Reliability & Risk Division
ASQ Excellence Through Quality™

Risk Management for UPS Systems (Uninterruptible Power Supply) used in Server Farm Infrastructure

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Electra Energy Group

Introduction

Uninterruptible Power Systems (UPS) are key feature of the Risk Management systems for Data Centers that ensure reliable power. No loss of data is a requirement.

A critical failing of these UPS systems are the poor reliability of the batteries and thus batteries are a critical element in Risk Management.

Current State

Reliability is achieved through **Redundancy** by buying 1.5 times more batteries.

Manufacturers commonly have a 30% scrap rate

→

Future State

Reliability is achieved through **Better Batteries**

Result of better design and development practices, as well as improved processes and inspection

Data Center UPS

Utility Grid → ATS & Distribution Panel ← Generator

ATS & Distribution Panel → Energy Storage → Power Distribution Unit → Load

Why are batteries important in Cloud Data Centers?

- Tier 4 Data centers (highest reliability) are powered and cooled by utility power with diesel generators as back-up

- Generators take time to spool up

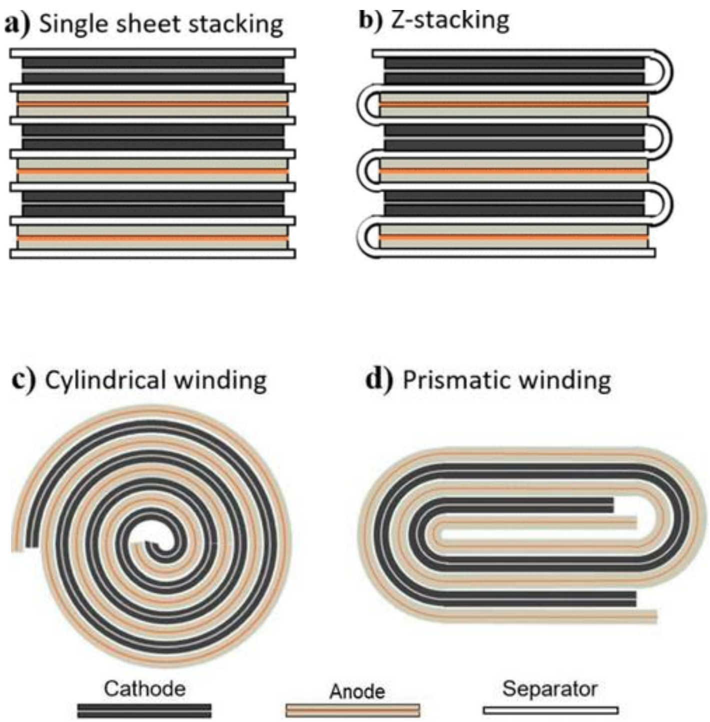
- UPS (Uninterruptible Power Supply) batteries bridge the 30-90 second gap generators require to come online

Types of UPS Batteries

There are several types of UPS batteries:

- Valve Regulated Lead Acid (VRLA)
- Flooded Cell or VLA batteries
- Lithium-Ion batteries
- Sodium Ion

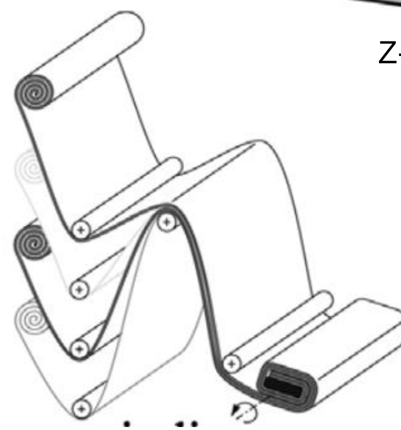
Electrode Arrangements and Assembly



Electrode Arrangements

Stacked

Z-Folded



Prismatic
and Cylindrical

Electrode Assembly

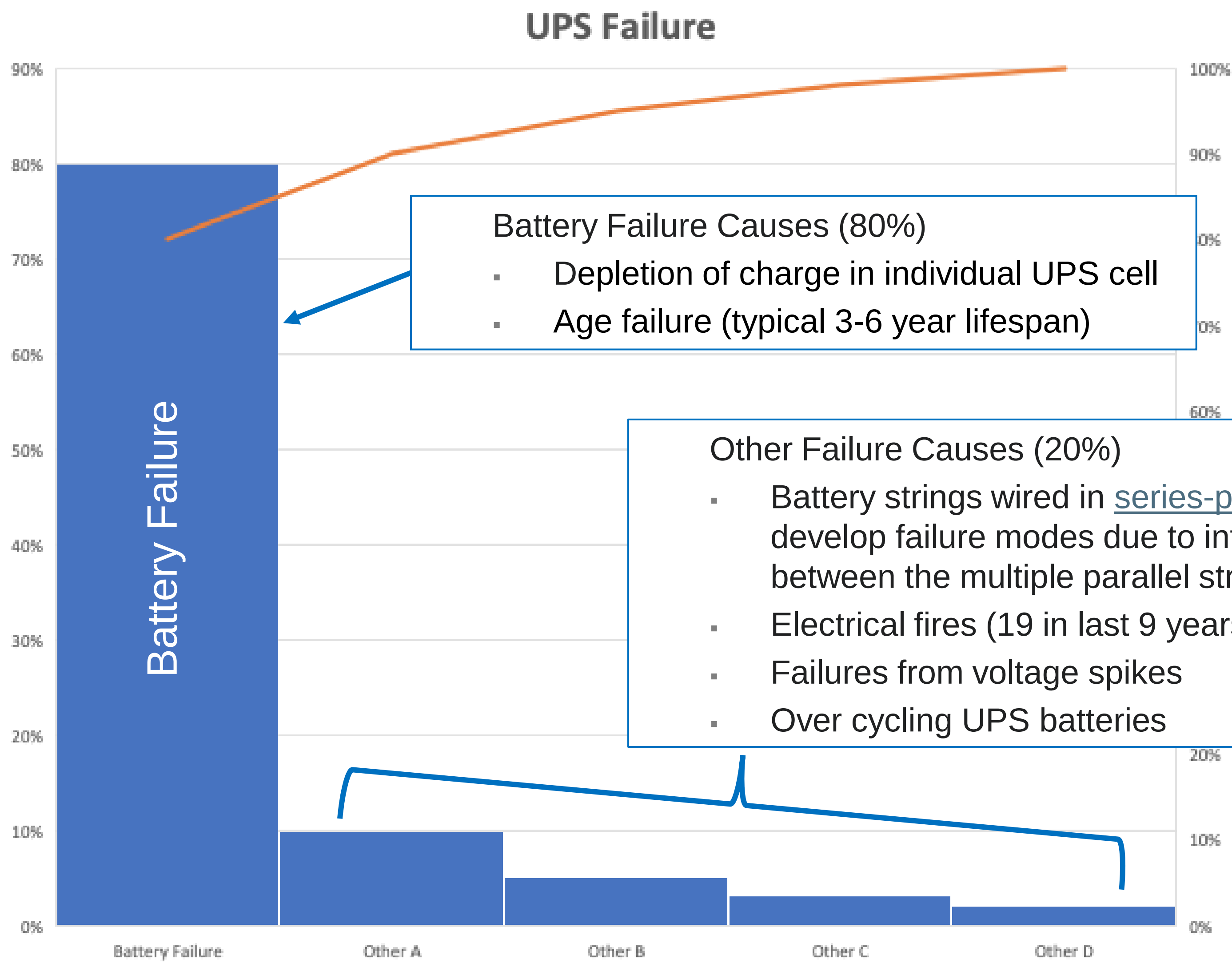
Ref: From Materials to Cell: State-of-the-Art and Prospective Technologies for Lithium-Ion Battery Electrode Processing
Jianlin Li*****, et.al. *Chem. Rev.* 2022, 122, 1, 903–956 October 27, 2021

Current Industry Reliability Method

Redundancy is the current reliability method for Risk Management

- Due to the poor reliability of batteries, UPS design criteria is 1.5 times the power needed, driving large costs due to the risk of poor battery quality and reliability.
- UPS for global data centers is an $11B market in 2022, so reducing the design criteria from 1.5 to 1.1 (small individual cell failure contingency) could save $4B annually.
- UPS failures typically cost $200K to $500K per hour.

Pareto Chart of UPS Failure Causes



Battery Failure Causes (80%)

- Depletion of charge in individual UPS cell
- Age failure (typical 3-6 year lifespan)

Other Failure Causes (20%)

- Battery strings wired in series-parallel can develop failure modes due to interactions between the multiple parallel strings.
- Electrical fires (19 in last 9 years)
- Failures from voltage spikes
- Over cycling UPS batteries

Reducing Battery Failure Rates

Some of the causes of failure are manufacturing/ process related and some are design / development related. Some ways to improve battery quality:

Manufacturing

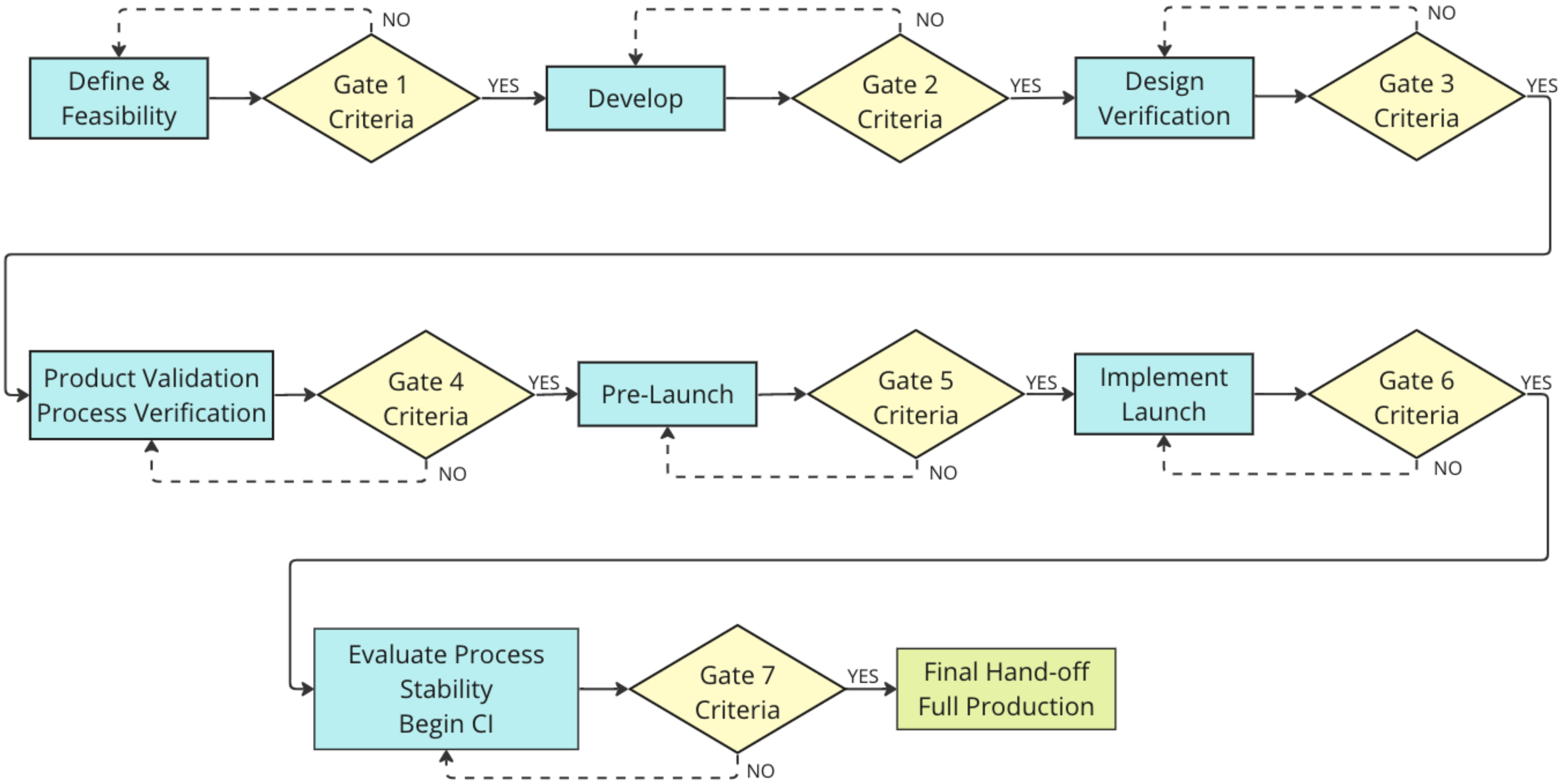
Poor manufacturing can be worked around by determining what, if any, critical inspections are missing and by increasing inspection frequencies to 100% for critical assemblies.

Design

Considering that generally 60% to 70% of failure problems are designed into a product or system, there should be a heavy emphasis during development for engineering excellence, Design for Manufacturing (DFM), Design for Reliability (DFR), communication and collaboration

A **Stage Gate** process is useful for task tracking and management for product excellence for both Design and Manufacturing

Stage Gate Process



Stage Gate Design / Manufacturing Meetings

- Stage Gate Process is vital for reliability for battery designers and manufacturers
- Doing so helps identify the DFMEA and PFMEA topics to be addressed as well as key specification parameters
- Small investment in development that ensures reliability as cheaply as possible.
- Correcting design defects in manufacturing can be 100X as expensive as catching the problem in the design stage.

Some Root Causes of Battery Failure

- Failure of Electronics or PCBs
- Failure of Software
- Failure of BMS
- Electrical Shorts
- Inconsistent electrodes
- Inconsistent anode and cathode materials
- Battery Separator faults like defective folding
- Electrolyte fill inconsistent
- Defective seals on cell enclosure
- Bus bar attachment and assembly
- Corroded terminals
- Chemistry of ion transfer and build up of dendrites in some cases
- Mount of cells in enclosure

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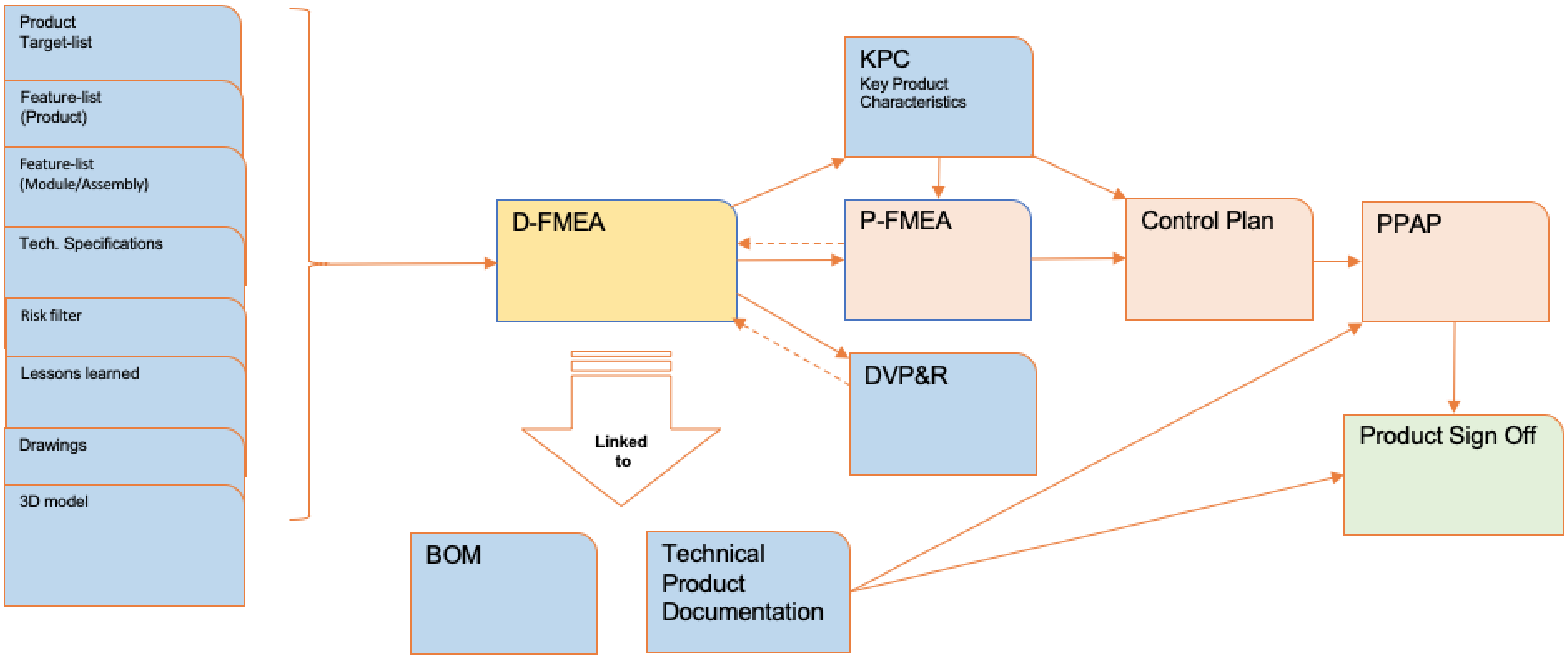
We will discuss;
1. A FMEA example
2. Lack of proper specifications

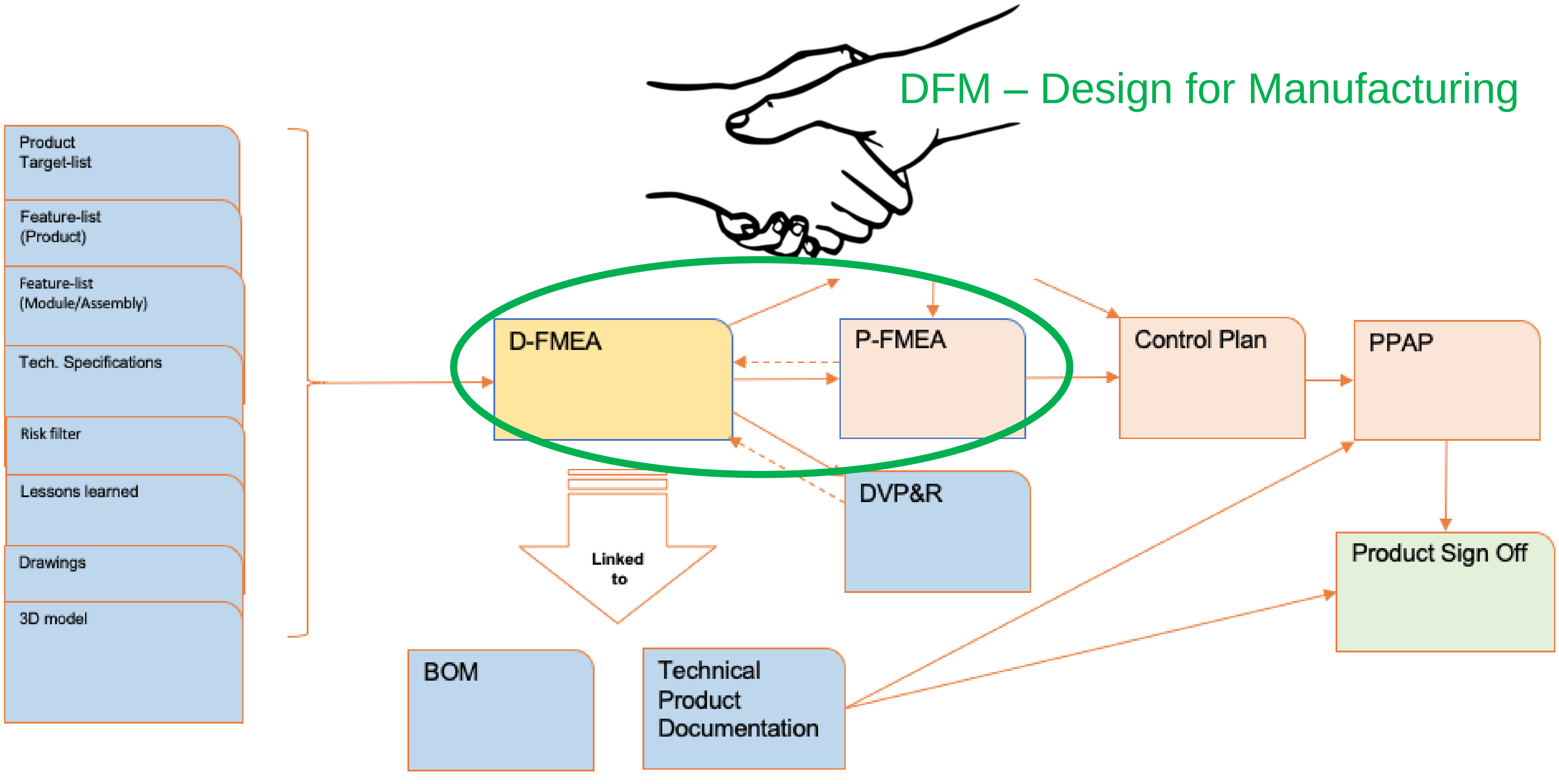
Failure Mode and Effects Analysis (FMEA)

- FMEA addresses development risk mitigation
- FMEA is often used to consider parts and not interlinking systems
- The DFMEA/ PFMEA divide often enables designers to throw any manufacturing related issues over the wall and be ignored until it is too late
- Design for Manufacturing (DFM) is important! Collaborative work or Simultaneous Engineering works well to fix this problem

FMEA – Typical Process Flow

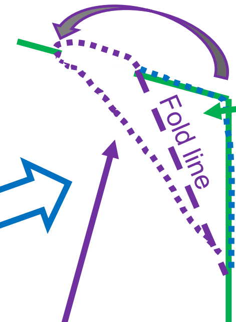


FMEA – Typical Process Flow



Separator Defect Folds

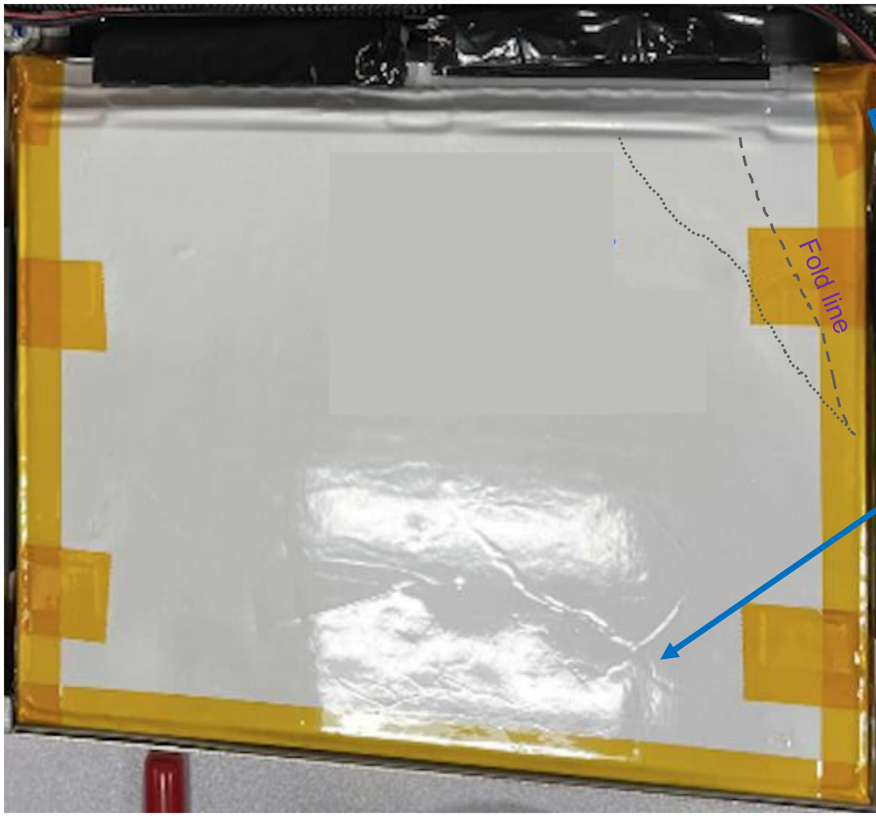
Separator is folded over from the corner



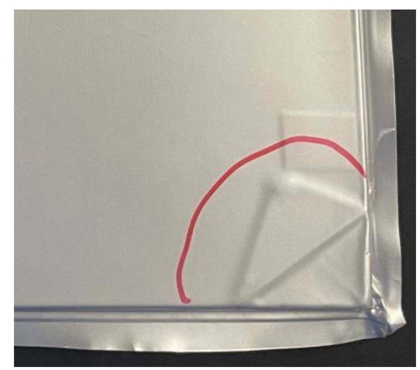
Exposed electrode

Folded over separator

Breakout View



Wrinkles in separator



DFMEA of Separator Defect Folds

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DESIGN FAILURE MODE AND EFFECTS ANALYSIS

System:		**Part #**		**System Interface Teams:**	
Subsystem:		**Part #**		**Core Team:**	
Component:		**Part #**		**Design Responsibility:**	

Item/Function	Potential Failure Mode	Potential Effect(s) Of Failure	Severity Index	Classification	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls		Detection	RPN
							Prevention	Detection		
Perforated Electrode Separator Sheet (Separator) Function: Allow electrolyte to pass thru. Keep electrodes separated.	Separator Folding	Short Circuit / Battery Degradation & Potential Thermal Runaway	9	CC	Folded separator exposes the electrodes allowing them to touch and short out.	3	Design the cell / jelly roll to minimize the chance of folding.	Determine acceptable parameters for the separator specification thru analysis and testing.	7	189
Separator	Separator Folding	Short Circuit / Battery Degradation & Potential Thermal Runaway	9	CC	Folded separator exposes the electrodes to each other allowing dendrites to bridge the gap between the 2 electrodes and short out.	3	Design the cell / jelly roll to minimize the chance of folding.	Determine acceptable parameters for the separator specification thru analysis and testing.	7	189
Separator	Separator Folding	Short Circuit / Battery Degradation & Potential Thermal Runaway	7	QC	Electrolyte is inhibited from passing from one electrode to another.	4	Design the cell / jelly roll to minimize the chance of folding.	Determine acceptable permeability parameters for the separator specification thru analysis and testing.	6	168

DFMEA of Separator Defect Folds - Mitigation

	Product: V6.1		DFMEA Number:	
	Prepared By:		Design Release Date:	YYYY-MM-DD
			Date (Orig): YYYY-MM-DD	Rev YYYY-MM-DD

Current Design Controls						Actions Results				
Prevention	Detection	Detection	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Sev	Occr	Det	RPN
Design the cell / jelly roll to minimize the chance of folding.	Determine acceptable parameters for the separator specification thru analysis and testing.	7	189	1. Determine acceptable separator parameters thru analysis and test and incorporate into the specification. (max/min allowables)	DRE is ultimately responsible.	Separator Folding has been addressed in the specifications and in the processes that have been validated thru analysis and testing.	9	2	3	54
				2. Engage DFM and Process departments to ensure the requirements of no separator folding are met.	DRE is ultimately responsible.	Joint sessions held and the results were added to the PFEMA.	9	2	2	36
				3. Feedback from Manufacturing needs to flow back to Engineering.	Mfg Engineering is responsible for developing the process and for providing feedback to the DRE. DRE is responisible for design improvements	Process is developed and tested. Results were discussed with Engineering and improvements to the design were implemented.	9	2	2	36
Design the cell / jelly roll to minimize the chance of folding.	Determine acceptable parameters for the separator specification thru analysis and testing.	7	189	1. Determine acceptable separator parameters thru analysis and test and incorporate into the specification. (max/min allowables)	DRE is ultimately responsible.	Separator Folding has been addressed in the specifications and in the processes that have been validated thru analysis and testing.	9	2	3	54
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PFMEA of Separator Defect Folds

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PROCESS FAILURE MODE AND EFFECTS ANALYSIS

System:		Part #		System Interface Teams:	
Subsystem:		Part #		Core Team:	
Component:		Part #		Design Responsibility:	

Item/Function	Potential Failure Mode	Potential Effect(s) Of Failure	Severity Index	Classification	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Process Controls		Detection	RPN
							Prevention	Detection		
Pouch Cell Z-Folding Appratus / Electrodes are stacked and wrapped with the separator.	Separator Corners are Folded Over in process	Short Circuit / Battery Degradation & Potential Thermal Runaway	9	CC	Separator trimming does not meet specifications	3	Machine Calibration to Specifications	Manual in process inspection difficult.	7	189
	Raw Material is received with creases.	Short Circuit / Battery Degradation & Potential Thermal Runaway	9	CC	Incoming Separator Roll Defective - Material on the Roll has Creases	3	Incoming Material Inspection	Raw material inspection for Creases.	7	189
	Separator becomes bunched in process.	Short Circuit / Battery Degradation & Potential Thermal Runaway	9	CC	Separator misalignment during processing allows it to become folded or bunched, particularly on one side.	4	Machine Calibration to Specifications	Manual in process inspection difficult.	7	252

PFMEA of Separator Defect Folds - Mitigation

	Product: V6.1		**PFMEA Number:**			
	Prepared By:		**Design Release Date:**	YYYY-MM-DD		
			Date (Orig):	YYYY-MM-DD	**Rev**	YYYY-MM-DD

Current Process Controls		**Detection**	**RPN**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Results**				
Prevention	**Detection**					**Actions Taken**	**Sev**	**Occr**	**Det**	**RPN**
Machine Calibration to Specifications	Manual in process inspection difficult.	7	189	Manufacturing Engineering will develop processes to ensure the equipment will not drift out of spec.If process is difficult to maintain, consult engineering.	Manufacturing Engineering with possible equipment manufacturer involvement	In process controls added.	9	2	5	90
Incoming Material Inspection	Raw material inspection for Creases.	7	189	Examine Automated Inspection and Test the Process before implementing.	Manufacturing Engineering with possible raw material supplier involvement	Automated Inspection Process was implemented				
Machine Calibration to Specifications	Manual in process inspection difficult.	7	252	Examine Automated Inspection and Test the Process before implementing.	Manufacturing Engineering with possible equipment supplier involvement					0

Specifications lacking at various stages of Design and Manufacturing

Design and Process Specifications are vital for consistent product and success for reliability. Problems can be generated by:

- Inadequate incoming material controls and specifications
- Lack of process tolerances and measurement systems
- Lack of in-process measurement or automated measurement
- Incomplete specs need DOE work completed to find optimum material parameters
- Process variables, calendaring for example, not specified or DOE investigated
- Measurement System Analysis to verify measurement systems
- Not utilizing standards, like IEEE for board design for example
- Traceability of product and components

Conclusions

- Battery manufacturers and designers should improve batteries through Stage Gate Management, detailed specs, FMEA, DFM and thorough verification/ validation testing when developing their products

Current State		Future State
Reliability is achieved through Redundancy by buying 1.5 times more batteries. Manufacturers commonly have a 30% scrap rate	→	Reliability from Better Batteries Result of better design and development practices, as well as improved processes and inspection

- Improved reliability for Risk Management can be gained by better product consistency and higher quality as opposed to redundancy with savings in the billions of dollars

References

- AIAG/VDA FMEA Handbook, June 2019
- From Materials to Cell: State-of-the-Art and Prospective Technologies for Lithium-Ion Battery Electrode Processing, Jianlin Li*, et.al. Chem. Rev. 2022, 122, 1, 903–956 October 27, 2021
- DigitalInfra.com, Data Center Fires, May 25, 2023

Questions?

For help with your power improvement journey contact:

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