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Systems Engineering Report
'Thinking Design'

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Abstract

The development of an explosive device for precise, minimal-collateral impact demands rigorous attention to safety, functionality, and compliance. This report investigates the application of systems engineering principles to the design of such a device, with a particular focus on safety-by-design methodologies. By examining tools such as stakeholder mapping, Quality Function Deployment (QFD), Failure Modes and Effects Analysis (FMEA), Functional Modelling, and N² analysis, this report evaluates how safety and stakeholder needs were integrated throughout the system life cycle. Emphasis is placed on the selection of a shoulder-launched missile platform and the design of critical sub-systems including the Safety and Arming Unit (SAU) and Exploding Bridgewire (EBW). Through the use of engineered non-detonable systems (ENDs), the hierarchy of controls, and structured manufacturing safeguards, this report presents a data-driven and evidence-based assessment of how a systems approach enabled the creation of a robust, resilient, and inherently safe explosive system.

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1 Introduction

The successful design of ordnance, munitions, and explosives (OME) systems demands a structured, methodical approach, especially when operational effectiveness must be precisely balanced with stringent safety and collateral constraints. This report documents the systems engineering process undertaken to address a complex design challenge: the development of an explosive device capable of neutralising a hostile communications centre located within the second floor of an urban office block.

1.1 Given Mission Brief Description

The device must be deployed accurately from at least 100 metres away, function reliably in a confined room, and achieve its primary objective.

- *Disable the communications capability, while minimising collateral damage to surrounding infrastructure and harm to occupants.*

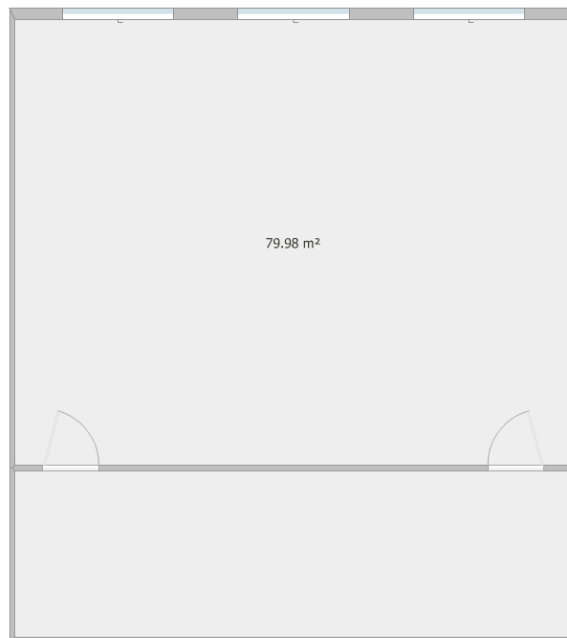


Figure 1 Target Interior

The broader scenario under consideration includes a 10m x 8m x 4m room enclosed by rendered filled cavity block walls and internal soft block partitions,

equipped with UPVC double-glazed windows and accessed only through barred doors during operational periods.

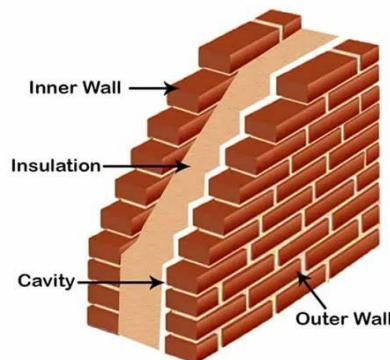


Figure 2 Target Exterior

There are typically six operatives stationed within the room, highlighting the need to design an effect that is both targeted and measured. While the primary mission is to neutralise the communications equipment, a stretch goal includes immobilising/ disorientating rather than eliminating occupants requiring precise control over blast direction, fragmentation, and timing.

Within this module, student teams were formed to simulate a professional engineering design team environment, each member assuming a functional role such as Research & Development, Performance Trials, Manufacturing, Safety, or Breakdown Analysis.

The report reflects the work conducted from the perspective of safe by design within the team and explores the use of key systems engineering tools to guide decision-making.

Members	Initials	Roles
Gareth James	GJ	R&D
Rachel Mccolm	RM	Safety of the process
Libby Jones	LJ	Safety of the Product
Charles Hadley	CH	Test and Eval
Dan Garton	DG	Manufacturing
Lewis Gray	LG	Disposal

Table 1 Role Delegation

2 Design Project Management

Design project management phase in systems engineering is the structured coordination of each of the life cycle phases. Using technical activities, resource tools, and stakeholders to ensure the successful development, integration, and delivery of complex systems that meet defined requirements as seen below [1].

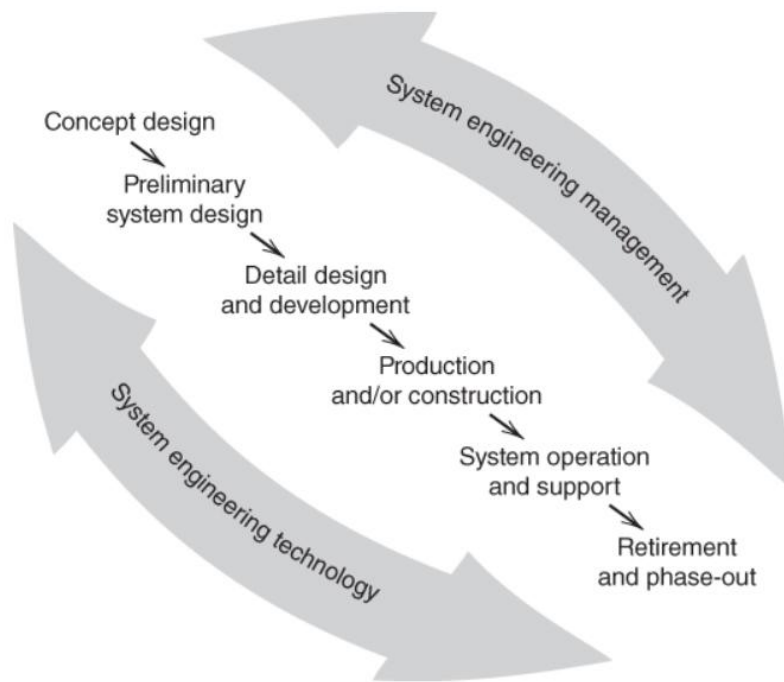


Figure 3 Life Cycle Phases of System Engineering a Product [2]

2.1 Key customer requirements.

To identify key customer requirements, the Voice of the Customer (VoC) methodology was applied, this supported identification and analysis of the stakeholders as well as their influence on the project and communications they have with each other [3] this can be seen visually in the figures below [4].

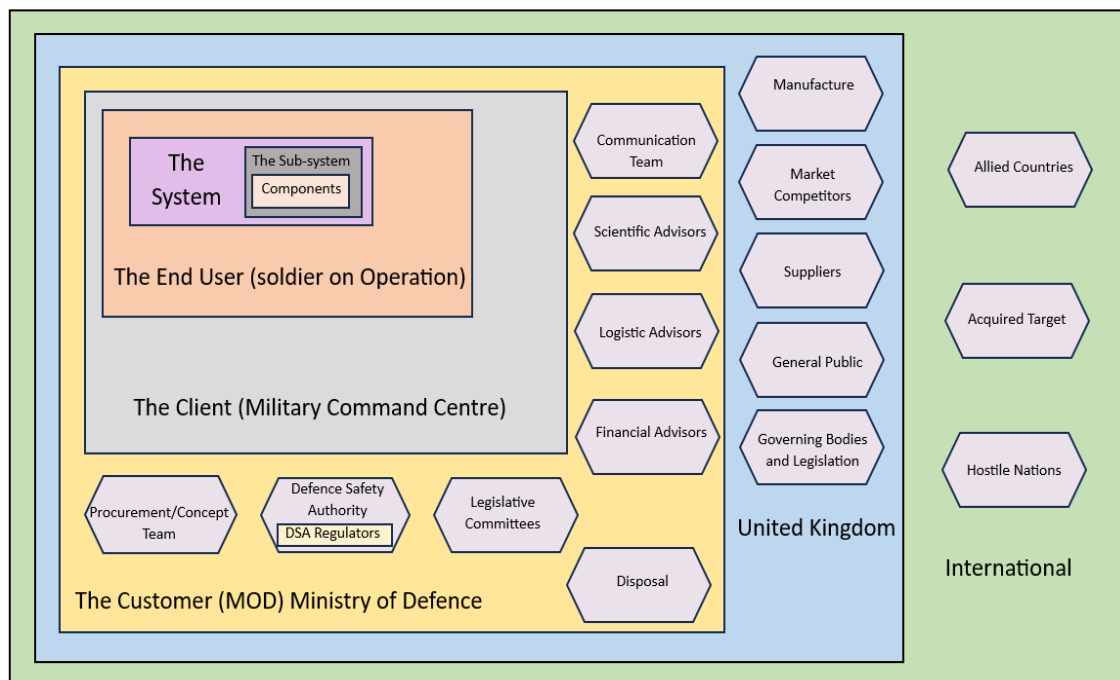


Figure 4 Stakeholder Boundary Map

Figure 3 defines who is relevant: Visually distinguishing between internal and external stakeholders, or those directly involved vs. indirectly affected.

Sets project scope: Helps avoid scope digressing, by clarifying which stakeholders' needs must be prioritised. Ensuring engagement with the right people.



Figure 5 Stakeholder Influencer Map

Figure 4 ranks stakeholders by involvement and interest: Identifying which stakeholders affect project decisions or outcomes most. More influential stakeholders' requirements may carry more weight in design trade-offs.

Manages expectations and risks: Anticipates who may support or resist aspects of the project, informing engagement strategies.

Improves stakeholder engagement planning: Ensures high-influence stakeholders are informed and satisfied.

This identification of relations was later utilised for other tool sets such as, Quality Function Deployment (QFD).

By engaging with identified end users, project sponsors, and stakeholder authorities through structured interviews, focus groups and industry data, found in Annex A. Enabled translation from broad expectations, like operational reliability, safety, and deployability to be converted into measurable engineering parameters. This was then captured through a verb relationships denoted in Table 3.

Table 2 Accurate Verb Selection for Requirements

Verb	Definition
Must	Indicates a legal mandatory requirment
Shall	Indicates a mandatory requirment
Should	Indicates a desirable requirment
May	Indicates either an optional requirment, or a statement relating to how mandated requirments can be achieved.
Will	Indicates either a statement of intent, or a statement relating to something outside the scope of the system being developed but is relevant to the system.

An affinity diagram transformed a messy list of stakeholder requirements into clear, organised categories this was crucial for defining system functions, setting priorities, and making informed design choices.

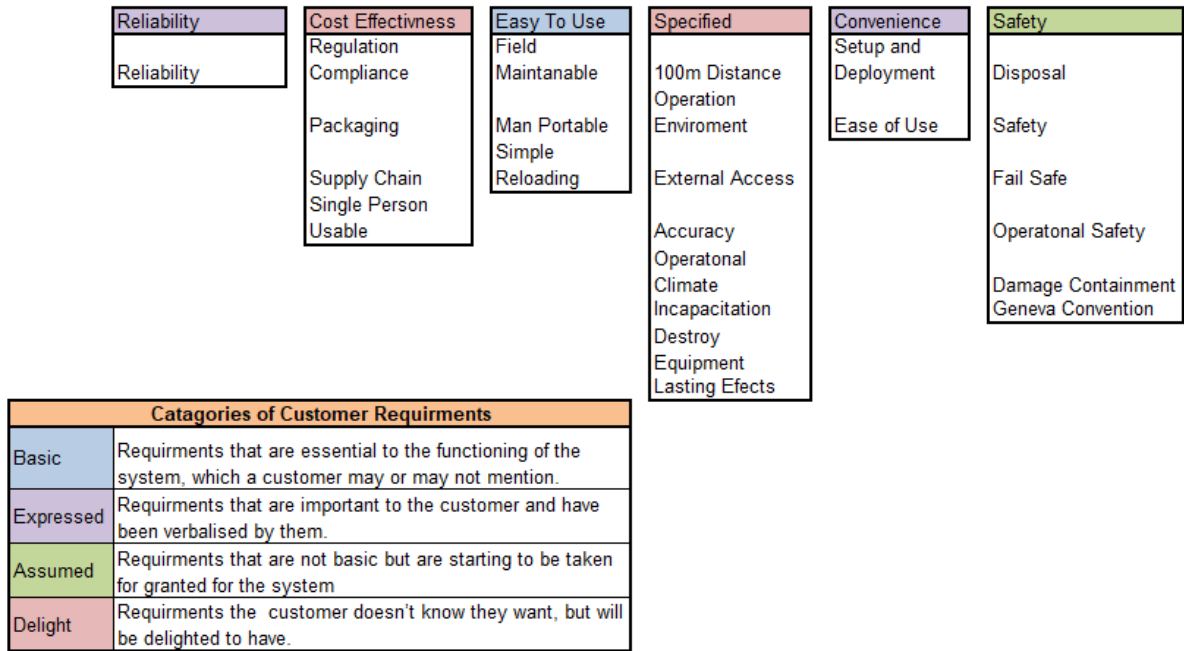


Figure 6 Affinity Diagram

Using these stakeholder identification tool sets, the whole system level stakeholder requirements were comprised, this can be found in Figure 7.

Stakeholder	Operational Requirement	Priority	Requirement Type	Level 2 Name	L2 Description
Customer	Deliver a Safe and Reliable Product to the customer at a competitive Price		NFS	Regulation Compliance	The system must comply with all relevant legislation,
Logistics	Deliver a Safe and Reliable Product to the customer at a competitive Price		OR	Packaging	The system should be packaged in standard packaging where possible
Logistics	Deliver a Safe and Reliable Product to the customer at a competitive Price	Old	NFS	Supply Chain	The munition shall be compatible with the existing Supply chain
1st Party (User)	Deliver a Safe and Reliable Product to the customer at a competitive Price		NFP	Field Maintainable	The system will be field maintainable where required.
1st Party (User)	Deliver a Safe and Reliable Product to the customer at a competitive Price		NFP	Reliability	The performance shall be reliable with failures of 1e-6 per year
Customer	Deliver a Safe and Reliable Product to the customer at a competitive Price		NFP	Operational Climate	The system shall perform in cold and hot climates A1 - C2
Customer	Deliver a Safe and Reliable Product to the customer at a competitive Price	Old		Fail Safe	The fail safes to ensure the system shall function in the event of a misfire
1st Party (User)	Deliver a Safe and Reliable Product to the customer at a competitive Price		1 NFS	Man Portable	The system shall be Man Portable
1st Party (User)	Deliver a Safe and Reliable Product to the customer at a competitive Price	Old		Single Person Usable	The system should be single person useable.
Customer	Neutralise the Target			Lasting Effects	The system should deliver a disruptive effect that will last no longer than 12h
Customer	Neutralise the Target		1 NFP	External Access	The entry to the room should be gained through an external wall
Customer	Neutralise the Target		1 NFP	Incapacitation	The Customer requires that the system should incapacitation or elimination of the Comms Users
1st Party (User)	Neutralise the Target		NFP	Simple Reloading	The system should have a simple unload / reload procedure
Customer	Neutralise the Target		NFP	100m Distance	The delivery system shall be able to perform from a minimum distance of 100m.
Customer	Neutralise the Target		NFP	Damage Containment	The damage be contained to the target room.
1st Party (User)	Neutralise the Target		F	Accuracy	The system must be accurate to a 0.25m radius at 100m.
1st Party (User)	Neutralise the Target			Setup and Deployment	The system shall have a Rapid setup and Deployment time.
Customer	Deliver a Safe and Reliable Product to the customer at a competitive Price			Operation Environment	The system shall be able to be used in multiple environments (Urban and Rural)
Customer	Neutralise the Target			Destroy Equipment	The system shall deliver a terminal effect.
Customer	Deliver a Safe and Reliable Product to the customer at a competitive Price			Operational Safety	The system must be safe under operational Conditions (Backblast, Signature etc)
1st Party (User)	Neutralise the Target			Ease of Use	The system shall be easy to use.
Customer	Deliver a Safe and Reliable Product to the customer at a competitive Price			Disposal	The system must have a safe disposal method.
Customer	Deliver a Safe and Reliable Product to the customer at a competitive Price			Safety	The system must be safe throughout the CADMID Cycle
New					

Figure 7 Customer and Stakeholder Initial Requirements

Pairwise comparison of requirements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Calc		Calc
1 = No Preference, Reciprocal = 1 2 = Slight Preference, Reciprocal = 0.5 5 = Preference, Reciprocal = 0.2 9 = Strong preference = 0.11	The customer required that the system comply with all relevant legislation	The logistics team require the system to be packaged in standard packaging where possible	The Logistics team require that the munition shall be compatible with the existing Supply chain	The customer requires the system to deliver a disruptive effect that will last no longer than 12h	The Customer required the entry to the room be gained through an external wall	The Customer Requires the incapacitation or elimination of 6 Comms Users	The User Requires the system be field maintainable where required	The User require a simple unload / reload procedure	The User require reliable performance with failures of 1e-6 per year	The customer requires the system to perform in cold and hot climates A1 - C2	The customer requires the delivery system to be able to perform from a distance of 100m Minimum	The customer requires the damage be contained to the target room	The customer requires fail safes to ensure system functionality in the event of a misfire	The User Requires the system to be portable with TIFT (Man Portable)	The User Requires the system be single person useable	The Customer Requires the system complies with the Geneva Suggestions	The system must be accurate to a 0.25m radius at 100m	Row Product	nth root of row product	Total Normalised
The customer required that the system comply with all relevant legislation	1	9	2	1	1	9	5	5	0.2	1	0.2	0.2	0.5	0.5	1	1	9	46.6	1.25354621	5.957934773
The logistics team require the system to be packaged in standard packaging where possible	0.11	1	1	1	5	0.11	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.11	0.11	10.24	1.146646129	5.449853217
The Logistics team require that the munition shall be compatible with the existing Supply chain	0.5	1	1	0.2	0.2	0.11	0.2	0.2	0.2	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.11	5.42	1.104527234	5.249667834
The customer requires the system to deliver a disruptive effect that will last no longer than 12h	1	1	5	1	0.2	0.2	0.2	0.2	0.11	0.11	0.11	0.11	0.2	0.2	0.2	0.1	0.11	10.05	1.145383559	5.443852393
The Customer required the entry to the room be gained through an external wall	1	0.2	5	5	1	2	9	9	9	9	5	5	9	9	9	2	2	91.2	1.30404871	6.197966296
The Customer Requires the incapacitation or elimination of 6 Comms Users	0.11	9	9	5	0.5	1	9	9	9	9	2	2	1	5	5	0.11	0.2	75.92	1.290057857	6.131469672
The User Requires the system be field maintainable where required	0.2	5	5	5	0.1	0.1	1	2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.11	0.11	20.02	1.192770008	5.669073744
The User require a simple unload / reload procedure	0.2	5	5	5	0.1	0.1	0.5	1	0.2	0.5	0.11	0.11	0.11	0.2	1	0.11	0.11	19.35	1.190384096	5.65773383
The User require reliable performance with failures of 1e-6 per year	5	5	5	9	0.1	0.1	5	5	1	1	1	1	9	9	9	0.11	1	66.31	1.279828295	6.082849953
The customer requires the system to perform in cold and hot climates A1 - C2	1	5	2	9	0.1	0.1	5	2	1	1	9	9	5	5	9	0.11	9	72.31	1.286366168	6.113923576
The customer requires the delivery system to be able to perform from a distance of 100m Minimum	5	5	5	9	0.2	0.5	5	9	1	0.1	1	1	1	9	9	0.11	1	61.91	1.274669794	6.058332298
The customer requires the damage be contained to the target room	5	5	5	9	0.2	0.5	5	9	1	0.1	1	1	1	5	5	0.11	1	53.91	1.264337158	6.009222686
The customer requires fail safes to ensure system functionality in the event of a misfire	2	5	5	5	0.1	1	5	9	0.1	0.2	1	1	1	5	5	0.11	9	54.51	1.265160598	6.013136381
The User Requires the system to be portable with TIFT (Man Portable)	2	5	5	5	0.1	0.2	5	5	0.1	0.2	0.1	0.2	0.2	1	1	0.11	0.11	30.32	1.222251393	5.809194764
The User Requires the system be single person useable	1	5	5	5	0.1	0.2	5	1	0.1	0.1	0.1	0.2	0.2	1	1	0.11	0.11	25.22	1.209081547	5.746600275
The Customer Requires the system complies with the Geneva Suggestions	1	9	5	9	0.5	9	9	9	9	9	9	9	9	9	9	1	1	116.5	1.322965698	6.287876166
The system must be accurate to a 0.25m radius at 100m	0.11	9	9	9	0.5	5	9	9	1	0.1	1	1	0.1	9	9	1	1	73.81	1.287920719	6.121312143
																		833.6	21.03994517	100

Figure 8 Pairwise Comparison



Figure 9 Pairwise Comparison Results Graph

Figure 7's results graph provides insights into the system's primary focus areas. Safety legislation and entry accuracy were identified as the top priorities, although all results were closely ranked. This indicates a well-balanced set of stakeholder concerns. These findings will be used to inform the identification of critical system functionalities in the next phase of the design process.

2.2 Critical system functionality.

The functional flow diagram is foundational for analysing how a design performs throughout its life cycle. From a safety perspective, this tool helped expose emergent behaviours system level outcomes that arise from the interaction of other subsystems. For example, during the detonation phase, we identified the potential for blast overpressure to reflect off internal soft block walls, potentially endangering areas beyond the target room. This early insight allowed us to consider blast-shaping and directional control solutions at the concept stage.

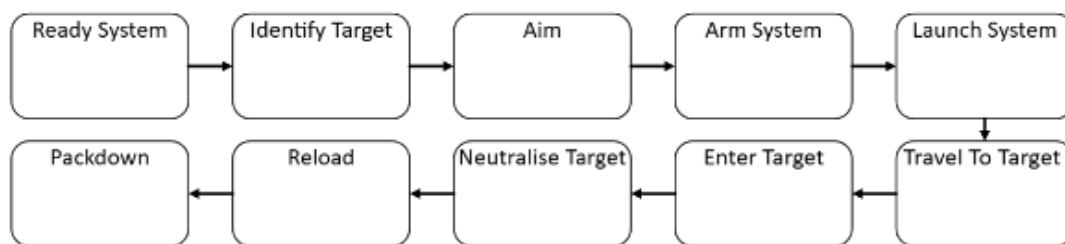


Figure 10 Standardised Functional Flow Diagram for Explosive Device

In QFD 1, Stakeholder requirements were translated into functional responses using a verb-noun format (e.g. “Arm weapon”, “Aim weapon”, “Neutralise target”). From the safety viewpoint, “Ready system”, was a high-priority function seen in Figure 11, due to operator protection there was a direct link to safety legislation. These results, weighted from pairwise comparisons, ensured that safety-critical functions received appropriate design emphasis and were not overshadowed by purely performance driven goals.

How	Importance	Ready System	Identify Target	Aim	Arm Weapon	Launch/ Release Munition	Arm Warhead	Travel to Target	Enter Target	Neutralise Target	Reload	Pack down	Add requirements detail and definition in here.
Requirements													
Regulation Compliance	4.7		1						3	9			
External Access	5.2		3	9				3	9	9			
Incapacitation	5.1								9	9			
Man Portable	4.9	9	1	3							9	9	
Packaging	4.6	3									3	3	
Lasting Effects	4.7								3	3			
Field Maintainable	4.9	3		1							3	3	
Simple Reloading	4.9	9									9	3	
Reliability	5.1	9	3	3	9	9	9	3	3	3	1	1	
Operational Climate	4.9	9	3	3	1			3			9	3	
100m Distance	5.2		3	3				9					
Damage Containment	5.1		3	1				3	9	9			
Accuracy	5.2			9				9	9				
Setup and Deployment	5.1	9		3							9	9	
Operation Enviroment	5.0	3	3	3				3	3	3			
Destroy Equipment	5.2								9	9			
Operational Safety	5.2	3				9		3			3	3	
Ease of Use	5.1	9	9	9							9	9	
Disposal	5.1						3		3	3		3	
Safety	4.9	3	1	3	3	1	9	1	1	1	3	3	
		343	151	254	65	97	105	190	311	292	288	244	
Target													
Benchmark													
Ideal Value													

Figure 11 QFD1 Whole system



Figure 12 QFD1 Functional Importance Results Graph

All functions identified in QFD 1 were put through a Functional Failure Means and Effects Analysis (FFMEA), using the five standard failure modes:

- **No Function**
- **Wrong Function**
- **Too Much Function**
- **Too Little Function**
- **Intermittent Function.**

In this section, particular focus is given to the highest-rated function from QFD 1, Ready System. Across all failure modes, the root cause was consistently identified as a faulty system or unit, with detection and prevention measures primarily attributed to either human factors (operator error) or design safeguards. From a safety perspective, these findings directly informed the design solutions section, ensuring that the Ready System function was treated as a critical risk area requiring robust fail-safes, clear user interfaces, and stringent manufacturing standards.

System Purpose		Neutralise Contents	O- Probability of Occurance		I: Very Rare > 10: Frequent						
			S- Severity of Occurrence		I: No Effect > 10: Most Severe						
		D- Probability of Detection		I: No Detection > 10: Certain Detection							
Owner	Function	Function Failure Mode	Effects					RPN	Design Sugestions/		
			On System	On Customer	S	Cause	O			Detection/ Prevention Method	D
LJ	Ready System	Too Much	Damage the System	Replacement repair cost	8	Unit error	8	Training	8	512	
			Premature initiation	Reputaional Damage / Death	9	System Failure	3	Design	9	243	
		Too Little	Failure to neutralise	Threat escalates to customer	9	System Familiarity	2	Training and design	9	162	
			Wrong target nutralised	Reputaional Damage	8	User Error	5	Training and Intel	7	280	
		No Supply	Threat escalates to customer	9	System Failure	3	Design	9	243		
			No System to Neutralise Mission Failed/ Loss of Life	Reputaional Damage	9	System Failure	3	Design	9	243	
		Wrong Supply	System will not initiate	Reputaional Damage	8	Unit error	8	Training	8	512	
			System Damage or Destruction	Financial Loss	7	System Failure	2	Human Factors	9	126	
		Intermittent	Unreliable System	Replacement repair cost	8	Unit error	8	Training	8	512	
			Mission may not be completed	Reputaional Damage	9	System Failure	3	Design	9	243	
DG	Enter Target	Too Much	Penetrate too far	More colateral damage	8	Over penetrative ability	3	Testing and Design	3	72	
			Overshoot	Unintended damage to civilian area	8	Over propulsion	3	Propulsion QC check	3	72	
		Too Little	Not able to penetrate the target	Mission failed, civilian damage	8	Little penetrative ability	3	Testing and Design	3	72	
			Fall short	Infrastructure damage	8	Under propulsion	3	Propulsion QC check	3	72	
		No Supply	Mission failed, Incorrect colateral damage	5	Run out	2	Organisation	8	80		
			Desired effect not achieved Delay in effect	Target may be moved	5	Damage to system	2	QC control	7	70	
		Wrong Supply	Wrong effect	Too great effect	8	Incorrect reload	2	Training	8	128	
			Wrong effect	Too little effect	8	Human error	2	Training	8	128	
		Intermittent	Increased cost in multiple systems required	5	Manufacturing defects	4	QC chacking	8	160		
			Unreliable effect	Manufacturing defects	8	Testing and Design	3	48			
LG	Neutralise Target	Too Much	Collateral Damage To System	User Death	10	Premature Ignition	8	Design	8	640	
			Death of 3rd Party	Bad Publicity	10	Excessive Payload	8	Design	7	560	
		Too Little	Subject to counter-battery fire	Mission Failed	9	Insufficient Payload	7	Design	8	504	
			Threat still present	Mission Fail	9	Insufficient Payload	7	Design	3	189	
		No Supply	Fail to initiate	Bad Reputation	8	Faulty Booster	6	Quality Control	3	144	
			Can't complete mission	Costs for Replacements	8	No Payload	7	Quality Control	7	392	
		Wrong Supply	Wrong munition for mission	Mission can't be conducted	8	Poor Logistics	4	Quality Control	7	224	
			Incompatible Ammunition	Costs for Replacements	6	Poor Logistics	4	Quality Control	7	168	
		Intermittent	Unknown success rate	Mission result in a superpos	7	Poor Guidance	6	Design / RnD / Quality Control	1	42	
			Loss in confidence in system	Costs for system improvements	10	Unreliability	5	Quality Control	10	500	

Figure 13 FFMEA On Whole System Pre-Concept

2.3 Concept derivation and design choices

A N² Functional analysis was conducted to compare generic functions against requirement categories, particularly emphasizing safety-critical interactions. This matrix allowed identification of where unsafe coupling might occur between functions, flagging areas where unintended behaviors or emergent safety risks could arise.

N2 Relation Graph - CH											Row Sum	Feature
Ready System	1	1	1	1					1		5	Ready System
	Identify Target	1		1		1					3	Identify Target
1	1	Aim		1		1					4	Aim
1			Arm Weapon	1	1		1	1			5	Arm Weapon
1	1	1		Launch	1	1	1	1			7	Launch Munition
1			1		Arm Warhead			1			3	Arm Warhead
	1	1	1	1		Travel to Target	1	1			6	Travel to Target
			1			1	Enter Target	1			3	Enter Target
			1		1		1	Neutralise Target			3	Neutralise Target
1									Reload		1	Reload
1				1					1	Pack down	3	Pack down
Column Sum	6	4	4	5	6	3	4	4	5	2	0	
Feature	Ready System	Identify Target	Aim	Arm Weapon	Launch/Release Munition	Arm Warhead	Travel to Target	Enter Target	Neutralise Target	Reload	Pack down	
Feature Sum	11	7	8	10	12	6	10	7	8	3	2	

Figure 14 N2 Functional Analysis (A)

N2 Relation Graph - DG												Feature
Ready System		system must be ready to be aimed	System must be ready to be aimed	Must be ready to launch					System must be ready to be reloaded	If system is ready must be packed down		Ready System
	Identify Target	Target must be identified to aim		Target must be identified to launch		must be identified to launch manually						Identify Target
System needs to be ready to aim	Target must be identified to aim	Aim		must be aimed to launch		Must be aimed to launch to target						Aim
System needs to be ready to be armed			Arm Weapon	Must be armed prior to launch	Weapon must be armed to arm warhead		Weapon need to be armed to deliver effect		Must be armed to deliver effect			Arm Weapon
System needs to be ready to launch	Target must be identified to launch	system must be launched if it is aimed		Launch	Must be armed to launch	must be launched to launch to target	Weapon must be launched to deliver target	System needs to be launched to neutralize target				Launch Munition
System needs to be ready to arm warhead				Weapon must be armed to arm warhead	Arm Warhead			Must be armed to deliver effect				Arm Warhead
	Target must be identified to launch manually	Target must be identified to launch manually	System must be armed to launch	Must be launched to deliver target		Travel to Target	Must be armed to launch to target					Travel to Target
			Must be armed to deliver target using the precision charge			Must be armed to launch to target	Enter Target	Must be armed to deliver target				Enter Target
			System must be armed to launch		Must be armed to launch to neutralize effect		Must be armed to launch to neutralize	Neutralize Target				Neutralize Target
Ready system to reload									Reload			Reload
If system is ready must be packed down				Launch pack down					Reloads must be packed down	Pack down		Pack down
Feature	Ready System	Identify Target	Aim	Arm Weapon	Launch	Arm Warhead	Travel to Target	Enter Target	Neutralize Target	Reload	Pack down	

Figure 15 N2 Functional Analysis (B)

Functional Means Analysis (FMA) was conducted, a divergent thinking approach was used to generate a wide range of possible design solutions for each function, before applying elimination criteria, seen in figures 28-30.

Function	Means											
Ready System	Hand Assemble Weapon	Telescopic	Tripod Launcher	Handheld	Unpack	Make Ready						
Identify Target	Manual Aiming	Laser Designator	GPS Location	Visual ID	Smoke Marker	Tracer	Estimate	AI Assisted				
Aim	Manual Aiming	Laser Designator	GPS	Visual ID In Optical Sight	Thermal	Wire Guided	Estimate	Telescope	FPV	AI Assisted	Tow Wire	
Arm Weapon	Mechanically	Electrical Controller	Pin	Switch	Program							
Launch/ Release Munition	Robot dog	Drone	Compressed gas launch	Air drop - glide	Sling Shot	Propellant Charge	Boost Rocket motor	Spring Loaded	Rail Gun	Hand Launch		
Arm Warhead	Mechanical	Electrical SAU	Timed Fuse	Setback	Rotational	Hydrostatic	Magnetic	Radiometric	None			
Travel to Target	Drone	Robot Dog	Gravity-assisted drop	Sustain Rocket motor	Fin stabilised	Glide	Teleport					
Enter Target	EFP	Kinetic Impact	Blast	Minor Frag	Sonic Shattering of window	Personel Infiltration	Gaseous					
Neutralise Target	Shock	Blast Warhead	Major Frag	Flame	Noise	Flash Bang	Water	EMP	Chemical	Gas		
Reload	single use / New unit	Breach loaded	Muzzle loaded	Transfer control unit	Magazine Fed							
Pack down	Collapsible Control Unit	Disposable	Throw it away-able	Single Use	Sling	Box	Back-Pack/Rucksack	Fold				

Figure 16 Functional Means Analysis Whole System

Elimination Criteria	
Elimination Reason	Description
Reliability	Unreliable will not be purchased
Cost	To expensive will become unafordable.
War Crime	Against the Geneva Convension
Collateral Damage	To much damage is unacceptable
Time	If employmet time is excessive it wont be used
Excessive Risk	Risk is not ALARP
Theoretical	Not Feasable

Figure 17 FMA Elimination Criteria

Designs were grouped based on similarities in operation, risk profile, or physical principles. This created the initial pool of concepts to be evaluated further.

Option	1	2	3	4	5	6
Function	EMP Device	Robot Dog	Shoulder Launched Missile	Drone	40mm Grenade	Glider
Ready System	Tripod Launcher	Un-pack	Hand Assemble Weapon	Un-pack	Shoulder launcher	Unpack
Identify Target	Laser Designator	Manual Aiming	GPS Location	Visual ID	Look Through Optic	GPS
Aim	Visual ID	Thermal	Visual ID In Optical Sight	FPV	Manual Aiming	Manual control
Arm Weapon	Electrical	Program	Electrical Controller	Pin	Safety Switch	Electronic
Launch/ Release Munition	Compressed gas launch	Robot dog	Boost Rocket motor	Sprin Release	Trigger	Slingshot
Arm Warhead	Setback	Timed Fuse	Eletrical SAU	Mechanical	Delayed Contact	Electrical
Travel to Target	Rocket motor	Robot Dog	Sustain Rocket motor	Drone	Ballastic Trajectory	Glide/ propeller
Enter Target	Shape Charge	Kinetic Impact	EFP	Sonic Shattering of Window	Go Through Window	Kinetic impact
Neutralise Target	EMP	Chemical	Blast Warhead	Blast/Frag/Gas (LSD)	Gas	Payload - blast
Reload	Transfer control unit	single use / New unit	single use / New unit	Magazine Fed	Breach Load	New unit
Pack down	Back-Pack/Rucksack	Single Use	Collapsible Control Unit	Back-pack/Ruck-sack	Sling	Single use
Elimination Reason	Theoretical				Reliability	Reliability

Figure 18 System Level Functional Means Analysis (FMA)

After applying the elimination criteria during the FMA stage, three viable design concepts remained. None of these were excluded on safety, regulatory, or functional grounds, making them suitable candidates for deeper comparative evaluation.

Each design was weighted against key system requirements identified earlier (e.g., safety, ease of use, regulatory compliance, accuracy).

WHATs - Requirement Title	Relative Importance Equal	Anti Structure Munition (A T4)	Robot Dog	Shoulder Launched Missile	Drone
Regulation Compliance	4.7	0	1	1	1
External Access	5.2	0	0	0	-1
Incapacitation	5.1	0	1	1	1
Man Portable	4.9	0	-1	1	1
Packaging	4.6	0	0	1	-1
Lasting Effects	4.7	0	1	0	0
Field Maintainable	4.9	0	-1	1	-1
Simple Reloading	4.9	0	-1	1	0
Reliability	5.1	0	0	0	0
Operational Climate	4.9	0	0	0	0
100m Distance	5.2	0	0	1	0
Damage Containment	5.1	0	1	1	1
Accuracy	5.2	0	1	1	1
Setup and Deployment	5.1	0	1	1	0
Operation Environment	5	0	0	0	0
Destroy Equipment	5.2	0	0	1	1
Operational Safety	5.2	0	1	0	0
Ease of Use	5.1	0	1	0	-1
Disposal	5.1	0	1	0	1
Safety	4.9	0	1	0	0
Ranking		0	35.51	54.96	15.67

Figure 19 Pugh Diagram

The **shoulder-launched missile design** scored highest in the Pugh diagram, offering the best balance of safety, accuracy, and operational control. It was therefore selected for further development and taken forward to the design development phase.



Figure 20 Whole System Design Sholder Launched Missile

QFD 2 mapped design parameters (the "how") to functional requirements (the "what") with specific attention to strong correlations along the leading diagonal. identify key design characteristics.

Design feature	QFD 1 Importance	QFD 2 Importance	Hand Assemble Weapon - Cotel Unit and Weapon Tube	GPS Target ID	Visual ID in Optical Sight	Arm Weapon : Electrical Controller Unit	Boost Rocket Motor	Electrical SAU	SustainRocket Motor	EFP	Blast Warhead	Consumable Missile Tube	Collapsible Control Unit	Functionality Detail
Ready Sysem	343	3.43	9			3		9				9	9	
Identify Target	151	1.51		9	9									
Aim	254	2.54	3	3	9									
Arm Weapon	65	0.65	3			9		9						
Launch/ Release Munition	97	0.97	3			3	9							
Arm Warhead	105	1.05					3	9						
Travel to Target	190	1.90		9	3		9		9					
Enter Target	311	3.11				9		9	3	9				
Neutralise Target	292	2.92				9		9			9			
Reload	288	2.88	9					9				9	1	
Pack down	244	2.44	9									9	9	
			91	38	42	73	29	126	26	28	26	79	56	

Figure 21 Whole System QFD2

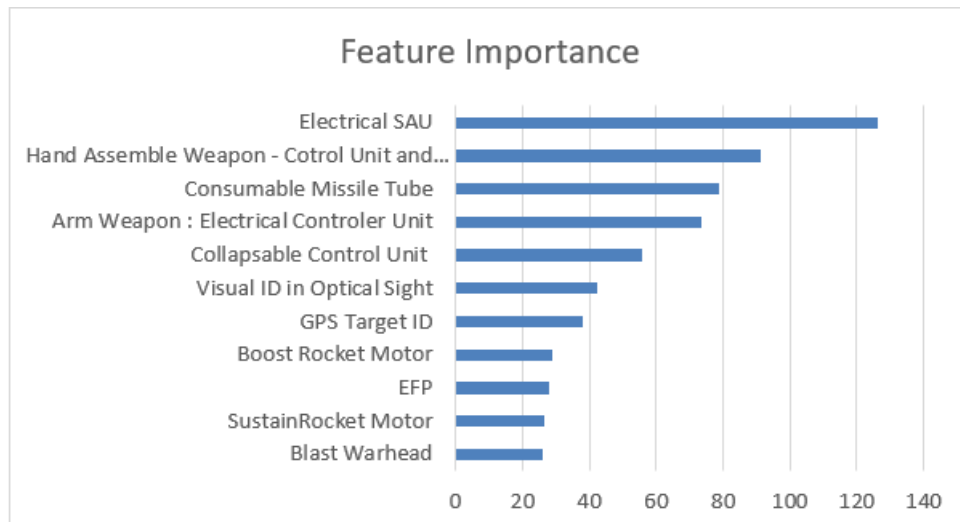


Figure 22 QFD 2 Whole System Results Graph

N2 Relation Graph - CH												Row Sum	Feature
Discardable Packaging										1	1	2	Discardable Packaging
	GPS Target ID	1										1	GPS Target ID
	1	Visual ID Through Optical Sight										1	Visual ID Through Optical Sight
	1		Arm Weapon: Electrical Control Unit	1	1	1		1				5	Arm Weapon: Electrical Control Unit
				Smart Rocket Motor	1	1						2	Smart Rocket Motor
			1	1	Electrical SAU	1	1	1				5	Electrical SAU
			1	1	1	Sustain Rocket Motor						3	Sustain Rocket Motor
			1		1		EPF	1				3	EPF
			1		1		1	Blunt Warhead				3	Blunt Warhead
				1					Canumable Missile Tube	1		2	Canumable Missile Tube
1									1	Collapsible Control Unit		2	Collapsible Control Unit
Column Sum	1	2	1	4	4	5	3	2	3	2	2		
Feature	Discardable Packaging	GPS Target ID	Visual ID Through Optical Sight	Arm Weapon: Electrical Control Unit	Smart Rocket Motor	Electrical SAU	Sustain Rocket Motor	EPF	Blunt Warhead	Canumable Missile Tube	Collapsible Control Unit		
Feature Sum	2	2	2	9	6	10	6	5	6	4	4		

Figure 23 N2 Solutional Analysis (A)

N2 Relation Graph - DG												Feature	
Discardable Packaging										Discardable Packaging	Control unit only pack done	Discardable Packaging	
	GPS Target ID	Visual ID is confirmed GPS coordinates are correct											GPS Target ID
	GPS ID is required to be able to get Visual ID	Visual ID Through Optical Sight											Visual ID Through Optical Sight
	Once GPS Target is confirmed weapons can be aimed		Arm Weapon: Electrical Control Unit	Rocket launcher used to provide initial ECU aimed	The ECU aims the electrical SAU	THE ECU aims the rocket motor		The ECU aims the blast warhead					Arm Weapon: Electrical Control Unit
				Smart Rocket Motor	SAU initiates the blast rocket motor	Provides propulsion and blast initiation analysis							Smart Rocket Motor
				ECU provides the SAU	Sekizash initiates warhead 2	Electrical SAU	Time duration safety feature 3	Ignites EPF	Ignites Warhead				Electrical SAU
				SAU initiates the blast rocket motor	Provides propulsion and blast initiation analysis	Time duration safety feature 3	Sustain Rocket Motor						Sustain Rocket Motor
				Arms the EPF		Arms EPF		EPF	Payloads				EPF
				Arms warhead		Arms Warhead		Payloads	Blunt Warhead				Blunt Warhead
										Canumable Missile Tube	Eng Inoperational		Canumable Missile Tube
										Eng Inoperational	Collapsible Control Unit		Collapsible Control Unit
Feature	Discardable Packaging	GPS Target ID	Visual ID Through Optical Sight	Arm Weapon: Electrical Control Unit	Smart Rocket Motor	Electrical SAU	Sustain Rocket Motor	EPF	Blunt Warhead	Canumable Missile Tube	Collapsible Control Unit		

Figure 24 N2 Solutional Analysis (B)

The results from QFD 2 and the solution-based N² analysis were used to cross-reference key system designs. Both independently identified the Safety and Arming Unit (SAU) as the critical sub-system, confirming its importance in achieving safe and controlled operation.

Once QFD 2 and the solution-based N² analysis confirmed the SAU as the critical sub-system, the systems engineering toolsets were repeated at the sub-system level to ensure safety was maintained in design and manufacture.

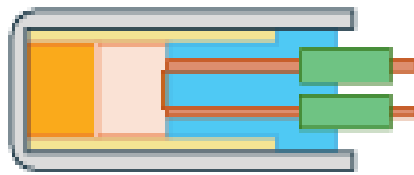


Figure 25 Critical Sub-system, Safety Arming Unit (SAU)

2.1 Potential failure modes.

2.1.1 Whole System Failure Mode

The overall system was designed to meet the customer requirement for man-portability, but this introduced significant safety concerns. During the FFMEA of the mounting system, the human factor was identified as a major risk. The worst-case scenario was an unintended detonation resulting from the mount being dropped while loaded.

Failure Mode and Effects Analysis (FMEA) is a structured process for identifying failures and potential risks in a product or process during the phase of design development [5].

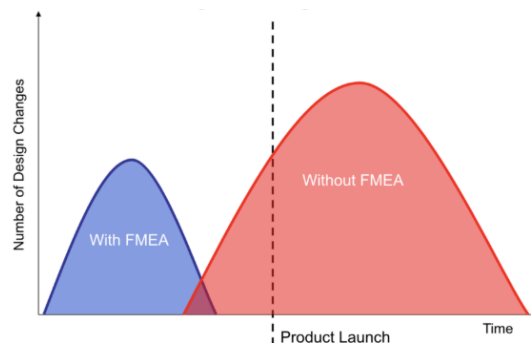


Figure 26 Design and Development Process [5]

System Purpose		Neutralise Contents	O- Probability of Occurrence				1: Very Rare > 10: Frequent					
			S- Severity of Occurrence				1: No Effect > 10: Most Severe					
			D- Probability of Detection				1: No Detection > 10: Certain Detection					
Owner	Function		Function Failure Mode	Effects								
			On System	On Customer	S	Cause	O	Detection/ Prevention Method	D	RPN	Design Suggestions/ Comment	
LI	Push fit Mount	Too Much	Disform connector elements, not connect, fail to ground or system failure	detonates unpredictably or fails to follow its launch sequence correctly, compromising mission effectiveness and safety	10	Human Error, Design safety	10	Incorporate automated system checks that alert operators if the current supply is missing.	4	400	Uni Directional Fit	
		Too Little	Insufficient pressure might fail to mount, fail to ground	detonates unpredictably or fails to follow its launch sequence correctly, compromising mission effectiveness and safety	10	Human Error, Design safety	10	Training Procedures to minimise the safety risk and a new design that gravity does not effect	4	400	No current Detection/ Preventative measures in place. Requirement: System needs to be designed to allow the appropriate signal input.	
		No Supply	Without any connection , system will fail to preform	mission failure and severe implications This may result in a missile that launches incorrectly, fails to detonate, or exhibits reduced performance, leading to potential mission risks and diminished customer confidence in the product's safety and reliability.	8	Human Error, Design safety	6	Incorporate automated system checks that alert operators if the	10	480	Training Protocols	
		Wrong Supply	Could be fit at wrong angle, causing damage to unintended target	This may result in a missile that launches incorrectly, fails to detonate, or exhibits reduced performance, leading to potential mission risks and diminished customer confidence in the product's safety and reliability. Customers could face a missile that behaves unpredictably, with variable performance parameters that undermine confidence in the system's operational reliability and safety.	8	Human Error, Design safety	6	Uni Directional Fit	4	192	Uni Directional Fit	
		Intermittent	An erratic or unstable cnection can lead to unpredictable performance. This may cause inconsistent ignition or partial initiation, affecting the missile's performance and reliability.		6	Human Error, Design safety	7	Vibration-resistant Locking	3	126	Uni Directional Fit	

Figure 27 Push to Fit Mount FFMEA

System Purpose		Neutralise Contents	O- Probability of Occurrence			1: Very Rare > 10: Frequent						
			S- Severity of Occurrence			1: No Effect > 10: Most Severe						
			D- Probability of Detection			1: No Detection > 10: Certain Detection						
			Effects									
Owner	Function	Function Failure Mode	On System	On Customer	S	Cause	O	Detection/ Prevention Method	D	RPN	Design Suggestions/ Comments	
U	Dove Tail Mount	Too Much	No Effect , system will stop at aprpriate fit pressure	Secure lock	1	Human Error, Design safety	1	Training Procedures introduced	10	400	Uni Directional Fit	
		Too Little	Insufficient pressure might fail to mount, fall to ground	detonates unpredictably or fails to follow its launch sequence correctly, compromising mission effectiveness and safety	10	Human Error, Design safety	5	minimise impact detonation	10	150	SAU to be non impact initiated	
		No Supply	Without any conection , system will fail to preform	mission failure and severe implications	10	Human Error, Design safety	0	Incorporate automated system checks that alert operators if the current supply is missing as well as personnel checks and training.	10	100	Training Protocols	
		Wrong Supply	No Effect , system will only fit one way	Secure lock	10	Human Error, Design safety	0	Uni Directional Fit	10	100	Training Protocols	
		Intermittent	No Effect , system will only fit one way	Secure lock	11	Human Error, Design safety	1	Uni Directional Fit	10	100	Training Protocols	

Figure 28 Dove Tail Mount Fit FFMEA

To address this, we applied the **hierarchy of controls** [6]:

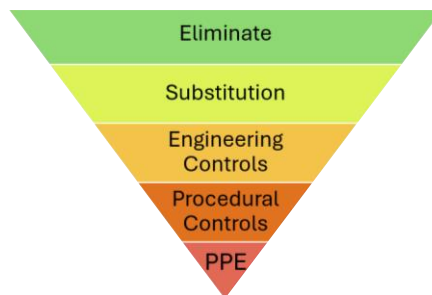


Table 3 Hierarchy of Controls [7]

- **Elimination** was not feasible, removing the mount would prevent the system from meeting customer requirements for single person usable as the complete unit would be too heavy for a single operator.
- **Substitution** was implemented by changing the mount interface from a push-fit to a dovetail system, significantly improving security and alignment under field conditions.

This design change was re-evaluated through FFMEA and showed a clear reduction in failure modes related to accidental dislodging or improper mounting.

- **Engineering Controls** were also considered, including built-in locking features and shock-absorbing elements to reduce risk during firing.
- **Administrative Controls** such as standardised loading procedures dual personnel checks and user training were proposed to mitigate remaining risks.
- Finally, **PPE** (e.g., Body Armour and blast shields during assembly) serves as the last layer of defence.

By utilising the hierarchy of controls, the reduction of Risk Priority Number (RPN) was 748, calculated as a product of severity, likelihood, and detectability, demonstrating improved system safety.

OCCURRENCE RATINGS			
Rating	Description	Criteria	Probability of Failure
1	Remote Occurrence	Failure highly unlikely to occur. History of similar design satisfactory with no failures	1 in 1,500,000
2	Very Slight Occurrence	Failure very unlikely to occur. History of very few failures	0.000067
3	Slight Occurrence	Very few and infrequent failures	0.000067
4	Low Occurrence	Few and infrequent failures may be expected	0.0005
5	Medium Occurrence	Some failures likely, but not in major proportions	0.0025
6	Regular Occurrence	Regular failures may be expected	0.0125
7	Moderately High Occurrence	Frequent failures may be expected	0.05
8	High Occurrence	Failure of major proportions may be expected	0.125
9	Very High Occurrence	Frequent failures. History of similar design issues	0.33
10	Extremely High Occurrence	Constant failure	0.5

Figure 29 FFMEA Occurrence Key

PREVENTION/DETECTION RATINGS		
Rating	Description	Criteria
1	Remote probability of failure reaching the user	A known prevention/detection method exists for similar systems with a strong history of excellent performance and is included in the system requirements
2	Very Slight probability the failure mode will reach the user	A known prevention/detection method exists for similar systems and is included in the system requirements
3	Slight probability the failure mode will reach the user	A known and robust prevention/detection method exists for other systems and is included in the system requirements
4	Low probability the failure mode will reach the user	A known prevention/detection method exists for other systems and is included in the system requirements
5	Medium probability the failure mode will reach the user	A known and robust prevention/detection method exists for other systems but is not included in the system requirements
6	Moderately probability the failure mode will reach the user	A known prevention/detection method exists for other systems but is not included in the system requirements
7	Moderately High probability the failure mode will reach the user	An experimental prevention/detection method exists for other systems and is included in the system
8	High probability the failure mode will reach the user	An experimental prevention/detection method exists for other systems but is not included in the system
9	Very High probability the failure mode will reach the user	No known prevention/detection method but functionality is included in the system requirements
10	It is certain that the failure mode will reach the user	No known prevention/detection method and no requirement to do so specified

Figure 30 FFMEA Prevention/ Detection Key

Severity	
Rating	Definition
1	Failure of subsystem system, No injuries
2	Failure of system, No Injuries
3	Failure of subsystem system, Minor injuries
4	Failure of system, Minor Injuries
5	Loss of capability, No injuries
6	Loss of capability, Minor injuries
7	Catastrophic failure, Hospitalisation of casualties
8	Catastrophic failure, Multiple life changing
9	Catastrophic failure, Single Death
10	Catastrophic failure, Multiple Deaths

Figure 31 FFMEA Severity Key



Figure 32 Push to Fit Mount Whole System Design

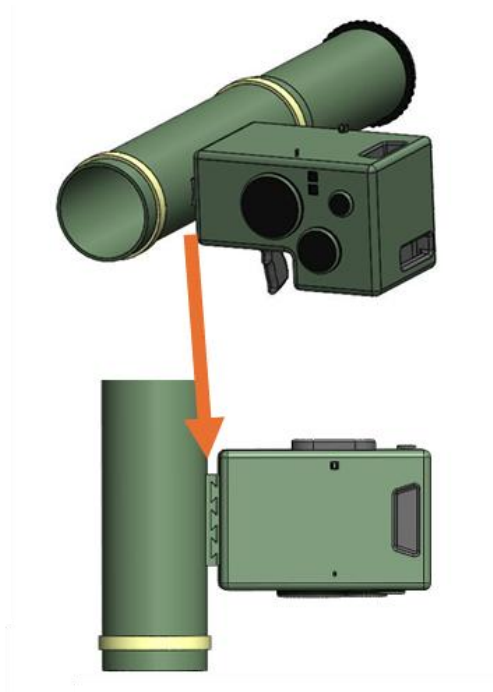


Figure 33 Dove Tail Fit Mount Whole System Design

2.2 Critical design features.

2.2.1 Sub-System SAU Engineering Tools

Stakeholder	Operational Requirement	Priority	Requ	Level 2 Name	L2 Description	Level 3 Name	Level 3 - Sub System Description
Customer	Product to the customer at a competitive Price		NFS	Regulation Compliance	The system must comply with all relevant legislation	Regulation Compliance	The SAU must comply with all relevant legislation, including DSA 03
Logistics	Product to the customer at a competitive Price		OR	Packaging	The system should be packaged in standard packaging where possible	H83 Container	The SAU shall fit inside a H83 Container
1st Party (User)	Product to the customer at a competitive Price		NFP	Field Maintainable	The system will be field maintainable where required.	External Safety Check	The SAU shall have an external safety check procedure.
1st Party (User)	Product to the customer at a competitive Price		NFP	Reliability	The performance shall be reliable with failures of 1e-6 per year	Reliability	The SAU shall be reliable with performance failures of 1e-8 Per Use
Customer	Product to the customer at a competitive Price		NFP	Operational Climate	The system shall perform in cold and hot climates A1 - C2	Operating Temperature	The SAU shall have an operating temperature of 30 to + 40
Customer	Product to the customer at a competitive Price	Old		Fail Safe	The fail safes to ensure the system shall function in the event of a misfire	Fail Safe	The SAU shall fail safe in the event of miss sequence of safety events
1st Party (User)	Product to the customer at a competitive Price		1 NFS	Man Portable	The system shall be Man Portable	Weight (500g)	The SAU shall weigh no more than 500g
Customer	Neutralise the Target			Lasting Effects	The system should deliver a disruptive effect that The entry to the room should be gained through	System Initiation Charge Initiation	The SAU shall support the initiation of the
Customer	Neutralise the Target		1 NFP	External Access	The delivery system shall be able to perform from a minimum distance of 100m.		The SAU shall be able to initiate the primary and Devices to detect setback and Time duration since set back.
Customer	Neutralise the Target		NFP	100m Distance	The system must be safe under operational Conditions (Backblast, Signature etc)	Safety Devices operational conditions	The SAU must be safe under all operational conditions
Customer	Product to the customer at a competitive Price			Disposal	The system must have a safe disposal method.	Disposal	The SAU must have a safe disposal method that supports refurbishment
Customer	Product to the customer at a competitive Price			Safety	The system must be safe throughout the CADMID Cycle	Safety	The SAU must be safe throughout the CADMID cycle
Customer	Product to the customer at a competitive Price	From FFMEA		Safety	Quality Assurance Checks must be carried out during all stages of manufacture	QA Checks	Quality Assurance Checks must be carried out during all stages of manufacture
		From FFMEA	FP	FTB Intergration		FTB Intergration	The SAU shall mechanically intergrate with the FTB
		From FFMEA	FP	Missile Intergration		Missile Attachment	The SAU shall mechanically intergrate with the Missile
		From FFMEA	NFP	Manufacturing QC Checks			The Manufacturing of the SAU shall contain sufficient QC Checks
		From FFMEA		SAU Connector		SAU Connector	The SAU Shall have a connector that is compliant with the Mil Standards and ESD

Figure 34 SAU Stakeholder Requirements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Calc		Calc	
	Regulation Compliance	Charge Initiation	Disposal	External Safety Check	Fail Safe	FTB Integration	H83 Container	Removed (NA)	Missile Attachment	Operating Temperature	QA Checks	Reliability	Safety	Safety Shear Devices	Safety in operational conditions	SAU Electrical Connector	System Initiation	Weight (500g)	Row Product	nth root of row product	Total Normalised	
1	Regulation Compliance	1	9	1	0.1	1	9	9	1	0.5	0.5	0.1	0.1	1	0.2	0.5	1	0.1	9	44.1	1.2084312	5.617108299
2	Charge Initiation	0.1	1	9	9	9	9	9	1	9	9	9	9	0.5	0.2	9	9	1	9	111.8	1.26596614	5.884545943
3	Disposal	1	0.1	1	0.1	0.1	0.2	0.2	1	2	0.2	0.1	0.1	0.1	0.1	9	0.1	2	17.5	1.15385677	5.363431893	
4	External Safety Check	9	0.1	9	1	1	5	9	1	5	5	1	0.1	1	1	5	5	0.2	1	59.4	1.226561482	5.701382653
5	Fail Safe	1	0.1	9	1	1	9	9	1	1	2	2	1	1	1	1	9	1	1	51.1	1.217365655	5.658638013
6	FTB Integration	0.1	0.1	5	0.2	0.1	1	5	1	5	9	2	1	0.2	5	5	9	1	2	51.7	1.218076395	5.661941722
7	H83 Container	0.1	0.1	5	0.1	0.1	0.2	1	1	2	0.5	1	0.5	0.5	0.2	0.2	0.5	0.2	13.4	1.138558212	5.292320143	
8	Removed (NA)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	1.155483173	5.370991845	
9	Missile Attachment	2	0.1	0.5	0.2	1	0.2	0.5	1	1	2	2	0.5	0.5	2	5	1	0.5	5	25	1.174618943	5.459939974
10	Operating Temperature	2	0.1	5	0.2	0.5	0.1	2	1	0.5	1	2	1	0.2	0.1	0.5	0.5	0.5	22.2	1.167663349	5.427608532	
11	QA Checks	9	0.1	9	1	0.5	0.5	1	1	0.5	0.5	1	1	0.2	0.1	0.2	0.2	0.2	26.5	1.178046121	5.475870406	
12	Reliability	9	0.1	9	9	1	1	2	1	2	1	1	1	0.2	0.5	1	0.5	0.5	2	41.8	1.205199143	5.602084842
13	Safety	1	2	9	1	1	5	2	1	2	5	5	5	1	1	5	5	0.5	2	53.5	1.220162544	5.671638695
14	Safety Shear Devices	5	5	9	1	1	0.2	5	1	0.5	9	9	2	1	1	1	5	0.5	5	61.2	1.228393674	5.709899165
15	Safety in operational conditions	2	0.1	9	0.2	1	0.2	5	1	0.2	2	5	1	0.2	1	1	0.1	1	2	32	1.189207115	5.527749661
16	SAU Electrical Connector	1	0.1	0.1	0.2	0.1	0.1	5	1	2	5	2	0.2	0.2	9	1	0.1	5	33.1	1.191218418	5.537098731	
17	System Initiation	9	1	9	5	1	1	2	1	2	2	5	2	2	2	1	9	1	9	64	1.231144413	5.722685332
18	Weight (500g)	0.1	0.1	0.5	1	1	0.5	5	1	0.2	0.2	2	0.5	0.5	0.2	0.5	0.2	0.1	1	14.6	1.143451222	5.315064149
																			740.9	2151040391	100	

Figure 35 SAU Pairwise

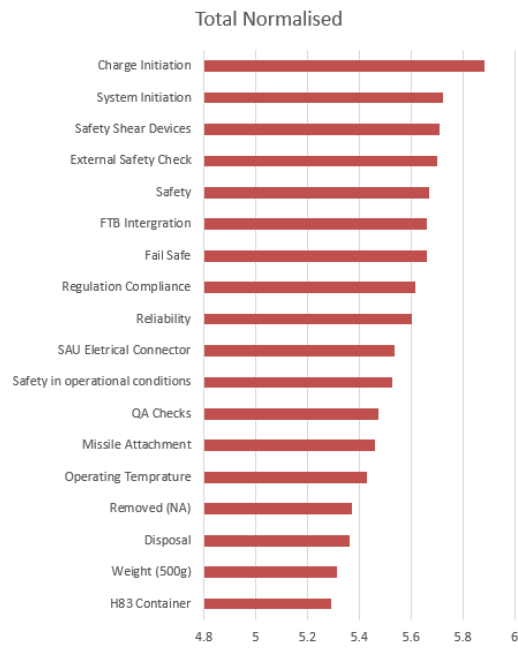


Figure 36 SAU Pairwise Results Graph

Level 1	
SAU	Contain Components
	Protect Componets
	Electronic Circuirty
	Safety Conformation
	Sequential Safety Device 1
	Sequential Safety Device 2
	Sequential Safety Device 3
	Power Buffer
	Delay Second detonation
	Provide PC Initiation
	Provide FTB Initiation
	Receive Electronic Inputs
	FTB Interface
	Missile Structure Interface

Figure 37 SAU Required Functionality

[illegible]

Figure 38 SAU QFD1

The SAU's generic functionalities were identified (e.g., safe arm/disarm, fail-safe initiation) and mapped it against filtered requirements, translated to the component level. Requirements were ranked using a pairwise comparison, revealing the most critical SAU functions were from a safety viewpoint.

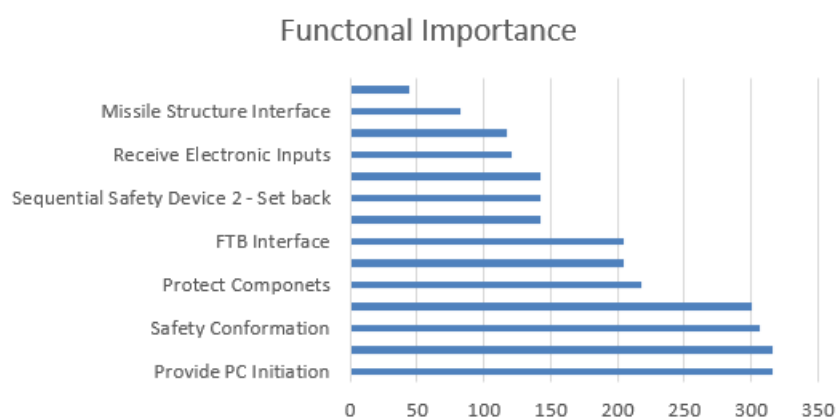


Figure 39 SAU QFD1 Results Graph Functional Importance

System Purpose		Neutralise Contents	O- Probability of Occurance		1: Very Rare > 10: Frequent						
			S- Severity of Occurrence		1: No Effect > 10: Most Severe						
			D- Probability of Detection		1: No Detection > 10: Certain Detection						
Owner	Function	Function Failure Mode	Effects					RPN	Design Sugestions/ Comments		
			On System	On Customer	S	Cause	O			Detection/ Prevention Method	D
LJ	Contain Components	Too Much	may not get sufficient input	System is not armed	9	Material Expansion	1	Material Conformation Tests	9	81	No current Detection/ Preventative measures in place. Requirement: System needs to be designed to allow the aproprate signal input.
		Too Little	Doesn't make complete sub-system	System not as intended	10	Design defects	1	QA Checks	9	90	
		No Supply	No SAU	System would not deliver effect.	10	Design defects	1	NA	10	100	
		Wrong Supply	System not as intended	Not able to deliver effect	10	Human Factors, Resorsing limitations	1	Incorrect Fitment	10	100	
		Intermittent	System not as intended	Not able to deliver effect	9	Human Factors, Resorsing limitations	1	Incorrect Fitment	7	63	
DG	Protect Compone	Too Much	Too much weight in the SAU	Decreased portability	1	Too much material in case	1	Testing	7	7	Material testing
		Too Little	Components break fail in ignition	Misson failure	7	Case is too weak	1	Testing	7	49	Material testing
		No Supply	Components break fail in ignition	Misson failure	7	No case No protection	1	QC	10	70	
		Intermittent	Intermittent ignition	Reputational damage	7	Intermittent damage	1	Testing	9	63	
LG	Circuitry	Too Little	No Power to Components	No Function	10	Not enough circuitry to carry power	1	Design / Quality Control	10	100	Robust Q&A assessment
			No Interaction between Components	Incomplete Weapon Functionality	8	Not enough circuitry to carry power	1	Design / Quality Control	10	80	Robust Q&A assessment
		No Supply	No Power to Components	No Function	10	No Circuitry	1	Design / Quality Control	10	100	Robust Q&A assessment
		Wrong Supply	No Power to Components	No Function	10	Incompatible Power Supply	1	Design / Quality Control	10	100	Robust Q&A assessment
			Component Damage	No Function	10	Power Surge	1	Design / Quality Control	10	100	Robust Q&A assessment
RM	Safety Conformation	Too Much	Result too high	Unsafe	10	Damage to component	3	Robust Design	10	300	
		Too Little	Result too low	Unsafe	10	Damage to component	5	Robust Design	10	500	
		No Supply	No result	Damaged component	10	Damage to component	4	Robust Design	10	400	
		Wrong Supply	Result too high	Unsafe	10	Damage to component	3	Robust Design	10	300	
			Result too low	Unsafe	10	Damage to component	3	Robust Design	10	300	
		Intermittent	Varying Results	Unreliable and unsafe	10	Damage to component	6	Robust Design	10	600	

Figure 40 SAU FFMEA

Each SAU functions were assessed for potential failures highlighting the need for robust human-factor controls and error detection in arming operations, further analysis can be found in section 2.3.

Function	Means						
Contain Components	Cylinder	Inerlocking Plates	Conical	Resin encased	Metal Case	Plastic Case	Cast
Protect Componets	Rubber Filling	Shock Absorbing Pads	Custom Case	Shock Gel	Suspended/Spring	Resin/Rubber mould	
Electronic Circuirty	PCB Board	Inline	Surface Mount PCB	Single Sided PCB	Mechanical		
Safety Conformation	Interlocking	Series	Parallel	Eletrical	Resistance Check	Built In Test	Pins
Sequential Safety Device 1 - Controler Safety Conformation	Switch	Magnet	Software Resistance Check	Relay	Singe Activation Switch	Compliant Mechanism	MOSFET
Sequential Safety Device 2 - Set back	Inertial	Mechanical Tilt Sensor	Compliant Eletrical Mechanism	MOSFET			
Sequential Safety Device 3 - Time delay	Slow burn pyro	Electronic	Delay Composition	Capacitor Disscharge linked to Relay	Mechanical Timer	MOSFET	
Power Buffer	Capacitor	Battery	Impulse/storage	Inertial Storage	NA		
Delay Second detonation	chemical delay	pyrotechnic composition	electronic signal	Capacitor	Mechanical Timer		
Provide PC Initiation	Stab	Chemical	EBW	Det Cord			
Provide FTB Initiation	Stab	Chemical	EBW	Det Cord	HE Booster		
Receive Electronic Inputs	Mil Stan Contacts	Impact	Stab	Shock	NA		

Figure 41 SAU FMA

Elimination Criteria	
Elimination Reason	Description
Reliability	Unreliable will not be purchased
Cost	Too expensive will become unaffordable.
Inefective	
Impractical	
Time	If employment time is excessive it wont be used
Excessive Risk	
Theoretical	
EMR Vulnerable	
Chosen Option	

Figure 42 SAU Elimination Criteria

Point Det Fuze	Mechanical SAU	Eletrical SAU
Conical	Conical	Metal Case
Custom Case	Custom Case	Rubber Filling
Mechanical	Mechanical	Single Sided PCB
Interlocking	Interlocking	Resistance Check
Switch	Switch	Software Resistance Check
Inertial	Mechanical Tilt Sensor	Compliant Eletrical Mechanism
Delay Composition		Capacitor Disscharge linked to Relay
NA	NA	Capacitor
pyrotechnic composition	Mechanical Timer	pyrotechnic composition
Stab	Stab	EBW
HE Booster	HE Booster	HE Booster
NA	NA	Mil Stan Contacts

Figure 43 SAU Design Options

WHATs - Requirements	QFD 1	Mechanical SAU	Electrical SAU	Point Det Fuze (Default)
Contain Components	182	0	0	0
Protect Componets	189	0	1	0
Electronic Circuitry	293	0	1	0
Safety Conformation	268	1	1	0
Sequential Safety Device 1 - Controler Safety Conformation	130	0	0	0
Sequential Safety Device 2 - Set back	130	0	0	0
Sequential Safety Device 3 - Time delay	130	0	0	0
Power Buffer	39	0	1	0
Delay Second detonation	101	0	0	0
Provide PC Initiation	282	0	0	0
Provide FTB Initiation	282	0	0	0
Receive Electronic Inputs	109	0	1	0
Ranking		268	898	0

Figure 44 SAU Pugh Diagram

The SAU design options were identified through the Functional Means Analysis (FMA) and compared using a Pugh diagram. This allowed for an evidence-based selection process, ensuring the chosen Electrical SAU best met safety and integration needs. The tool helped link system requirements directly to design choice, reducing bias and supporting a traceable, and a safe-by-design approach.

N2 Solution Graph - CB														Ranking	Feature
Problem	Contain Components	Protect Components	Electronic Circuitry	Safety Conformation	Sequential Safety Device 1: Controller Safety Conformation	Sequential Safety Device 2: Setback	Sequential Safety Device 3: Time Delay	Power Buffer	Delay Second Detonation	Provide PC Initiation	Provide FTB Initiation	Receive Electronic Inputs			
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 45 SAU N2 Functional Analysis (A)

N2 Relation Graph - BG													Failure
Control Component	The timing profile of the control component												Control Component
The timing profile of the control component	Control Component	1	Predefined the response time of the control component										Control Component
1	Electronic Circuitry	The electronic circuitry of the control component	Initial delay safety delay				Electronic not back up	Capacitor time delay	Power buffer			Hard electronic input	Electronic Circuitry
Predefined the response time of the control component	The electronic circuitry of the control component	Safety Confirmation	Initial delay safety delay	Initial delay safety delay	Initial delay safety delay					Safety must be completed before PC	Safety must be completed before FTB		Safety Confirmation
Initial delay safety delay	Initial delay safety delay	Sequential Safety Device 1 - Controller Safety Confirmation	Initial delay safety delay	Initial delay safety delay	Initial delay safety delay								Sequential Safety Device 1 - Controller Safety Confirmation
		Sequential Safety Device 2 - Set back		Sequential Safety Device 2 - Set back	Sequential Safety Device 2 - Set back								Sequential Safety Device 2 - Set back
		Sequential Safety Device 3 - Time delay		Sequential Safety Device 3 - Time delay	Sequential Safety Device 3 - Time delay								Sequential Safety Device 3 - Time delay
	Capacitor time delay						Power Buffer	Power Buffer					Power Buffer
	Power buffer						Power Buffer	Power Buffer					Power Buffer
										1			
		Safety must be completed before PC								Provide PC	Delayed for FTB to initiate the building	Electronic input	Provide PC
		Safety must be completed before FTB								Provide FTB	Delayed for FTB to initiate the building	Electronic input	Provide FTB
	Hard electronic input									Electronic input	Electronic input	Electronic input	Electronic input
Failure	Control Component	Control Component	Electronic Circuitry	Safety Confirmation	Sequential Safety Device 1 - Controller Safety Confirmation	Sequential Safety Device 2 - Set back	Sequential Safety Device 3 - Time delay	Power Buffer	Power Buffer	Provide PC	Provide FTB	Electronic input	Electronic input

Figure 46 SAU N2 Functional Analysis (B)

Design feature	Importance	Metal Case	Rubber Filling	Single Sided PCB	Resistance Check	Software Resistance Check	Compliant Electrical Mechanism	Capacitor Discharge linked to Rel	Capacitor	pyrotechnic composition	EBW	HE Booster	Mil Span Contacts	
Functionality														9 - Definite Relationship 3 - Slight relationship 1 - Small Relationship
Contain Components	10	9	9	9						1		1	1	Functionality Detail
Protect Components	10	9	9	1										
Electronic Circuitry	10				9	9	9	9	9		9		9	
Safety Confirmation	10					3	3	3	3	3	9	3		
Sequential Safety Device 1 - Controller Safety Confirmation	10				9	9	9	3	3	1	9	1	9	
Sequential Safety Device 2 - Set back	10					3	1	1						
Sequential Safety Device 3 - Time delay	10			1		1	3	3	9					
Power Buffer	10			1		1	9	9						
Delay Second detonation	10			1		1	9	9						
Provide PC Initiation	10			1		3	1	1		9	3			
Provide FTB Initiation	10			1		3	1	1		9	3			
Receive Electronic Inputs	10			9	9	9	9	9	9	9				
	10													
		180	180	240	270	300	420	480	450	140	540	110	190	0
Target														
Benchmark														
Ideal Value														
How Much???														

Figure 47 SAU QFD 2

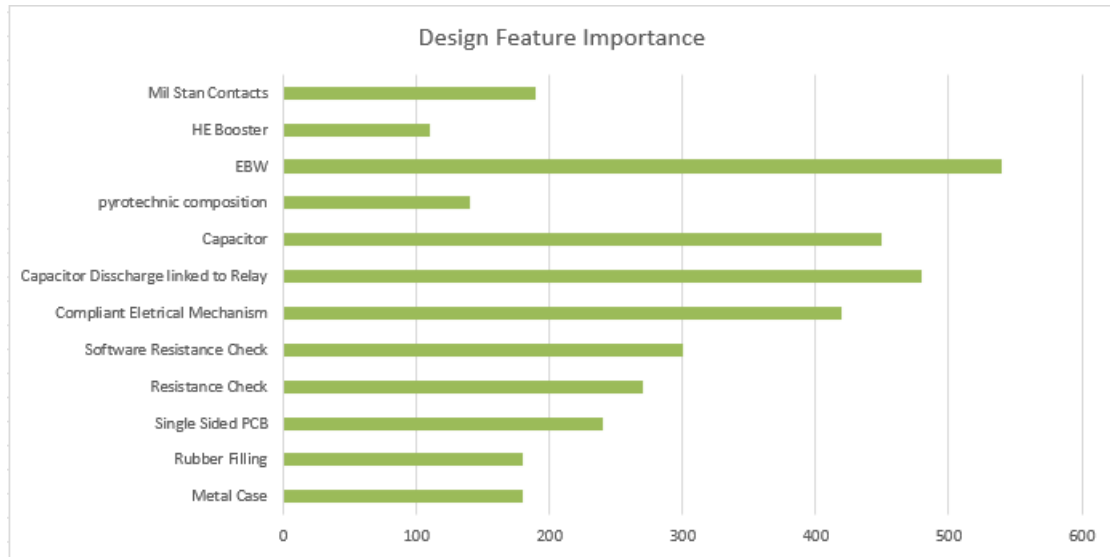


Figure 48 SAU QFD 2 Results Graph

Both QFD 2 and Functional-based N² analysis identified different critical components for safe system functioning confirmation.

QFD 2 highlighted the Exploding Bridgewire (EBW) as the top priority. This reflects its critical role in delivering a reliable, precise initiation, essential for system-level safety and controlled detonation.

The N² analysis, focused on functional integration and interactions, identified PETN (the primary explosive) as most significant. This relates more to manufacturing safety, handling risk, and control of energetic materials.

Because of this focus was based on the Exploding Bridge Wire (EBW), from a safe by design perspective.

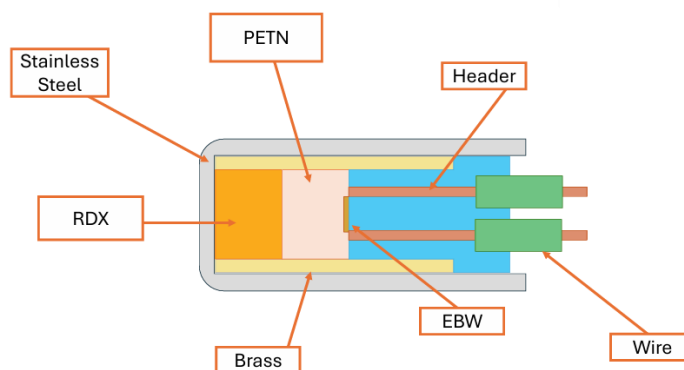


Figure 49 Critical Component Explosive Bridge Wire (EBW)

2.3 Sub System Potential failure modes.

Due to the risk of impact-induced initiation, an electrical initiator was integrated into the system to increase control over the firing sequence. From a safe-by-design perspective, the critical sub-system, Electrical Safety and Arming Unit (SAU), was subjected to an FFMEA.

Purpose	Neutralize Contents	O- Probability of Occurrence				1: Very Rare > 10: Frequent							
		S- Severity of Occurrence				1: No Effect > 10: Most Severe							
		D- Probability of Detection				1: No Detection > 10: Certain Detection							
Function	Function/Failure Mode	Effects										Design Suggestions/Comments	
		On System	On Customer	S	Cause	O	Detection/Prevention Method	D	FPN				
Provide Current (To EBW)	Too Much	Overcurrent may cause premature or unintended initiation	detonates unpredictably or fails to follow its launch sequence correctly, compromising mission effectiveness and safety	10	A malfunction in the power supply regulation, faulty current limiter, or design errors in the control circuitry could cause excessive current delivery.	10	calibration tests, quality components 3 LODS	1	110				
	Too Little	Insufficient current might fail to heat the bridge wire adequately, resulting in a dud or incomplete initiation. This would prevent the intended detonation sequence from being reliably triggered.	A missile that does not launch as expected leads to mission failure and potentially in an unsafe state.	6	Degraded power supply components, increased resistance due to aging or contamination of the bridge wire, or poor wiring connections.	10	Redundant power sources, conduct regular testing of the power delivery system, and perform preventive maintenance. Installing diagnostic sensors to verify current levels in real time will help prevent undercurrent situations.	1	60	No current Detection! Preventative measures in place. Requirement: System needs to be designed to allow the appropriate signal input.			
	No Supply	Without any current, the bridge wire remains inert, meaning the missile would fail to initiate its detonation sequence.	mission failure and severe implications	2	Likely causes include a complete failure in the power supply system, open circuits (e.g., wiring breaks), or disconnected components due to assembly errors.	3	Incorporate automated system checks that alert operators if the current supply is missing.	1	6				
	Wrong Supply	supplying the wrong type or polarity or current (or an incorrect voltage level) may either fail to trigger the bridge wire or cause unintended behavior (e.g., reverse polarity causing damage). This can compromise the initiation sequence and the missile's overall performance.	This may result in a missile that launches incorrectly, fails to detonate, or exhibits reduced performance, leading to potential mission risks and diminished customer confidence in the product's performance and reliability.	2	This could be due to miswiring during assembly, design errors in the power distribution system, or incorrect configuration of the firing circuitry.	3	Implement design reviews and rigorous wiring verification processes, coupled with polarity checks and proper labeling of all electrical connections. Automated test procedures that simulate correct and incorrect supply conditions can also detect such errors before product release.	1	6				
	Intermittent	An erratic or unstable current can lead to unpredictable bridge wire heating. This may cause inconsistent ignition timing (increased jitter) or partial initiation, affecting the missile's performance and reliability.	Customers could face a missile that behaves unpredictably, with variable performance parameters that undermine confidence in the system's operational reliability and	6	Intermittent supply issues might arise from loose connections, intermittent contact due to vibration, or fluctuations in the power supply due to inadequate filtering.	7	Vibration-resistant connectors and install circuit monitoring that continuously logs current stability. Regular inspection and environmental stress tests during manufacturing can help identify and correct intermittent issues.	2	84				

Figure 50 Critical Sub-System FFMEA

Analysis revealed overcurrent conditions within the system could potentially result in unintended initiation. To mitigate this, ENDS methodology was applied. ENDS stands for Engineered Non-Detonable Systems. It's a design philosophy used in munitions and explosives engineering to ensure a system cannot initiate unintentionally, even under fault, misuse, or adverse conditions.

It focuses on building in multiple layers of safety, making the system inherently safe by design, rather than relying solely on external controls or procedures.

- **Isolation:** Ensure that critical energy paths (e.g. between power source and detonator) are physically or electrically separated until arming conditions are safely met.
- **Incompatibility:** Design components so that incorrect assembly, connection, or use is physically or logically impossible (e.g. keyed connectors, different interface types).

- **Inoperability:** The system should be unable to function (i.e., inoperable) unless all safety conditions are satisfied — preventing initiation in unsafe or unintended conditions.
- **Independence:** Safety features (like interlocks or LODs) should not rely on a single mechanism or shared failure mode; each should operate independently to maintain redundancy and integrity.

specifically following the Four Is principle and identified the need for three independent Lines of Defence (LODs) to build in redundancy.

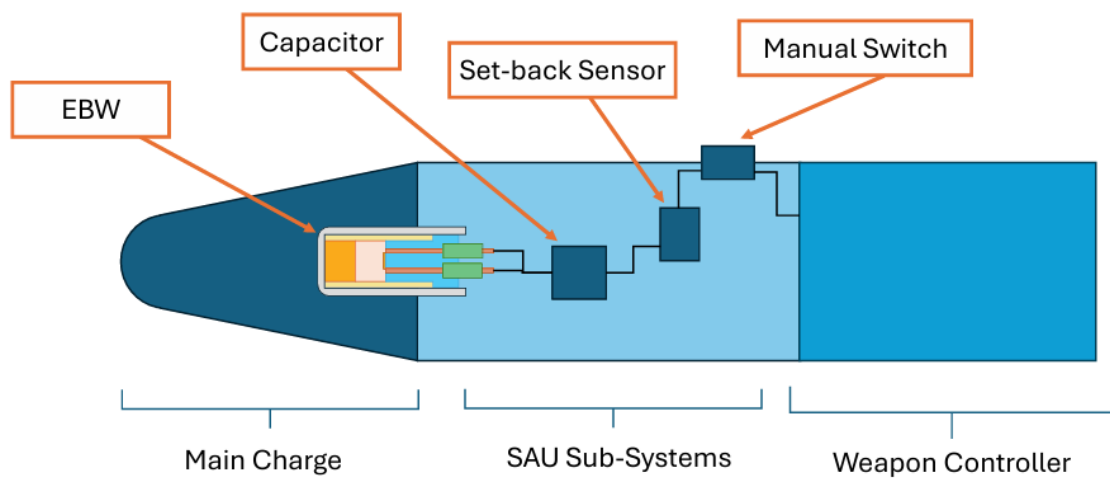


Figure 51 SAU Sub-System Break Down

Each LOD introduces an additional safeguard against electrical faults, ensuring the system remains safe under abnormal or fault conditions, and that initiation is only possible under tightly controlled, authorised circumstances.

This was then fed back into the design process and was later verified by Test and Evaluation team to undergo safety verification trials.

2.3.1 Critical Component EBW Engineering Tools

From Functional Decomposition	Function: Fuze EBW	Means							EBW Final Selection
	Casing	Mill	Press Form	Print	Extrude	Fold	Turn	Cast	Press Form
	Brass waveguide	Mill	Press	Print	Extrude and Cut	Fold	Turn	Cast	Extrude and Cut
	Booster	Mechanical	Hydraulic Press Booster	Hand	Pneumatic	Robot	Hammer	Ram in case	Hydraulic Press Booster
	Primary	Mechanical	Hydraulic Press Primary	Hand	Pneumatic	Robot	Hammer	Ram in case	Hydraulic Press Primary
	Assemble Wire	Robot Position and Solder	Hand	Print	soldering	welding	extruding		Robot Position and Solder
	Insert EBW	Hand	Robot Positioning	Mass assembly line					Robot Positioning
	Header	Melt Cast and Pour	printed	wrapped	pressed				Melt Cast and Pour

Figure 52 EBW Functional Means Analysis

Design feature	Importance	Press Form	Extrude and Cut	Hydraulic Press Booster	Hydraulic Press Primary	Robot Position and Solder	Robot Positioning	Melt Cast and Pour	
Functionality									Functionality Detail
Casing	5	9	3	1	1		3		
Brass waveguide	5	3	9		9				
Booster	5	1		9	1				
Primary	5	1	1		9		3		
Assemble Wire	5					9	9		
Insert EBW	5	1	1		1	3	9		
Header	5							9	
Target		75	70	50	105	60	120	45	0
Benchmark									
Ideal Value									
How Much???									

Figure 53 EBW QFD 3

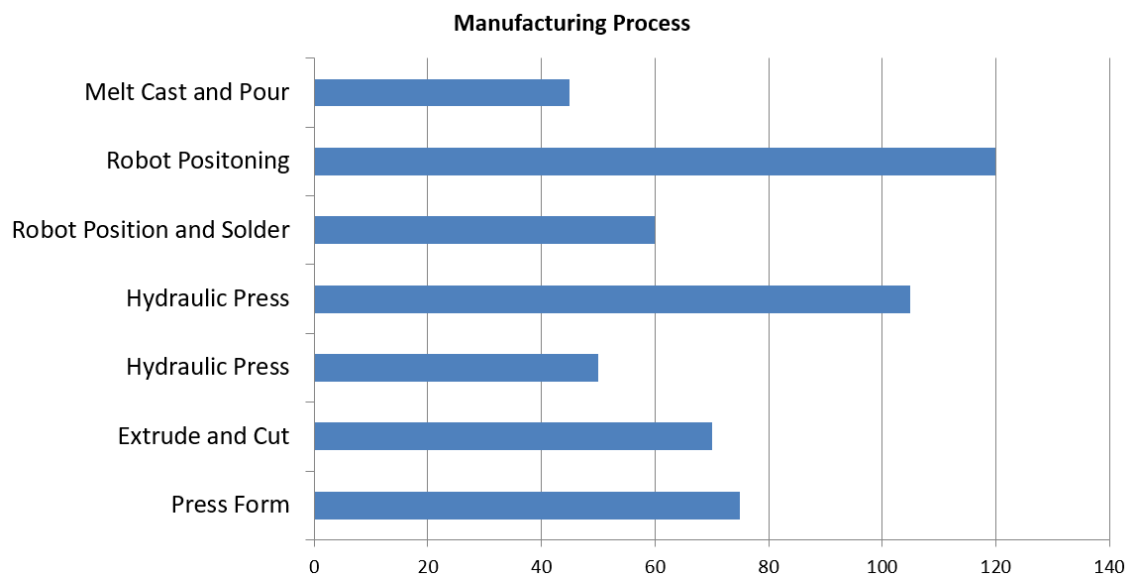


Figure 54 EBW QFD 3 Results Graph

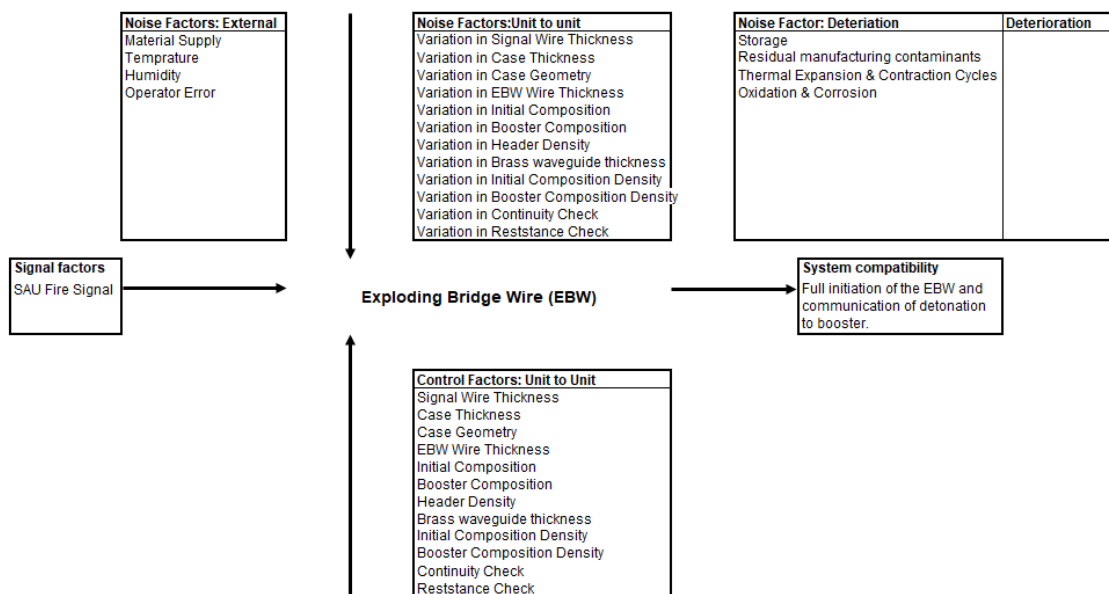


Figure 55 EBW P-Diagram

The P-Diagram identified key noise factors such as human error, environmental temperature, and component wear. Mapping these against intended control measures highlighted system sensitivities and guided targeted safety features to reduce variation and prevent failure.

Performance Characteristics	Design control parameters	Weighting of design control parameter	NOISE FACTORS																				Relative Importance of noise in meeting performance via control factor																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
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Figure 56 EBW What Why

A What-Why table was developed during the EBW design process to ensure each design decision directly supported system-level requirements, particularly around safety and reliability. By explicitly mapping technical features (What) to their justifications (Why), the team was able to verify alignment with functional safety goals and regulatory expectations. This approach ensured traceability from concept through to integration and informed the choice of the EBW over other arming solutions.

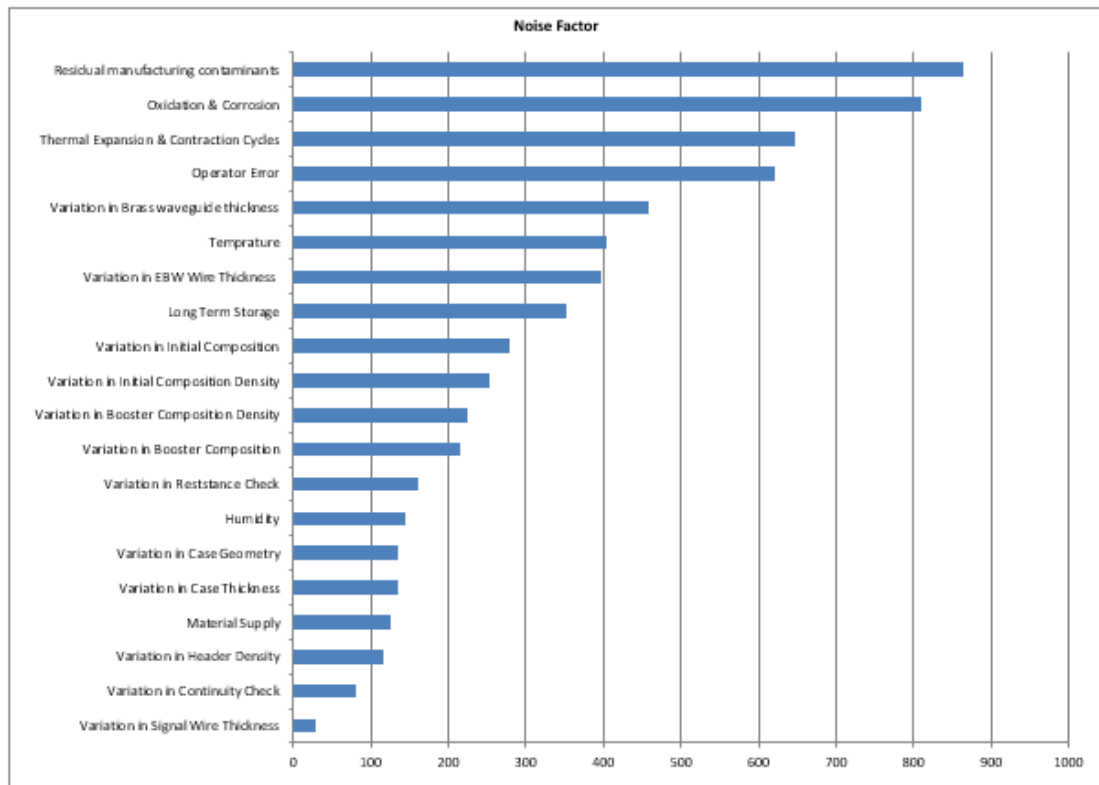


Figure 57 EBW What Why Noise Factors Results Graph

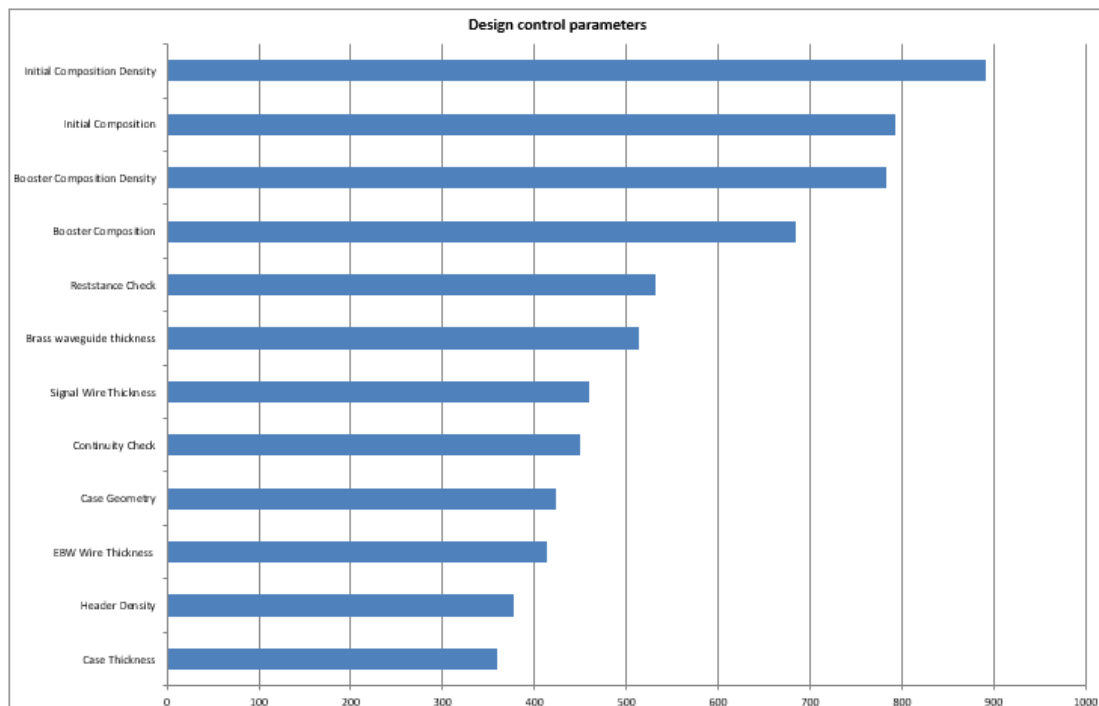


Figure 58 EBW What Why Design Controls Results Graph

N2 Relation Graph - LJ

Brass Sleeve				Confinement	Confinement	
	Brass Wave guide					
		Copper Cable	Signal			
			Gold Bridgewire	Initial Shockwave		Material Interface
				Low Desnsity PETN	Secondary Shockwave	Material Interface
					RDX	
				Material Interface	Material Interface	Stepped

Shockwave to Main Filling

Figure 59 EBW N2 Solutional Analysis (A)

N2 Relation Graph - LJ

1

Brass Sleeve				1	1		2	Brass Sleeve
	Brass Wave guide						0	Brass Wave guide
		Copper Cable	1				1	Copper Cable
			Gold Bridgewire	1		1	2	Gold Bridge Wire
				Low Desnsity PETN	1	1	2	Low density PETN
					RDX		0	RDX
				1	1	Stepped	2	Stepped

0 0 0 1 3 3 2

Figure 60 EBW N2 Solutional Analysis (B)

2.4 The manufacturing processes involved.

Stakeholder	Requirement	Requirement Type	Level 2 Name	L2 Description	Level 3
Ops	Simple to follow		SOP Follow	The manufacturing process shall be simple to follow	
Engineer	Minimal human factors		Human factors	The manufacturing process shall have minimal human factors	
Engineer	Minimal noise factors		noise factors	The manufacturing process shall have minimal noise	
safety	Safe to transport		Safe to transport	Materials and partial manufactured articles must be safe to transport	
Safety	Safe to store		Safe to store	Materials and partial manufactured articles must be safe to store	
Safety	Safe to process		Safe to Process	Safe at all points in manufacture	
safety	Safe to disposal		Safe to Dispose	Safe to dispose of at all points of manufacture	
Safety	Safe to packaging		Safe to package	Safe in packaging as components and final	
Safety	Safe to Employees		Safe to employees	Safe for exposure to employees	
Supply chain	Align with supply chain		Supply chain	Should align with available supply chains	
Project management	Fit into times scales of contracts		Contract timelines	Must follow contracted timelines with customer	
Design authority	Product made to spec		To spec	the product must be made to the specification of the customers	
Maintenance	Easy PM		PM	Should be designed for easy PMs to take place	
Maintenance	Easy maintenance		Easy repair	Easy for repairs to take place	
Legislation	Adhere to all legislation		Regulation compliance	Must adhere to all regulation	
Disposal	Easy to dispose of		Simple disposal	Should be easy to dispose of	
Disposal	Available disposal routes		disposal routes	Must have disposal routes available	
Customer	End up with functional device		Functional device	Must have a functional device	
Customer	Reliable		Reliable	Must be a reliable device	
Upper management	Cost effective		Cost effective	Should be cost effective	
Upper management	Time effective		Time effective	Should be time effective	
Upper management	High yield manufacture		High yield manufacture	Should be cost effective	
Upper management	Space effective		Space effective	Should be cost effective	
Local public	Minimal interference (Noise, light, roads)		Minimal interference	Should cause minimal effect to local public	
Quality control	To spec product		quality product	Should have a quality product	

Figure 61 Manufacturing Stakeholder Requirements

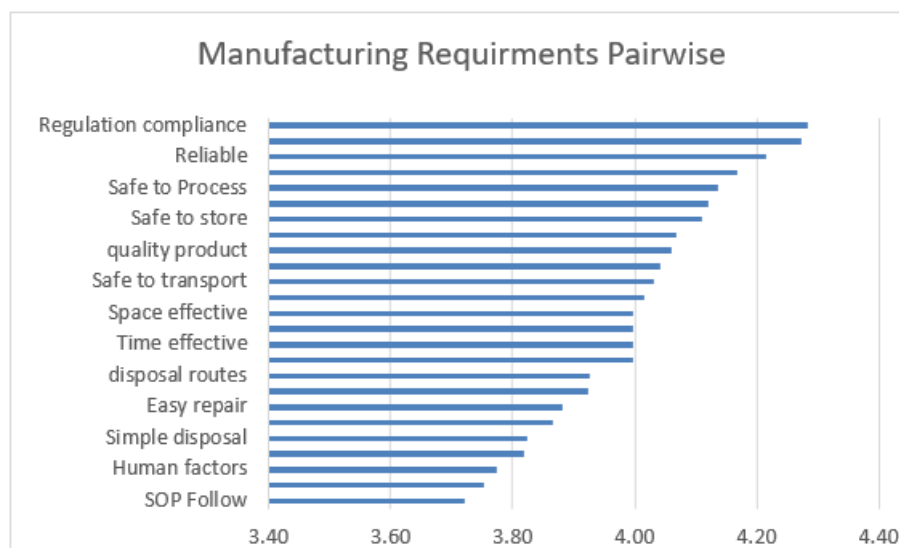


Figure 62 Manufacturing Pairwise Results Graph

Prioritising the requirements using the pairwise gave clear preference of compliance with regulations when manufacturing.

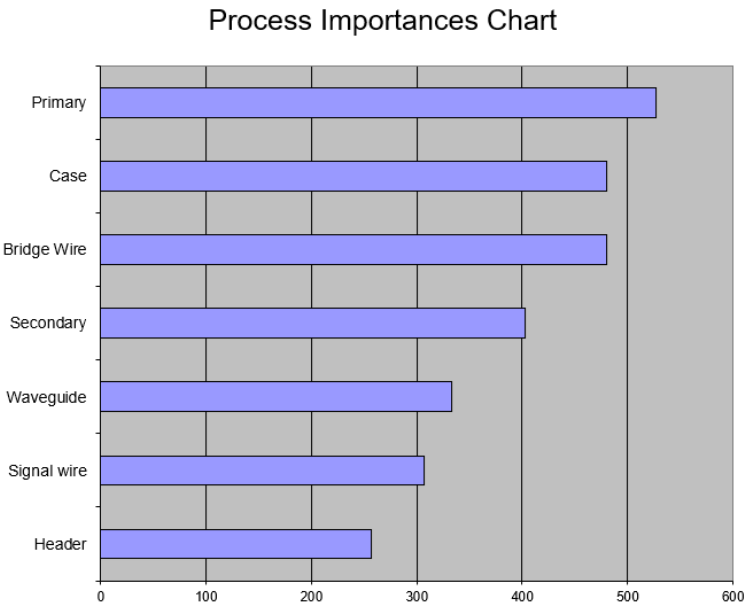


Figure 63 Manufacturing QFD1

QFD 1 ranked relationships between manufacturing requirements and process functionality. This gave clear favour to the Primary Pellet withing the EBW. This was then the critical manufacture component taken forward for a breakdown in analysis.

Function	Concept Names					
Material weight out	digital Scales	guess	dosing machine	pre weighed out	Mechanical scale	
Decant into Machine	Scoop	hand	gravity			
Pellet shape	melt cast	pressed	mix and cast	mix in case		
Dimension check/ QC	hand	AI	Machine	chemical testing	No go guage	Desity output

Figure 64 Manufacturing FMA

From the FMA, the process was beginning to emerge.

2.5 Critical process steps.

Process flow	SOP instruction	Safety Check	PPE/Tooling
Enter building	Once key have been gained documentation has been signed off and a copy of the mix card is available, access the building unhooking the front door, signing in and completing the HAPTM test	Ensure HAPTM pass is completed	
Building checks	Complete the building check list in the building book and log the temperature and humidity	Ensure all fire exit bars are removed and clearways clear in case of an event	
Turn on equipment	Switch the motor on in the control room for the press and boot the control room PLC		
Turn the CCTV on	Switch the CCTV unit and TV on		
Unlock castell key	Walk to Bay 2 (The Press room), open the castell lock		
Enter room	Enter the Room		
Check room	Check the room and toolings condition, check the CCTV is aimed at the press	Ensure no contamination and	
Leave	Leave the Room		
Castell lock	Close the door and the castell lock taking the key with you	Ensure the door is shut and sealed appropriately	
Head to control room	Walk to the control room		
Castell key into control unit	Place the castell key into the press control panel		
Ensure approach lever is in neutral	Ensure the control lever is in the upright position (Slow)		
Raise press to upper location	Raise the Press to the upper location		
Put safety lock on	switch the safety pin on	Listen for audible pin motion	
Set tonnage according to mix card	Set the tonnage to the tonnage set out by the mix card	Ensure the mix card is signed off on TC	
Unlock castell	From the Press CU		
Unlock castell lock	Using the castell key unlock the castell Door		
Enter Room	Enter the room		
Set up statimeter	Place the statimeter onto the pressing pedestal	Check the calibration date	
Focus CCTV on statimeter	Ensure the CCTV is pointed at the statimeter readout		
leave	Leave the Bay		
Castell lock	Lock the castell door and take the key with you		
Castell lock in CU	Put the Castell key in the CU		
Safety pin off	Disengage the safety pin		
Fast approach set	Push the lever forward to the fast approach position		
Click lower	Click the lower button on CU		
As approach is near set to slow approach	As the press approaches the drift click the speed lever into the upright position to activate slow approach		
Read the tonnage on the statimeter	Once the press has impacted the statimeter wait for the mix cards specified duration and read the tonnage displayed and record it.	Check the tonnage on the CU	

Figure 65 Standard Operating Procedure (SOP)

SOP identified the step-by-step process of manufacturing the critical component primary pellet, this was then fed into the PFMEA to identify potential failures and noise that could develop.

Operation Number	Operation Description	Potential Failure Mode	Mode Class	Potential Effects of Failure	S V E	Potential Causes	Prevention Controls	D C	Detection Controls	D E T	RPN	Comments
1	Enter building	No building	Both	Process unable to complete	1	Loss of keys	Key press	1	Key press and sign	1	1	Unable to manufacture
2	Building checks	Building not suitable (Humidity, temperature, cleanliness)	Both	Delayed or cancelled start	3	Poor maintenance	PM	2	Maintenance schedule / Clean	1	6	Failed building check
3	Turn on equipment	Failed to turn on	Both	Delayed or cancelled start	1	Failed electrical system	PM	2	Fuse paneling	1	2	
4	Set CCTV to press	Failed to put on	Product Quality	Requires readjusting	1	Human error	CCTV checks	2	CCTV camera	1	2	Re angle camera
5	Unlock castell key											
6	Enter room											
7	Check room	Clean? Contamination?	Product Quality	Contaminated pellet	3	Poor housekeeping	House keeping and inspection	2	Inspection	1	6	
		Equipment good condition	Product Quality	Not to spec pellet	3	Poor maintenance or use	Training and PM schedule	3	Inspection	2	18	
		Explosive locker empty?	Product Quality	IF an event was to occur this would worsen the effect and is against the license	4	Poor house keeping	Inspection	2		2	16	Against processing license, severity dependant on stored explosive
8	Leave											
9	Castell lock											
10	Head to control room											
11	Ensure approach lever is in neutral position	Lever stuck in position	Both	Difficulty controlling the press	2	Failure of system	PM	1	Visual check	1	2	
12	Raise press to upper location	Failed to raise to the upper position	Process safety	Equipment is not in suitable condition	2	Failure of system	PM	1	Visual check	1	2	

Figure 66 Process Failure Means Effects Analysis for Manufacture

Critical Process Steps were identified from the PFMEA:

The room check (Op 7) is the most critical, especially regarding explosive manufacturing conditions and equipment maintenance.

These steps needed stricter preventive controls, training, or redesign to reduce risk. These were identified in the below sections, Process Control Plan (PCP).

Critical Process steps

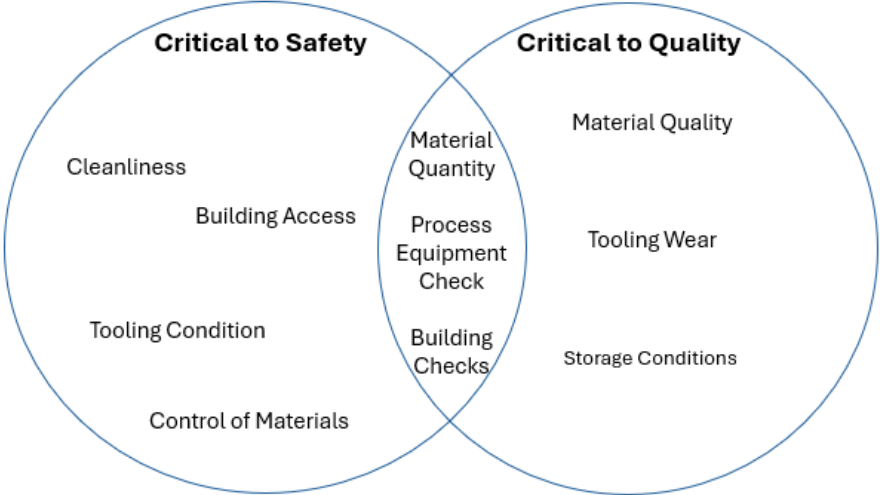


Figure 67 Critical Process Venn Diagram

		Operational assessment					Process Controls											
		manufacturing controls and Aids	Difficulty	Frequency	Severity	Detectability	RPN	Humidity control and monitoring	Temperature control and monitoring	Chemical analysis before processing	Material quantity - Scales	Tooling inspections - PTC	No go gauge	Density analysis	Tonnage	Press speed		
Process parameters	Target Values																	
Humidity			2	3	3	5	90	0	3					3				
Temperature			2	3	3	5	90	3	0	3				3				
material quality			5	2	0	0	150	3	3	0								
Material quantity			1	5	5	5	125			0								
Tooling wear			5	3	5	3	225			0	3	3		1				
Pellet dimensions			3	5	5	5	375			3	3	0	3	3	3	3		
Pellet density			3	5	5	4	300			3	3	0	0	0	0	0		
Press tonnage			1	1	3	5	15					0	0	0	3	0		
Press speed			1	1	3	5	15					0	3	0	0	0		
								1530	1530	1620	2250	3150	5325	5865	4230	4005	0	0

Figure 68 Manufacturing QFD4

QFD Level 4 links directly to process design and control — it focuses on translating critical process characteristics (the “What’s”) into effective control strategies (the “How’s”). This mirrors the function of the PFMEA and Process Control Plan, which were used in this project to identify high-risk steps and apply targeted controls to mitigate them [4].

For example, PFMEA identified high RPN scores around material contamination and explosive handling. These “What’s” (critical to safety and quality) were then carried over into the Control Plan, where specific “How’s” were defined: visual inspections, equipment checks, and environmental condition monitoring.

In essence, QFD 4 acted as a structured bridge between failure risk (PFMEA) and control strategy (Process Plan), ensuring critical process risks were backed by robust, targeted controls that support both product quality and operator safety.

2.6 Process control measures.

Operation Number	Operation Description	Machine, Device, Jig, Tool	Characteristic to be controlled		Class	Control Method								Reaction Plan if Control Method fails
			Product Characteristic	Process Parameter		Element Evaluated / Measured	Specification / Tolerance	Evaluation / Measurement	Sample		Record	Assurance of Control (Incl. Procedure)		
									Size	Frequency				
PIP Manufacturing														
1	Enter building	Keys	-	-	CTS		Key access controlled	Key access controlled				Key log books		Security to be notified
2	Building checks	Condition of building	Free from contamination, Temperature, humidity	Contamination, temperature, humidity	CTS	CTQ	Visual condition, Temperature and humidity of building	Specified in mix card	Visual, Thermometer, hygrometer	Bays	Start of shift, breaks, end of shift	Building check book	Visual standard, Measurable controls	Open windows, turn on steam, mop the floor.
3	Turn on equipment	Press	Ability to run the process	Pressing capability	CTS		LED and audible confirmation	Ability to run	visual and audible	1	Start of shift	N/A	Operator confirmation	Process cannot continue and Maintenance callout
4	Turn the CCTV on	CCTV	Monitor press	Function of the press	CTS		Visual confirmation	Visual of Press	Operator discretion	1	Before each use of Press	N/A	Operator confirmation	
5	Unlock castell key	Castel	Process capability	Process capability	CTS									
6	Enter room	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Check room				CTS	CTQ								
	Leave													
10	Castel lock				CTS									
12	Head to control room	-			CTS									

Figure 69 Manufacturing Process Control Plan

Following the PFMEA, a Manufacturing Process Control Plan was developed to enhance control of operations identified as high risk. It translated PFMEA outputs, particularly for contamination checks and explosive material handling into actionable control points. Each operation was assigned control measures (e.g., visual inspections, environment checks, equipment confirmations), classifying critical steps as CTS (Critical to Safety) or CTQ (Critical to Quality). This structured control method ensures early detection of failure conditions and enables pre-emptive action to maintain safe, compliant, and repeatable manufacturing processes.

2.7 Waste and end of life disposal.

The disposal strategy was developed using a structured systems approach to meet both safety and regulatory demands.

Stakeholder	Requirement	Priority	Requirement Type	Level 2 Name	L2 Description	Level 3
Public	Minimal Public Interference			Minimal Interference	The disposal of the munition shall interfere with, and inconvenience, the public to a minimal degree.	
Disposal contractors	Safety			Safety	Munition shall be disposed of in a safe manner.	
Disposal Contractors	Reliability			Reliability	Munition shall be disposed of in a reliable manner	
Disposal Contractors	Environmental Impact			Environmental Impact	Munition shall be disposed of in a manner which reduced the impact of the environment	
Disposal Contractors	Efficiency			Efficiency	Munition shall be disposed of in an efficient manner, beholden to the requirements of safety and environmental impact.	
Regulatory Bodies	Regulation			Regulation	Munition shall be compliant with all requirements as laid out by the regulatory bodies.	
Disposal Contractors	Cost			Cost	The Munition shall be disposed of in a manner where cost is kept as low as possible while abiding by regulations and legislations, and where safety is not compromised.	
Disposal Contractors	Qualification			Qualification	Disposal shall be carried out by Suitably Qualified and Experienced Personnel (SQEP)	
Disposal Contractors	Method			Method	Disposal shall be carried out via a pre-existing method that is known to be safe and reliable	
Disposal Contractors	Clean Up			Clean Up	Disposal shall be carried out in a manner where the collection and removal of debris and contaminants is as safe and effective as is considered practicable.	

Figure 70 Disposal Stakeholder Requirements

The process began with identifying high-level requirements for end-of-life handling, including environmental impact, regulatory compliance, operator safety, and feasibility. A pairwise comparison was used to rank these requirements, with regulatory compliance emerging as the most important driver.

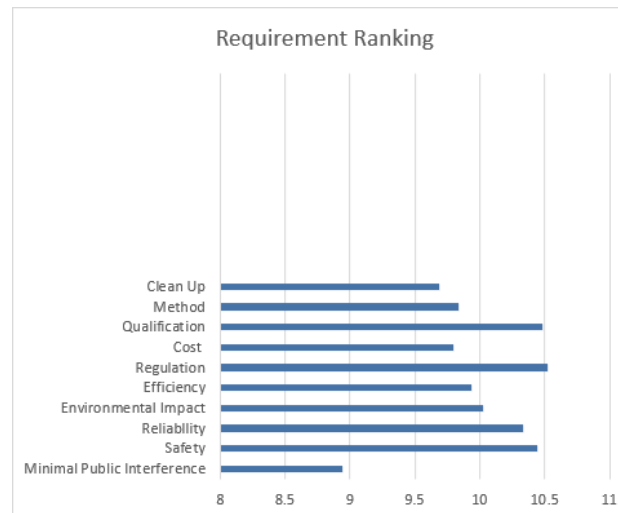


Figure 71 Disposal Pairwise Comparison

This was followed by a QFD 1 analysis, which reinforced that safety, reliability of method, and ease of cleanup held equal critical weight.

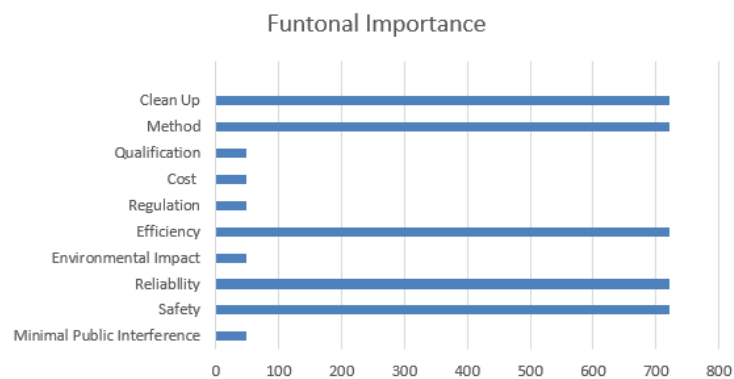


Figure 72 Disposal QFD1

Based on these priorities, a Functional Means Analysis (FMA) was conducted to explore possible disposal options.

Function	At Stage	Means						
Disposal of Telescopic Launch Tube	Manufacture	Shredder	Incinerator	Melt	Blow up	Solvent	Landfill	Cryofracture
	End of Life	Shredder	Incinerator	Melt	Blow up	Solvent	Landfill	Cryofracture
Disposal of Waste	Manufacture	Bin	Incinerator	Chemical Treatment	Bag			
	End of Life	Bin	Incinerator	Chemical Treatment	Bag			
Disposal of CLU	Manufacture	Shredder	Blow Up	Recycle	Landfill			
	End of Life	Shredder	Blow Up	Recycle	Landfill			
Disposal of SAU	Manufacture	Deatomise	Blow Up	Incinerator	Cryofracture			
	End of Life	Deatomise	Blow Up	Incinerator	Cryofracture			
Disposal of Rocket Motor	Manufacture	Incinerator	Blow Up	Solvent	Cryofracture			
	End of Life	Incinerator	Blow Up	Solvent	Cryofracture			
Disposal of Main Charge	Manufacture	Incinerator	Blow Up	Solvent	Cryofracture			
	End of Life	Incinerator	Blow Up	Solvent	Cryofracture			
Disposal of Preliminary Charge	Manufacture	Incinerator	Blow Up	Solvent	Cryofracture			
	End of Life	Incinerator	Blow Up	Solvent	Cryofracture			
Disposal of the Munition Case	Manufacture	Shredder	Blow Up	Incinerator	Landfill	Open Burn		
	End of Life	Shredder	Blow Up	Incinerator	Landfill	Open Burn		
Disposal of the Guidance Unit	Manufacture	Shredder	Blow Up	Incinerator	Landfill	Open Burn		
	End of Life	Shredder	Blow Up	Incinerator	Landfill	Open Burn		
Disposal of the Control Unit	Manufacture	Shredder	Blow Up	Incinerator	Landfill	Open Burn		
	End of Life	Shredder	Blow Up	Incinerator	Landfill	Open Burn		

Figure 73 Disposal FMA

This informed QFD 2, where incineration and shredding were the two highest-scoring options. Ultimately, shredding was selected as the primary disposal route due to its practicality, lower risk, and compatibility with safety protocols. The tritium component, being a radioactive isotope, will be handled separately and disposed of through certified third-party specialists such as Eckert & Ziegler (Germany).

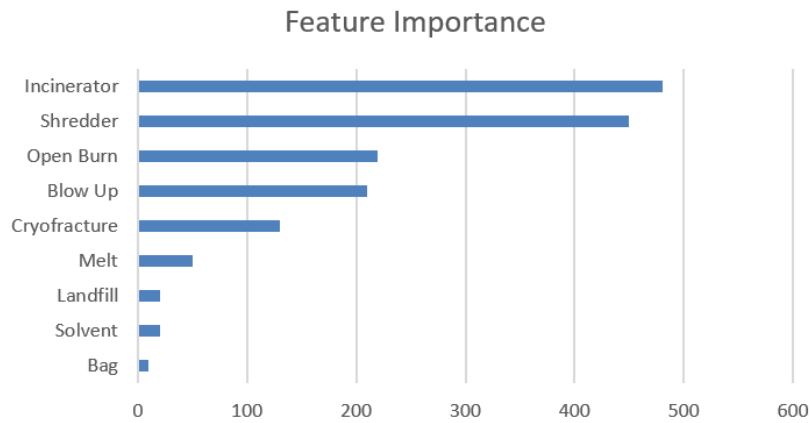


Figure 74 Disposal QFD2

This methodical decision-making process ensured that the chosen disposal path aligns with regulatory standards while minimising operational and environmental risks.

3 Conclusion

This report demonstrates the application of systems engineering principles to the safe-by-design development of an explosive device for precise, low-collateral impact. Tools such as stakeholder mapping, QFD, FFMEA, FMA, and N² analysis were applied at system and sub-system levels to embed safety throughout the life cycle, from concept to disposal.

Stakeholder requirements, especially safety, accuracy, and compliance, guided key decisions. The choice of a shoulder-launched missile, combined with focused design of the Safety and Arming Unit (SAU) and Exploding Bridgewire (EBW), illustrated how traceable, evidence-based methods can enhance functionality while managing risk.

The use of the hierarchy of controls, engineered non-detonable systems (ENDs), and manufacturing controls highlighted a proactive approach to hazard prevention. These measures ensured operational effectiveness and resilience against failure modes, human error, and environmental stress.

Overall, the systems engineering approach delivered a mission-effective, portable, and inherently safe solution aligned with both user needs and technical feasibility.

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Appendices

Appendix A Research Stakeholder Articles

A.1 Gemba Visit

Gemba Visit:

Observations of troops in Light role:

Troops in Light Role capability (being dismounted if in a mechanised Infantry Unit) refers to the front-line soldier operating on foot in all environments.

These environments include Open Countryside, Woods, Forests, and in the Urban environment.

To access the urban environment (in a conventional wartime scenario) the fighting soldier must transition through all environments to gain access to the Urban environment.

Where warfighting has evolved since WW2, the infantry soldier is required to be flexible yet remain fully competent in all operational environments. Tactics and doctrine have changed over time, as well as the nature of warfare. Where most of the fighting in the last century was geared towards conventional operations, events around the turn of the century resulted in a transition to Counter insurgency operations.

With conflicts taking place across the Middle East, Africa, and Eastern Europe, the operational environment remains varied, however most operations (and key locations relevant to infrastructure) revolve around the urban environment.

Infantry Organisation:

To understand the needs of the end user, their methods and capabilities must be understood.

Most of the “work” (Such as clearing buildings/houses/streets) is conducted by the Rifle Companies.

This is a physically demanding job role, which requires high levels of fitness to be able to carry the equipment, and deliver the effects required by the commanders on the ground.

Where doctrine has been modified (over time) there has been an attempt made to reduce the scales of equipment carried by each individual soldier, however this has proven difficult due to the complexities of changing environments and operational demands.

Kit Equipment:

The infantry soldier carries the following operational kit:

This is either carried on their belt kit, in a daysack, or worn attached to their body armour system.

Appendix A Table 1 Gemba Operational Kit

Kit	Description	Observations/Notes
Helmet & Body Armour	Current Issued VIRTUS System	5-10kgs (with plates fitted)
Rifle	L85 A3/L129 A1/GPMG	7 kgs (approx.) – 13.5kg
Grenade	Smoke/HE – 2x	0.5-1kg
Ammunition	330 Rounds (6x magazines & 5 in a bandolier which must be loaded by the soldier)	2-3kgs
Radios	Anything from a Personal Role Radio, up to and including a 352 Bowman radio (and batteries)	5-8kgs

Night/Thermal Sight	Every individual is issued 1x HMNVIS/NVG Other kit includes a Thermal Optic (2x per section) And Additional CWS	A mixture of Passive Night vision and thermal kit- 1-2kgs
Medical kit	This will be taken by every individual -	In some cases, there will be 1x team medic in each fire team – each carrying a small trauma kit either in or attached to their daysack/backpack) Personal items negligible – team kit 3-4kgs
Water	A minimum of 1 litre	1kg +
Food	A minimum of 24 hrs	0.5-1.0kg
Warm Kit	Normally a woolly hat/sheath(scarf)/and a warm top	0.5 – 1.0kg
Wet Kit	Gore-Tex Jacket and Trousers	0.5 – 1.0kg
	Total weight range:	31.0kg – 44.5kg

Operational Environment:

The exercise was conducted in Colehill Down on Salisbury Plain. This was designed to simulate a European Village for the purposes of training within the confines of the UK.

This is situated on Salisbury Plain, with woodblocks on the west and East sides of the village.

The buildings are representative of generic European architecture, and are made up of a combination of 1, 2 and 3 storey buildings. They constructed of single block and Concrete with a standard sized window across the majority of buildings. Room Sizes vary in each building and can be seen as representative of a standard sized family home (2-3 d size). There are smaller 1 storey structures Stakeholder communications.

Appendix B Safety Compliance

Appendix B Table 1 Safety Compliance Documents

Safety Compliance Documents	
DSA 02.OME Regs	
HSE Manual Handling	
DSA 03.OME	
Def Stan 00-056	Safety Management Requirements
AOP-4518	Disposal
AOP-21	Itiation system
AOP-4187	Fuzing
AASTP-05	Storage Ops
AASTP-1	Storage/Transport
AQAP-2110	Quality Assurance
DSA 03.OME 108	Itiation system Qualtiy Assurance
AEP-4685	Human Intagrations
DSA 03.OME 101	Design Requirments
DSA 03.OME Pt 2	Facitlity Safety
JSP 815	Safety Management Systems Framework

Appendix C Requirements Traceability Table (RTT)

Appendix C Table 1 RTT

Customer Requirement	Design Feature / Analysis Addressing Requirement
Comply with all relevant legislation	Lifecycle safety assurance, regulatory alignment through QFD and FFMEA
Packaged in standard packaging where possible	Implicit via modular shoulder-launched format; not directly discussed
Compatible with existing supply chain	Use of shoulder-launched platform suggests compatibility; future logistics analysis recommended
Field maintainable where required	Robust sub-system design, modular components, maintainability implied
Failure rate of $\leq 1e-6$ per year	FFMEA, fault analysis, engineered fail-safes (e.g., EB'w, SAU)
Operate in A1-C2 climate range	Environmental variation discussed; specific DEF-STAN ranges Annex B
Fail-safes for misfire scenarios	SAU design, EB'w integration, and resilience to human error explicitly covered
Man-portable system	Selection of shoulder-launched platform
Single-person usability	Portability, ease of use, rapid deployment features
Disruptive effect lasting ≤ 12 hours	Terminal effect discussed; duration not explicitly defined
Entry through external	Capability through missile platform, entry through window
Incapacitate or eliminate Comms Users	Terminal effect designed to neutralise target; lethal vs non-lethal mode not specified
Simple unload/reload procedure	Usability and single-person operation implied; not explicitly described
Operate from a minimum distance of 100m	Requirement considered during delivery system selection
Damage contained to target room	"Minimal-collateral impact", achieved through precision and system accuracy
Accuracy of 0.25m at 100m	Performance specification integrated into system design and safety criteria
Rapid setup and deployment	Implicit in platform choice and operational context
Useable in multiple environments (urban and rural)	Environmental adaptability addressed via system resilience and general-use context
Deliver a terminal effect	Mission effectiveness and functional lethality included in system concept
Safe under operational conditions (e.g. backblast, signature)	Addressed in FFMEA, backblast mitigation, engineered safety solutions (ENDs)
Easy to use	Human factors, simplicity, and operational efficiency considered
Safe disposal method	Lifecycle safety embedded from concept to disposal
Safe throughout CADMID cycle	Comprehensive system engineering approach spans full life cycle