30th Annual **INCOSE**
international symposium

Virtual Event
July 20 - 22, 2020

Issue Investigation and Engineering Change on Legacy Products

What’s the Problem?

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Charlotte Natalie Dunford graduated with an Engineering Doctorate in Systems from the University of Bristol in 2016 and received a Bachelor of Applied Science in Mechanical Engineering from the University of British Columbia in 2003. Her doctorate was funded by the Engineering and Physical Research Council and Rolls-Royce plc. She works as a Project Systems Engineer at Rolls-Royce plc. Previously, she worked as a Research Engineer in the Space and Atmospheric Physics Group at Imperial College London. She is a Chartered Engineer and Member of the Institution of Mechanical Engineers and the International Council on Systems Engineering.

Andrew Pickard joined Rolls-Royce in 1977 after completing a Ph.D. at Cambridge University in Fatigue and Fracture of Metals and Alloys. He is a Rolls-Royce Associate Fellow in System Engineering, a Fellow of SAE International, a Fellow of the Institute of Materials, Minerals and Mining, a Chartered Engineer and a member of INCOSE. He is immediate past Chair of the SAE Aerospace Council, represents Rolls-Royce on the INCOSE Corporate Advisory Board and is Chief of Staff for INCOSE.

Contents

What’s the Problem?

- No established generic best practice for legacy products. Through working on many legacy tasks we have established one in Rolls-Royce Defence
- Common issues
    1. Poor Communication
    2. Finding Information
    3. Requirements Structure
    4. Narrow scope
    5. Solution-driven approaches
- Note the nature of Rolls-Royce products requires rigorous systems engineering so our approach may be more than you need for your products

Case Study 1 – The Component

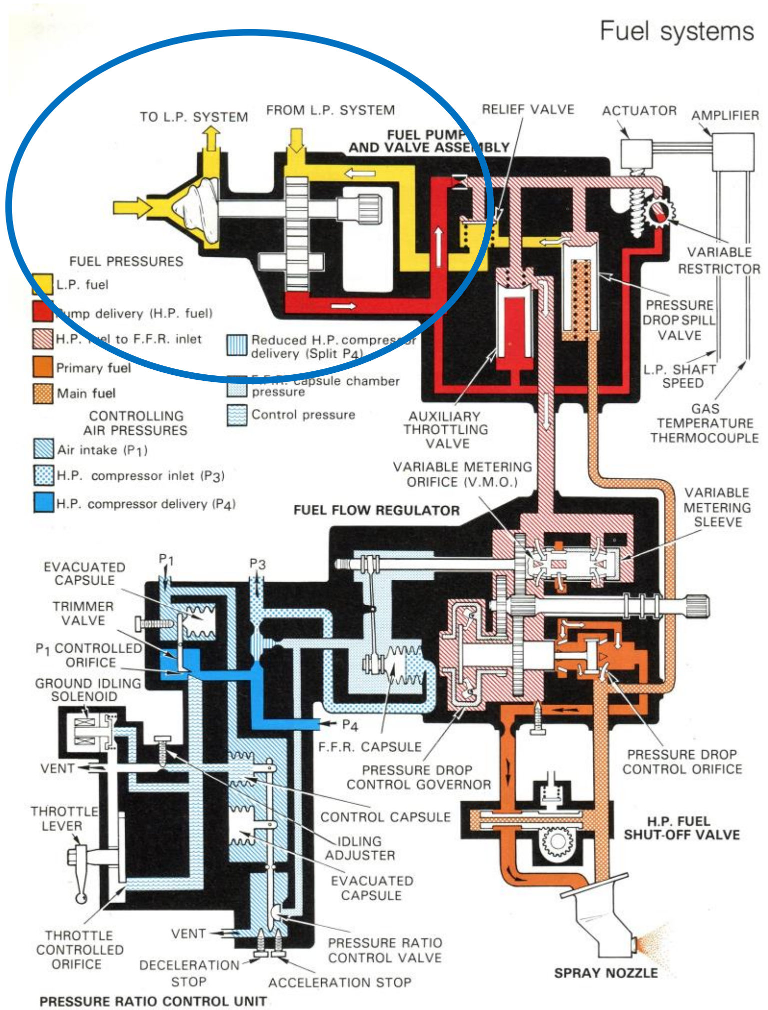


Fig. 10-12 A pressure ratio control system.

Fuel Pump and Metering Unit

- Illustrative only – from “The Jet Engine” (Rolls-Royce)
- Concentrate on the LP and HP Fuel Pumps

Small change to increase fuel pumping capacity

- Increased width of gear teeth in HP Fuel Pump

HP Pump failed low temperature running qualification test

- Multiple destructive failures on test
- Elastomeric seals that act as springs to locate the gears
- No change to this feature from the original design

Previous design had passed the low temperature running qualification test

- What had changed?

Case Study 1 – The System

Fuel systems

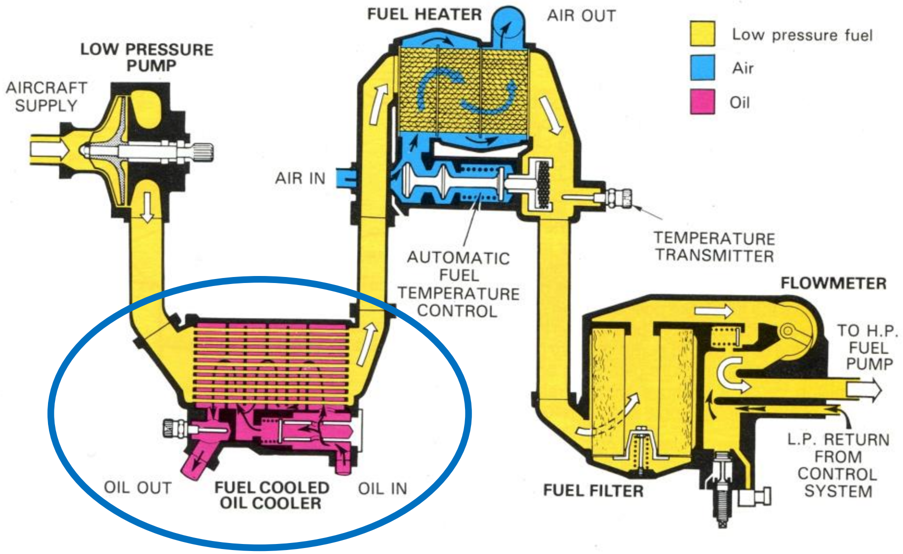
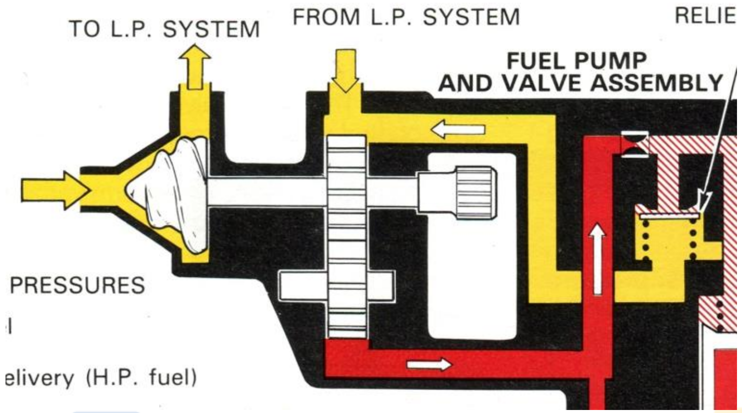


Fig. 10-13 **A low pressure system.**



LP Fuel Pump system

- Illustrative only – from "The Jet Engine" (Rolls-Royce)
- Fuel from the LP Pump goes through the Fuel Cooled Oil Cooler before transfer to the HP Fuel Pump

Operating Manual Instruction

- "Run at Ground Idle conditions until the Oil has come up to Temperature", at which point the Pilot can run at full power

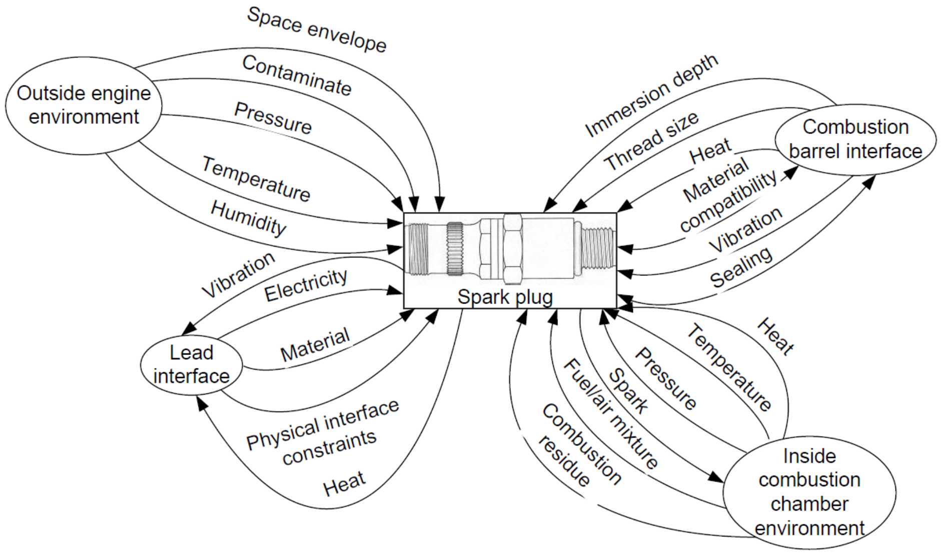
Fuel Temperature at the inlet to the HP Fuel Pump:

- Significantly warmer than that specified in the low temperature running qualification test

Rerun of the low temperature running qualification test

- The unit passed the test with the higher fuel temperature of the fuel at the HP Fuel Pump inlet

Case Study 2 – solution to requirement



Situation

- Obsolete but working plug
- Specification over 50 years old
- Limited budget as historic engine

Approach

- Develop functional understanding by analysing physical interface of plug to develop context diagram.
- Context diagram cross referenced with historic specification and current best practice and regulations.
- Obsolete but working plug part of requirements set. Back to back testing and functional performance results required as part of RFQ to supplier to complete requirements set.
- New requirements set defined and stored according to current best practice.

Case Study 3 – The Non-Problem

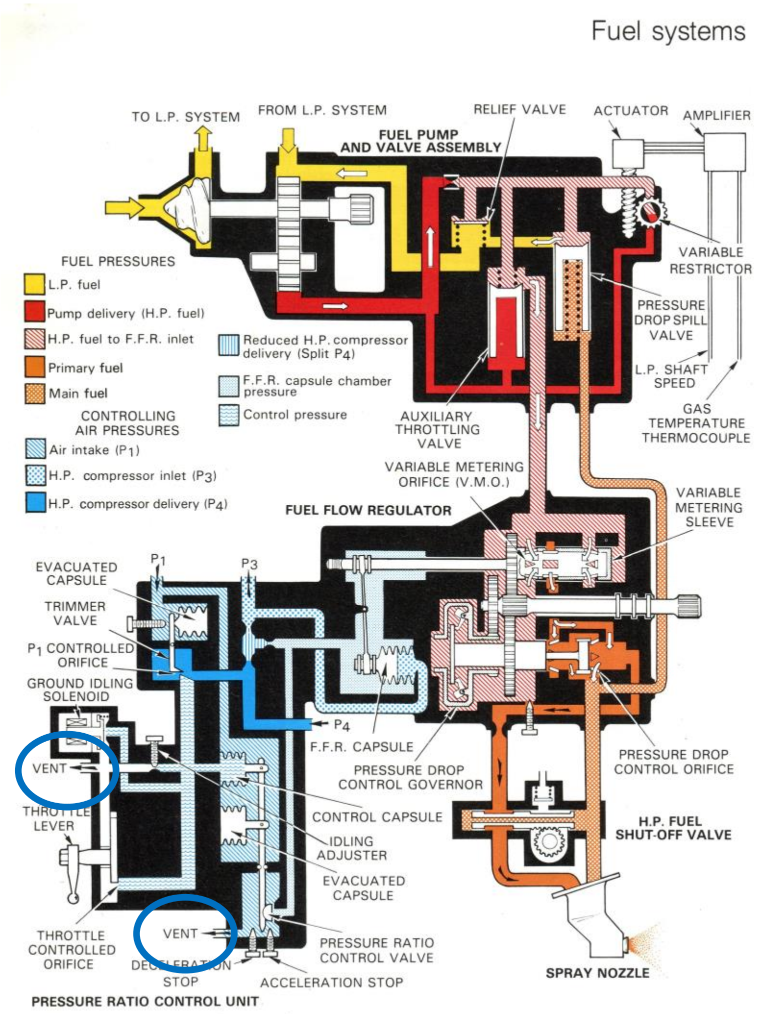


Fig. 10-12 A pressure ratio control system.

Fuel Pump and Metering Unit

- Illustrative only – from “The Jet Engine” (Rolls-Royce)
- Concentrate on the Fuel Vents

Vent valves can get stuck open

- How much fuel can spill through the vent?
- Not defined in the requirements for the engine

Discussion with the Customer

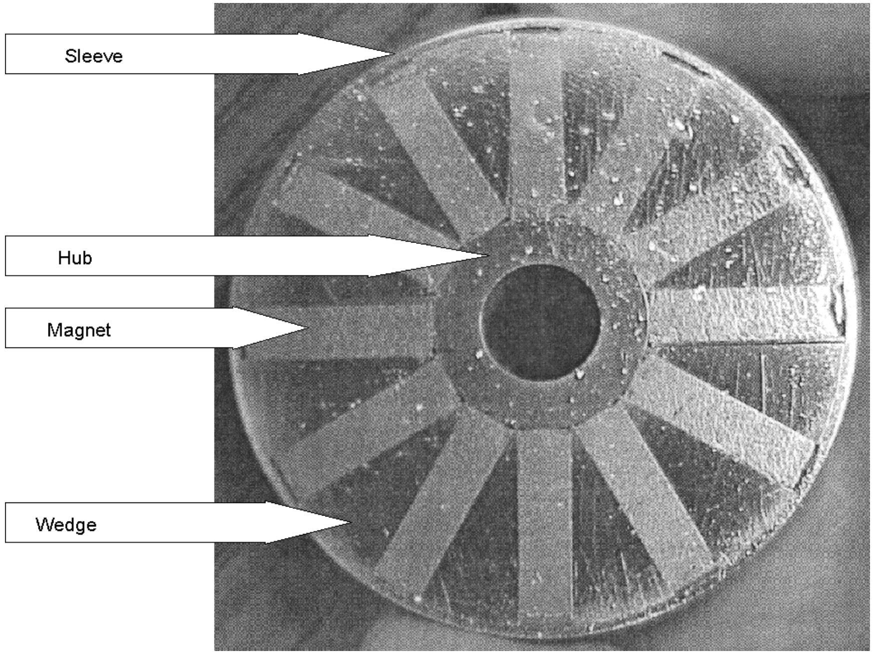
- Immediate reaction was “None”
- Not realistic as there are valid reasons for having vent valves

Maintenance Manual sets a limit on the amount of time that fuel can flow through the vent valve when the engine is started

- If time is exceeded, maintenance action is taken on the vent valve
- Quantity based on flow rate and time was acceptable

No design change required!

Case Study 4 – An In-Service Issue



Permanent Magnet Alternator

- Generates electrical power to supply the engine control system when the engine is running
- Construction includes a sleeve that is heat-shrunk around the assembly

Several failures occurred in service (in quick succession)

- Rotation of the magnet/wedge assembly due to loss of interference fit of the sleeve
- Partial or complete failure of the sleeve

Unauthorized change in sleeve heat treatment

- Reduced the yield strength of the sleeve material
- Not enough to explain the failures, though

Supplier visit revealed other issues that explained the failures

- Over-speed test on every unit (never revealed any issues!)
- Trimming of magnet strength created “unclamped” zone

Heat treatment restored and over-speed test eliminated

Verifying the Changed Systems

Case Study 1:

- The unit passed the Ground Survival cold soak test with the revised fuel inlet temperature based on the System model This verified the acceptability of the design.
- Subsequently in service there have been no issues related to cold soak temperatures in over 20 years of fleet operation

Case Study 2:

- Back to back testing of a new part against obsolete but acceptable part can be a cost effective and technically acceptable way to verify acceptability of a new part

Case Study 3:

- A better understanding of the requirement showed that the existing system was acceptable. Hence there was no need for verification because there was no change to the system. This understanding and agreement of the requirement was validated with the customer.

Case Study 4:

- Analysis showed that elimination of the over-speed pass-off test, combined with restoration of the heat treatment conditions for the sleeve and configuring the trimming of magnetic properties to minimize impact on sleeve interference fit, resulted in an acceptable design with no change to the external fit, form or function of the Permanent Magnet Alternator rotor. There have been no failures of the new standard of permanent magnet alternator rotor in over 15 years of fleet operation.

Enabling Better Systems Engineering

- Participative approach: make sure everyone has a common understanding of the problem or opportunity and the objectives. Review the project charter together. This helps ensure appropriate stakeholder communication.
- Accessible Language: Use language all skill sets/stakeholders can understand. Be careful with acronyms.
- Understand Root Cause: Do a proper root cause analysis, don’t skimp on it. This helps set the correct scope.
- Tailoring: Choose the appropriate tools based on the scope of the task.
- Hand-holding: Guidance on generic design activities, techniques and tailoring complemented by SME coaching – Boundary Diagram, Context Diagram examples.
- Knowledge Management: Document the change appropriately. Make it easier to find the information next time.

Applying SE to Legacy Products

Legacy Program Design Changes - Process Map

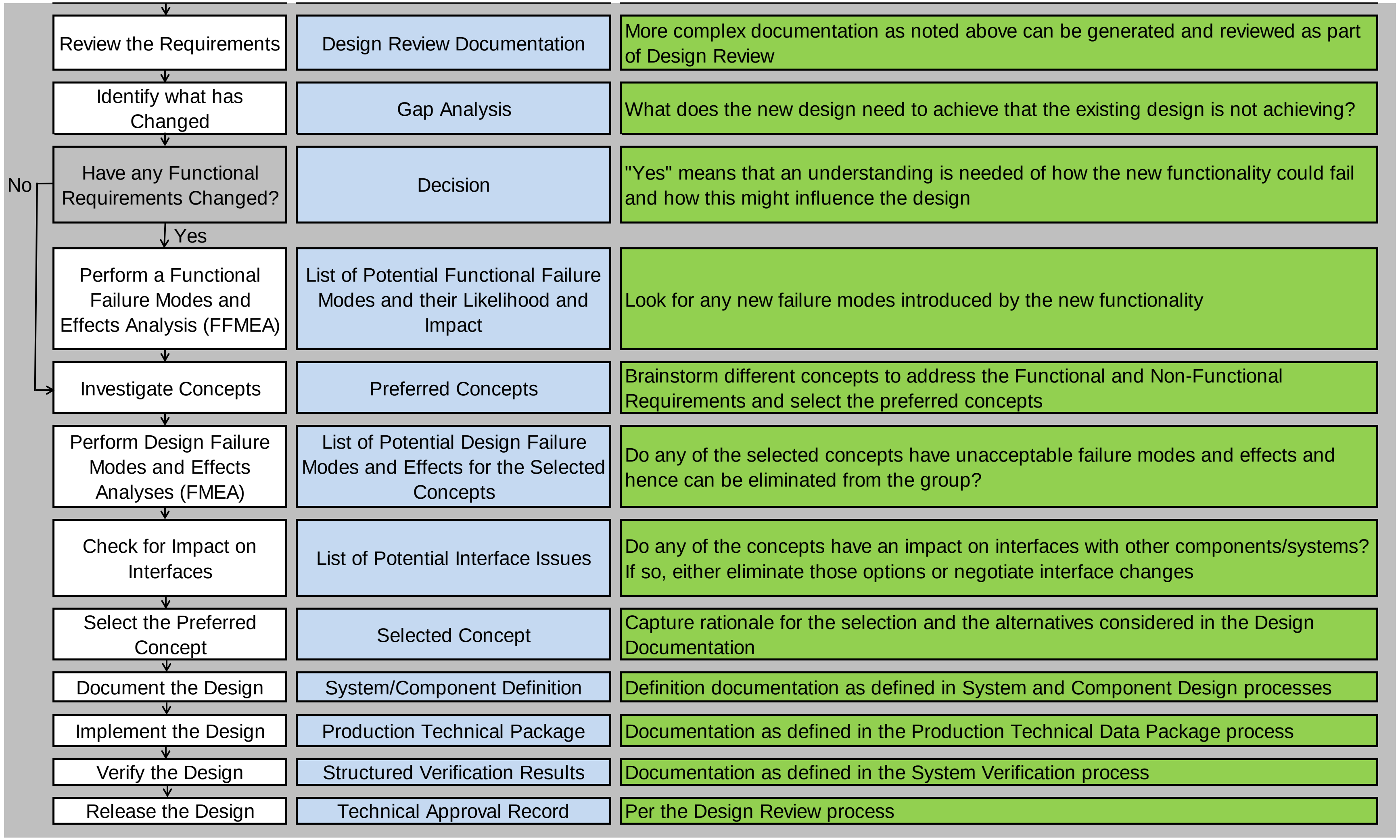
Process	Output	Notes
Understand the Task	Preliminary Problem Definition	What have you been asked to do?
Identify Stakeholders	List of Stakeholders and Roles	Who could be impacted by the design change?
	Stakeholder Map	Who are the stakeholder groups and when is their input needed?
	Stakeholder Influence Map	Which stakeholders need to be represented in the Integrated Product Team?
Define the Problem	Problem Statement	Do the stakeholders have a common understanding of why a design change is needed?
Is the Proposed Design Change to Address a Shortfall?	Decision	"No" means that the existing design is fit for purpose (meets the current needs) but that an improvement has been proposed (e.g. cost reduction). "Yes" means that the current design has a shortfall relative to expectations and a root cause analysis is required to understand why.
Do a Root Cause Analysis	Root Cause Identification	Why does the current design have a shortfall relative to expectations?
Identify Interfaces	Boundary Diagram	What other systems/components does the part interface with?
	Context Diagram	What is the relationship between this part and the other parts?
Identify the Functions	Tree Diagram	What does the component need to do to meet the design need?
Document the Functional Requirements	Functional Requirements	Research existing requirements (old Design Review Records, Specs, Drawings)
	Partially completed Requirements template	Start capturing requirements. Use the xRD template if the requirements list is long or complicated
Identify the Non-Functional Requirements	List of Non-Functional requirements	How well are the functions to be performed (performance requirements)? What other attributes (non-functional system requirements) need to be captured and recorded (e.g. weight, cost, etc)?
Document the Non-Functional Requirements	Non-Functional Requirements	See the Practitioner Awareness Guide on Requirements Management
	Partially completed Requirements template	Start capturing requirements. Use the xRD template if the requirements list is long or complicated
	Use Case Diagrams	Use when the requirements are complicated and include many use cases
	Completed Requirements template	Use the xRD template if the requirements list is long or complicated

There is likely to be iteration here

Key step for Emergent Changes

See Beasley et al (2015) for the xRD Template

Applying SE to Legacy Products



Review the Requirements	Design Review Documentation	More complex documentation as noted above can be generated and reviewed as part of Design Review
Identify what has Changed	Gap Analysis	What does the new design need to achieve that the existing design is not achieving?
Have any Functional Requirements Changed?	Decision	"Yes" means that an understanding is needed of how the new functionality could fail and how this might influence the design
Perform a Functional Failure Modes and Effects Analysis (FFMEA)	List of Potential Functional Failure Modes and their Likelihood and Impact	Look for any new failure modes introduced by the new functionality
Investigate Concepts	Preferred Concepts	Brainstorm different concepts to address the Functional and Non-Functional Requirements and select the preferred concepts
Perform Design Failure Modes and Effects Analyses (FMEA)	List of Potential Design Failure Modes and Effects for the Selected Concepts	Do any of the selected concepts have unacceptable failure modes and effects and hence can be eliminated from the group?
Check for Impact on Interfaces	List of Potential Interface Issues	Do any of the concepts have an impact on interfaces with other components/systems? If so, either eliminate those options or negotiate interface changes
Select the Preferred Concept	Selected Concept	Capture rationale for the selection and the alternatives considered in the Design Documentation
Document the Design	System/Component Definition	Definition documentation as defined in System and Component Design processes
Implement the Design	Production Technical Package	Documentation as defined in the Production Technical Data Package process
Verify the Design	Structured Verification Results	Documentation as defined in the System Verification process
Release the Design	Technical Approval Record	Per the Design Review process

Key step for Emergent Changes

Conclusions

- Develop a common understanding among the stakeholders of the problem (or opportunity) to be addressed – Case Study 3
- For emergent changes, do a thorough root cause analysis to understand the true problem – Case Study 4
- Don’t “rush to solution” – you may be wasting money – Case Study 3
- Don’t underestimate the scope of a change – think “System”, not “Component” and think of all of the system artefacts that may be impacted – Case Study 1
- Manage changes to interfaces – these are often poorly controlled – Case Study 1
- Be especially careful where the change involves a change in functionality – explore the potential new failure modes and effects introduced. Be wary of functional changes that change just one component – think System - Case Study 1
- Plan how you will verify the changed system when you are establishing the requirements – pull in the verification team to review the requirements before developing concept solutions - Case Study 2

What is your experience of legacy changes?

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