Systems Engineering & Reliability Engineering: A Powerful Partnership for Success

Product engineering in today's world takes on new dimensions and challenges. Systems are more multifaceted than ever before, melding mechanical components, high-tech electronics, and ever increasingly complex software. The manufacturing process has become similarly complex with robotics, huge operations, and the integration of components from a variety of suppliers. Plus, businesses must continue to adapt to an ever changing, diverse, and globally dispersed workforce.

The need for a holistic approach has never been more profound as all these moving parts have been added to the challenges facing engineers today. This is the driving principle for Systems Engineering: to understand these challenges and overcome them to deliver reliable, quality products. When the strengths of Reliability Engineering are integrated with Systems Engineering, an ultimate partnership that drives product success is achieved.

RELYENCE CORPORATION

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Introduction

This paper will explore how Systems Engineering and Reliability Engineering can work together to provide a powerful partnership for success. Some of the key reasons Systems Engineers turn to Reliability Engineering to ensure successful product delivery include:

- Achieving a cohesive approach to quality and reliability in order to overcome the fragmented approach commonly seen.
- Bringing teams together to work towards a common goal in order to overcome the issues arising with teams operating in silos, such as design engineering being disconnected from manufacturing.
- Eliminating issues that repeatedly occur due to lack of communication and feedback loops.
- Capturing knowledge and experience so lessons learned can be cycled back to improve product development and the manufacturing process for the next generation.
- Consolidating tools in a single, integrated platform so data resides in a central location accessible to all and information is shared for efficiency and consistency.

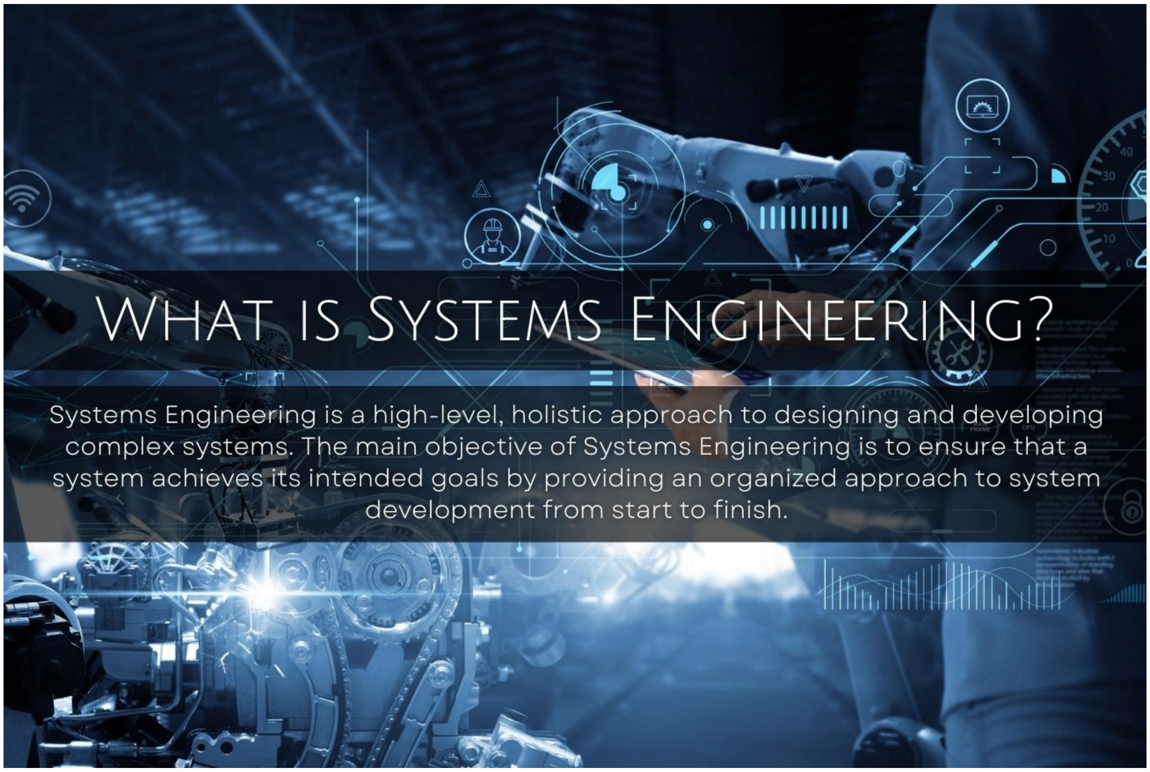
Due to Relyence's strong foundation in reliability and quality, this paper is written from the Reliability Engineering perspective. It is beyond the scope of this paper to delve into all the various aspects of Reliability Engineering techniques and principles; however, explore the Relyence web site for a wealth of information. Read on to learn more about Systems Engineering and how Reliability Engineering methodologies offer tools for all stages of the product life cycle.

What is Systems Engineering?

Systems Engineering is a high-level, holistic approach to designing and developing complex systems. The main objective of Systems Engineering is to ensure that a system achieves its intended goals by providing an organized approach to system development from start to finish. While Systems Engineering itself is not a core engineering discipline such as mechanical or environmental engineering, it provides a methodology for combining all aspects and disciplines involved in product design and development in order to effectively create and deploy successful systems.

A significant component of Systems Engineering is that it is not only intended to focus on the technical details of the system production, but on everything that contributes to it or affects it. So, for example, when it considers all the engineering aspects of design and development requirements, it also looks at outside influencing factors such as the overall organization's involvement, the process, and the human elements that also have impacts on system development.

Systems Engineering offers a well-organized, problem-solving approach to stepping through the product life cycle from inception to retirement. At the high level, the stages of a product life cycle include planning, design and development, testing and verification, manufacturing, and deployment. Each of these stages is then broken down further to include various elements such as requirements definition, functional definition, risk assessment, control plans, compliance audit tracking, and incident report handling to name a few. While team members across a wide spectrum of disciplines are involved in all these steps along the way, it is the task of the Systems Engineer to look at the overall Systems Engineering process and keep things properly on track for success.



What are the Systems Engineering Standards?

There is not a single definitive standard for Systems Engineering. However, System Engineers turn to a number of standards to aid in their work. There are broad standards that can aid in overall process organization and management and there are technical standards that are useful during specific times in the product life cycle depending on the task at hand.

Standards for Systems Engineering include ISO/IEC/IEEE 15288 and ISO/IEC/IEEE 15289. ISO/IEC/15288, entitled "Systems Engineering – System Life Cycle Processes" offers helpful guidance on terminology and the processes used in the product life cycle from an engineering perspective. This standard applies broadly to complex manufactured systems with its inclusion of aspects such as hardware, software, data, processes, and humans. ISO/IEC/IEEE 15289, entitled "Content life-cycle information items (documentation)" provides details on specific documents and other informational products that need to be created and maintained during the system life cycle.

Several standards that are helpful in the application of 15288 and 15289 are available as well. ISO/IEC TR 24748-2 provides a guide for the application of 15288. Also, two standards that are specifically useful in the defense sector include IEEE 15288.1 "IEEE Standard for Application of Systems Engineering on Defense Programs" and IEEE 15288.2 "IEEE Standard for Technical Reviews and Audits of Defense Programs".

As each step of the life cycle progresses, Systems Engineers turn to a wide array of applicable standards that can help in the product design and development stage, as well as the analysis phase. For example, standards such as MIL-HDBK-217 offer methodologies for MTBF analysis, and the AIAG & VDA and MIL-STD-1629 FMEA standards define accepted techniques for failure assessment and risk analysis.

A very helpful resource for Systems Engineers is the International Council on Systems Engineering (INCOSE). They provide a solid foundation for Systems Engineering and also have a Systems Engineering Handbook. INCOSE offers a wealth of information and support for professionals in the Systems Engineering field.

What do Systems Engineers do?

Systems Engineers are responsible for the overall management of all the components of the product life cycle in order to design, create, and deploy any type of complex system to ensure system success. The main goal of a Systems Engineer is to make sure that the system they are working on achieves, and possibly exceeds, its requirements and established goals.

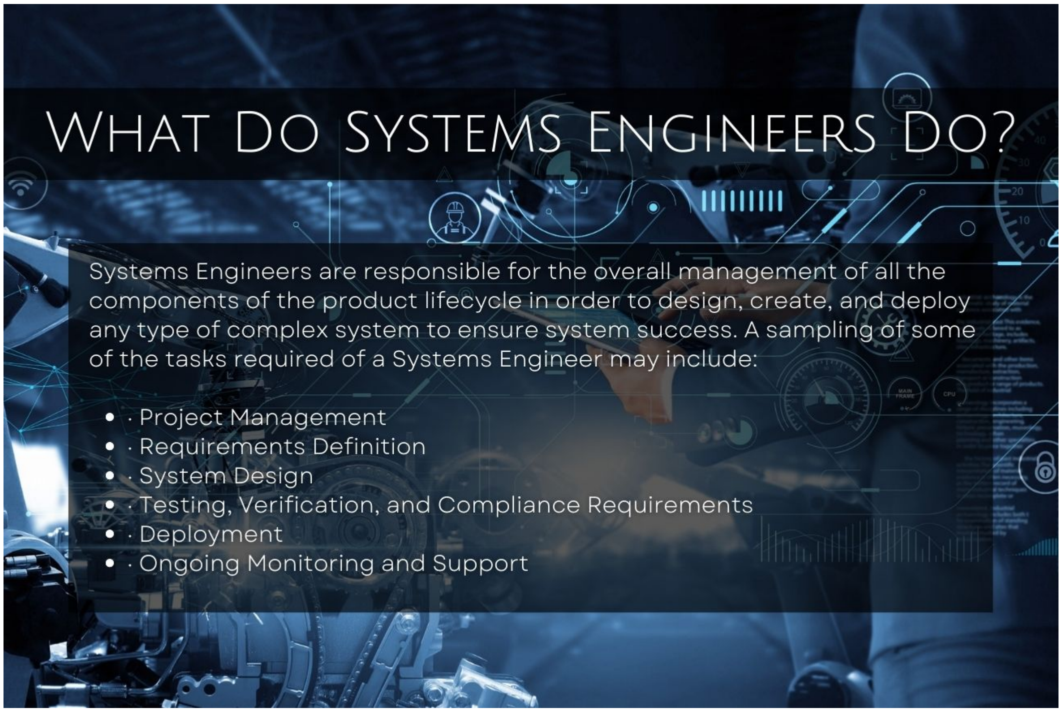
Some of the responsibilities of Systems Engineers can include:

- Project Management: Overall management of a project, potentially including budget management and scheduling.
- Requirements Definition: Working with a cross-organizational team to develop the key functional requirements of the system.

- System Design: Working with engineers to design the components needed in the system, including defining the technical requirements and assessing technology selection.
- Testing, Verification, and Compliance Requirements: Helping to establish testing protocols and procedures for testing and verification and making sure compliance needs are met.
- Deployment: Making detailed plans for product manufacture and field deployment.
- Ongoing Monitoring and Support: Tracking fielded products, resolving issues, and working on continuous improvement efforts.

These are some of the tasks a Systems Engineer may be assigned. However, because the key element of Systems Engineering is looking at the entirety of the product life cycle, the System Engineer's responsibility list is all-encompassing and fluid.

With their broad role that encompasses all divisions of the organization, Systems Engineers must possess proficiency across a range of skills to be effective. Systems Engineers are first and foremost engineers, so their technical abilities are a requirement for success. However, organizational skills are critical, as are communication and interpersonal skills. As with all jobs that work across the organization, the abilities to multi-task and solve complex problems are crucial.



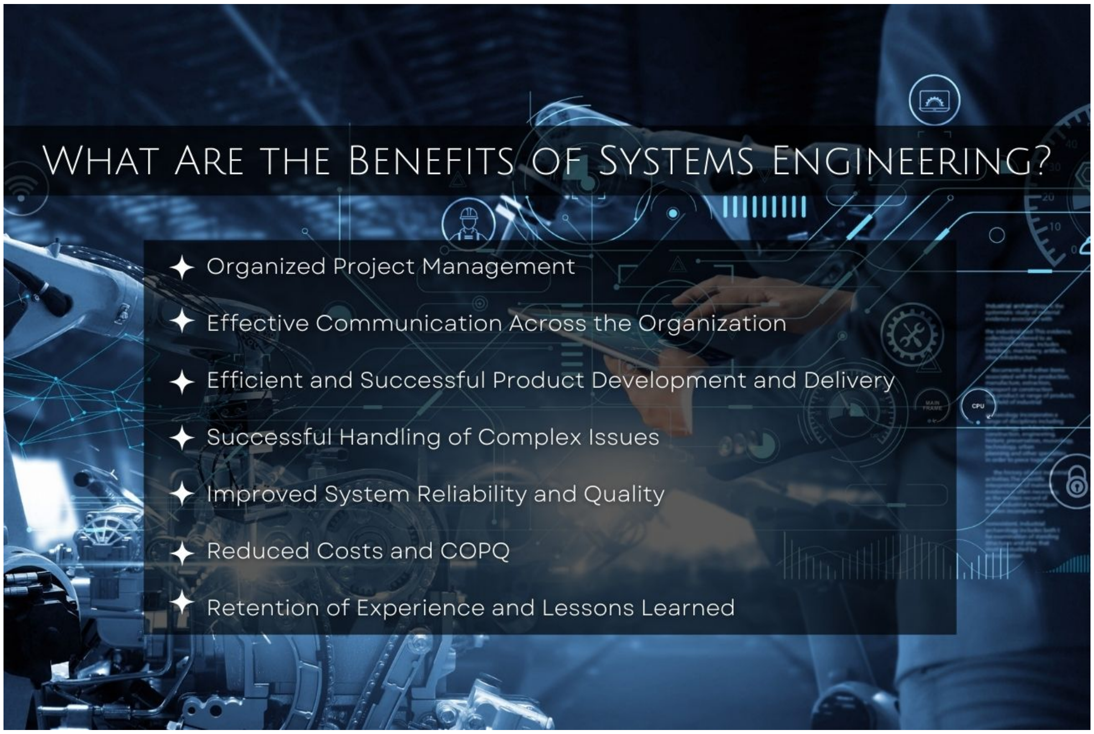
What are the benefits of Systems Engineering?

The key advantages of the System Engineering discipline are a result of the "whole system" approach. Because there is a team assigned to reviewing the process from start to finish, it greatly improves the probability of successful system delivery.

- **Organized Project Management**
  Applying the principles and adhering to the standards of good practices of Systems Engineering means there is an established, organized approach to the entire product life cycle. This ensures that the steps of the process are outlined from initial product concept through to delivery, allowing for a well-managed life cycle.
- **Effective Communication Across the Organization**
  Because there is an engineer, or team of engineers, responsible for the system from start to finish, there is a defined point of contact at any stage in the process. Additionally, it is a vital role of the System Engineer to keep everyone informed of the process including any issues or complications as they arise. In this manner, the Systems Engineering team is a single source of responsibility for system success.
- **Efficient and Successful Product Development and Delivery**
  Every product development cycle involves a wide range of teams and team members. In larger organizations, diverse teams are accountable for individual aspects of the overall project. However, it is important that all team members are not only aware of their individual goals, but also that they understand the overall markers for success of the project as a whole. Systems Engineers aid in both objectives: making sure teams understand their unique goals and are also aware of the "big picture". Importantly, Systems Engineers ensure that product requirements are being met - the key indicator of product success.
- **Successful Handling of Complex Issues**
  Because complex system development involves so many aspects – multiple engineering disciplines, multiple teams, multiple objectives – unexpected issues commonly arise. Having a well-managed process and a team with cross-functional knowledge of the system, ensures that any complexities that arise can be capably handled.
- **Improved System Reliability and Quality**
  A key indicator of product success is squarely focused on its reliability and quality. No system will be deemed successful if reliability and quality issues arise. Even if project schedules and budgets are met, the delivery of unreliable product is unacceptable. For this reason, reliability and quality goals must be clearly established from the outset. Importantly, reliability must be designed in. Reliability analysis tools provide the tools needed to ensure reliable products are delivered.

  There are reliability analysis tools that offer analysis during all portions of the product life cycle from initial design through to delivery. One example of the impact reliability tools can make in the Systems Engineering process is through the use of Reliability Prediction, or MTBF Analysis. Reliability Prediction can be performed on a system during the design process to provide an estimated failure rate of system components. Reviewing the predicted reliability metrics, engineers can pinpoint reliability issues early on. This enables them to revise the design early on and make changes that will avoid future problems and minimize cost.

- **Reduced Costs and COPQ**
  Because of the organized and managed approach of Systems Engineering, efficiency will naturally be a result. There will be less time lost due to lack of communication or poorly managed assets. Additionally, the end product is ensured to meet all requirements. This means that product releases will not be marred by ineffective systems that don't meet intended objectives, are unreliable, or exhibit poor quality or performance. Cost of Poor Quality (COPQ) is an often-overlooked expense of poor product life cycle planning and analysis which can be avoided by applying the principles of Systems Engineering.
- **Retention of Experience and Lessons Learned**
  Because Systems Engineers take part in the entire process, they gain valuable knowledge along all steps of the product life cycle. These lessons learned can then be applied to future system design and development and are not lost as next generation products are developed.



How does Systems Engineering relate to Reliability Engineering?

Reliability Engineering focuses on analyzing system reliability during the product life cycle. It is a critical component of Systems Engineering where its concepts are used to ensure products meet their reliability goals.

Reliability Engineering is especially useful in the design phase of product development to ensure reliability is designed into the system. The earlier in the life cycle reliability and quality is analyzed, the easier and far less costly it is to make design adjustments to improve problem areas. Reliability Engineering tools are also highly capable of analyzing risk and offer valuable techniques for product risk assessments.

Failure Mode and Effects Analysis, or FMEA, is an example of how reliability tools can impact the Systems Engineering process. FMEA enables engineers to review all potential failure modes of a system and consider the resulting effects of those failures. Engineers can then review those effects that are high risk and work to eliminate them or mitigate their effects. Making these critical changes during the design process is substantially less costly than dealing with these issues once the product is out in the field. If undiscovered until deployment, the resulting issue can not only cause a redesign or even a retooling of the manufacturing process, but also results in reputational harm that can be even more costly to your business.

Reliability Engineering analysis tools are also adept at aiding in all aspects of the life cycle. For example, techniques for testing and verification, controlling the manufacturing process, maintaining systems in the field, and tracking and handling customer issues are all important parts of the Reliability Engineer's tool set.

In terms of ensuring system quality and performance, Reliability Engineering principles and tools offer unmatched capabilities for Systems Engineers.

What Reliability Engineering Tools are Useful in Systems Engineering?

From project start to finish, there are a number of Reliability Engineering analysis tools that can aid in the Systems Engineering process. By reviewing the steps of the product life cycle, it is easy to see which analysis tools are most useful as the system progresses from design through to development and delivery.

Planning and Requirements Definition

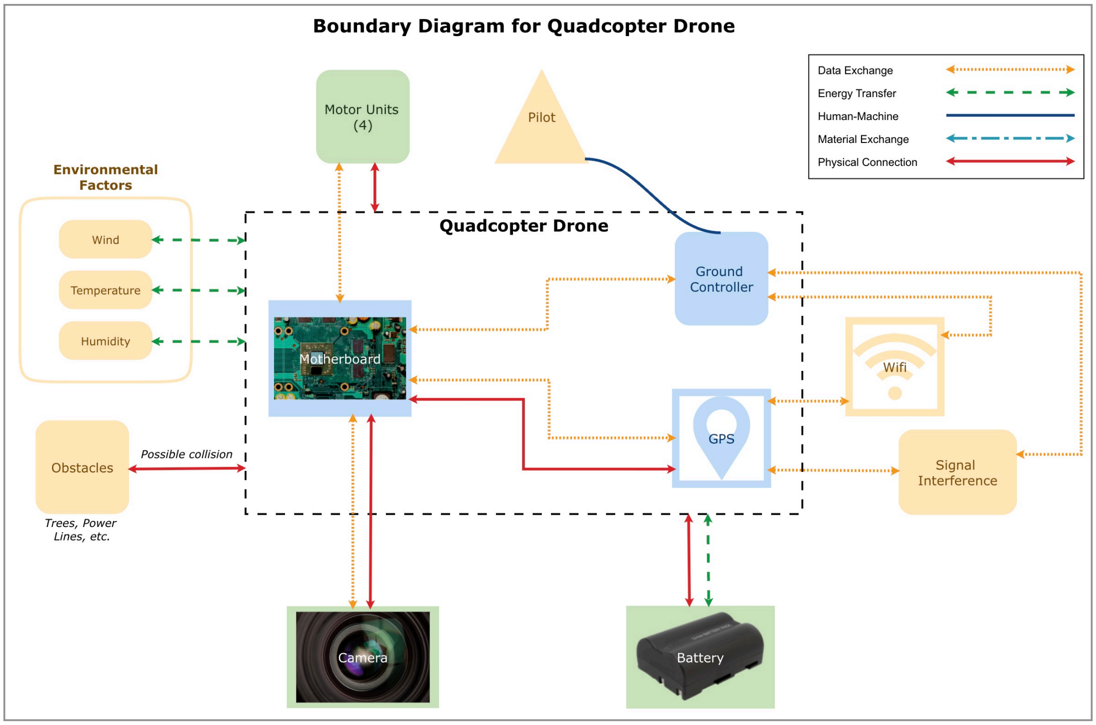
The initial phase of any product development cycle is defining and refining system requirements. This phase is vital because it sets the stage for the rest of the product life cycle. Requirements definitions ensures that the System Engineers, as well as the entire team, understand the core objectives and the elements which are of utmost importance. The critical component of planning and requirements definitions is defining the items by which system success will be measured.

In this early stage, engineers often look to analysis tools that provide an easy way to see a broad overview of all the system elements or aid in understanding the "big picture." Because the system is not yet designed, this phase is more fluid and provides an early time to get cross-functional team input. Software analysis tools such as Boundary Diagrams and Process Diagrams are helpful to provide support for planning efforts.

Boundary Diagrams

Boundary Diagrams are used to provide a visual representation of the components of a system including the interfaces between components and external factors, such as environmental effects and human interactions. The intent of a Boundary Diagram is to improve the understanding of the system under consideration by providing a graphical diagram of its interactions with internal and external elements. They can be useful as an upfront brainstorming tool to ensure the scope of analysis is well understood and all appropriate factors are taken into consideration.

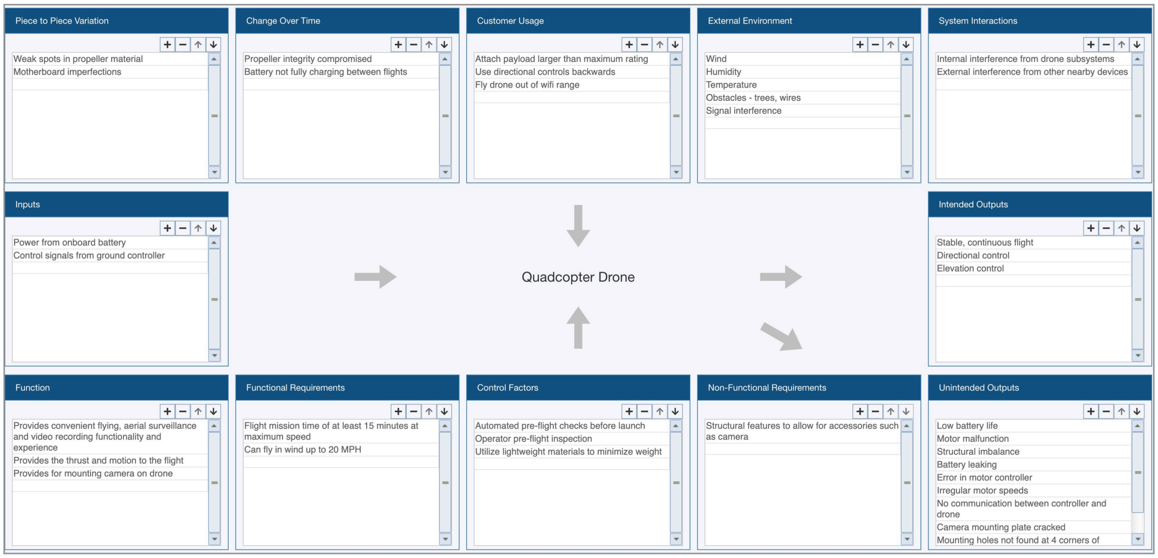
An important aspect of the consideration of interfaces in Boundary Diagrams is that this analysis aids in future FMEA efforts, and ultimately impacts product design. With early identification of potential hardware and software failures through Boundary Diagrams, this information can be directly transferred to the FMEA, providing an excellent starting point for analysis, as well as helping to ensure all important risks are covered.



P-Diagrams

Boundary Diagrams and P-Diagrams work in combination to ensure your FMEAs, which follow in the next phase of the product life cycle, are complete and efficient. The interfaces of the Boundary Diagram are the starting point of identified functions in your FMEA.

Parameter Diagrams, or P-Diagrams, offer a high-level overview that aid in completion of the FMEA for the product or process under review. P-Diagrams provide a way to review all the inputs that should be considered in order to achieve the required outputs. The factors identified in the P-Diagram can be the contributing failure modes, causes, or effects of those functions. The P-Diagram can ultimately provide key inputs to the FMEA as it focuses on inputs, outputs, control factors, and noise factors. Having all this information upfront at the start of your FMEAs provides a solid foundation for your risk assessments and gives you confidence that you are accounting for all potential risks. They can be especially helpful when designing complex systems that have many interactions and specific design requirements. Because P-Diagrams provide a compact visual overview, they can aid in understanding the overall system and the interactions of various factors influencing successful operation.



Design and Development

The design and development stage is central to overall system delivery. It is when vital design decisions are made and tested, prototypes are developed, and detailed analysis is of utmost importance. It is in this stage where several Reliability Engineering tools play a key role to ensure the system will meet its goals and objectives. FMEA (Failure Mode and Effects Analysis), Reliability Prediction, RBD (Reliability Block Diagram), and Fault Tree Analysis (FTA) are tools that are widely used by engineers throughout all industry sectors.

Failure Modes and Effects Analysis (FMEA)

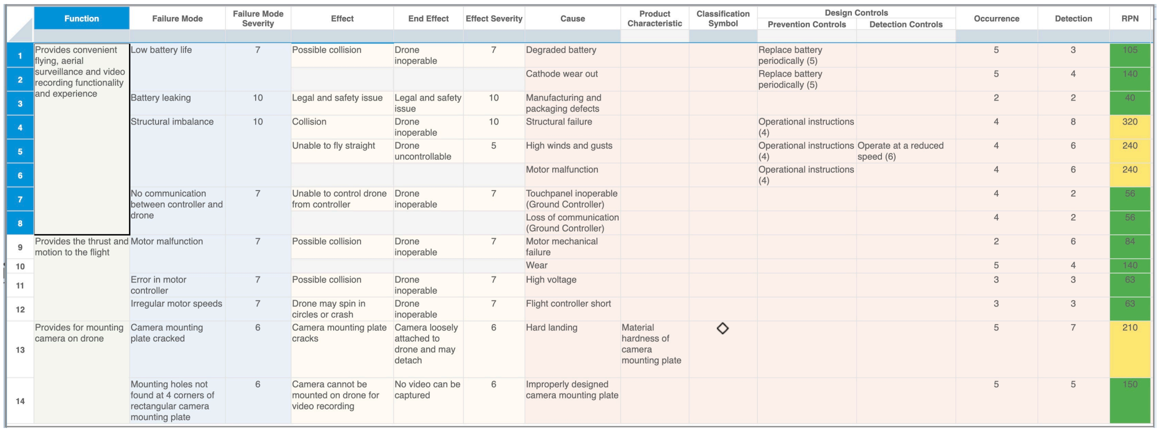
FMEAs provide a systematic approach for performing failure analysis of a product, process, or system. A FMEA begins by evaluating all possible failure modes of the item being analyzed, then determining the possible causes and resulting effects of those failures. You then assess the risk level associated with each of the failure modes, based on a set of established criteria. Finally, you find ways to detect, mitigate, or prevent the failures deemed most critical.

FMEA is the most commonly used tool in reliability engineering and in some cases is required for compliance. FMEA itself is made up of various elements that all link together to provide a thorough analysis platform. Elements of FMEA include Design FMEA (DFMEA), Process FMEA (PFMEA), Boundary Diagrams, P-Diagrams, Process Flow Tables (PFT), Process Flow Diagrams (PFD), Design Review and Verification

Reports (DVP&R), Control Plans (CP), Inspection Plans, Checklists, and Work Instructions.

At the start of a new product or a next generation product cycle, it can be very helpful have all lessons learned from prior or existing systems available. This is where an integrated platform such as Relyence can provide a major benefit. Relyence FMEA's innovative Knowledge Bank™ is a databank of reusable failure information, enabling you to capture vital data throughout your process and retrieve it for reuse when applicable.

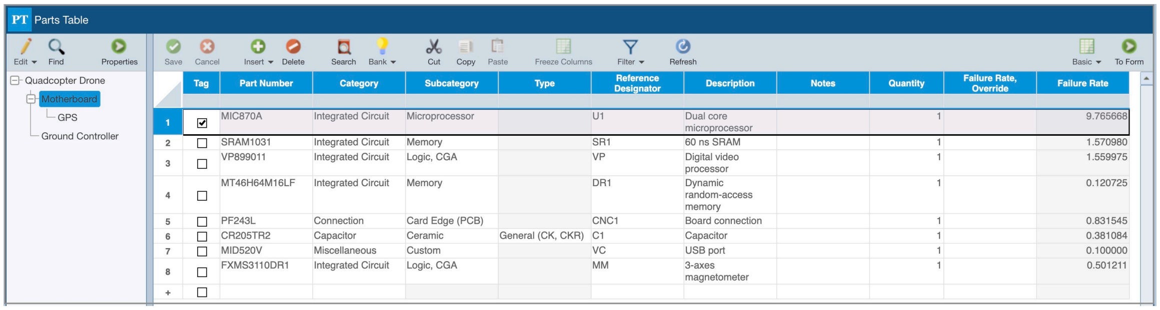
For details on FMEAs, review our definitive overview, or visit our blog for a wealth of articles on FMEA use and operation.



	Function	Failure Mode	Failure Mode Severity	Effect	End Effect	Effect Severity	Cause	Product Characteristic	Classification Symbol	Design Controls: Prevention Controls	Design Controls: Detection Controls	Occurrence	Detection	RPN
1	Provides convenient flying, aerial surveillance and video recording functionality and experience	Low battery life	7	Possible collision	Drone inoperable	7	Degraded battery			Replace battery periodically (5)		5	3	105
2							Cathode wear out			Replace battery periodically (5)		5	4	140
3		Battery leaking	10	Legal and safety issue	Legal and safety issue	10	Manufacturing and packaging defects					2	2	40
4		Structural imbalance	10	Collision	Drone inoperable	10	Structural failure			Operational instructions (4)		4	8	320
5				Unable to fly straight	Drone uncontrollable	5	High winds and gusts			Operational instructions (4)	Operate at a reduced speed (6)	4	6	240
6							Motor malfunction			Operational instructions (4)		4	6	240
7		No communication between controller and drone	7	Unable to control drone from controller	Drone inoperable	7	Touchpanel inoperable (Ground Controller)					4	2	56
8							Loss of communication (Ground Controller)					4	2	56
9	Provides the thrust and motion to the flight	Motor malfunction	7	Possible collision	Drone inoperable	7	Motor mechanical failure					2	6	84
10							Wear					5	4	140
11		Error in motor controller	7	Possible collision	Drone inoperable	7	High voltage					3	3	63
12		Irregular motor speeds	7	Drone may spin in circles or crash	Drone inoperable	7	Flight controller short					3	3	63
13	Provides for mounting camera on drone	Camera mounting plate cracked	6	Camera mounting plate cracks	Camera loosely attached to drone and may detach	6	Hard landing	Material hardness of camera mounting plate	◇			5	7	210
14		Mounting holes not found at 4 corners of rectangular camera mounting plate	6	Camera cannot be mounted on drone for video recording	No video can be captured	6	Improperly designed camera mounting plate					5	5	150

Reliability Prediction and MTBF Analysis

Reliability Prediction, sometimes referred to as MTBF Analysis, is one of the most common techniques used by engineers to evaluate product and system reliability. As its name implies, Reliability Prediction is a predictive methodology that enables you to estimate, or predict, your system's failure rate. Though an estimation methodology, the underlying analytical analysis used in Reliability Prediction has a strong statistical foundation. This means that the computed failure rate and MTBF values provide an accurate indicator of your product's expected performance.



	Tag	Part Number	Category	Subcategory	Type	Reference Designator	Description	Notes	Quantity	Failure Rate, Override	Failure Rate
1	☑	MIC870A	Integrated Circuit	Microprocessor		U1	Dual core microprocessor		1		9.765668
2	☐	SRAM1031	Integrated Circuit	Memory		SR1	60 ns SRAM		1		1.570980
3	☐	VP899011	Integrated Circuit	Logic, CGA		VP	Digital video processor		1		1.559975
4	☐	MT46H64M16LF	Integrated Circuit	Memory		DR1	Dynamic random-access memory		1		0.120725
5	☐	PF243L	Connection	Card Edge (PCB)		CNC1	Board connection		1		0.831545
6	☐	CR205TR2	Capacitor	Ceramic	General (CK, CKR)	C1	Capacitor		1		0.381084
7	☐	MID520V	Miscellaneous	Custom		VC	USB port		1		0.100000
8	☐	FXMS3110DR1	Integrated Circuit	Logic, CGA		MM	3-axes magnetometer		1		0.501211
+	☐										

Additional analyses that can be done within the scope of Reliability Prediction analysis provide ways to aid in the System Engineer's efforts, such as Allocation analysis, What-If? analysis, and Derating analysis.

Allocation Analysis

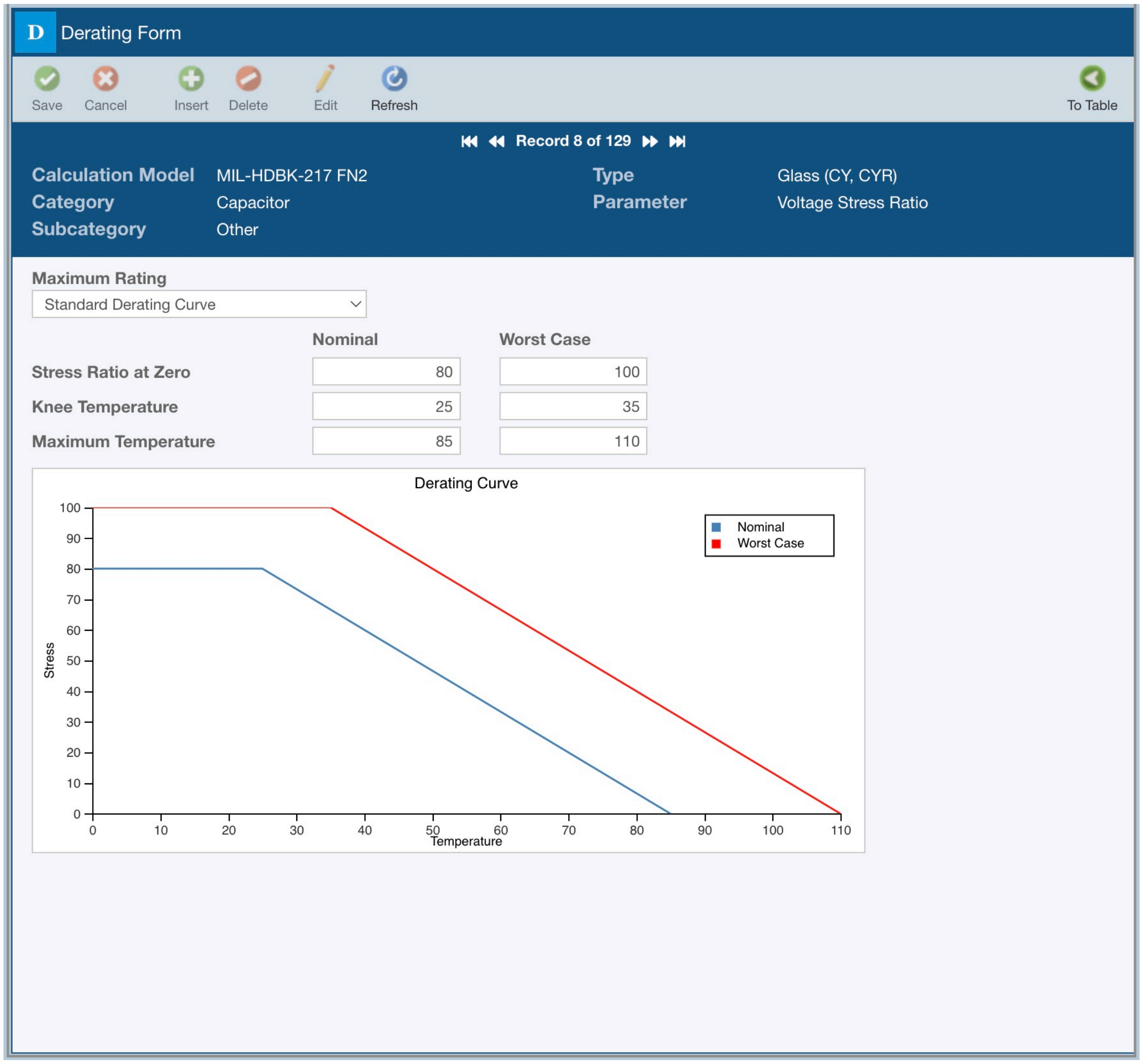
Allocation analysis is a process used to optimally distribute reliability goals across a system in order to meet an overall reliability objective. For example, Systems Engineers may have a specific reliability goal either internally driven or contractually mandated. In this situation, it is important to effectively distribute that goal down to subcontractors and suppliers in a reasonable fashion. By establishing reliability goals for each subcontractor, or each subsystem, a Systems Engineer can be assured that the overall objective will be achieved.

What-If? Analysis

What-If? analysis is a valuable tool for assessing the impact of design tradeoffs on your reliability calculations, especially in early design stages. Performing What-If? studies provides a way to evaluate reliability and MTBF using various design alternatives, delivering metric-based results for making critical design decisions. You can create any number of trade-off studies by changing a variety of data parameters such as temperatures, environments, quality levels, operating stresses, and duty cycles to assess the impacts on predicted reliability. The ability to assess reliability using comparative results helps you confidently make design decisions.

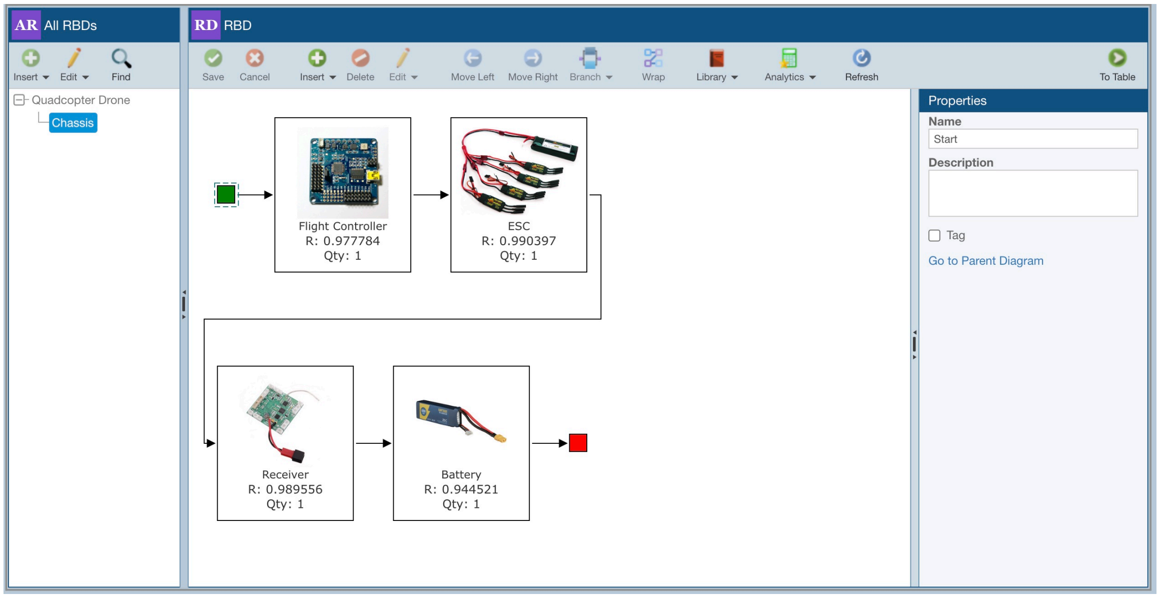
Derating Analysis

All electronic devices are subjected to various stresses, such as electrical (for example voltage or current), temperature, and environmental (for example vibration or shock). Component data sheets often include information on maximum stress levels that a component should be subjected to in a design. Derating, or operating a component at less than its maximum stress, is employed in order to prolong a component's life and, ultimately, maintain a high level of overall product reliability.



Reliability Block Diagrams (RBDs)

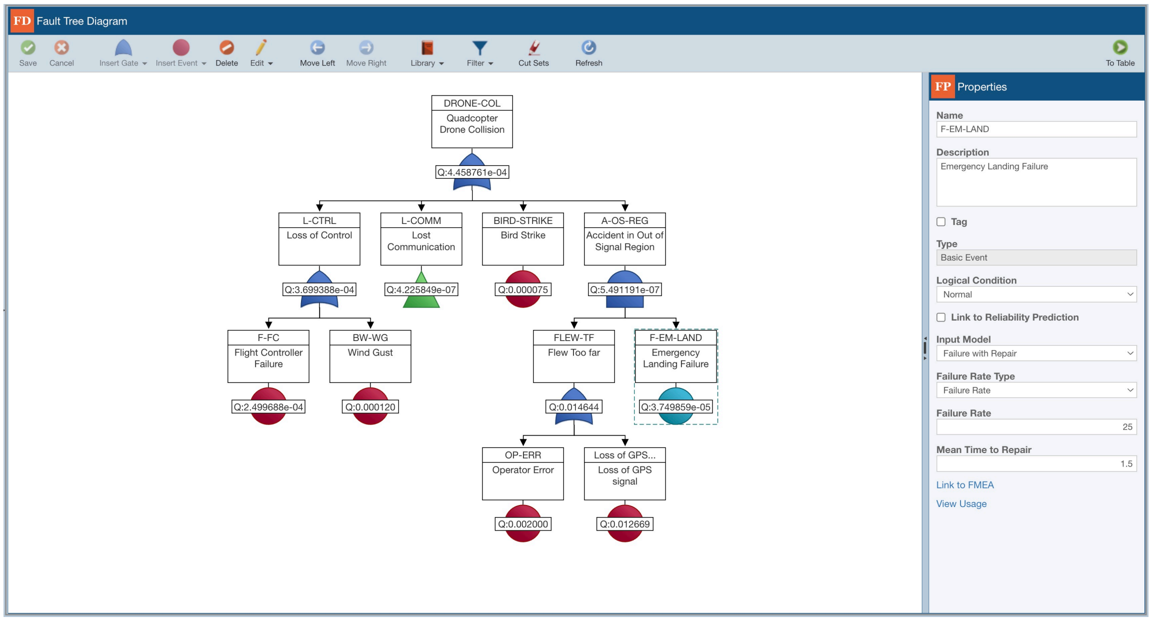
RBD analysis provides a comprehensive and powerful system modeling platform. RBD is a methodology for assessing the failure or success paths through a complex system. For example, RBDs can analyze systems that incorporate fail safes or redundancy, such as backup power supplies, to increase overall product reliability. RBDs offer a clean, visual system model using blocks to represent components or elements of a system with connector lines to indicate their relationships to one another. Behind the scenes, a powerful analytical engine can then compute a wide range of performance metrics including availability, reliability, downtime, and number of failures over a given time period. Oftentimes, RBD are used to assess the impact of redundant components, or redundant paths in a system. Redundancy in terms of RBD analysis means that when a component or path fails, a secondary component or path can take over to keep the system up and running.



Reliability Prediction and RBD provide a solid foundation for the Systems Engineering objective to *design for reliability*.

Fault Tree Analysis (FTA)

Fault Tree Analysis is a top-down deductive approach used to analyze risk and safety issues. It is a methodology used to determine the probability that an unwanted event will occur. The unwanted event is often the failure of a product, system, or process. It can be used for the analysis of highly catastrophic events such as the crash of an airliner, or less critical events, such as a personal drone crashing on landing. The objective of an FTA is to assess the probability, or likelihood, of the undesirable event occurring and then take steps to eliminate, mitigate, or minimize its occurrence to keep failure risk at an acceptable level.



Testing & Verification

Design Verification Plan and Report (DVP&R)

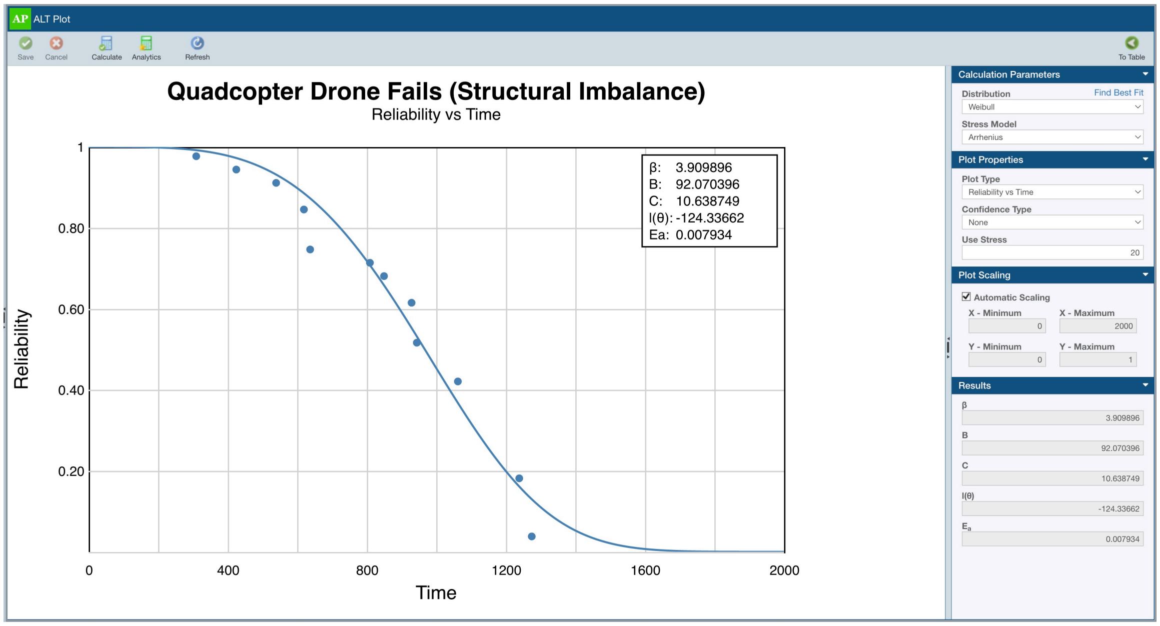
The purpose of DVP&R is to manage and document your tasks associated with verifying that your product meets the design requirements. In the *Plan* portion of DVP&R, your design specifications or product requirements are listed along with the tests used to verify that your requirements and/or specifications have been met. In the *Report* portion of DVP&R, the results of your tests are recorded. You can track pass-and-fail testing, as well as keep track of progress and issues that may arise. DVP&R is a tool that ensures you have an organized approach to validation of product design, provides feedback to know how well your design is progressing in relation to verifying it meets requirements, and maintains all this information in a central place for efficiency and future design iterations.

	Function	Requirement	Verification Plan									Verification Report				
			Test Number	Regulatory	Test Name	Procedure	Duration	Acceptance Criteria	Due Date	Tag	Attachments	Test Findings	Test Results	Test Completed By	Notes	Attac
1	Provides convenient flying, aerial surveillance and video recording functionality and experience	Attain 32' altitude	1		Altitude test	Fly fully charged drone to max height and hold. Verify altitude and time with altimeter readings in flight profile recording. Video record all flight tests.		Attain 32' height and hold for at least 5 seconds	9/15/2022	☐		Max height reached about 33.5'.	Pass	Andrew Hill	Keep specs at 32' for wifi limitations.	
2		Attain speed of 18 m/s at 35 degree inclination	2		Speed test	Use ground markings and timer to verify speed at zero wind conditions.		Attain 18 m/s speed at 35 degree inclination with zero wind	9/15/2022	☐		Max speed attained was 17.8 m/s.	Fail	Andrew Hill	Retest when new design rev is available.	
3		10 minute flight duration on fully charged battery	3		Flight duration test	Fly drone on fully charged battery until failure.		10 minute flight time on fully charged battery	10/20/2022	☐		Variability was 10-12 minutes on multiple tests.	Pass	Andrew Hill		
4		180 degree field of view with 3-axis image stabilization	4		Camera verification	Use camera independently. Zoom and focus with stabilization ON and OFF to verify operation. Verify field of view.		180 degree field of view, 3-axis image stabilization	10/20/2022	☐		Good stabilization at max zoom settings.	Pass	Stephanie Hill		
5		14 MP full HD (1920 x 1080) image resolution	5		Image and resolution review	Load camera images onto computer and use accepted image software to verify image resolution.		14 MP full HD (1920x1080)	11/10/2022	☑					Image tests not yet completed.	
6		Store 8GB or 1 hour HD video	6		Video size review	Turn on camera for 1 hour and verify video size and recording length.		8 GB or 1 hour HD capture	11/10/2022	☑					Image tests not yet completed.	
7		Wifi range of 2 km with 2.4 GHz	7		Wifi test	Fly drone straight at 20m above ground until disconnect.		2 km with 2.4 GHz wifi	12/15/2022	☐		Connection lost at 1.5 km	Fail	Jeffrey Ford		
8												Connection lost at 2 km.	Pass	Jeffrey Ford	Be sure to fly in area without interference.	
9	Provides the thrust and motion to the flight	95% reliability at 50 flight hours	8		Drone motor accelerated life test	Laboratory bench test motors using ALT parameters.	1 month	ALT estimates of 95% reliability at 50 flight hours	12/15/2022	☐		See results in final ALT report.	Pass	Corey Beck		
10	Provides for mounting camera on drone									☐						

Accelerated Life Testing (ALT)

Accelerated life testing is a method of subjecting a product to a variety of high stress conditions to evaluate performance and try to induce failure to find potential weaknesses. ALT can evaluate any type of stress such as temperature, humidity, vibration, or any other type of environmental stress that your product may experience in its lifetime. For products that are intended to operate over a long time span, accelerated life tests are critical to assess the probability that they will meet their performance goals.

ALT analysis is a methodology for analyzing various types of accelerated life testing data in order to predict failure trends. ALT analysis essentially captures the data obtained through accelerated life tests and, using mathematical techniques, provides critical predictive measures on product reliability.



Manufacturing

Process FMEA (PFMEA)

PFMEAs are a type of FMEA used to analyze a process, such as the manufacturing of a component, product, or system. The principles of PFMEA are the same as those for Design Failure Mode and Effects Analysis (DFMEA): to provide an organized approach for identifying all possible failure modes, the effects of those failures, assessing associated risk, and eliminating or mitigating those deemed critical. The idea behind performing PFMEA on a manufacturing process is to ensure that the process is reliable and will produce components, products, or systems that meet requirements.

	Step Number	Process Step	Failure Mode	Failure Mode Severity	Effect	End Effect	Effect Severity	Cause	Product Characteristic	Classification Symbol	Process Controls: Prevention Controls	Process Controls: Detection Controls	Occurrence
1	50.05	Get size 10 socket and 4 bolts with 6mm diameter	Incorrect socket retrieved	3	Cannot fasten bolts	Camera cannot be attached to drone	3	Sockets of similar sizes not distinguishable					7
2			Incorrect bolts retrieved	3	Bolts too large, do not fit	Camera cannot be attached to drone	3	Incorrect labeling in part supermarket					4
3					Bolts too small, do not fit	Camera cannot be attached to drone	3	Bolts of similar sizes not distinguishable					7
4	50.10	Clamp camera onto drone body	Clamp loose	6	Cannot fasten camera to drone	Camera cannot be attached to drone	6	Clamp not tightened enough by operator			Preset position on clamp for camera installation		7
5			Clamp overtightened	6	Camera mounting plate cracks	Camera loosely attached to drone and may detach	6	Clamp overtightened by operator	Material hardness of camera mounting plate	◇			5
6	50.15	Fasten camera to drone body with bolts	Camera not securely fastened to drone	6	Camera detaches from drone	Camera not firmly mounted to drone	6	Bolt not torqued to required level		K		Periodic torque measurement inspection (7) Visual inspection of gap between bolt, camera, and drone (7)	4
7					Camera loose on drone	Camera not firmly mounted to drone	5						
8	50.20	Visually inspect for gaps between bolts, camera, and drone	Incorrect camera installation not caught	5	Poorly manufactured drone and camera delivered to customer	Customer complaint received	5	Incomplete work instructions on inspection steps					6
9	50.25	Correct camera installation on drone body	Camera not securely fastened to drone	6	Camera detaches from drone	Camera not firmly mounted to drone	6	Bolt not torqued to required level		K		Periodic torque measurement inspection (7) Visual inspection of gap between bolt, camera, and drone (7)	4
10					Camera loose on drone	Camera not firmly mounted to drone	5						
11	50.30	Remove clamp from drone body	Clamp not removable	3	Have to disassemble or	Loss of productivity	3	Clamp gears stuck			Monthly clamp gear cleaning by operator		3

Control Plans

Often as a final step in the PFMEA process, a Control Plan is created. The Control Plan details the methods you will use to control the Product and Process Characteristics to ensure they meet your requirements. The controls may define details such as specification, evaluation technique, tolerance, and sample size with frequency. Control Plans provide clear documentation of how critical design and process characteristics are controlled during the manufacturing process. For this reason, Control Plans are very useful in the creation of operator instructions, inspection plans, and checklists.

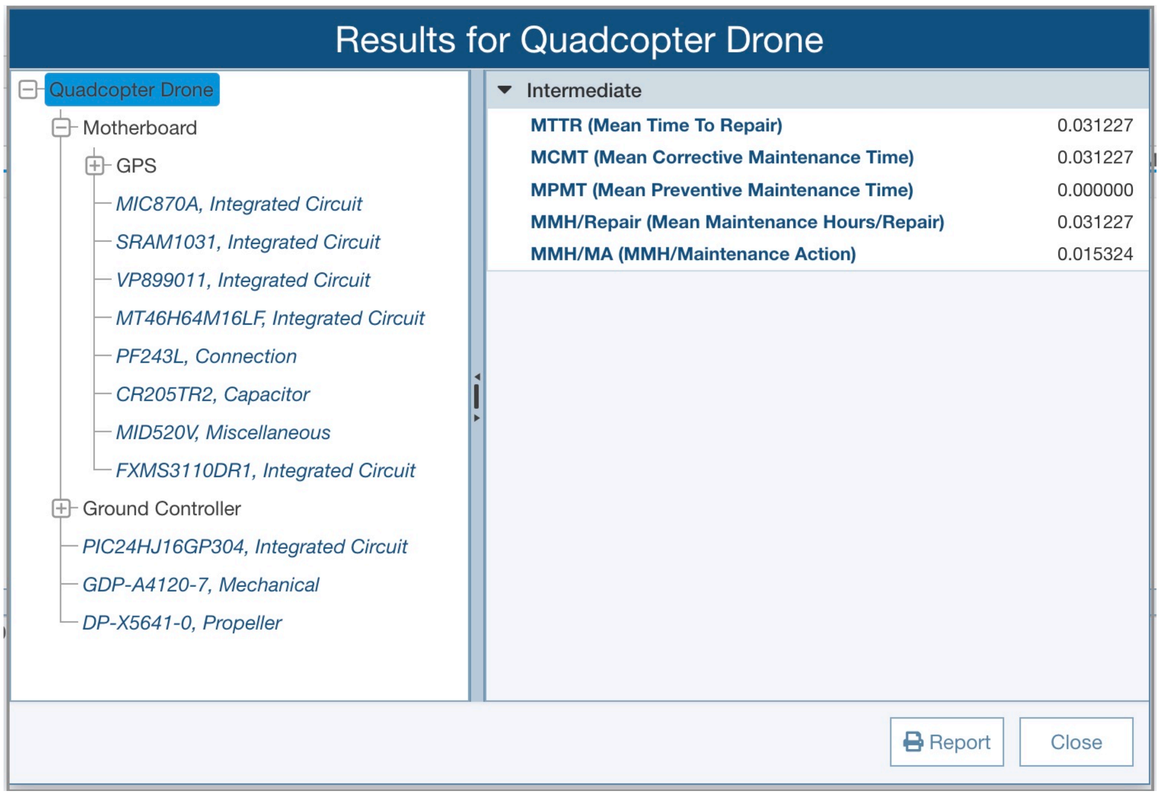
	Step Number	Process Step	Machine, Device, Jig, Tools for Mfg	PFMEA Characteristics: Number	PFMEA Characteristics: Product	PFMEA Characteristics: Process	PFMEA Characteristics: Class Symbol	Specification	Evaluation Technique	Sample: Size	Sample: Frequency	Process Control	Control Method	Reaction Plan
1	50.05	Get size 10 socket and 4 bolts with 6mm diameter												
2														
3	50.10	Clamp camera onto drone body	Clamp		Material hardness of camera mounting plate		◇							
4														
5	50.15	Fasten camera to drone body with bolts	Socket wrench, Torque meter	1	Camera bolt fastener diameter		K	Gap between bolt, camera, and drone is no more than 1mm	Visual inspection	1	Every assembly	Visual inspection of gap between bolt, camera, and drone	Place drone on a workbench with an overhead light, stand no more than 3 feet away, and view gap between bolt, camera, and drone.	Rework part to fully fasten camera to drone
6				1		Bolt torque	P	Bolt torque is 5 Nm +/- 1 Nm	In-station testing with digital torque meter	1	Every 4 hours	Periodic torque measurement inspection	Firmly place digital torque meter on bolt, engage meter until beep, read measurement on meter, verify measurement against 5 Nm +/- 1 Nm requirement.	Rework part to fully fasten camera to drone
7	50.20	Visually inspect for gaps between bolts, camera, and drone												
8														
9	50.25	Correct camera installation on drone body	Socket wrench, Torque meter	2	Camera bolt fastener diameter		K	Gap between bolt, camera, and drone is no more than 1mm	Visual inspection	1	Every piece	Visual inspection of gap between bolt, camera, and drone	Place drone on a workbench with an overhead light, stand no more than 3 feet away, and view gap between bolt, camera, and drone.	Rework part to fully fasten camera to drone
10				2		Bolt torque	P	Bolt torque is 5 Nm +/- 1 Nm	In-station testing with digital torque meter	1	Every 4 hours	Periodic torque measurement inspection	Firmly place digital torque meter on bolt, engage meter until beep, read measurement on meter, verify measurement against 5 Nm +/- 1 Nm requirement.	Rework part to fully fasten camera to drone
11	50.30	Remove clamp from drone body												
12														
13	50.35	Return size 10 socket to tool distribution												
14														

Deployment

Maintainability

One objective of Systems Engineering is to *design for maintainability*, or the idea that system design should consider the ways the system will be repaired and maintained while in the field. Important metrics to consider when evaluating system maintainability are MTTR (Mean Time to Repair) and MCMT (Mean Corrective Maintenance Time). Maintainability Prediction provides a methodology for assessing these measures, as well as additional useful metrics such as MPMT (Mean Preventive Maintenance Time), MaxCMT (Maximum Corrective Maintenance Time), and more.

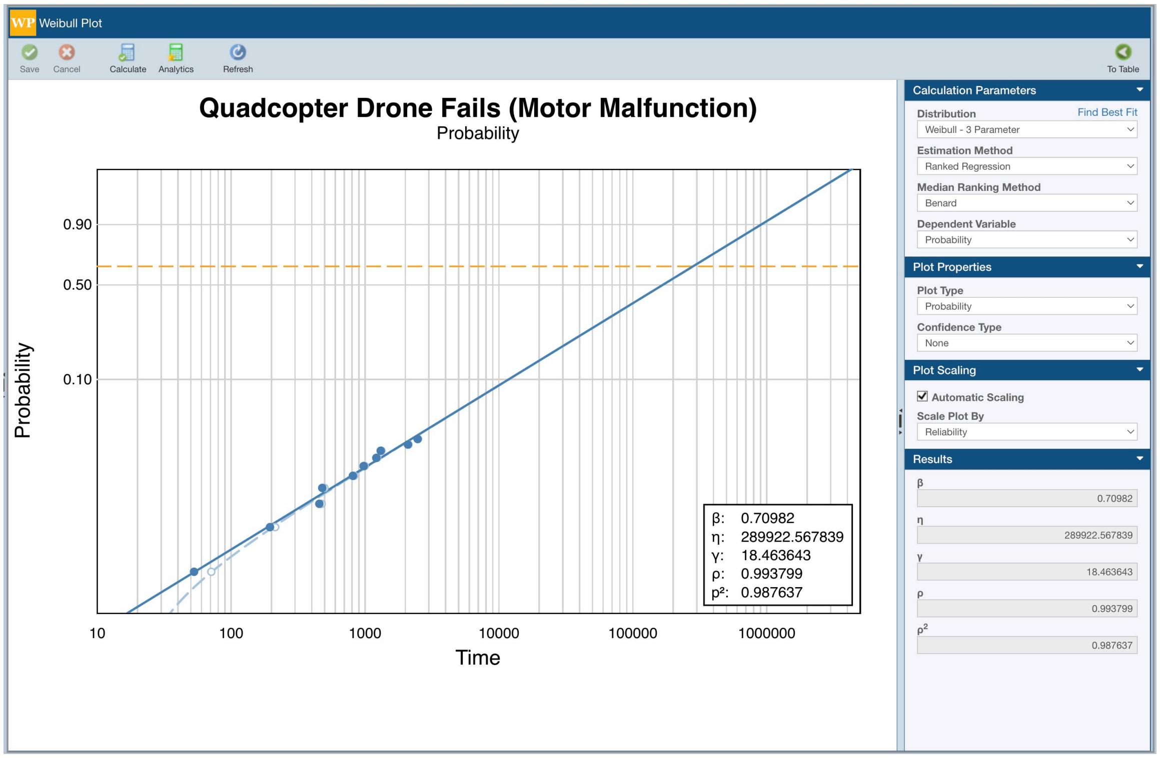
Additionally, repair metrics obtained as a result of Maintainability Prediction analysis can be used in conjunction with RBD analysis. By factoring in the repair times of system components, you can more accurately assess overall system performance measures such as availability.



Weibull Analysis

Weibull analysis is a methodology for analyzing various types of life data to predict failure trends. The core principle in Weibull analysis is to gather a sample set of life data, or data about failures over a time frame, and then apply statistical techniques in order to fit the data to a distribution. Using this information, you can then extrapolate the data to evaluate trends, assess the probability of a system operating over a time interval, analyze the mean life of a system, predict failure rate, or even determine a warranty period.

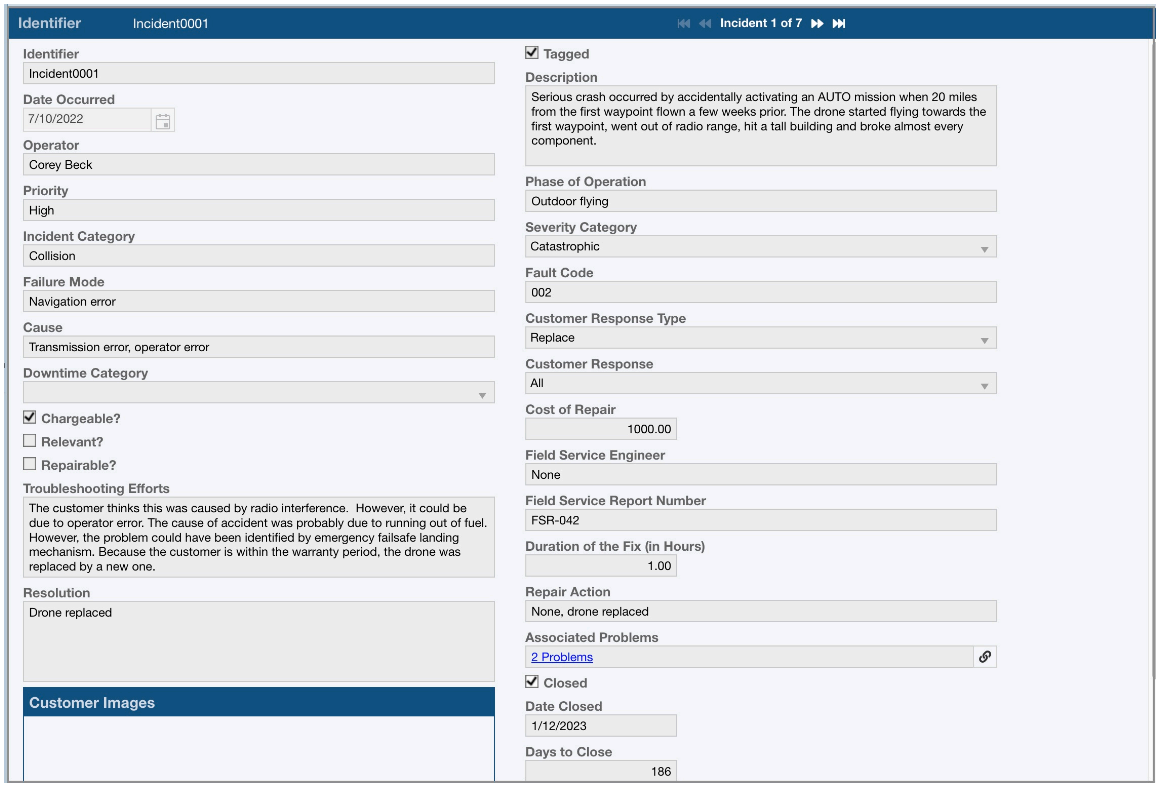
Weibull analysis is based on high-powered statistical analysis using different distributions, including, most notably, the Weibull distribution. The Weibull distribution is especially significant due to its versatility and its ability to model life data. It is one of the most widely used mathematical techniques for evaluating life data across a range of industries and across the product life cycle, which is why this type of life data analysis is commonly referred to as Weibull analysis.



FRACAS

FRACAS, or Failure Reporting, Analysis, and Corrective Action System, is a process for managing issues that occur with any type of system, product, or process. There are many other terms used to describe the same, or similar, process including CAPA (Corrective and Preventive Action), and CA (Corrective Action). FRACAS provides a well-accepted approach for monitoring and tracking products and systems once they have been delivered to the customer. This tool for providing in-service support for systems is typically part of an overall organization's QMS (Quality Management System) and compliments the overall Systems Engineering efforts.

There are several well-known process methodologies used in FRACAS, including 8D, PCDA, and DMAIC that are supported by FRACAS tools. Often, FRACAS platforms are customized to an organization's unique process for corrective action management. Sometimes, one of the well-established methodologies is used as a basis and then adapted to the organization's needs. In other cases, teams may design their own unique process they find most beneficial. Whatever process is established, FRACAS provides a means of improving reliability, quality, operation, and safety by systematically managing issues as they occur.



Not only does FRACAS provide a way to optimally handle issues from initial report through to closure, but it can also offer a wealth of data that can help to assess system performance in the field. For example, FRACAS can be used to compare predicted MTBF values to actual in-field MTBF. FRACAS is an important source of data about real-world system performance. This valuable information can then be utilized to help in the initial design and development stages of future products to establish requirements and performance goals.

Relyence Studio

Relyence Studio provides a diverse range of capabilities to support System Engineers at all phases of the product life cycle. From initial inception through to in-service monitoring and support, Relyence Studio helps in every aspect to ensure system success.

Relyence Studio integrates various key Systems Engineering activities in one central web-based platform for maximum efficiency promoting teamwork and collaboration across engineering teams regardless of location. With an eye on reliability and quality, Relyence Studio software tools enable you to be confident your systems will achieve their performance goals. Relyence Studio includes a wide range of Systems Engineering capabilities including FMEA, FRACAS, Fault Tree, Reliability Prediction, Maintainability Prediction, RBD, Weibull Analysis, and ALT Analysis. Reliability Studio can be tailored to your needs, so you can select which analyses you prefer, or utilize all for a best-in-class toolset. Plus, Relyence Studio provides a robust, well-rounded feature set that offers innovative features to make your Systems Engineering tasks more cohesive and organized. Some outstanding Relyence Studio capabilities include Workflow, Approvals, and Notifications, Dashboards, Knowledge Banks, always-in-sync, and unmatched customization capabilities.

Relyence Studio supports the various reliability engineering techniques described here, which can play a vital and beneficial role in Systems Engineering. Feel free to contact Relyence for further information or a personal demo, or try it out for free.