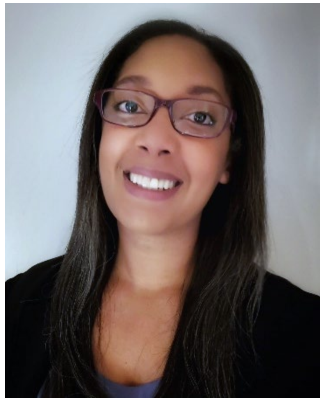
Reliability of large scale power delivery systems for Maritime Applications

Crystal Yannarella

L3Harris

Personal Overview



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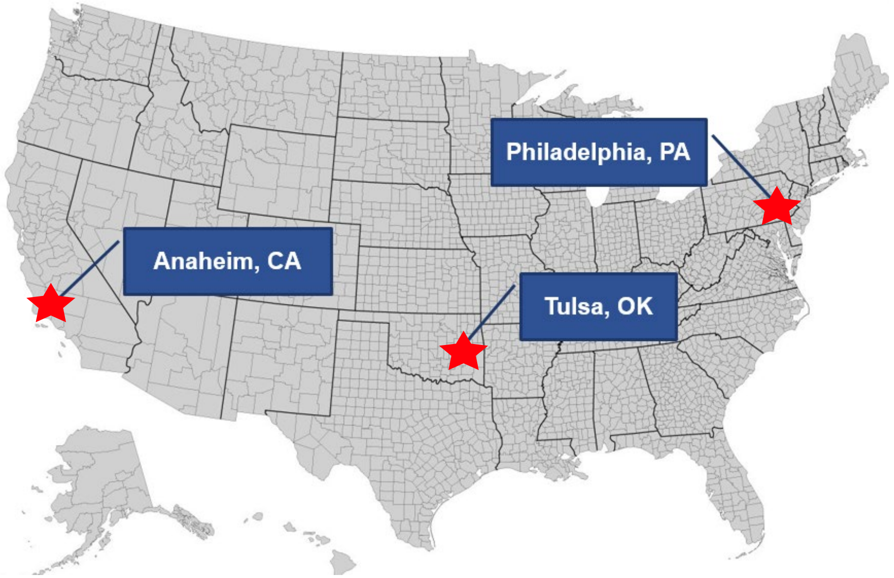
AT L3HARRIS WE ANTICIPATE AND MITIGATE RISK WITH END-TO-END SOLUTIONS THAT MEET OUR CUSTOMERS' MISSION-CRITICAL NEEDS ACROSS AIR, LAND, SEA, SPACE AND CYBER DOMAINS.

Every day we design and build systems that safeguard our world.



Biography:

- Crystal Yannarella is a Lead Project engineer at L3Harris Maritime Power Systems division.
- She possesses practical experience in all aspects of product design, development, system integration, test, and sustaining, as well as root cause/failure analysis, spanning the entire product development lifecycle for innovative complex systems.

  Crystal has successfully built a diverse technical network through her involvement with a variety of engagement activities with opportunities ranging from Employee Retention, Woman's Technology Conference, and college/job fair recruiting.

  When not working she enjoys time with her family and overly complex DIY projects at home.

Objective

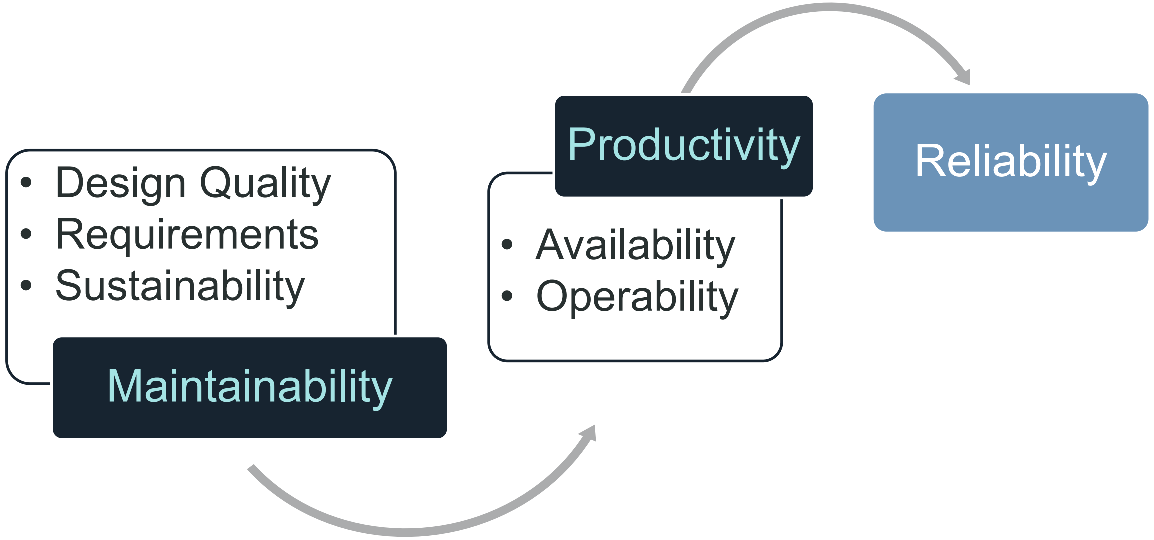
In today's presentation I will touch upon three major areas that contribute to some of the Maritime industry's problems and challenges that plague large scale power delivery system reliability.

The areas that affect system uptime reliability consist of:

- ***Environmental conditions*** like moisture, corrosion, confined space limitations and how these conditions can affect the lifetime reliability of the system
- ***Thermal maintenance, design*** and the relationship with fault detection in prolonging system health and longevity.
- ***Operational optimization*** and self-contained modular programmable construction and their role in decreasing field maintenance time.

Reliability
What does it mean?

System reliability: Is the conclusive probability that an entire system will execute the intended function, absent of any and all failures in any given environment under any conditions for the specified duration.



Reliability

Of large scale power delivery systems in the Maritime industry

Why is reliability a major issue for the Maritime industry?

- Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREG’s) is the International Maritime “Rules of the Road”
  - They govern the requirements for naval vessel operations and interactions (there are no “roads” at sea)
- Key Rules
  - Propulsion is of primary importance because, even at rest, the sea current (or the “road” beneath you) is moving and a risk of collision still exists with shore or other vessels
  - Radar is of secondary importance as the primary tool for avoiding collision because of its increased range and accuracy over visual observation
  - Both of these systems require electrical power to operate (i.e. lube oil pumps for the propeller, precisely regulated transformers for the radar)
- Point
  - Maintaining a reliable power supply and distribution system is crucial for safety at sea

Reliability

Of large scale power delivery systems in the Maritime industry

- The Maritime industry is made up of everything that utilizes and or is connected to the sea.
- Playing an impactful roll in everyone’s life either through travel, aid, Military, employment, shipping and receiving of goods or even the groceries that we consume.
- Reliability holds a very different standard when it come to the Maritime Industry!

Maritime Industry is made up of the following:

- Ports
- Passenger Ships
- Naval Ships
- Offshore Ships
- Fishing Boats
- Ecology
- Cargo Ships
- Tanker Ships
- Rescue Ships
- Military Vessels
- Tug Boats

Large scale power delivery systems are used for some of the most critical vessel functions:

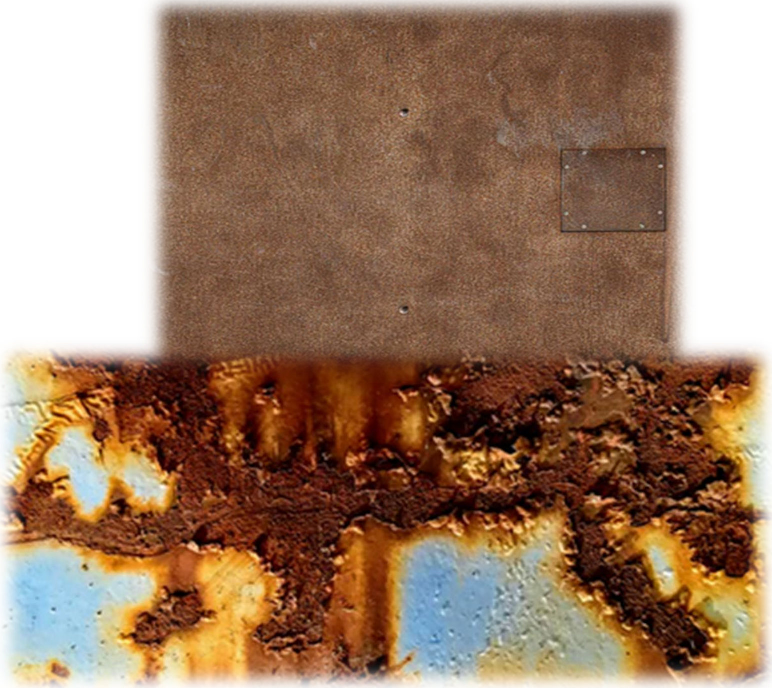
- Engine Propulsion
- Life Support Systems
- Fault Monitoring
- Air Conditioning
- Ballast Systems
- Radar Systems
- Weapons systems
- Medical Equipment

Reliability
Environmental conditions

Moisture can be one of the most destructive and dangerous elements in the Maritime industry, with the addition of high voltage electrical equipment, it highlights the criticality of moisture management to maintain system lifetime reliability.

- An increase in moisture in the air can lead to high humidity causing:
  - Mold
  - Condensation
  - Oxidation
  - Corrosion and rust

- According to Cornet the author of "*Corrosion in Archaeology*" Iron corrodes five times faster in sea water than in soil, and 10 times faster in sea water than in air. Steel is the number one material used in most maritime applications and is composed of 98%> iron. [1]



What does this mean for large scale power delivery systems in the Maritime industry?

Reliability

Environmental conditions

To understand how moisture causing humidity can lead to catastrophic system failures we must look at the power delivery system at the component level.

In the maritime environment, by time an end user sees, mold, rust, oxidation, condensation or corrosion inside of a system module it is often to late and the damage is already done.

- At the component level moisture and humidity damage can cause:
  - Component Swelling / warping
  - Corona
  - Degradation
  - Lifting of PCB lamination
  - Electro migration
  - Corrosion

Component	Humidity Effect
Capacitors, Ceramic	Case cracking
Capacitors, Electrolytic	Decreased insulation resistance increased dielectric breakdown increase in shorts
Capacitors, Tantalum	Decreased insulation resistance increased dielectric breakdown increase in shorts
Transistors	ncreased leakage current; decreased current gain , if sealed not effect
Connectors, standard	shorts fungus; corrosion of contacts lowered insulation resistance
Switches	Contacts arcing
Thermistors	Change in resistance

Effect Of Temperature And Humidity On Electronic Components & Reducing Or Eliminating Ess ; 5.4.4 Effect of Temperature and Humidity on some Ele https://www.tutorialsweb.com/reliability/reliability5.5.htmctronic Components

Without proper management and prevention, moisture can lead to system failures, equipment damage and even loss of life.

Reliability
Environmental conditions

How can this damage be prevented to ensure long-term system reliability ?

- Use of multi layered gaskets
- Waterproof insulation around cable connectors
- Industrial dehumidifiers
- Moisture Inhibitor solution
- Ventilation
- Moisture Sensor
- Maximizing the fatigue reliability with welded attachments
- Alloy composition variations
- Use of oxidized treated aluminum, fiber-reinforced plastic shells
- Shock hardening
- Paint stabilization binders, to reduce peeling
- Sacrificial anodes (Zn)
- Hermetically sealing of critical components

What is the best way to prevent moisture related environmental stress damage and why?

Reliability
Environmental conditions

What is the best way to prevent this moisture related environmental damage?

The best way to prevent moisture damage is to prevent it from even happening.

To do this one must fully understand the requirements of the system and understand the harsh environmental conditions the requirements were derived from.

The most reliable moisture prevention for large scale power delivery systems in the Maritime industry:

- Proper sealed enclosure
- Conformal / Hydrophobic Component sealing
- Fault detection
- Moisture sensors
- HVAC / ventilation/ thermal management
- Custom baffles designed to improve air flow

L3Harris Legacy Isolation Transformer

L3Harris Transformer 3500kVA 4160-460 VAC with AC cooled ventilation

Reliability
Environmental conditions

- Confined space and access limitations on Maritime vessels are a challenge within itself due to the size constraints. These limitations can greatly affect the lifetime reliability of the system.
- Some entry hatches have a diameter of less than 30 inches making equipment maintenance a challenge and leading to the following:
  - – Lack of accessibility
  - – Decreased visibility
  - – Moisture and humidity is increased
  - – Corrosion in enclosed spaces due to oxidation
  - – Maintenance safety risk

- **Solutions to consider:**
  - – Configurable and scalable equipment modules

iOSH Form Confined Space Working in Shipyards Presented by Darin Speed

Reliability

System uptime reliability

- Thermal management is one of the major factors in maintaining high levels of system uptime reliability. Like any electrical system, heat can be detrimental to long term stable system functionality.
- As large scale power delivery systems increase in complexity and functionality while decreasing in size and weight the risk of failures increase due to increased thermal issues.
- Thermal Management starts with the preservation of the components and their packaging.

According to Shavinder Singla, he wrote "*Capacitance of devices made with low-dielectric-constant titanates, such as C0G or NP0, remains practically constant with temperature and shows little change with aging. Capacitance of devices made with high-dielectric-constant titanates, such as X7R, is larger but exhibits wide variations with increase in temperature. In addition, leakage currents become unacceptably high at elevated temperatures, making it difficult for the capacitor to hold a charge.*"[2]

Component	Temperature Effect
Capacitors, Ceramic	Changes in dielectric constant and capacitance, lowered insulation resistance with high temp.
Capacitors, Electrolytic	Increased electrolyte leakage; shortened life, large change in capacitance, increased series resistance with low temp.
Capacitors, Tantalum	Electrolyte leakage; change in capacitance insulation resistance; series resistance
Transistors	Increased leakage current; changes in gain; increases in opens and shorts
Connectors, standard	Flash over, dielectric damage
Switches	Oxidation of contacts
Thermistors	Increased shorts and opens

Effect Of Temperature And Humidity On Electronic Components & Reducing Or Eliminating Ess ; 5.4.4 Effect of Temperature and Humidity on some Ele https://www.tutorialsweb.com/reliability/reliability5.5.htmctronic Components

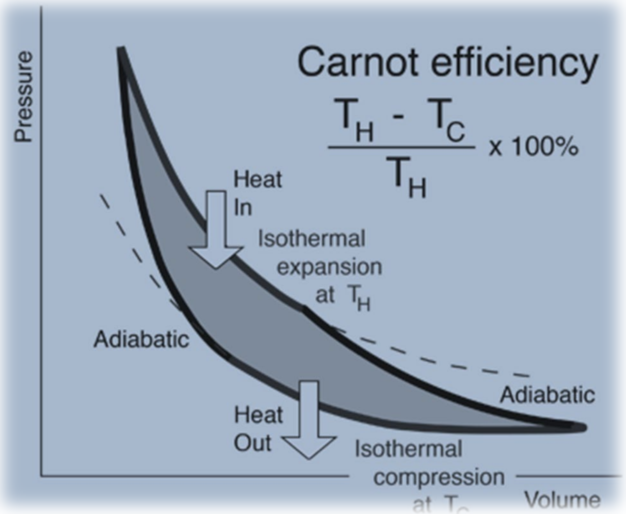
As large scale power delivery and conversion systems run, heat is generated at a higher rate as each component operates. This must be managed. If not, as the internal thermal temperature rises it will cause components to degrade, leading to decreased system uptime and resulting in decreased MTBF.

Reliability

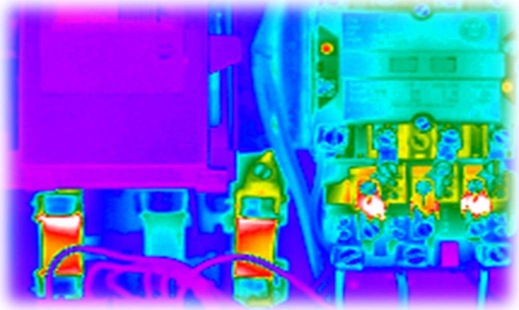
System uptime reliability – Continued

- Preventive measures can be taken to maintain and prolong system health.
- Thermal Management:
  - Software controlled thermal load balancing
  - Electrical thermograph and thermal imaging
  - SiC and GaN Semiconductor
  - Phase change materials (PCMs
  - Heat exchanger
  - Carnot Heat pump

The Carnot cycle is made up of 2 isothermal processes and 2 adiabatic processes, because of this it is considered a perfectly balanced heat engine. Allowing for the highest level of efficiency. [2]



hyperphysics.phy-astr.gsu.edu



Infrared Thermography from The Snell Group

Utilizing the "Reliability of Systems" method by Jaroslav Menčík, Understanding what drives MTTF can be integrated in detil design phases.[9]

$MTTF=\int_0^\infty R(t)dt=\int_0^\infty[\exp(-\lambda_1 t)+\exp(-\lambda_2 t)-\exp[-\lambda_1 t+\lambda_2 t]]\,dt=\lambda_1^{-1}+\lambda_2^{-1}-(\lambda_1+\lambda_2)^{-1}$ [9]

When combined with the strict Maritime Mil-STD, reliability can safely utilize components for extended periods.

With proper thermal management, large scale power delivery system can perform reliably for 30+ Years!

Reliability

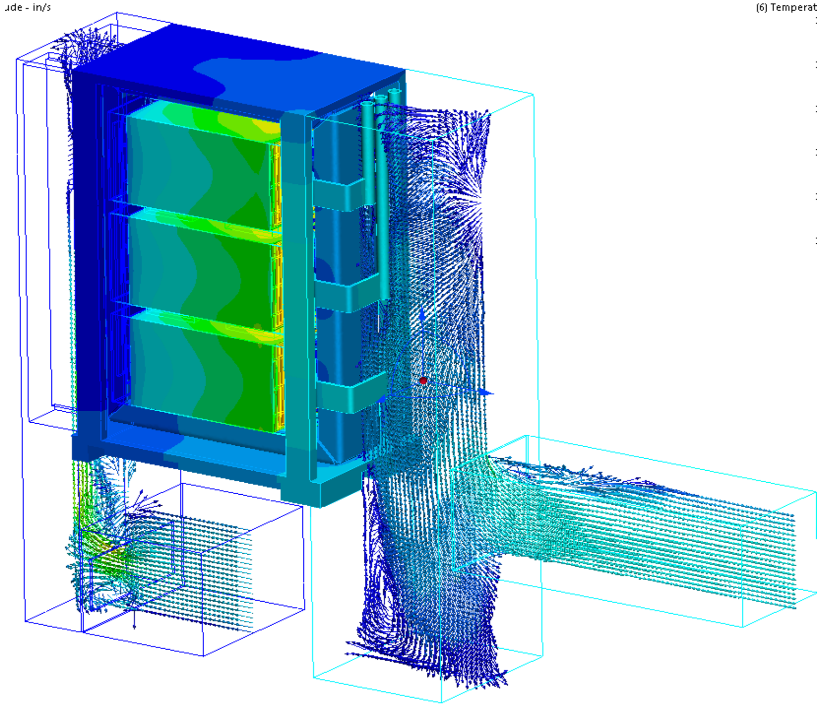
System uptime reliability – Continued

Thermal management is one of the major factors in maintaining high levels of system uptime reliability.

- Cooling Methods – Removes heat away from high power generating components
  - Natural Convection
  - Forced Air
  - Heatsink
  - Cold Plate
  - Heat Pipe
  - Air isolated cold water plates and water cooled conductors
  - Direct cooling – liquid spray
- Fault detection
  - Thermal Fault detection
  - Breaker resistance check
  - Fault clearance verification
  - Voltage out fault
  - Surge Protection
  - Remote Fault detection

L3Harris Fault Isolation Unit
Designed to protect critical 400 Hz power distribution systems by providing a controlled maximum allowable current draw in each individual circuit connected to the distribution system

L3Harris Air-Cooled Frequency Converter



L3Harris cooling model

Reliability
Lifetime

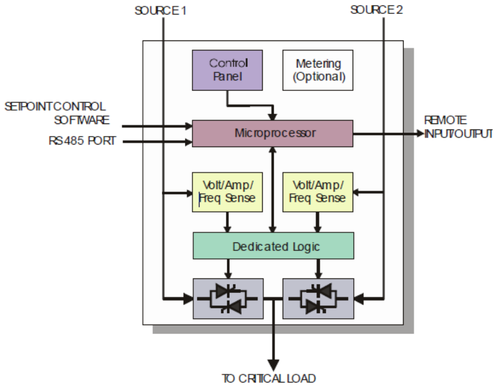
- Self-contained modular programmable construction is one of the most efficient ways to ensure successful maintenance.
- Modular maintenance that can be performed efficiently aids in extending the life time system performance
  - Line Replaceable Unit
  - Silicon-Controlled Rectifier (SCR) based technology
  - Precision digital sense and control circuits
  - Design and maintainability Simplification
  - Reduction of system diversity
  - Embedded software for power conversion algorithms
  - High-level applications interfaced with embedded modules
  - Depot/Repairs (AEGIS Certified) Field Service Training


L3Harris Power Modules - Line Replaceable Unit – Modular Design

Reliability
Lifetime

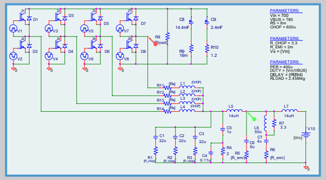
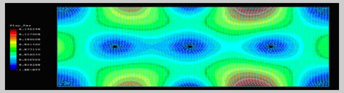
Use of support applications for component and system life prediction

- Utilize extensive engineering simulation and modelling capabilities through automation and support applications
  – Simulate WBG operation with defined inverter models –
  – Aid in Maintenance
- Fault isolation
- Design process/ Defining requirement
- Self—synchronization for parallel operation
- Built-in diagnostic test



L3Harris Precision digital sense and control circuits

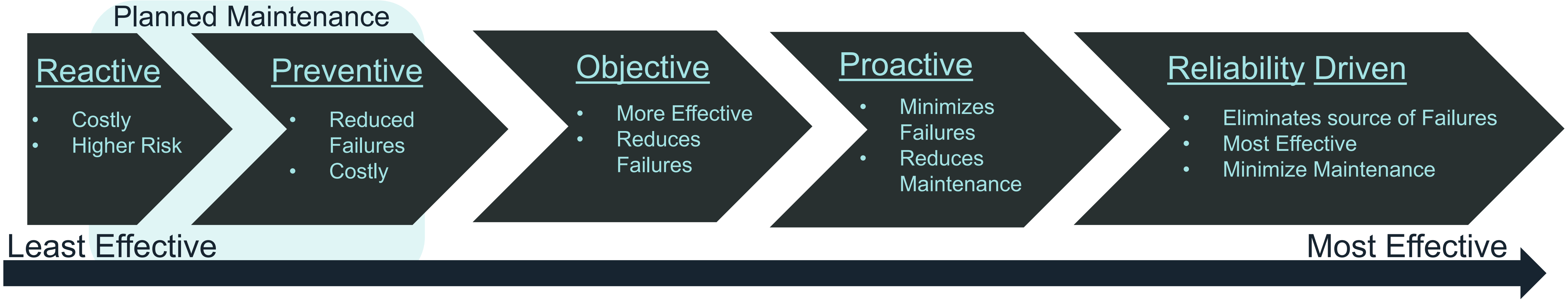
Support Applications

PCB Design	Power, Electrical and Digital, Controls Analysis Tools	Mechanical Analysis Tools	Software Coding, Verification and tracking	Requirement Capture and Analysis
• Cadence Capture CIS / CIP • Mentor Graphics Valor DfM / DfA • PCB Library Expert • Cadence Allegro 	• ORCAD PSpice Circuit and Analysis • Matlab / Simulink Controls Analysis – Mathworks • Simplorer Circuit Analysis • FPGA Firmware and VHDL Coding • Speedgoat - Control Prototyping	• 3D Computer Aided Design (CAD) – Autodesk Inventor • Structural / Dynamic Finite Elemental Analysis (FEA) – Ansys Mechanical • Computational Fluid Dynamics (CFD) Analysis – Autodesk 	• GSA Software • WindRiver • Rational Team Concert • Code Warrior • Visual Studio • Atlassian JIRA Software • Atlassian Bitbucket	• IBM Rational DOORS • Atlassian Jira Align • Atlassian Confluence • Jama Software

Reliability

Lifetime - Continued

- The lifetime reliability of the Maritime industry's large scale power delivery systems is directly related to design quality, requirements and the sustainability that forms efficient optimized life-cycle maintenance.
- Operational optimization's main goal is to ensure failure mitigation is reliability driven, by caring out operations in the most effective and efficient way possible.
- Component longevity methodologies are used to support life-cycle management and operational and optimization decisions.
- Numerical modeling and simulation coupled with experimentation to predict damage while meeting a variety of critical Military Standards (MIL-STD)



Closing Comments
Where does leave us

Maritime reliability is not to be taken lightly, with it comes a significant responsibility.

- In the Maritime Industry High Power Electrical conversion and distribution equipment contains many devices that are extremely sensitive to environmental conditions. In taking the time to understand these the environmental effects at the system, module and component level, we are able to interject improvements, solutions and lessons learned at the detailed design phase. This opening the gate for early stage rapid prototyping to increase the reliability of the equipment and overall system performance.
- While making smart material decisions that will aid system longevity.
- While increasing MTBF and longevity, decreasing failures all while driving down maintenance costs.
- The focus should remain on the development of reliability based applications and materials to support and enhance system performance, resilience, sustainability and maintainability throughout the system lifetime.

Questions?

Reference

[1] Cornet, J. 1970. Corrosion in Archaeology. In Scientific Methods in Medieval Archaeology, edited by R. Berger, pp. 437-454. University of California Press, Berkeley.

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[9] Jaroslav Menčík (April 13th 2016). Reliability of Systems, Concise Reliability for Engineers, Jaroslav Mencik, IntechOpen, DOI: 10.5772/62358. Available from: https://www.intechopen.com/books/concise-reliability-for-engineers/reliability-of-systems