tst)	HALT-AFR Calculator	RCA (Root Cause Anlys)	CLCA (Cls Loop corctv Actn)	PROTO PHASE
Vendor Assessmt	HASS (high Acl strs scrn)	ORT (ongng Rel Test)	OOBA (out of box audit)	Warranty Strategy	Field Reporting	MANUF PHASE

Adam Bahret

APEX RIDGE RELIABILITY

Product Development Process

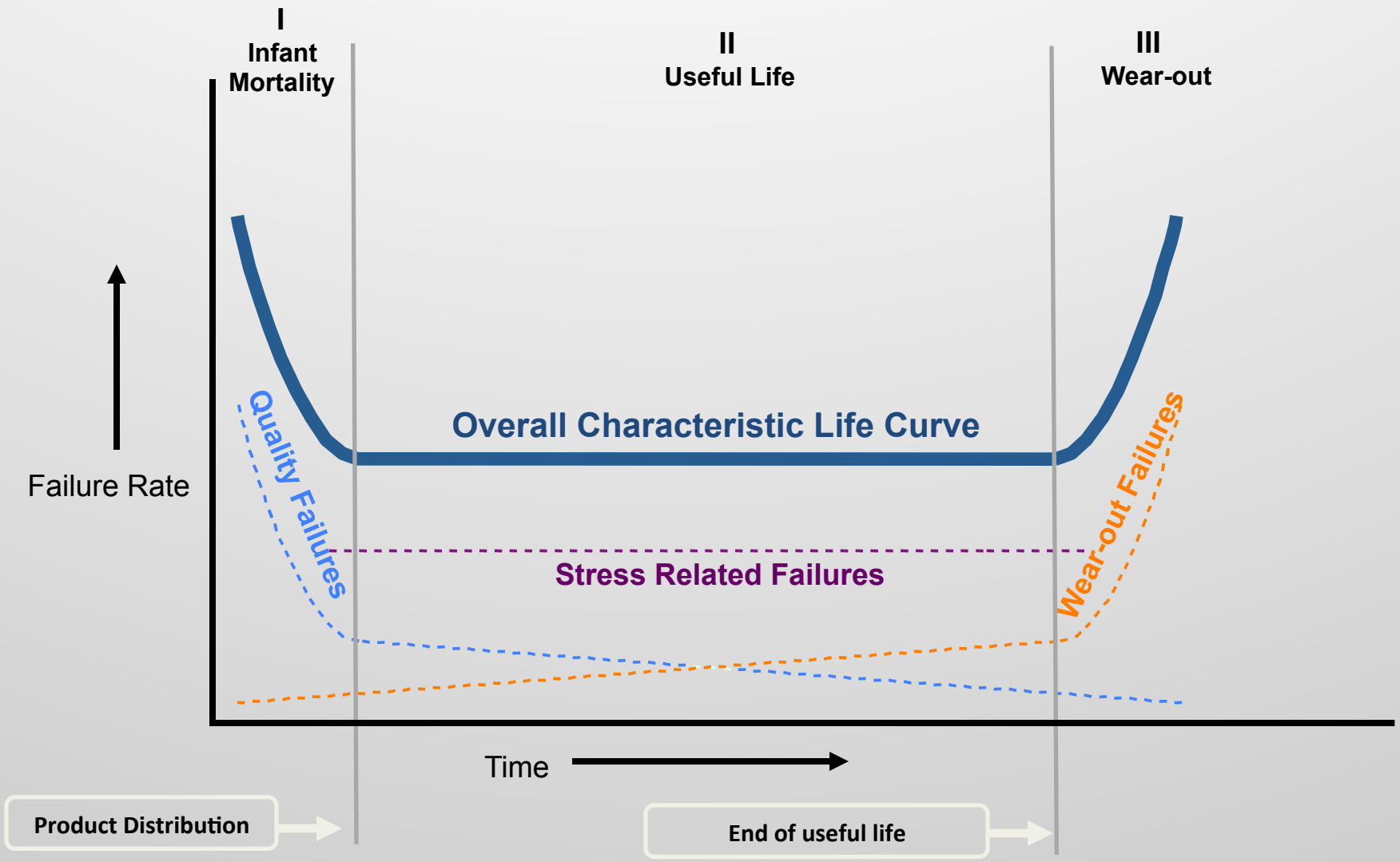


Adam Bahret

Product Performance

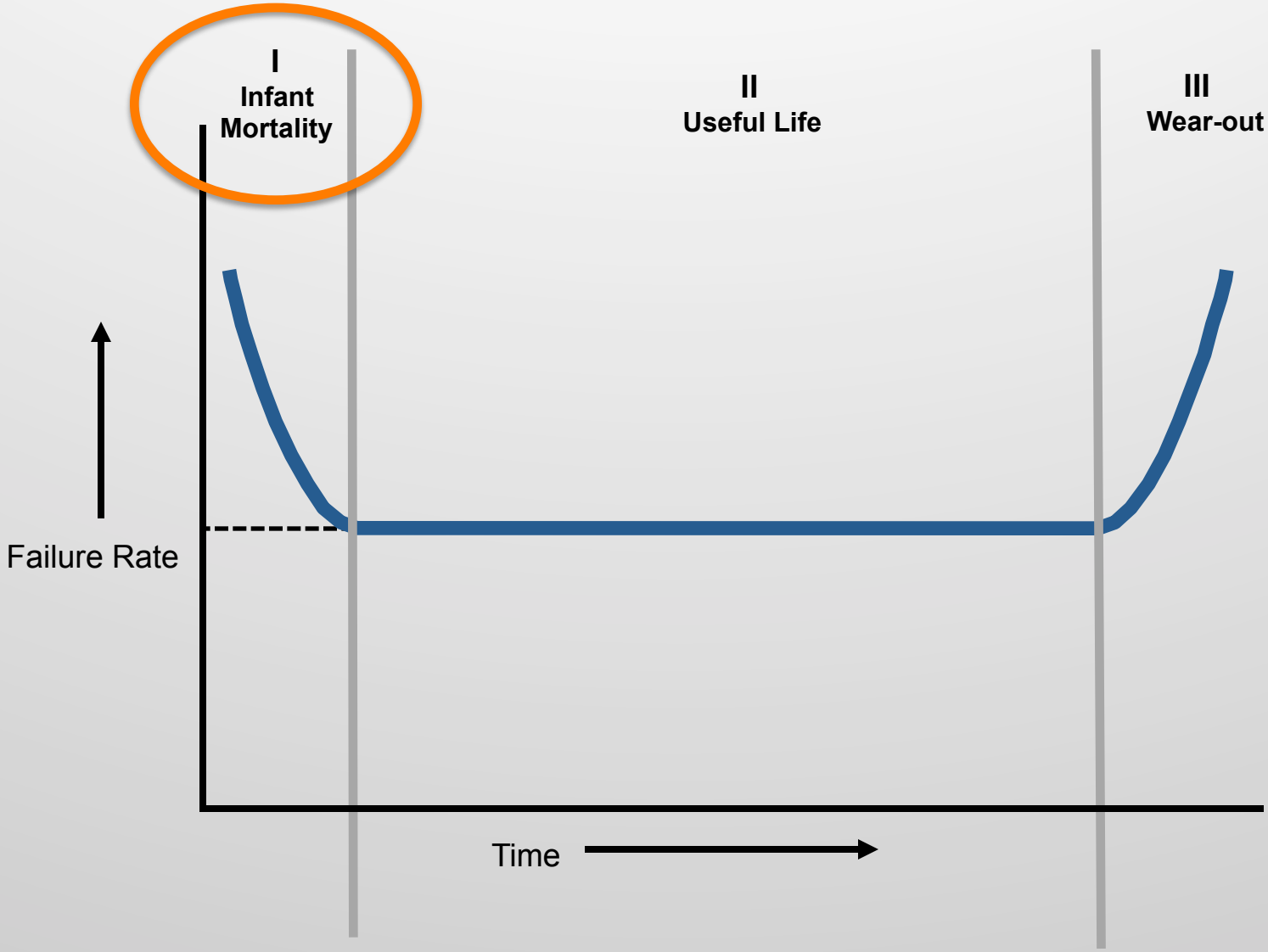
- What are we trying to improve?
- What are the metrics for design improvement?

Bathtub Curve

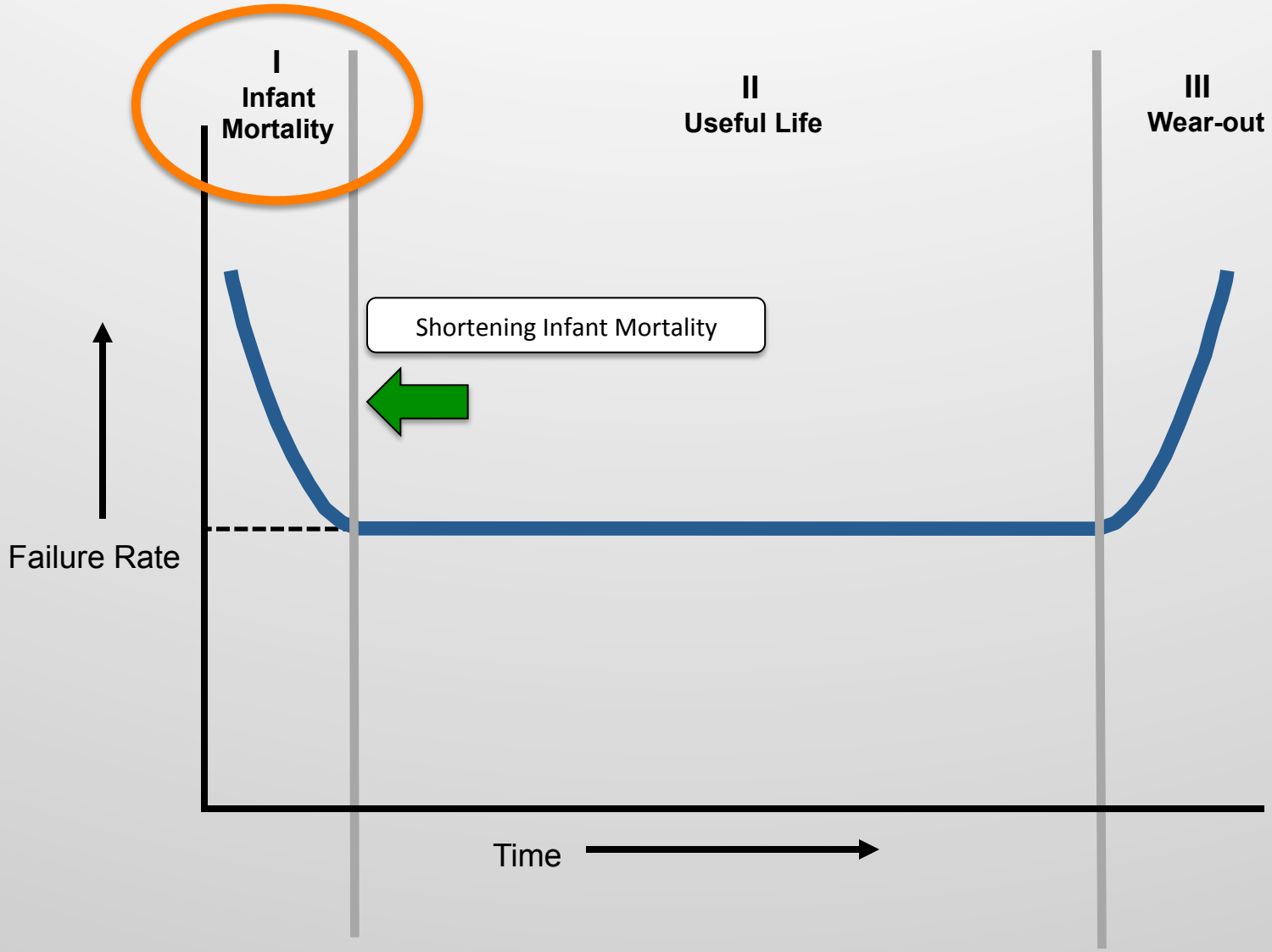


Adam Bahret

Bathtub Curve Metrics

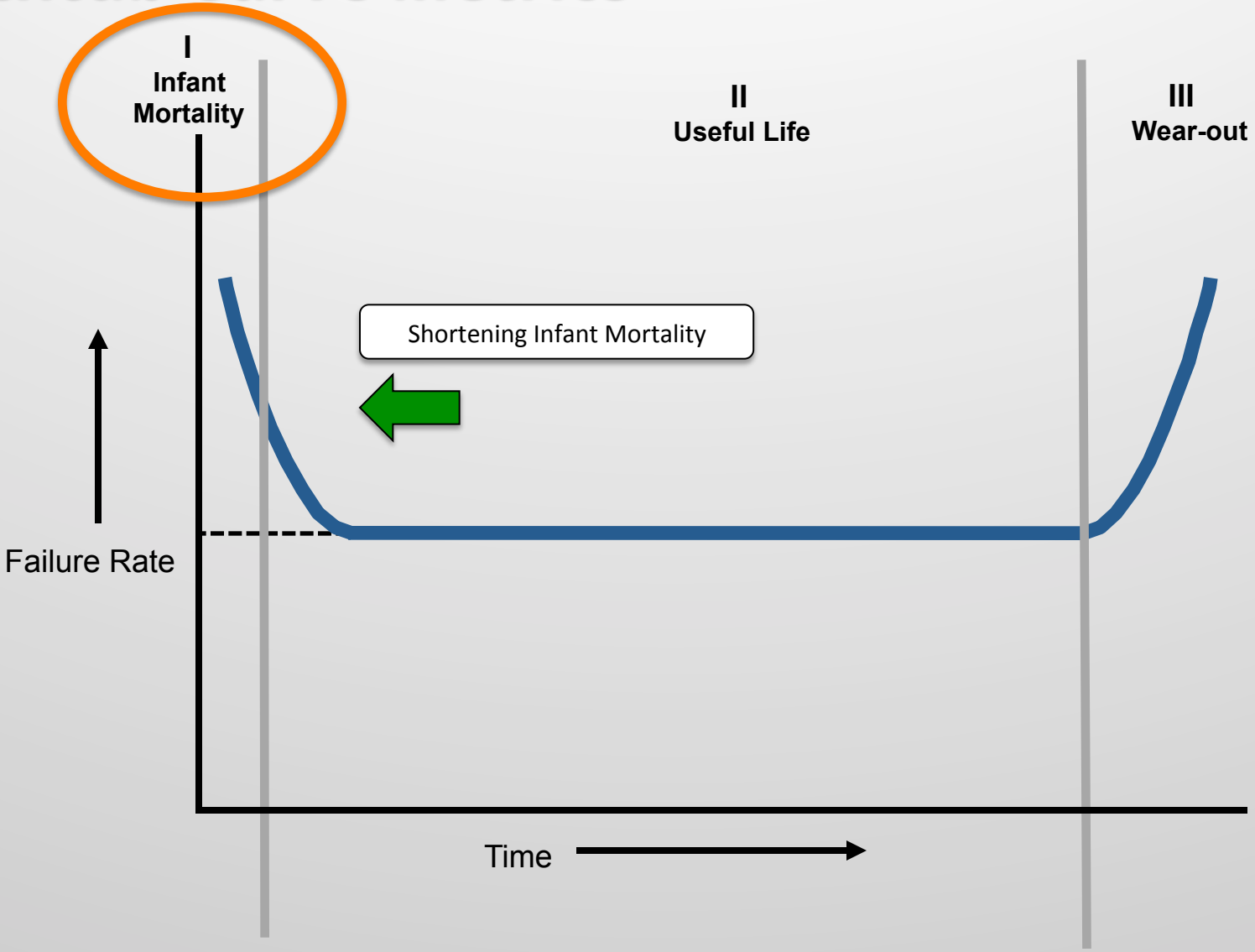


Bathtub Curve Metrics



Adam Bahret

Bathtub Curve Metrics



Adam Bahret

APEX RIDGE
RELIABILITY

HALT Improving Infant Mortality

- **HASS -Highly Accelerated Stress Screen**
  - In HASS all product is "screened" at stress levels above operating levels are applied in order to quickly uncover process weakness, thereby reducing quality based field failures.

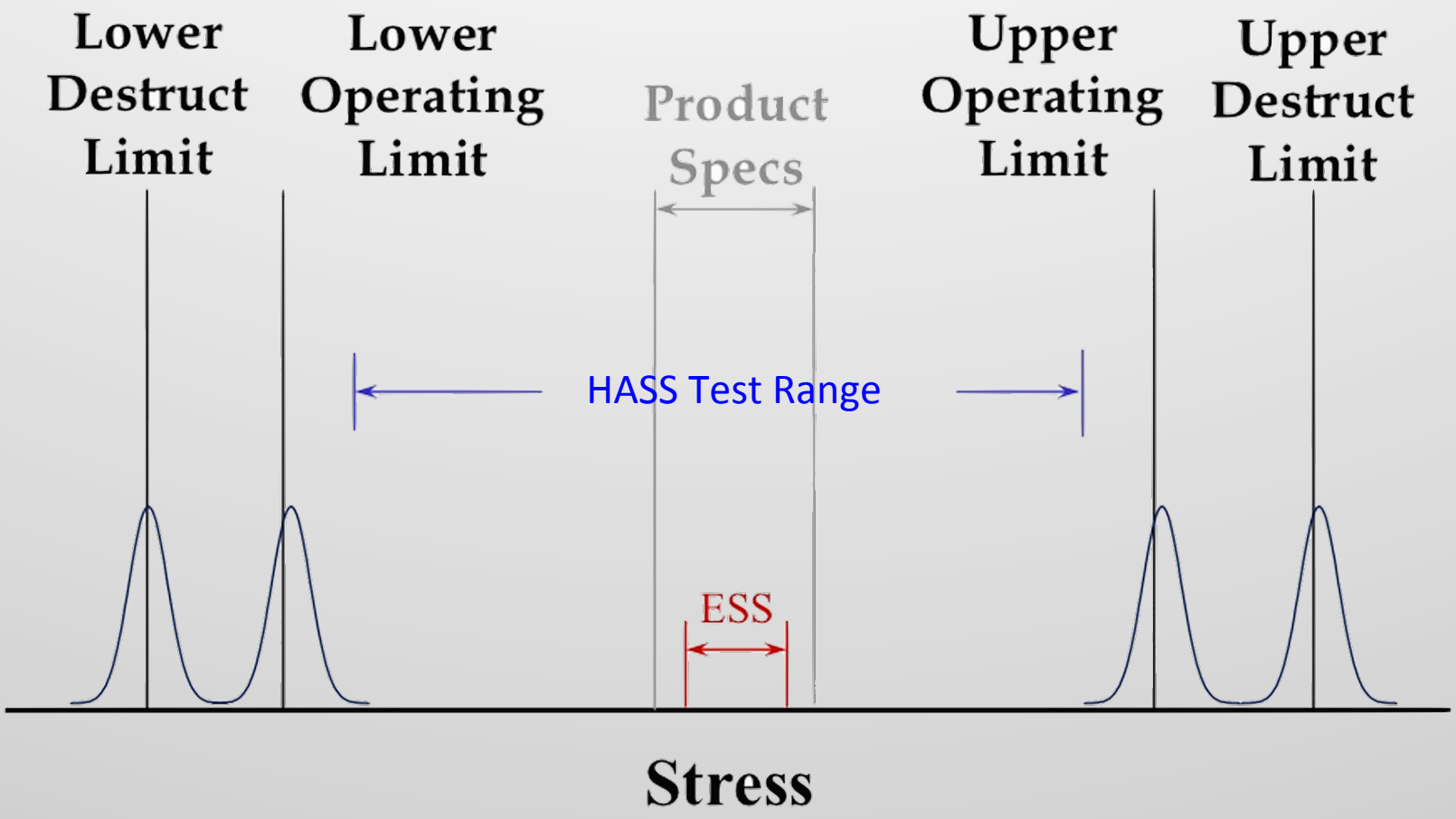
- **HASA –Highly Accelerated Stress Audit**
  - In HASA only a predetermined statistically significant portion of the produced units are screened.

What does HASS do?

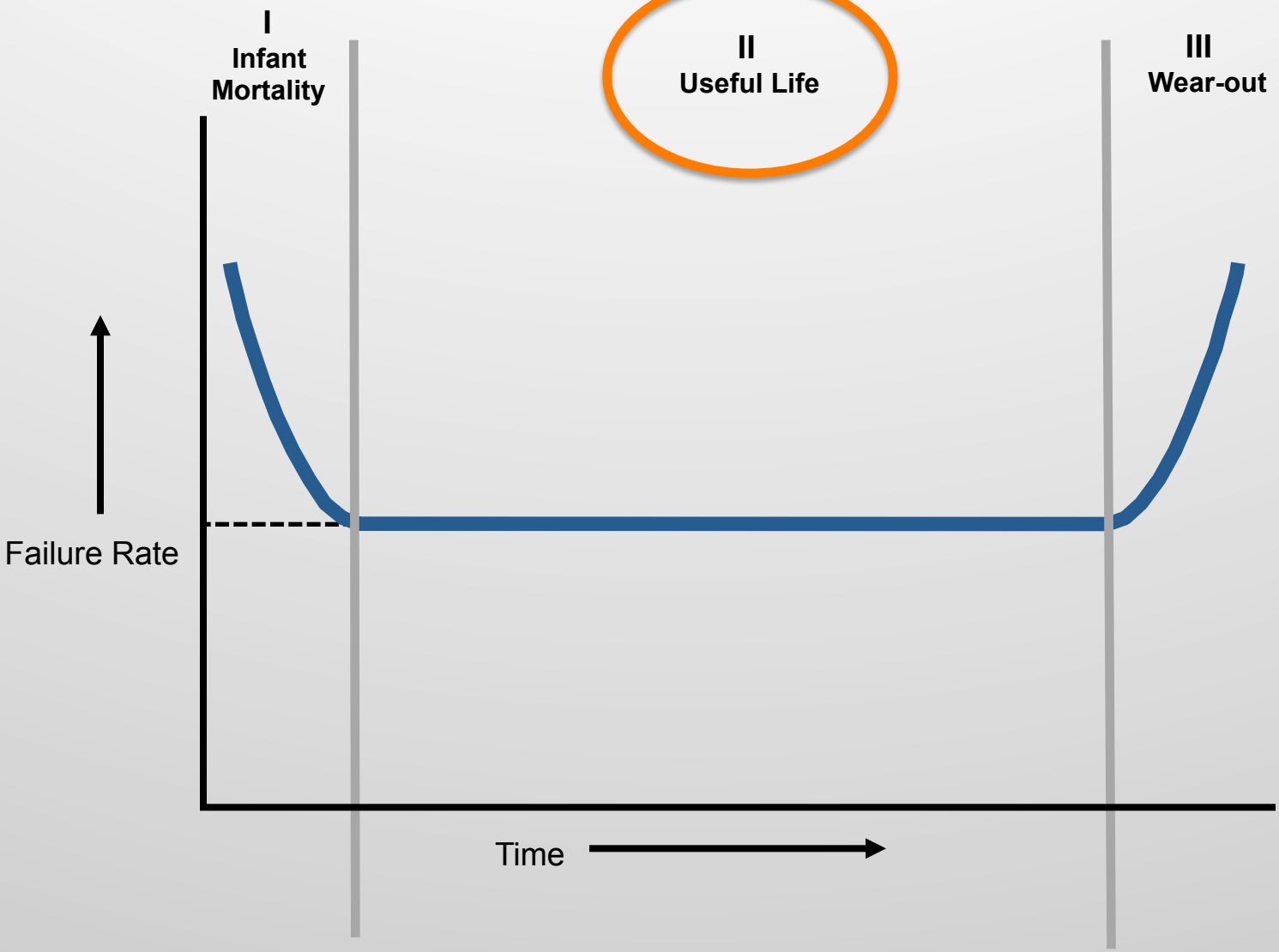
- Detect and correct Process changes
- Reduces production time and cost
- Increases out of box and field reliability
- Decreases field service and warranty cost
- Reduces infant mortality rate
- Finds failures not found in burn-in

-HASS can not be done without HALT

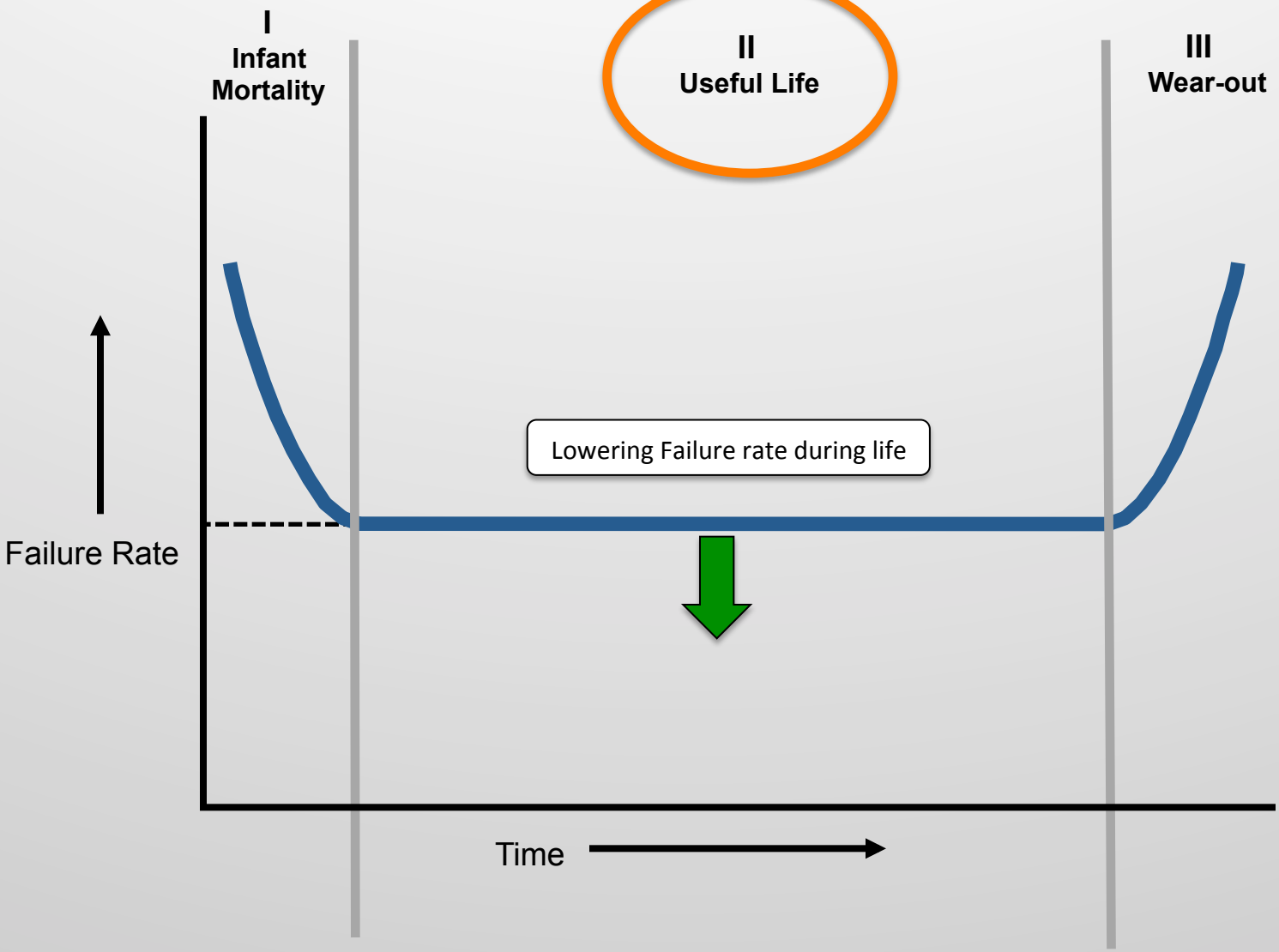
HASS Stress Range



Bathtub Curve Metrics

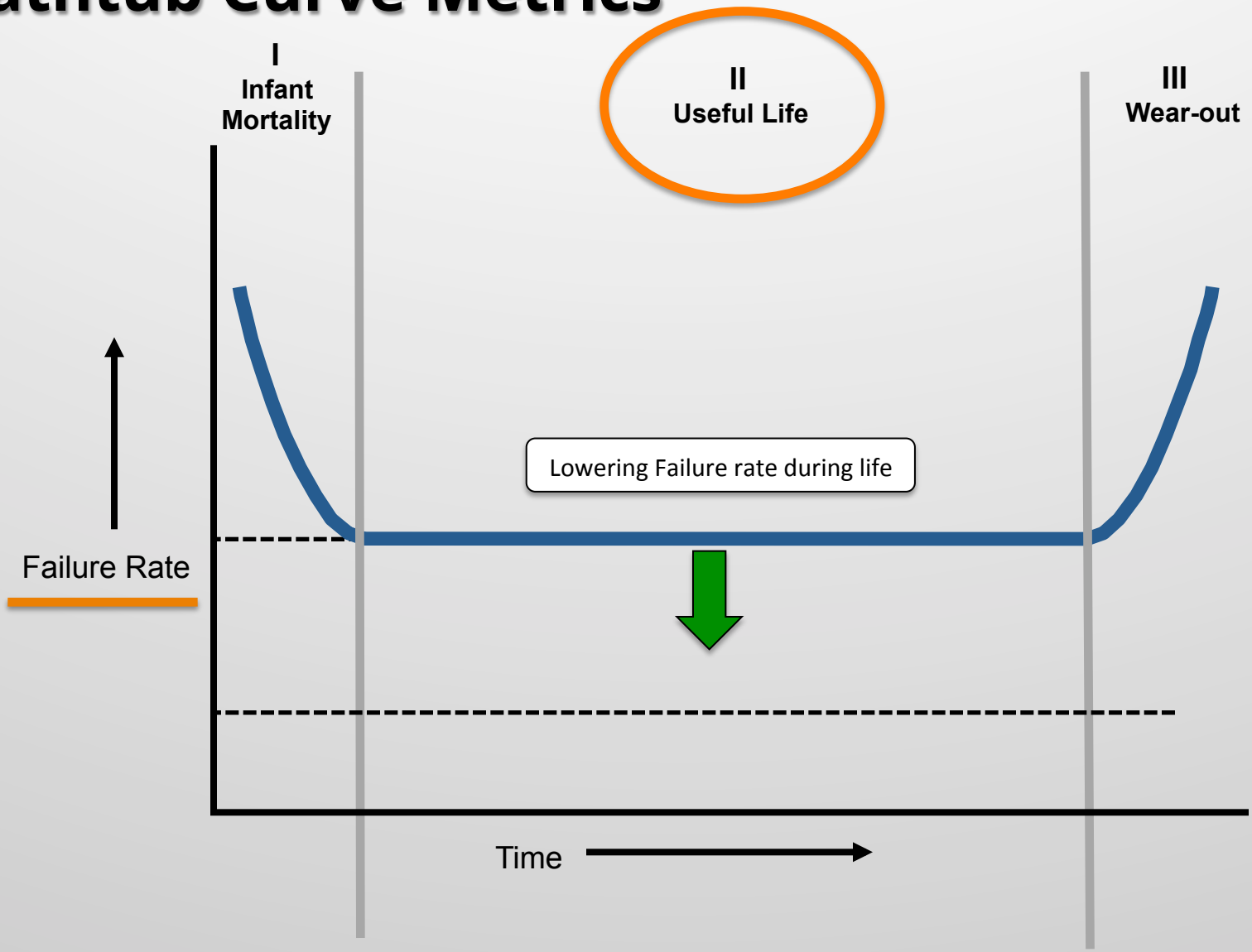


Bathtub Curve Metrics



Adam Bahret

Bathtub Curve Metrics



HALT and Improving Failure Rate

- **FMEA's**
  - Identifying areas of highest system criticality for testing focus
  - Identifying non relevant failure modes
- **FTA**
  - Identifying failure modes for FTA investigation
- **Design of Experiments (DOE)**
  - Identifying how to combine different stresses for HALT
  - A tool for root cause analysis after HALT

Product Development Process

Assess-ment

DFMEA

DOE
(Des Of Exprts)

Life Cycle Testing

Goal Setting | Gap Analysis | Bench-mark | Metrics | Block Diagrams

FMEA – "Failure Mode and Effects Analysis" is a methodology for understanding failure modes and identifying their impact on the system

FTA | Component Selection | Thermal Analysis | Derating Analysis | HALT Sub-Assemby

ID#	Part	Part Function	Failure Mode	Effects of Failure	Severity	Causes of Failure	Occur	Detect	RPN	Remarks
248	downstream pressure	input for secondary	does indicate corect pressure	over/under infusion	5	binding	4	5	100	Build a bench setup for downstream pressure sensor. Idnetify stresses
249	downstream pressure sensor	input for secondary flow calculation	does indicate corect pressure	over/under infusion	5	contamination	4	5	100	System Level testing will capture any shift in accuracy over time
233	**downstream pressure sensor**	indicate blockage	incorrect low pressure	infiltration	4	binding	4	5	80	physiological effects of over pressurization

Vendor Assessmt

HASS
(high Acl strs scrn)

ORT
(ongng Rel Test)

OOBA
(out of box audit)

Warranty Strategy

Field Reporting

MANUF PHASE

Adam Bahret

APEX RIDGE RELIABILITY

Product Development Process

Assess-ment

Goal Setting | Gap Analysis | Bench-mark | Metrics | Block Diagrams

FMEA – "Failure Mode and Effects Analysis" is a methodology for understanding failure modes and identifying their impact on the system

DFMEA

FTA | Component Selection | Thermal Analysis | Derating Analysis | HALT Sub-Assemby

DOE
(Des Of Exprts)

ID#	Part	Part Function	Failure Mode	Effects of Failure	Severity	Causes of Failure	Occur	Detect	RPN	Remarks
248	downstream pressure	input for secondary	does indicate corect pressure	over/under infusion	5	binding	4	5	100	Build a bench setup for downstream pressure sensor. Idnetify stresses
249	downstream pressure sensor	input for secondary flow calculation	does indicate corect pressure	over/under infusion	5	contamination	4	5	100	System Level testing will capture any shift in accuracy over time
233	**downstream pressure sensor**	indicate blockage	incorrect low pressure	infiltration	4	binding	4	5	80	physiological effects of over pressurization

Life Cycle Testing

Vendor Assessmt | **HASS** (high Acl strs scrn) | **ORT** (ongng Rel Test) | **OOBA** (out of box audit) | **Warranty Strategy** | **Field Reporting**

MANUF PHASE

Adam Bahret

Product Development Process

Assess-ment

Goal Setting | Gap Analysis | Bench-mark | Metrics | Block Diagrams

FMEA – "Failure Mode and Effects Analysis" is a methodology for understanding failure modes and identifying their impact on the system

DFMEA

FTA | Component Selection | Thermal Analysis | Derating Analysis | HALT Sub-Assemby

DESIGN PHASE

DOE
(Des Of Exprts)

ID#	Part	Part Function	Failure Mode	Effects of Failure	Severity	Causes of Failure	Occur	Detect	RPN	Remarks
248	downstream pressure	input for secondary	does indicate corect pressure	over/under infusion	5	binding	4	5	100	Build a bench setup for downstream pressure sensor. Idnetify stresses
249	downstream pressure sensor	input for secondary flow calculation	does indicate corect pressure	over/under infusion	5	contamination	4	5	100	System Level testing will capture any shift in accuracy over time
233	**downstream pressure sensor**	indicate blockage	incorrect low pressure	infiltration	4	binding	4	5	80	physiological effects of over pressurization

Life Cycle Testing

Vendor Assessmt | **HASS** (high Acl strs scrn) | **ORT** (ongng Rel Test) | **OOBA** (out of box audit) | **Warranty Strategy** | **Field Reporting**

MANUF PHASE

Product Development Process

Assess-ment

Goal Setting | Gap Analysis | Bench-mark | Metrics | Block Diagrams

FMEA – "Failure Mode and Effects Analysis" is a methodology for understanding failure modes and identifying their impact on the system

DFMEA

FTA | Component Selection | Thermal Analysis | Derating Analysis | HALT Sub-Assemby

DESIGN PHASE

DOE
(Des Of Exprts)

ID#	Part	Part Function	Failure Mode	Effects of Failure	Severity	Causes of Failure	Occur.	Detect	RPN	Remarks
248	downstream pressure	input for secondary	does indicate corect pressure	over/under infusion	5	binding	4	5	100	Build a bench setup for downstream pressure sensor. Idnetify stresses
249	downstream pressure sensor	input for secondary flow calculation	does indicate corect pressure	over/under infusion	5	contamination	4	5	100	System Level testing will capture any shift in accuracy over time
233	**downstream pressure sensor**	indicate blockage	incorrect low pressure	infiltration	4	binding	4	5	80	physiological effects of over pressurization

Life Cycle Testing

Vendor Assessmt | **HASS** (high Acl strs scrn) | **ORT** (ongng Rel Test) | **OOBA** (out of box audit) | **Warranty Strategy** | **Field Reporting**

MANUF PHASE

Adam Bahret

HALT & DFMEA

Assess-ment

Goal Setting | Gap Analysis | Bench-mark | Metrics | Block Diagrams

FMEA – "Failure Mode and Effects Analysis" is a methodology for understanding failure modes and identifying their impact on the system

DFMEA

FTA | Component Selection | Thermal Analysis | Derating Analysis | HALT Sub-Assemby

DESIGN PHASE

DOE
(Des Of Exprts)

Life Cycle Testing

ID#	Part	Part Function	Failure Mode	Effects of Failure	Severity	Causes of Failure	Occur	Detect	RPN	Remarks
248	downstream pressure	input for secondary	does indicate corect pressure	over/under infusion	5	binding	4	5	100	Build a bench setup for downstream pressure sensor. Idnetify stresses
249	downstream pressure sensor	input for secondary flow calculation	does indicate corect pressure	over/under infusion	5	contamination	4	5	100	System Level testing will capture any shift in accuracy over time
233	**downstream pressure sensor**	indicate blockage	incorrect low pressure	infiltration	4	binding	4	5	80	physiological effects of over pressurization

Vendor Assessmt

HASS
(high Acl strs scrn)

ORT
(ongng Rel Test)

OOBA
(out of box audit)

Warranty Strategy

Field Reporting

MANUF PHASE

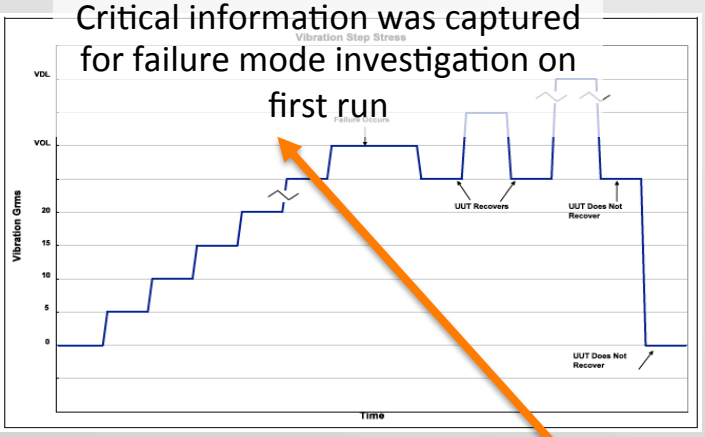
Adam Bahret

HALT and DFMEA

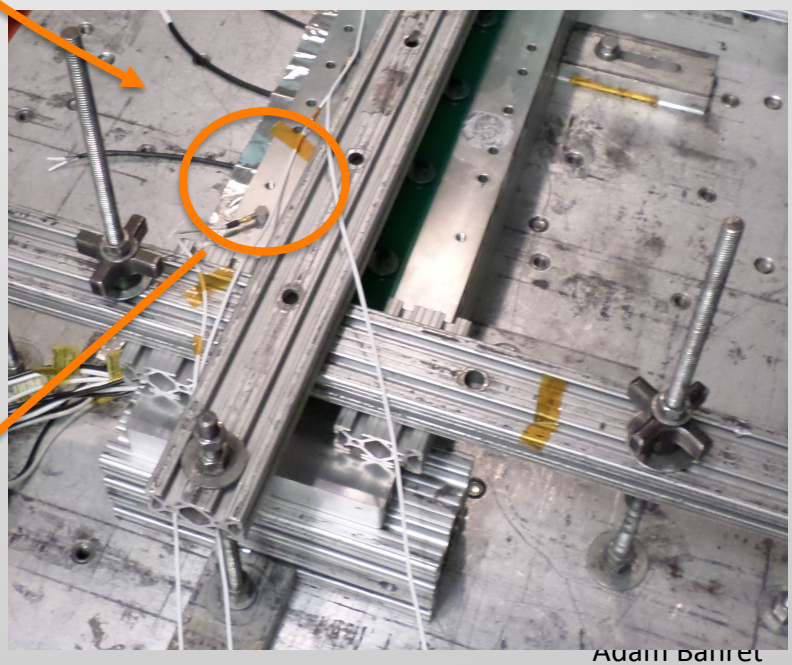
ID#	Part	Part Function	Failure Mode	Effects of Failure	Severity	Causes of Failure	Occur	Detect	RPN	Remarks
248	downstream pressure	input for secondary	does indicate corect pressure	over/under infusion	5	binding	4	5	100	Build a bench setup for downstream pressure sensor. Idnetify stresses
249	downstream pressure sensor	input for secondary flow calculation	does indicate corect pressure	over/under infusion	5	contamination	4	5	100	System Level testing will capture any shift in accuracy over time
233	**downstream pressure sensor**	indicate blockage	incorrect low pressure	infiltration	4	binding	4	5	80	physiological effects of over pressurization

How about using HALT in addition to the bench test?

Critical information was captured for failure mode investigation on first run



Put accelerometer right at pressure sensor/valve location as response for binding failure mode diagnosis



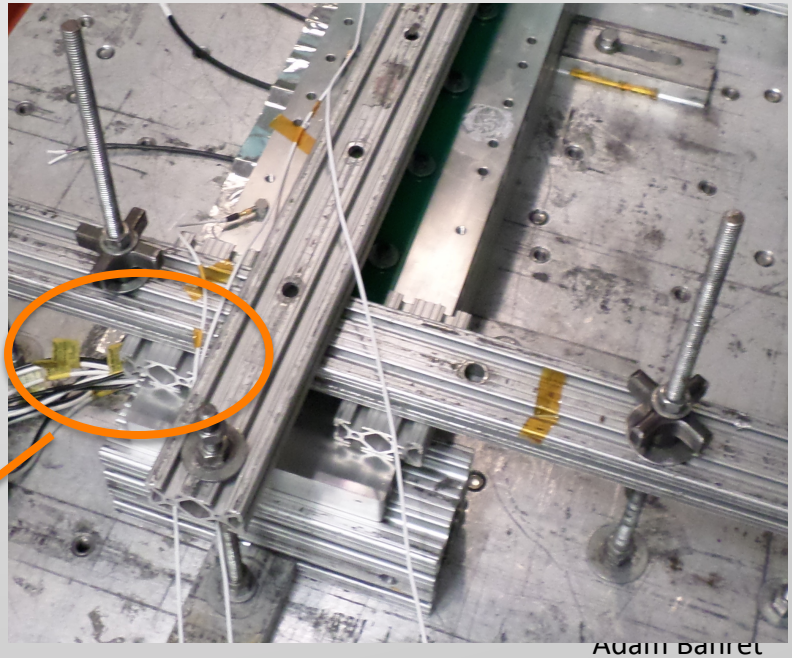
HALT and DFMEA

ID#	Part	Part Function	Failure Mode	Effects of Failure	Severity	Causes of Failure	Occur	Detect	RPN	Remarks
248	downstream pressure	input for secondary	does indicate corect pressure	over/under infusion	5	binding	4	5	100	Build a bench setup for downstream pressure sensor. Idnetify stresses
243	downstream pressure sensor	regulate pressure	incorrect high pressure	loss of valve control	4	Disconnect	~~3~~ 5	~~60~~ 5 100		tem Level testing will capture any t in accuracy over time
233	pressure sensor	indicate blockage	incorrect low pressure	infiltration	4	binding	4	5	80	physiological effects of over pressurization

Team revisits DFMEA and changes corrective/mitigative actions

Increase Occurrence of "Disconnect" Cause from a 3 to 5 which brings ID 243 into the "critical evaluation zone"

Discover in HALT testing that PCB connection easily disconnects



HALT & DOE

Assess-ment

DFMEA

DOE
(Des Of Exprts)

Design of Experiments (DOE) -A method to determine the relationship between factors affecting a process and the output of that process

- "Cause and Effect" relationships can be statistically related
- Interactions of multiple variables driving the "Effect" can be determined

Available Factorial Designs (with Resolution)

	Factors													
Runs	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Available Resolution III Plackett-Burman Designs

Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

HALT & DOE

Available Factorial Designs (with Resolution)

Runs	Factors													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Available Resolution III Plackett-Burman Designs

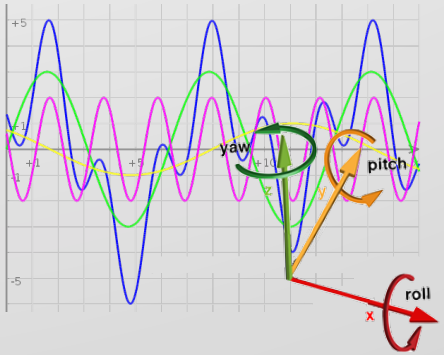
Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

What's the hardest part of setting up a DOE?

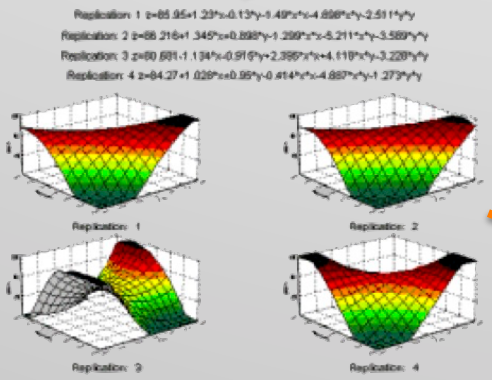
Selecting the most critical Factors and Levels

Create response results that show a clear link of inputs and outputs for the experiment

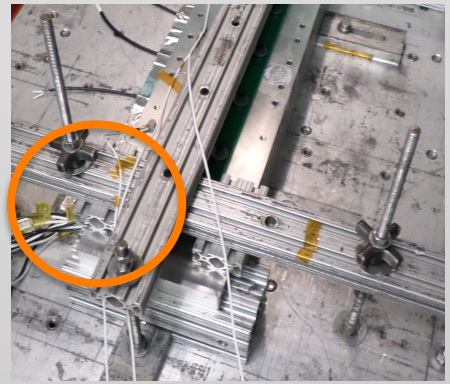
Multiple Simultaneous Frequency



Discoveries in HALT assist with selection of the critical matrix factors



Conclusive surface response



Adam Bahret

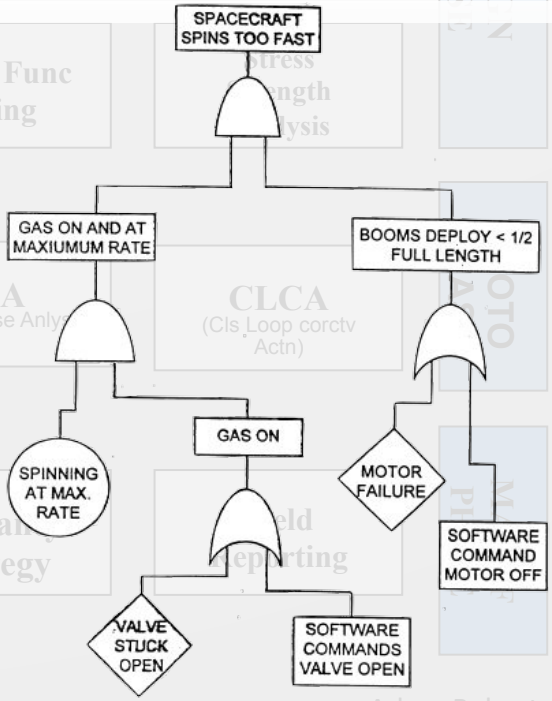
APEX RIDGE
RELIABILITY

HALT & FTA

Assess-ment	Goal Setting
FMEA	FTA
DOE (Des Of Exprts)	
Life Cycle Testing	
Vendor Assessmt	

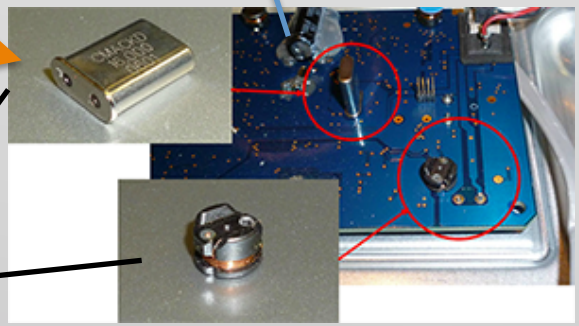
- Fault Tree Analysis (FTA) is a deductive approach for resolving an undesired event into its causes
- FTA is a top down failure analysis, looking back to the causes of a given event
- Specific logic symbols are used to to illustrate the event relationships

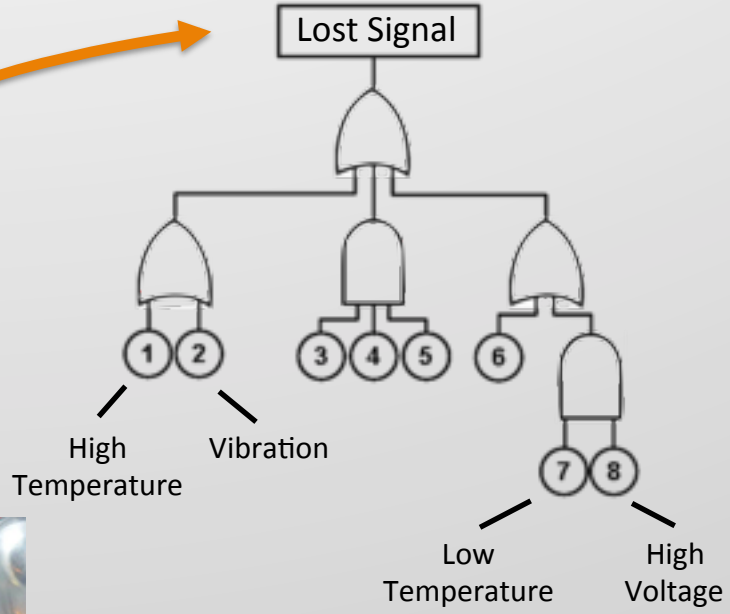
intermediate event	an event that happens between two other events
basic event	a failure in your system
undeveloped event	event with not enough information
external event	event expected to happen
AND gate	output happens if both of the children happen
OR gate	output happens if one of the children happens



HALT & FTA

- **HALT will expose failure modes that can be the subject of an FTA**
- **The stresses in HALT can be considered in the FTA structure**



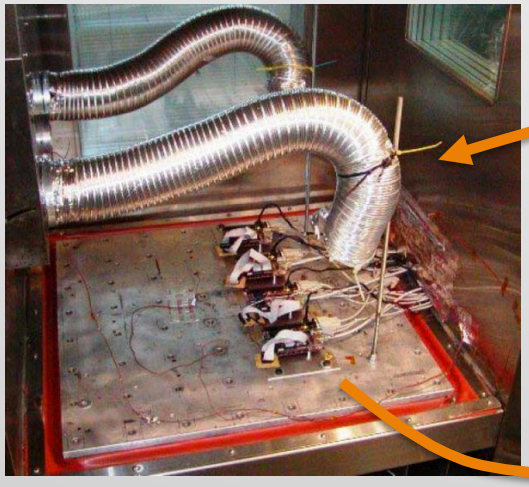


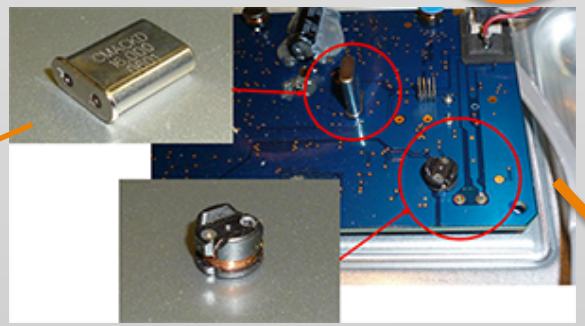
Lost Signal

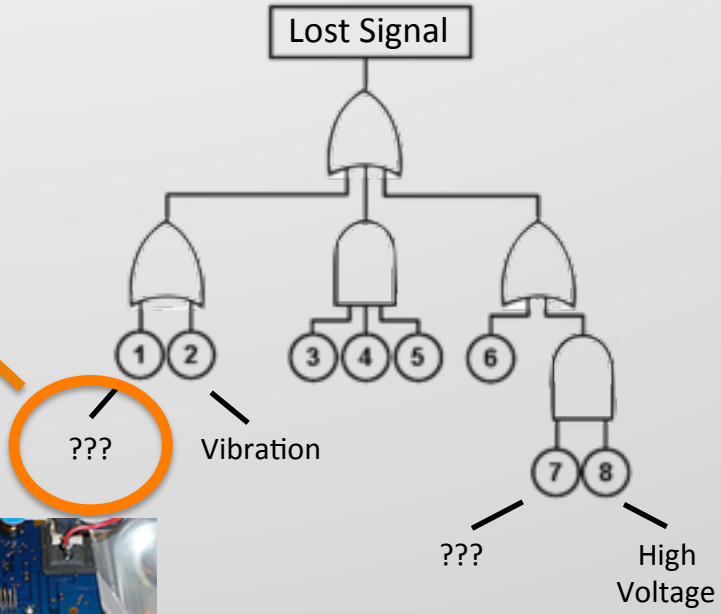
Broke Free

HALT & FTA

- **An FTA may not be able to completed with high confidence without experimentation**
- **HALT can very quickly identify relationships between stresses and failure modes**



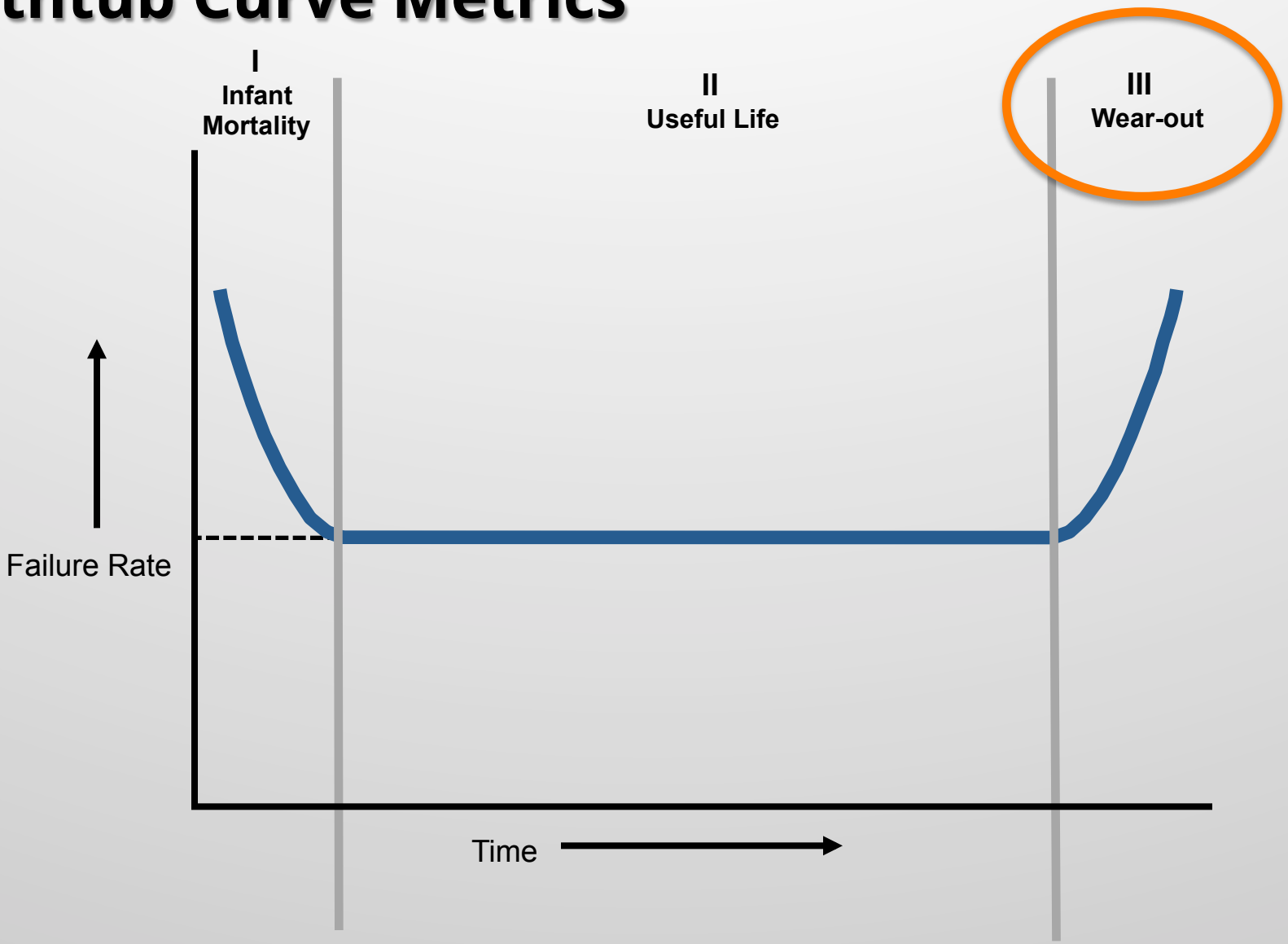




Broke Free With Temp and Vibration combination

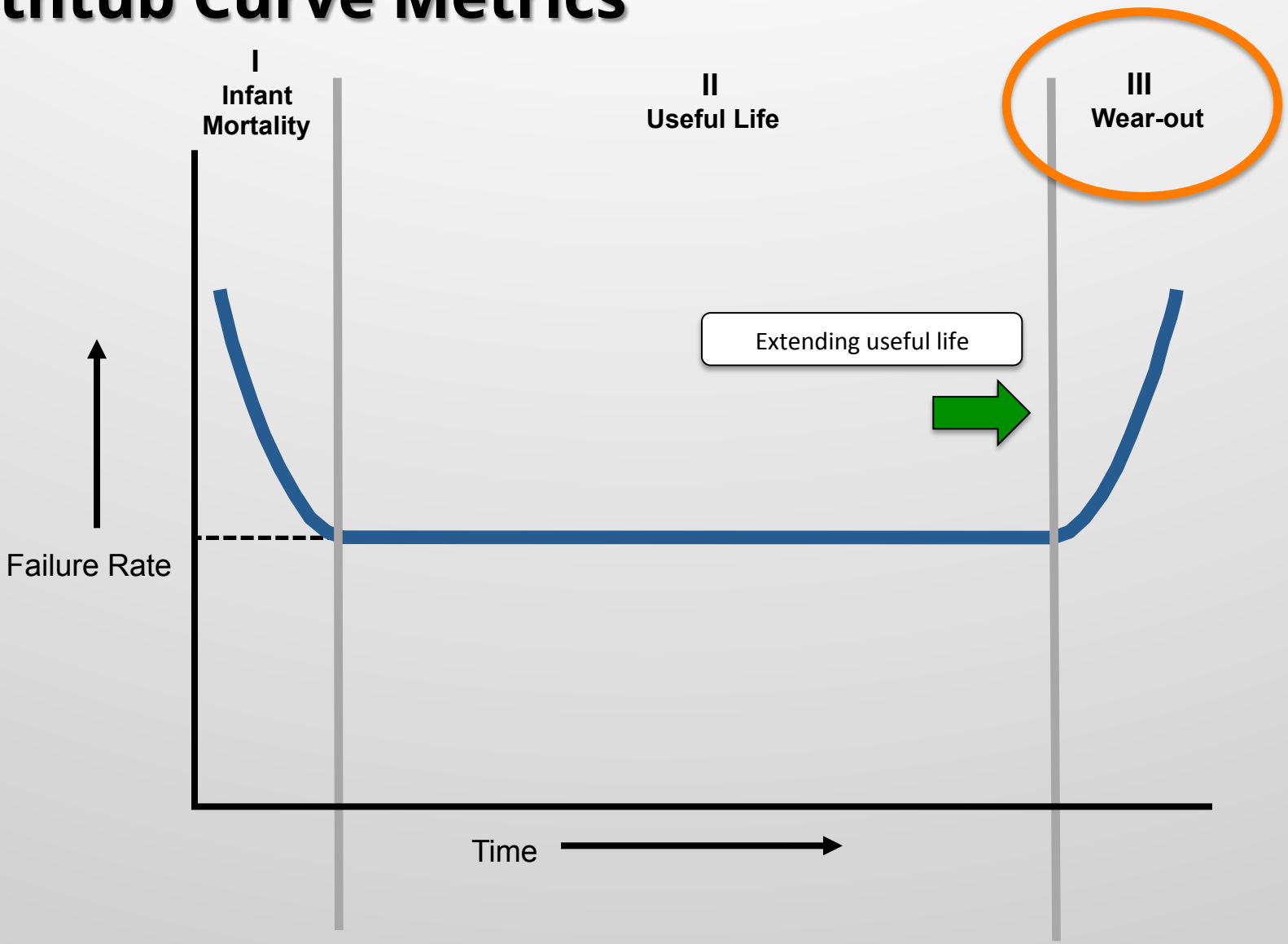
Resulted in Lost Signal

Bathtub Curve Metrics



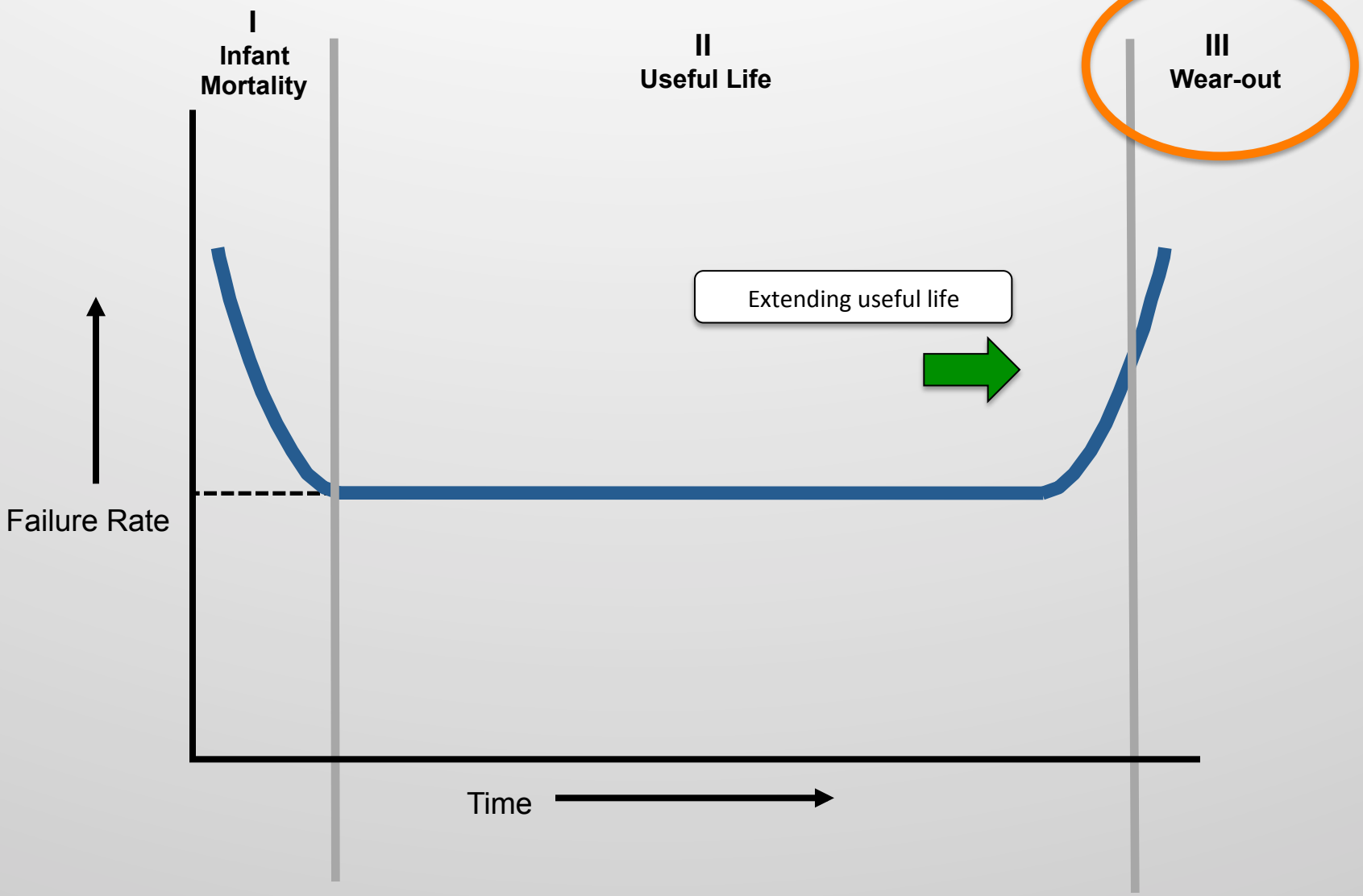
Adam Bahret

Bathtub Curve Metrics



Adam Bahret

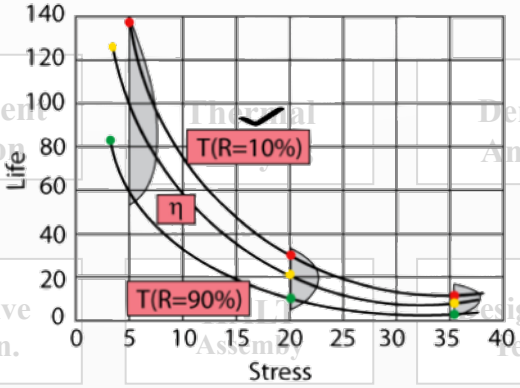
Bathtub Curve Metrics



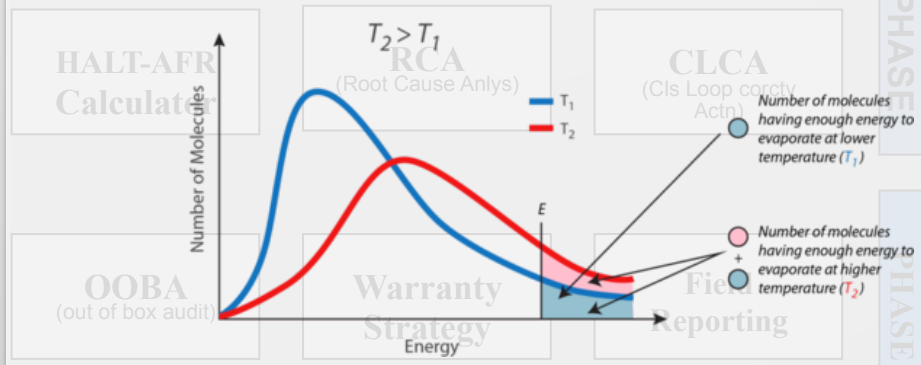
APEX RIDGE RELIABILITY

Product Development Process

- Accelerated Life Test (ALT) – Is the process of determining the reliability of a product in a short period of time by accelerating the use environment
- Common Models
  - Coffin Manson
  - Arrhenius
  - Power Weibull



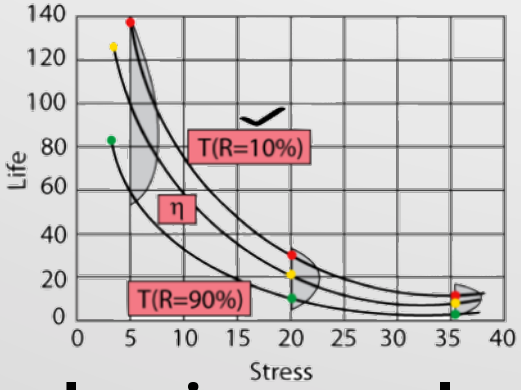
Life Cycle Testing	**HALT** System	**ALT** (Accel Life Test)
Vendor Assessmt	**HASS** (high Acl strs scrn)	**ORT** (ongng Rel Test)

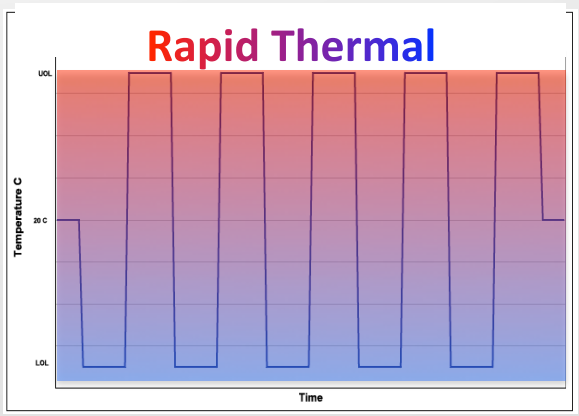


Adam Bahret

HALT & ALT

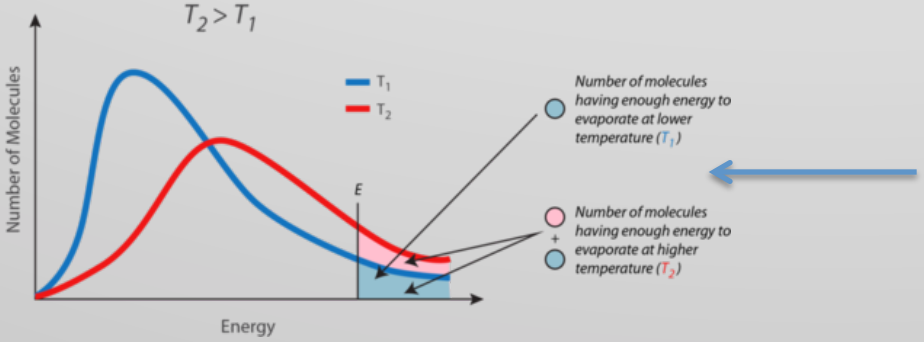
- **Coffin Manson accelerated life model**
  - Uses increases temperature range cycling to demonstrate useful life in a shorter time period

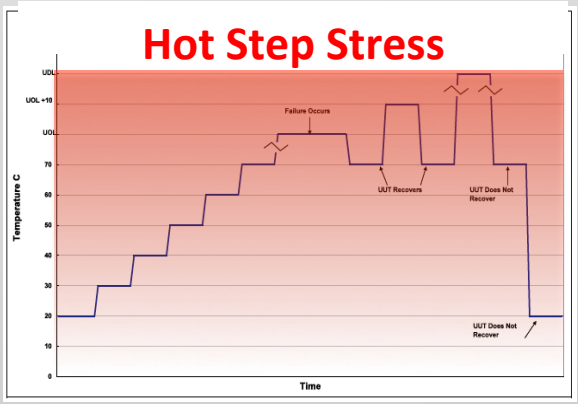




HALT

- **Arrhenius acceleration life model**
  - Uses elevated temperature to demonstrate useful life in a shorter time period





HALT

Root Cause Analysis & HALT

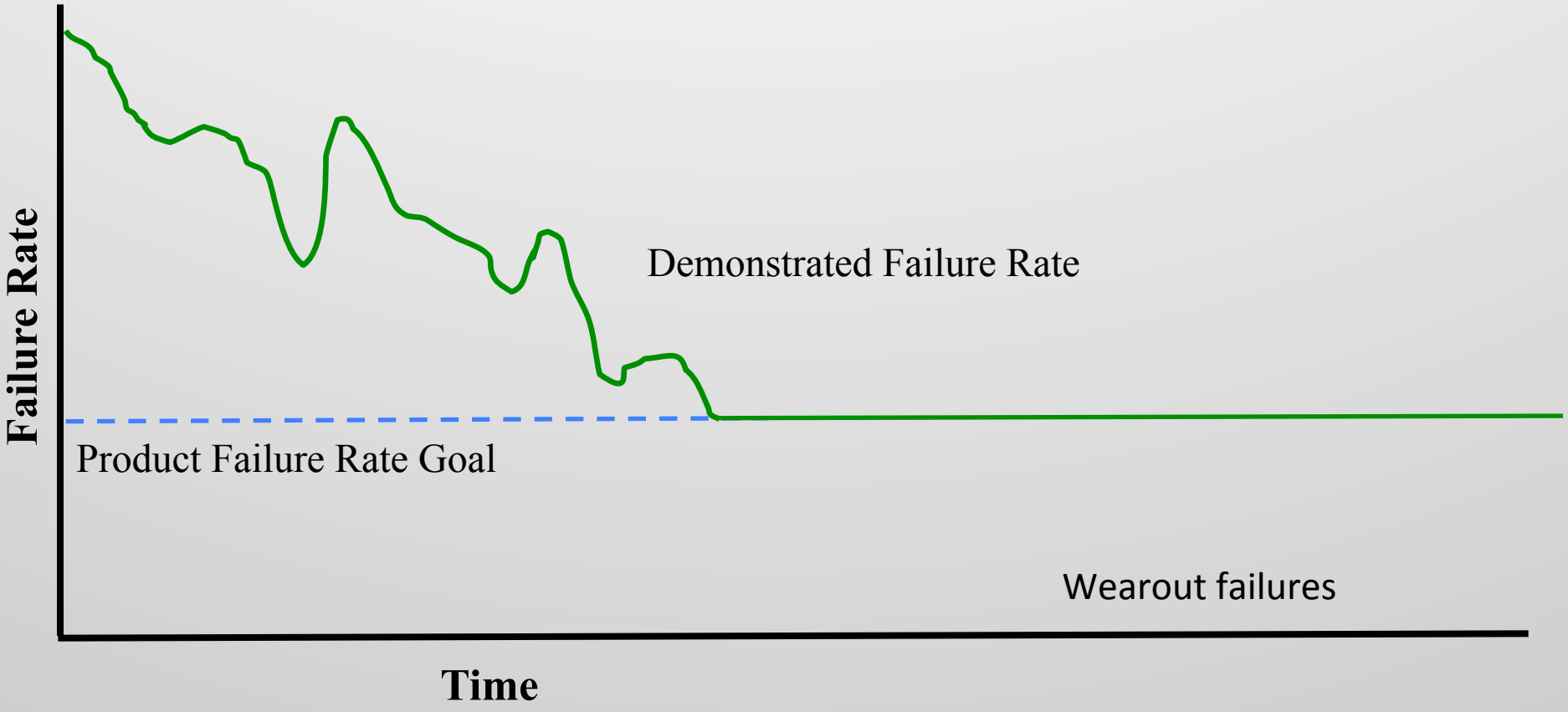
- **HALT yields a high number of failure types in a short time period**

- **This offers the opportunity to begin to investigate and classify failure types far in advance of their discovery in other test methods**

When doing a root cause analysis for any type of test the most important distinction is it a wear-out failure or stress failure?

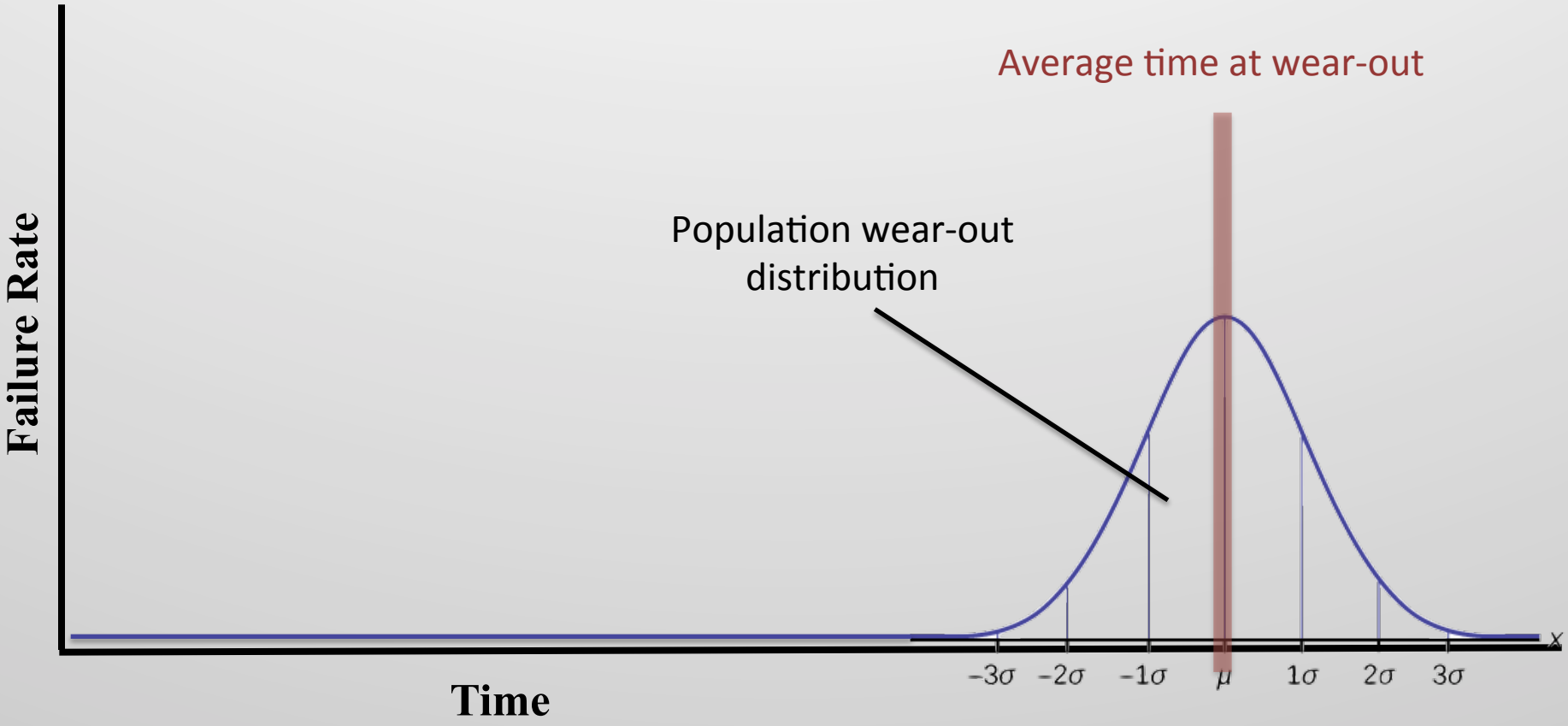
Root Cause Analysis & HALT

- **In a Reliability Growth program it is critical that only stress related failures are included in demonstrating the failure rate**



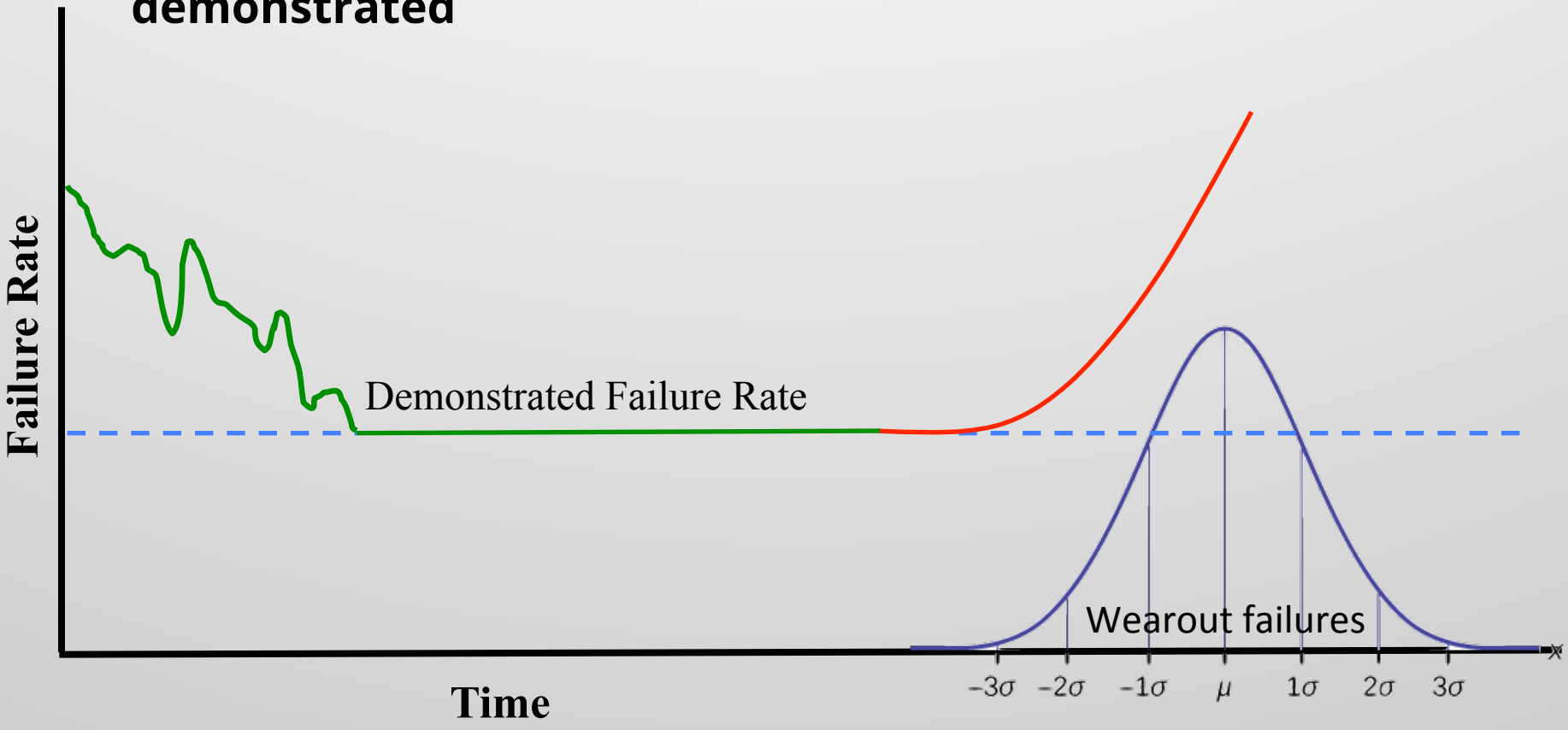
Root Cause Analysis & HALT

- **Wearout failures are grouped into normal distributions and dictate when the product should be removed from the population so it's "old age" doesn't pull down field performance**



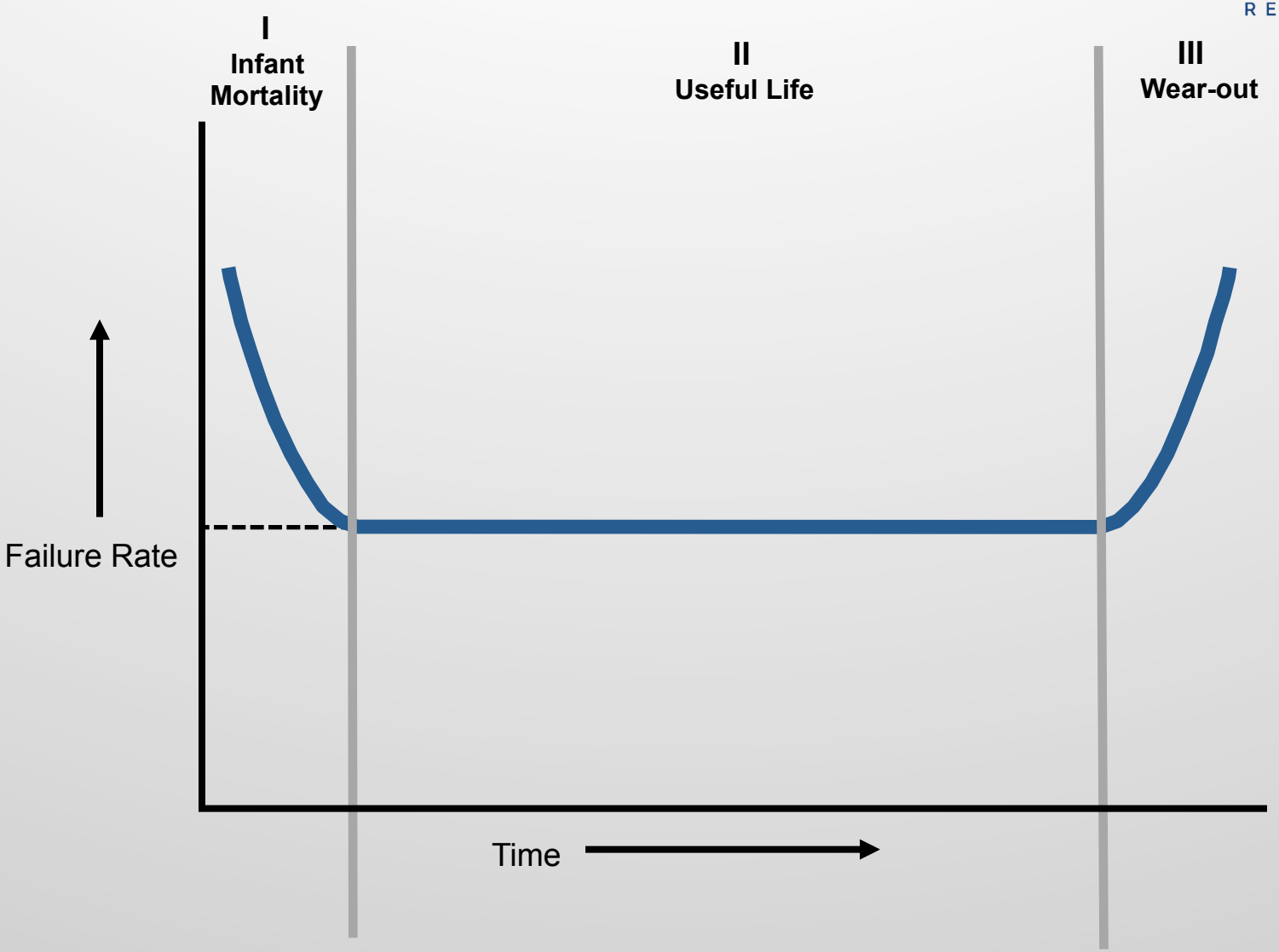
Root Cause Analysis & HALT

- If wear-out failures can't be distinguished from stress failures the demonstrated product failure rate in an RG program will be artificially low and the goal can not be demonstrated



Improving the Bathtub Curve

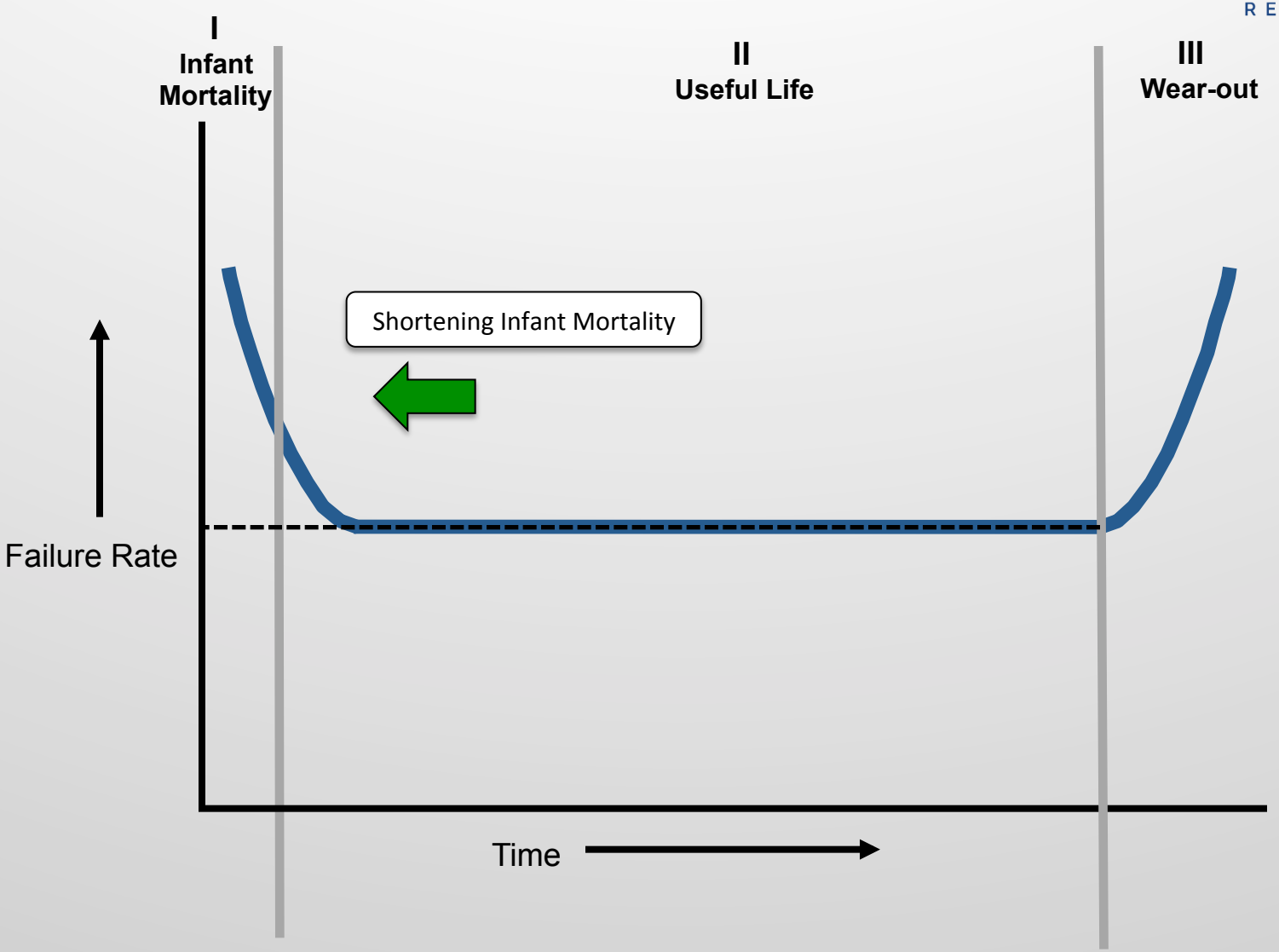
APEX RIDGE
RELIABILITY



Adam Bahret

Improving the Bathtub Curve

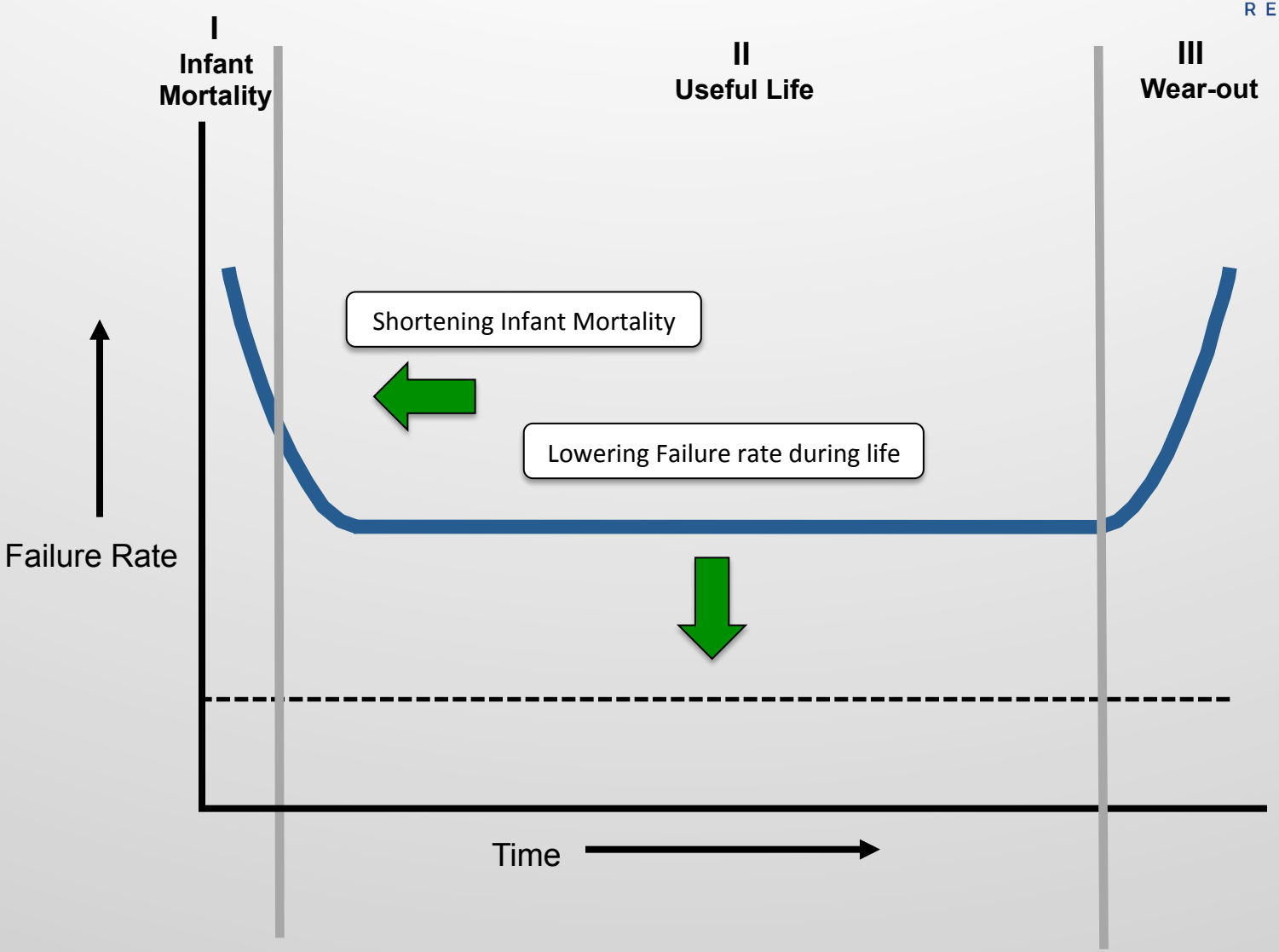
APEX RIDGE RELIABILITY



Adam Bahret

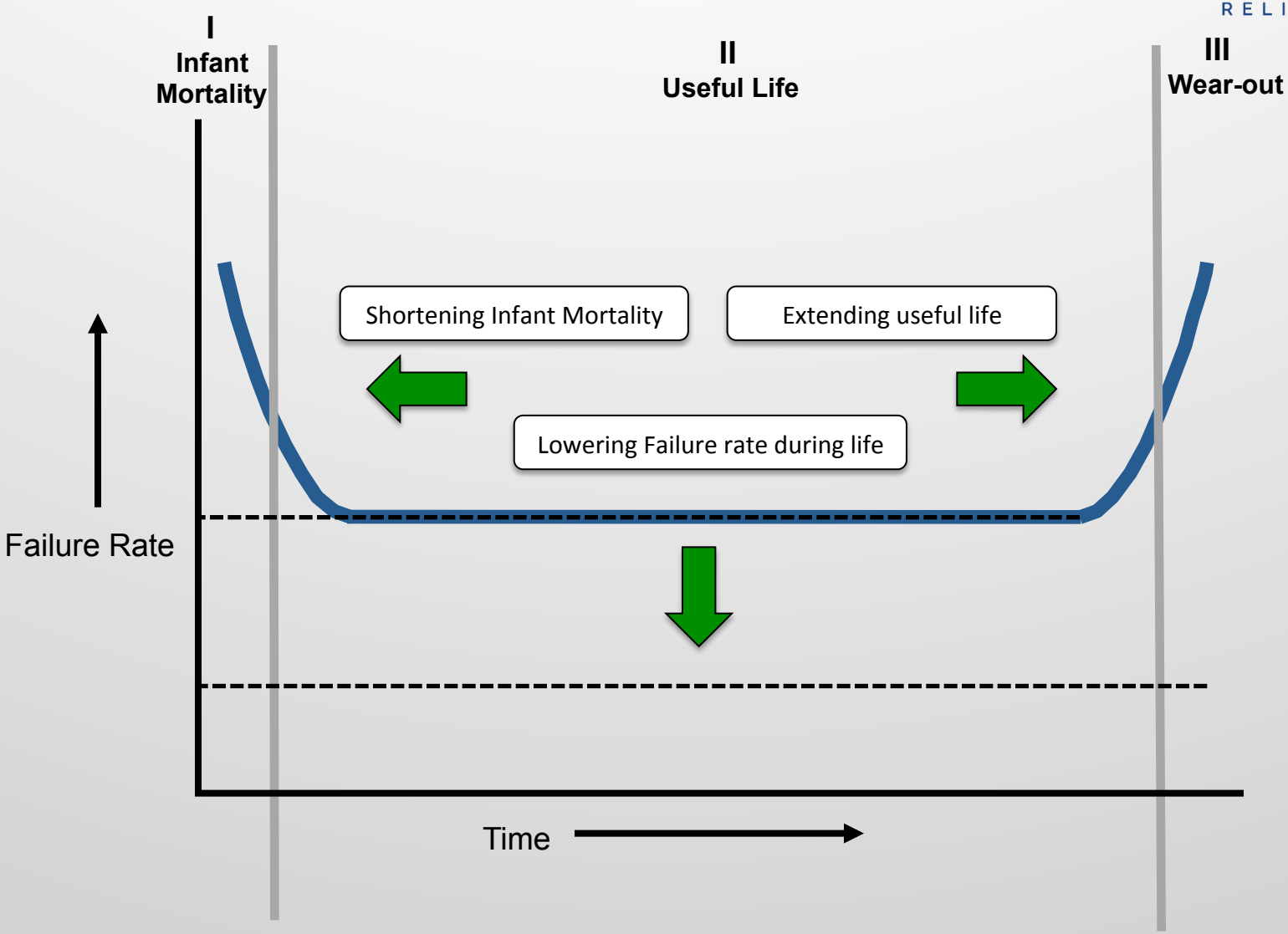
Improving the Bathtub Curve

APEX RIDGE
RELIABILITY



Improving the Bathtub Curve

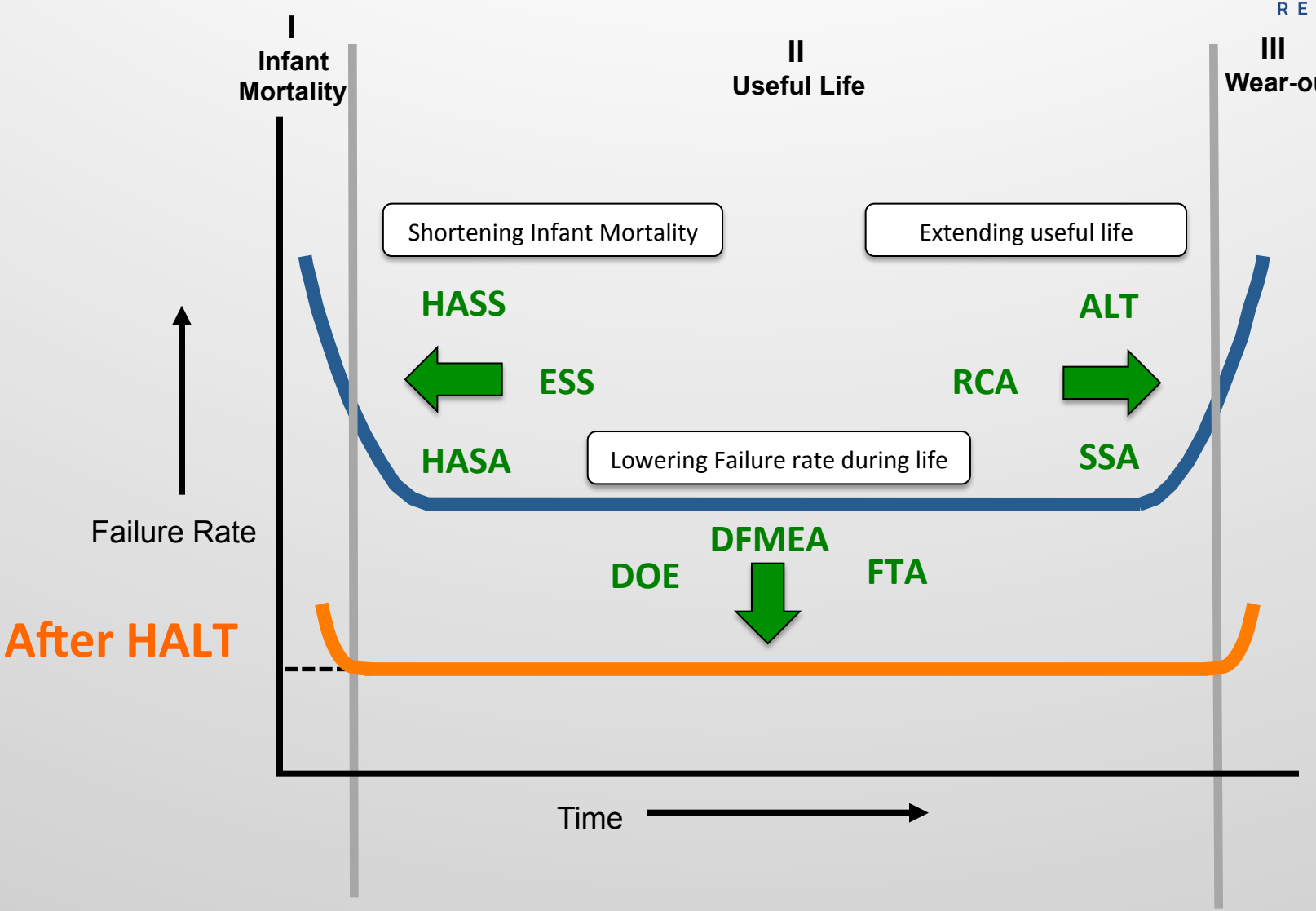
APEX RIDGE RELIABILITY



Adam Bahret

Bathtub Curve After HALT

APEX RIDGE RELIABILITY



Adam Bahret

APEX RIDGE
RELIABILITY

Thank You

Questions?