

ACDA5021 – Systems Engineering

Mine Clearance Design Report

Using Systems Engineering tools and methods to conceptualise a design for a humanitarian mine clearing operation and demonstrate its validity throughout the design and manufacturing process.

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Abstract

This report explores the design journey from the first stakeholder engagement through to manufacture of a concept solution for a humanitarian landmine clearing operation. Through thorough use of the systems engineering toolset, including the QFD ‘house of quality’, P-diagrams, what-why tables, Pugh matrices and FMEA failure analysis, it was possible to go from an initial set of requirements to a fully designed, tested, manufactured and operable solution ready for use in the field, designed and manufactured with full confidence in the design. The toolset provided allowed for identification of the most viable concepts, generating a qualification method to verify the design and identify the likely causes of failure, and a full analysis of the manufacturing process – including critical steps, key noises and key controls. The operation reinforced the benefits and importance of analysing and understanding systems.

Introduction

Introduction to Systems Thinking

Systems Engineering is defined by [1] as a means to guide the engineering and development of complex systems. Spurred on by the technological advances made during the Second World War [1], the modern world is full of complex systems, often containing complex subsystems within them, requiring input from a whole range of specialist disciplines. A modern-day aircraft's production process covers a wide range of engineering disciplines including, but not limited to, instrumentation, electronic, mechanical, propulsion and automotive engineers.

Systems thinking's primary objective is to find balance between disciplines. Figure 1 (from [1]) shows how a modern missile may be designed if done by specific disciplines.

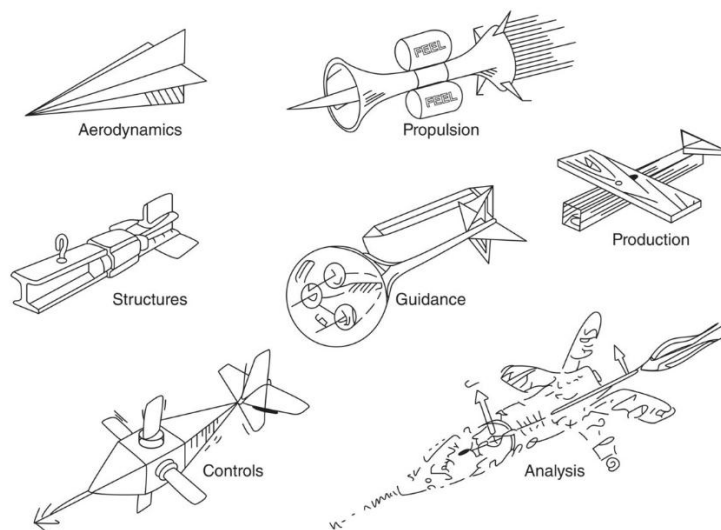


Figure 1: Ideal missile design from the point of view of specific engineering disciplines.

Each design would function perfectly within the primary discipline, but the system would be doomed to fail as a whole.

Systems thinking uses tools, data and considerable stakeholder engagement to balance the desires and needs of all designers and engineers involved in the creation of a complex system to produce the best overall system to meet customer demands and functional requirements.

Systems Engineering strives to find, predict and resolve faults at the earliest point through comprehensive failure mode analysis, when subsystems or components can simply be redesigned before a single prototype is even manufactured, instead of major problems being encountered post manufacture, when the costs and complexity of rectifying issues is significantly higher.

Customer Brief

The brief received for this task was that a military humanitarian convoy carrying critical medical supplies to a remote area was to encounter a minefield along its route in a mountainous, desert terrain, with little to no opportunity for circumvention of the road. As the road was to be needed to future civilian use, traversing the mined area and rendering it safe was the desired operation.

Enemy MANPAD threats persisted throughout the journey, rendering use of aeroplanes or helicopters impossible. The manned vehicles available for use consisted of standard 4x4 vehicles such as Toyota Hilux or Land Rover, so any solution had to be portable and light.

Python, a standard mine defeating system used in the military, is prohibited from being used due to the risk of explosive or fragment attack from enemy fire.

The customer wishes to know what the design is, the critical functionality, design features and critical manufacturing processes and controls.

Time is of the essence due to the nature of the supplies being carried.

Threat Analysis

The two key mine threats faced were by the Russian-built OZM-72 anti-personnel fragmentation mine, and the American-made M15 anti-tank mine. Table 1 compares and analyses the properties and threats posed by each device.

Mine	OZM-72	M15
Country of Origin	Russian Federation	United States of America
Casing	Steel	Steel
Composition	660g TNT	10kg Composition B
Critical Pressure	Triggered by tripwire	160kg (2kg with fuze-rod)
Effect Means	Bounding (1m) anti-personnel	Below ground anti-tank

Table 1: Comparison of OZM-72 and M15 landmines, the key threats faced in the operation [2], [3], [4], [5]

Figure 2 shows a diagram of the working of the OZM-72 anti-personnel mine, and figure 3 shows a diagram of the workings of the M15 anti-tank mine.

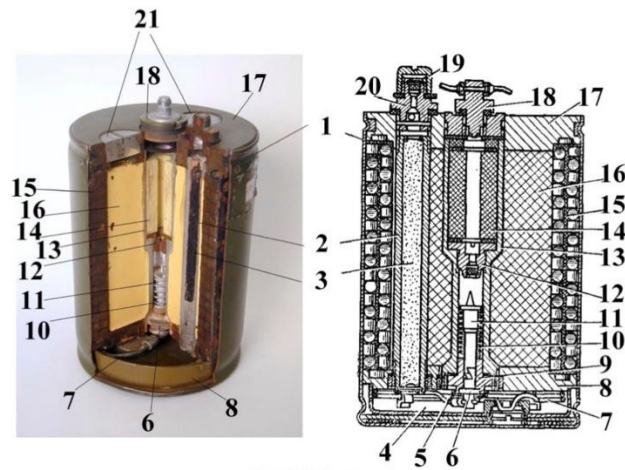


Fig. 2 OZM-72 cross section:
1 – outer container; 2 – tube; 3 – propelling charge; 4 – chamber; 5 – anchor wire with snap link; 6 – striker's heel; 7 – anchor wire; 8 and 17 – covers; 9 – collar; 10 – main spring; 11 – striker; 12 – collar with primer igniter; 13 – central sleeve; 14 – additional detonator (booster); 15 – body with fragments; 16 – main charge; 18 – plug; 19 – cap; 20 – collar with igniter and ball; 21 – filling slots.

Figure 2: OZM-72 anti-personnel mine [4].

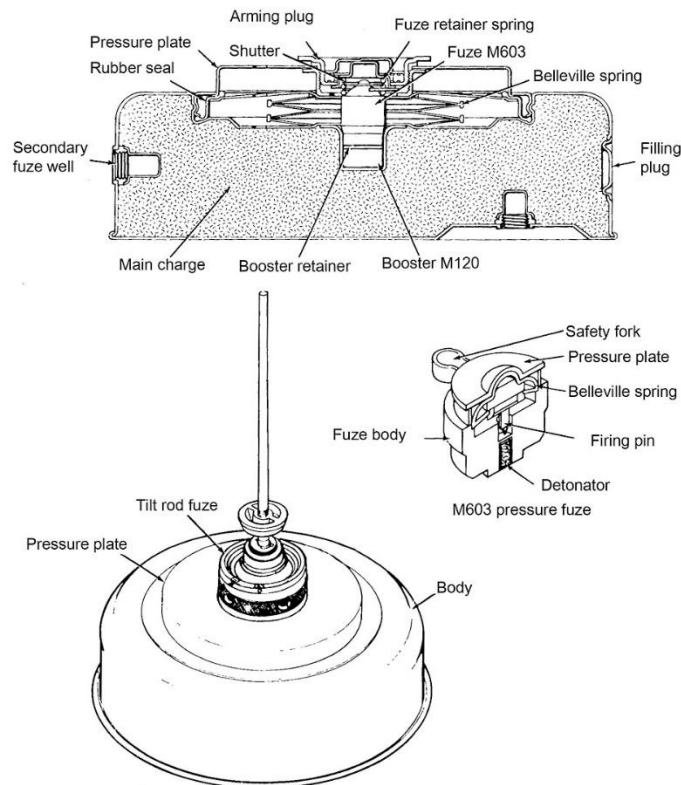


Figure 3: M15 anti-tank mine [3].

Research, Development, Design and Qualification

Rationalising Requirements

The first task of the design team was to rationalise the brief into a set of customer requirements. This consisted of filtering through the scope of the customer brief to find a set of expressed requirements for the system as a whole. Figure 4 shows the compiled list of requirements produced from this analysis.

The system shall detect buried or surface-laid mines typical of legacy and improvised mine threats.
The system shall render detected mines safe by removal, destruction, or permanent disabling.
The system shall be transportable and operable using light vehicles (Land Rover, Hi-Lux, or equivalent).
The system shall clearly mark mines cleared lanes and boundaries in a way visible to follow-on with light wheeled vehicles
The system shall function in high dust, sand, heat, and vibration conditions without degradation of performance.
The system shall clear the required route length within a time window compatible with urgent medical convoy movement.
The system shall limit blast, fragmentation, and collateral damage within the confined pass.
In the event of malfunction, the system shall default to a safe condition without creating additional hazards.
The system shall be designed to enable safe, compliant breakdown and disposal of all system components, including explosive payloads, electronic subsystems and structural elements in accordance with applicable environmental, explosive safety, and hazardous waste regulations at end of life.

Figure 4: Rationalised Requirements set produced from analysis of customer brief.

The next task was to compare the requirements against one another in a pairwise comparison matrix, which is a top-level tool for comparing pairs of requirements and ranking them based on importance according to the scale in Figure 5.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one activity over another.
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another.
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very very strong	
9 (absolute)	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation.

Figure 5: Pairwise Matrix relationship scale [6]

Using the scale in Figure 5, the team reviewed requirements using the pairwise matrix to create the matrix in Figure 6. Figure 7 shows the chart that is produced from this comparison process, with the longest bars representing the priority requirements for the solution.

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		1	2	3	4	5	6	7	8	9	Calc	Calc
	Pairwise comparison of requirements 1 = No Preference, Reciprocal = 1 2 = Slight Preference, Reciprocal = 0.5 5 = Preference, Reciprocal = 0.2 9 = Strong preference = 0.11											
		The system shall detect buried or surface-laid mines typical of legacy and improvised mine threats.	The system shall render detected mines safe by removal, destruction, or permanent disabling.	The system shall be transportable and operable using light vehicles (Land Rover, Hi-Lux, or equivalent).	The system shall clearly mark mines cleared lanes and boundaries in a way visible to follow-on with light wheeled vehicles	The system shall function in high dust, sand, heat, and vibration conditions without degradation of performance.	The system shall clear the required route length within a time window compatible with urgent medical convoy movement	The system shall limit blast, fragmentation, and collateral damage within the confined pass.	In the event of malfunction, the system shall default to a safe condition without creating additional hazards.	breakdown and disposal of all system components, including explosive payloads, electronic subsystems and structural elements in accordance with applicable environmental,	Row Product	nth root of row product
1	The system shall detect buried or surface-laid mines typical of legacy and improvised mine threats.	1	1	2	2	2	5	5	5	9	32	1
2	The system shall render detected mines safe by removal, destruction, or permanent disabling.	1	1	2	2	5	9	5	2	9	36	1
3	The system shall be transportable and operable using light vehicles (Land Rover, Hi-Lux, or equivalent).	0.5	0.5	1	2	5	2	1	5	9	26	1
4	The system shall clearly mark mines cleared lanes and boundaries in a way visible to follow-on with light wheeled vehicles	0.5	0.5	0.5	1	9	5	5	5	5	31.5	1
5	The system shall function in high dust, sand, heat, and vibration conditions without degradation of performance.	0.5	0.2	0.2	0.11	1	0.2	0.5	5	5	12.71	1
6	The system shall clear the required route length within a time window compatible with urgent medical convoy movement.	0.2	0.11	0.5	0.2	5	1	1	2	9	19.01	1
7	The system shall limit blast, fragmentation, and collateral damage within the confined pass.	0.2	0.2	1	0.2	2	1	1	2	1	8.6	1
8	In the event of malfunction, the system shall default to a safe condition without creating additional hazards.	0.2	0.5	0.2	0.2	0.2	0.5	0.5	1	1	4.3	1
9	The system shall be designed to enable safe, compliant breakdown and disposal of all system components, including explosive payloads, electronic subsystems and structural elements in accordance with applicable environmental, explosive safety, and hazardous waste regulations at end of life	0.11	0.11	0.11	0.2	0.2	0.11	1	1	1	3.84	1
												Total Normalised

Figure 6: Pairwise matrix for rationalise customer requirements.

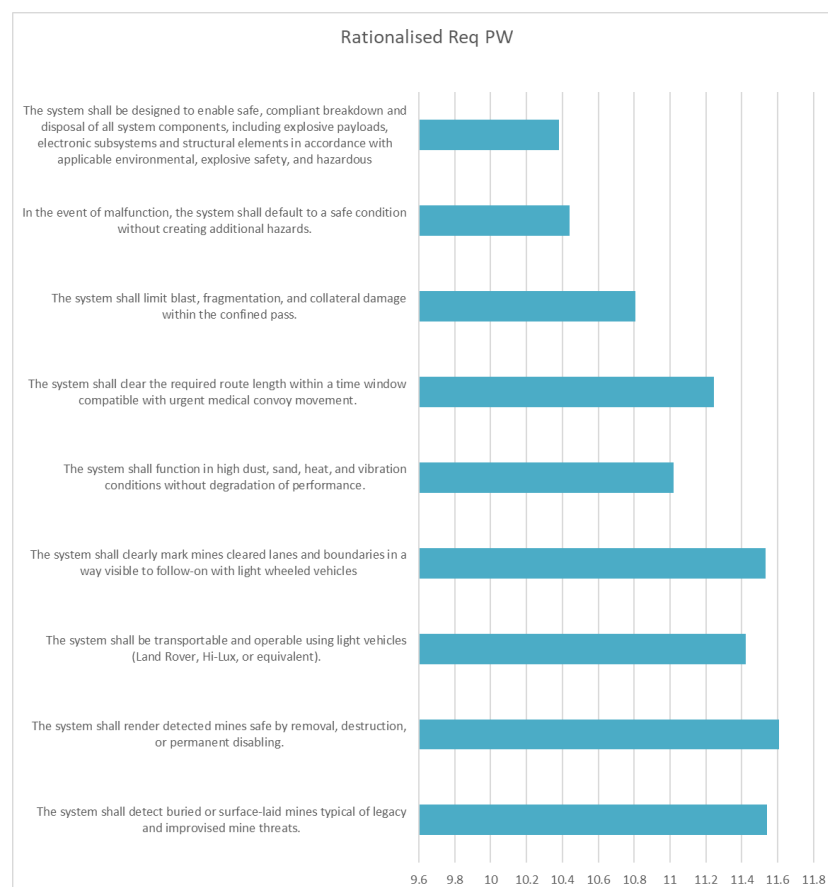


Figure 7: Chart comparing relative importances of customer requirements

Figure 7 shows that the three most important requirements, in order, were:

- The system shall render detected mines safe by removal, destruction or disabling.
- The system shall detect buried or surface-laid mines typical of legacy and improvised threats.
- The system shall clearly mark cleared lanes in a way that is visible to future transports.

It's essential to note that this doesn't mean no effort should be made to hit all requirements, but this analysis is important to refer back should there ever be a need to decide to prioritise the ability to perform one requirement over another. Systems engineering tools such as the pairwise comparison matrix give teams the assurance that any priority calls would be made with a rational and thought-out justification.

Finding Critical Functions

The next step in the process is to turn the customer stated non-functional system requirements into tangible functional requirements of the system. One of the best means for doing this is a Use Case, a detailed step-by-step operational timeline of the system, describing each function one-by-one from the start to the end of the system operation. These models are used to produce functional requirements for the system from the non-functional requirements often provided by a customer [7].

Completing the use case for this operation transformed customer requirements in to the list of functional requirements shown in Figure 8.

Deploy Clearance Capability	
Detect Explosive Hazard	Mark Cleared Route
Assess and Decide	Enable Convoy Transit
Neutralise or Removal	Recover and Redeploy
Verify Clearance	Render Safe or Dispose of System

Figure 8: Generated functional requirements from Use Case.

From this point, the first design QFD took place to find the critical functions. The QFD 1 'house of quality' is a critical step in the systems engineering process, bringing together required functionality, stakeholder requirements and target values, comparing requirements against functions, analysing the importance and difficulty of achievement, to visually demonstrate the most important functions. Figure 9 shows the QFD matrix concept.

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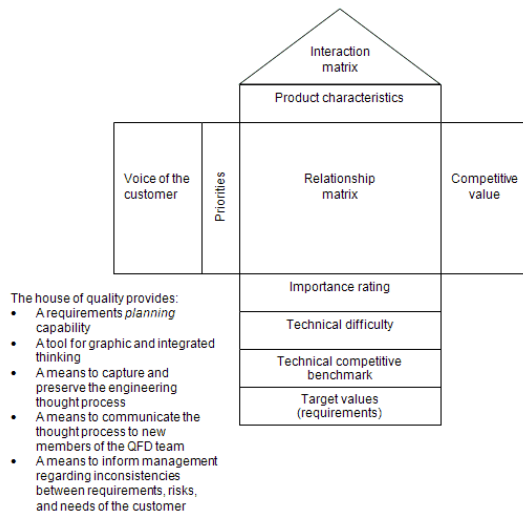


Figure 9: QFD 'House of Quality' [8]

Figure 10 shows the QFD 1 process carried out by the design team, whereby requirements and functions were related on a 1 (weak relationship), 3 (reasonably strong relationship) and 9 (critical relationship) scoring system, generating the chart in Figure 11, which shows the relative importance of functions.

How	Importance	Deploy Clearance Capability	Detect Explosive Hazard	Assess and Decide	Neutralise or Removal	Verify Clearance	Mark Cleared Route	Enable Convoy Transit	Recover and Redeploy	Render Safe or Dispose of System
Requirements										
The system shall detect buried or surface-laid mines typical of legacy and improvised mine threats.	11.54159738	3	9	3		9		9	1	
The system shall render detected mines safe by removal, destruction, or permanent disabling.	11.60976813	1	3	9	9			3	3	1
The system shall be transportable and operable using light vehicles (Land Rover, Hi-Lux, or equivalent).	11.42239274	9						9	1	
The system shall clearly mark mines cleared lanes and boundaries in a way visible to follow-on with light wheeled vehicles	11.53251289	1	3	9	1	3	9	9	3	
The system shall function in high dust, sand, heat, and vibration conditions without degradation of performance.	11.02086541	1	9	3	3	9	3	3	1	1
The system shall clear the required route length within a time window compatible with urgent medical convoy movement.	11.24494995	1	3		9	3	3	9	9	
The system shall limit blast, fragmentation, and collateral damage within the confined pass.	10.80770156	1			9					
In the event of malfunction, the system shall default to a safe condition without creating additional hazards.	10.43955157			1	3		1	1	3	9
The system shall be designed to enable safe, compliant breakdown and disposal of all system components, including explosive payloads, electronic subsystems and structural elements in accordance with applicable environmental, explosive safety, and hazardous waste regulations at end of life.	10.38066037				1			1	3	9
		104	308	208	308	274	104	500	287	240

Figure 10: QFD 1 process carried out by the team

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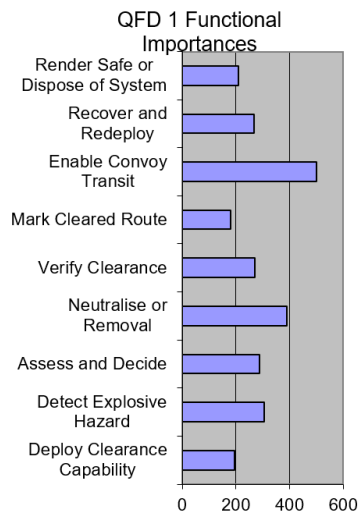


Figure 11: Relative importance chart of the functional requirements of the system.

Figure 11 shows that, in order, the three most critical functional requirements of the system were:

- Enable convoy transit – i.e. the convoy is able to traverse the full minefield to reach its destination.
- Neutralise or remove – i.e. the system defeats the threat posed by mines.
- Detect explosive hazard – i.e. the system can reliably detect threats.

This was a key milestone in the customer brief, who wanted to know the critical functionality of the system as a key objective.

Creating a Concept

With a full set of requirements and functions produced, a concept could now be created. To do this, a Function Means Analysis is first carried out. This is an opportunity to brainstorm all possible means of achieving each function, before analysis each one's trade-offs to ultimately rule them in or out as a possible solution. This is a key part of the process because more novel or futuristic solutions which have been researched have the ability to be returned to if the technology available were to change. The FMA process also generates assurance for all parties that full analysis of every possible means has been carried out.

Figure 12 shows the FMA carried out by the team. Solutions in red were ruled out after analysis, solutions in green were deemed likely valid, and solutions in amber were deemed to need further research.

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Deploy Clearance Capability	Drone	Man Portable	Unmanned Ground Vehicle (UGV)	Vehicle Mounted	Split Assembly	Animal Mounted											
Detect Explosive Hazard	Magnetometer	LIDAR	Ground Penetrating Radar	AI	Explosive Sniffing Animal	Crystal Ball	Tarot Cards	Foot Tapping	Prodding	Visuals							
Assess and Decide	AI	Visual		Aide Memoire	Call a Friend	50/50	Ask the Audience										
Neutralise or Removal	Explosive effector	Rifle fire	Demolitor	Laser	Sonic disturbance	Foot tapping	EDD	Don't	Plow	Grapple and hook	Goats	Python	UGV	Dropper done	Suicide done	Drone delivered	Force of Nature
Verify Clearance	Visual	Repeat scan	Sand's	Don't	AI	UGV	Explosive Sniffing Animal	Trained Personnel									
Mark Cleared Route	Flag	Paint	Rope / String	Glow Stick	Bread crumbs	Rocks / sticks / Environment	Barriers	Solar powered lights	Reflective markers								
Enable Convoy Transit	4x4 / Hilux / Defender	Tank	HGV	Sandbags	Digger	Tarmac	Plow	Steam roller	Concrete	Planks of wood	Railway	Helicopter	Clear new path	Mesh road			
Recover and Redeploy	Scare / replaceable	Fibre optic	Tow bar	Trailer	Return to home	Salt deposits	Bubble wrap	Bu magnet	Fishing net								

Figure 12: FMA carried out by the team.

In order to narrow the design down further into a fully fleshed concept, the team generated three possible solutions to the problem and then compared them using a Pugh matrix comparison.

Figure 13 details the three concept solutions against the military standard use of Python.

		Relative Importance	Relative Importance Weighted	Solution 1 (Python)	Solution 2 (Animals)	Solution 3 (Drone)	Solution 4 (Metal Detector)
WHATS - Customer Requirements	How much:- From QFD 1						
The system shall detect buried or surface-laid mines typical of legacy and improvised mine threats.		1	11.54159738	0	1	2	1
The system shall render detected mines safe by removal, destruction, or permanent disabling.		1	11.60976813	0	-1	0	-1
The system shall be transportable and operable using light vehicles (Land Rover, Hi-Lux, or equivalent).		1	11.42239274	0	2	1	2
The system shall clearly mark mines cleared lanes and boundaries in a way visible to follow-on with light wheeled vehicles		1	11.53251289	0	1	2	1
The system shall function in high dust, sand, heat, and vibration conditions without degradation of performance.		1	11.02086541	0	-1	0	-1
The system shall clear the required route length within a time window compatible with urgent medical convoy movement.		1	11.24494995	0	-1	-1	-1
The system shall limit blast, fragmentation, and collateral damage within the confined pass.		1	10.80770156	0	2	2	2
In the event of malfunction, the system shall default to a safe condition without creating additional hazards.		1	10.43955157	0	-1	1	2

Figure 13: Pugh Matrix comparing candidate solutions.

Pugh matrices compare the ability of candidate solutions to hit the customer requirements (weighted from the initial pairwise matrix) against a baseline method, but also against one another. At the end of the comparison, the solution with the highest total score is statistically the strongest candidate solution.

As a result, the full solution concept produced was as described in the Standard Operating Procedure outlined in Figure 14.

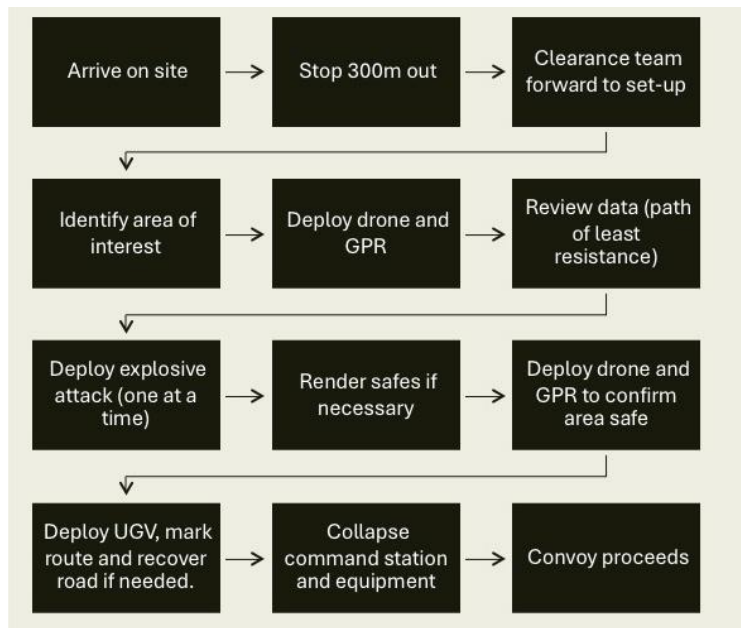


Figure 14: Generated Standard Operating Procedure for the task, from all design work.

The final concept design would therefore feature a number of additional components based on the research done to find components that best fit the requirements and functions described by the SOP, the exact brands to be determined from the qualification phase.

Qualification

Before any solution can go from conception to reality it must be subjected to a qualification process. The first step in the qualification and testing phase was to refer back to the critical functionality identified in QFD 1 (Figure 11) to find the key trials and tests required to guarantee function in the field.

Completing a QFD 2 process (Figure 15), mapping the components of the solution, instead of functions, with the customer requirements, found that the ground penetrating radar and unmanned ground vehicle were both critical components in the operation. As such, it was vital that tests and trials were able to assure the effectiveness of these components, which would be commercially purchased, and influence decisions over which component brands to purchase.

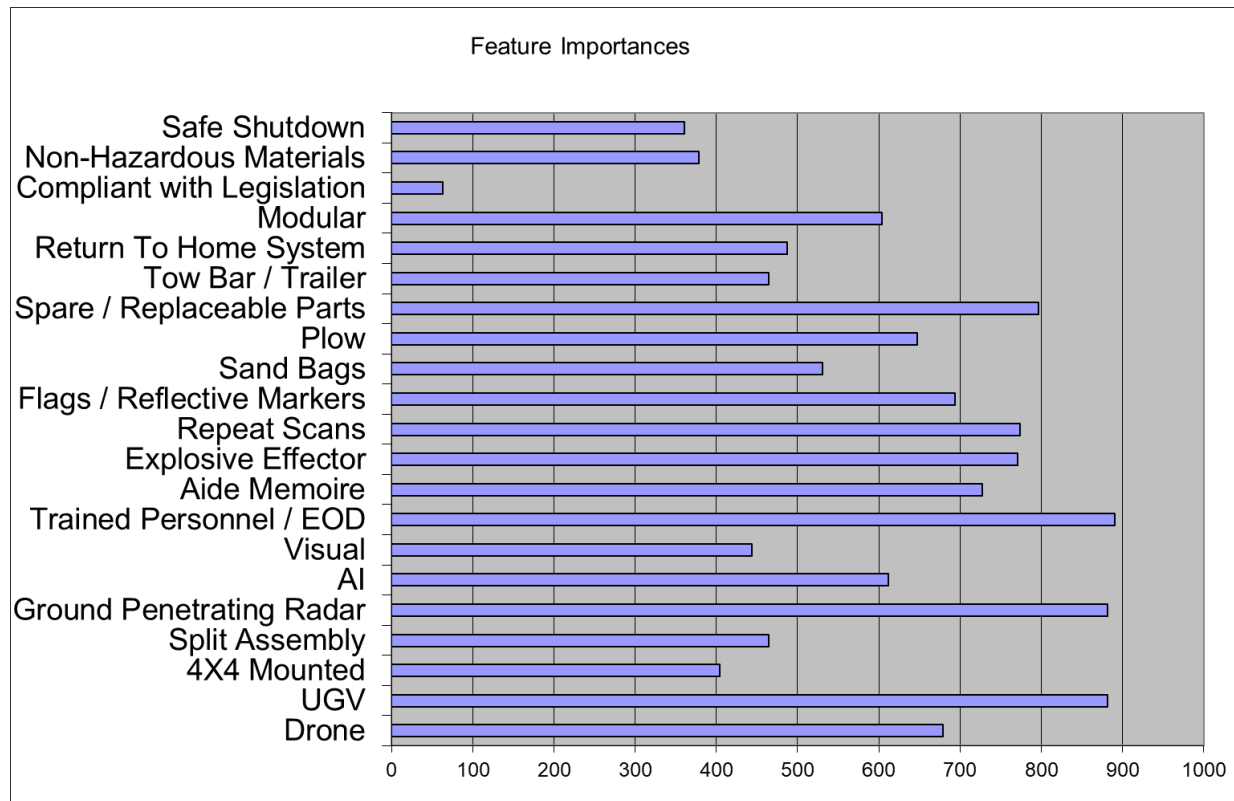


Figure 15: Feature importances chart highlighting critical components from the QFD 2 process.

From there, a comprehensive list of tests and trials to qualify the solution was created, covering the threat detection, threat defeat and pass-through phase of the operation.

To verify the effectiveness of the concept list of tests and trials, a Functional Metrics matrix was filled in to ensure that all requirements of the system were met simply by producing tests designed to meet the three key functions from QFD 1.

Figure 16 shows the Functional Metrics analysis matrix for the developed test regime.

FUNCTIONAL METRICS ANALYSIS		Test methods and relationship to requirements																
		Importance	Drone & Radar Sequential Environmental Testing		Identification Training	Final Detection Trials (with false alarms)		Payload & Delivery System Sequential Environmental	Payload placement trial (timed)	Charge Characterisation test	Firing Test against munition		UGV Sequential Environmental Testing	Plough Test (along edges of path) (timed)		Vehicle Proving ground trial (equivalent height)	Unmanned vehicle command testing	Prove Render Safe Procedures
Requirements																		
The system shall detect buried or surface-laid mines typical of legacy and improvised mine threats.		11.542	1	9	9												9	
The system shall render detected mines safe by removal, destruction, or permanent disabling.		11.61		1	1		1	3	9	9			3				9	
The system shall be transportable and operable using light vehicles (Land Rover, Hi-Lux, or equivalent).		11.422	9				9		3				9			9		
The system shall clearly mark mines cleared lanes and boundaries in a way visible to follow-on with light wheeled vehicles		11.533		1	1								1	9			9	
The system shall function in high dust, sand, heat, and vibration conditions without degradation of performance.		11.021	9				9	3	3	3	3		9	9		9		
The system shall clear the required route length within a time window compatible with urgent medical convoy movement.		11.245		3	3			3						3			1	
The system shall limit blast, fragmentation, and collateral damage within the confined pass.		10.808						1	9	9	9						1	
In the event of malfunction, the system shall default to a safe condition without creating additional hazards.		10.44						3	3	3	1			1		3	9	3
The system shall be designed to enable safe, compliant breakdown and disposal of all system components, including explosive payloads, electronic subsystems and structural elements in accordance with applicable environmental, explosive safety, and hazardous waste regulations at end of life.		10.381																9
			214	161	161	0	214	144	300	245	0	214	282	0	233	428	125	

Figure 16: Functional Metrics analysis for verifying ability of trials to hit customer requirements.

The Functional Metrics analysis verified that the full list of trials developed for the design solution was able to comprehensively display functionality against customer requirements.

The full list of trials and tests therefore selected for this operation were:

Threat Detection

- Sequential environmental testing¹ of drone and ground penetrating radar (GPR) to ensure performance in the field.
- Repeated identification training so the GPR can successfully identify threat signatures.
- Detection trials (including false alarms) so that the success of the identification training can be identified.

Threat Defeat

- Sequential environmental testing of the payload and delivery system to ensure performance in the field.
- Repeated testing of the delivery mechanism for assurance of correct placement and delivery in the field.
- Charge characterisation tests, such as EMTAP [9], so hazards can be fully understood.
- Live firing tests of the manufactured shaped charge against expected threats to verify performance.
- Render Safe Procedure – successful low order demolition of shaped charge in the event of malfunction as part of the breakdown and end of life plan.

Convoy Transit

- Sequential environmental testing of unmanned ground vehicle (UGV) to ensure performance in the field.
- Testing of route marking procedures to guarantee compliance with standards, as mapped in Figure 17 [10].

¹ Environmental Test [17]

Physical barriers may include fences, walls, ditches or other obstructions that prevent the unintentional entry into EO hazardous area.

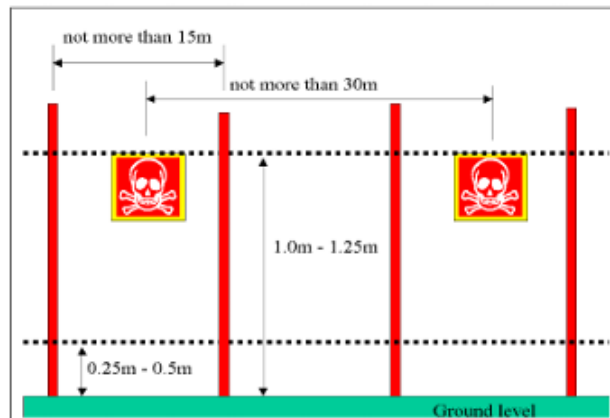


Figure B.3 – Example of physical barrier fence

Fences should be erected with two strands attached to uprights at 0.25 m to 0.5 m, and 1.0 m to 1.25 m above the ground (See Figure B.3). Fencing strands may be of any suitable durable material including wire, string, synthetic cord or tape. Uprights may include trees, buildings or existing structures and posts erected as part of the warning system and should be positioned not more than 15 m apart. EO hazard signs shall be attached to the top strand of the fence not more than 30 m apart and within 5 m of each turning point. If necessary, they may also be attached to uprights.

Figure 17: Figure B.3 from IMAS 08.40 demonstrating marking standards required for identified UXO and mines.

Vehicle Capability

- Command testing of drone, GPR and UGV to ensure system compatibility.
- Vehicle proving tests of 4x4s at military standard proving grounds² for assurance of vehicle survivability in the field.

Combined with a full operational evaluation, these tests have been designed through the use of systems engineering tools to provide a comprehensive assessment of the key functions, as well as the full range of customer requirements.

Failure Analysis

Any system runs the risk of failure, and this is amplified at the test and evaluation phase, where the system is not yet qualified for operational use.

In any function within a system there are five established modes of failure:

- No function
- Too much function
- Not enough function
- Intermittent function
- Unintended function

² Such as Bruntingthorpe [14], Millbrook [15], Hurn [16]

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It is understanding how these failure modes would present themselves, how easy they are to identify, and how they can be mitigated.

In order to understand potential failure modes better, a full Failure Modes Effects Analysis (FMEA) was conducted on every proposed test and trial to gauge the risk posed from each trial.

Figure 18 shows a snapshot of the FMEA carried out.

Test Regime	Trial	Importance	Failure Mode	Effect	S (1-10)	Cause	O (1-10)	D (1-10)	RPN
Threat Detection	Drive & Radar Sequential Environmental Testing	214	1. System is not tested	No information available on performance in mechanical and climatic environment	4	Malfunction of the test kit / Obstacles from trials vehicles	1	1	4
			2. System tested beyond specification	Excessive degradation of equipment and failure of the trial - hardware damage	7	Malfunction of the test kit / Human error during trial set-up	2	4	28
			3. System tested before specification	Excessive degradation of equipment and failure of the trial - hardware damage	7	Malfunction of the test kit / Human error during trial set-up	2	4	28
			4. System tested incorrectly	Excessive degradation of equipment and failure of the trial - hardware damage	7	Malfunction of the test kit / Human error during trial set-up	2	4	28
			5. System tested incorrectly	Excessive degradation of equipment and failure of the trial - hardware damage	7	Malfunction of the test kit / Human error during trial set-up	2	4	28
	Identification Training	161	1. Complete failure to identify threat signature	Unavailable system	8	Insufficient training data or poor software design	1	5	40
			2. Identifies all objects as a threat signature	False threat identified as threat - insufficient system	4	Insufficient training data or poor software design	2	5	20
			3. Fails to identify threat signature	Real threat missed - present a danger in operational field	9	Insufficient training data or poor software design	1	5	45
			4. Fails to consistently identify the same threat signature	Potential to miss real threat - present a danger in the operational field	9	Insufficient training data or poor software design	1	5	45
			5. System functions before point of detection	Operational failure in the presence of potential live ordnance	10	Human error / poor command / insufficient training data or poor software design / hardware damage	3	10	300
	Fixed Detection Trial (with false threat)	161	1. Fails to detect any threat	No threat detected - area remains clear	9	Human error / poor command / insufficient training data or poor software design / hardware damage	1	1	9
			2. System provides false positive readings	2b. Time wasted dealing with false positive 2b. Potential initiation of ordnance	9	Insufficient training data or poor software design / hardware damage / poor hardware design	2	5	90
			3. System provides false negative readings	Overgrown ordnance remains undetected by operators	9	Human error / poor command / insufficient training data or poor software design / hardware damage / poor hardware design	3	3	81
			4. Different results between groups of the same area	Operators lack clarity on safety of the operational area	9	Human error / poor command / insufficient training data or poor software design / hardware damage / poor hardware design	3	3	81
			5. Functionless before point of introduction	Potential RF exposure to personnel	10	Human error / poor command / poor software design / hardware damage / poor hardware design	3	10	300

Figure 18: FMEA snapshot from design workbook.

The FMEA consists of identifying the means of presentation of failures, analysing the severity, likelihood of occurrence and the ease of detection in order to find an aggregated risk between 0 and 1000 for each trial. The risk level determined by the final RPN influences whether or not further mitigations are needed, as shown in Table 2.

RPN Key:	
< 100	Low Risk
101 - 150	Acceptable Risk
151 - 200	Mid Risk
201 - 300	Potentially Unsafe Risk
301 - 500	Broadly Unsafe Risk
500 <	Unacceptable Risk

Table 2: RPN key from FMEA

Whilst all tests and trials proposed a level of risk, only a small number of trials presented risks deemed to be safety critical, taken to be any failure mode with an RPN of above 200.

In every instance, safety critical risks related directly to the introduction of live ordnance into the trials arena.

Table 3 identifies the highest risk trials from the FMEA, their RPN value, and the additional mitigations put in place to reduce the risk to an acceptable level.

Failure	RPN	Mitigation
Intermittent function of GPR during final threat assessment trials – whereby GPR is incapable of detecting live threats, leaving unexploded and undetected UXO in the arena.	486	- Identification training will not use live munitions to begin with only introducing them when the training data is more competent. - The location of all training munitions will be known to the trials staff and recorded in trials documentation.

		Severity reduces as trial goes on and GPR fine-tunes identification abilities.
Explosives functioning before their intended moment of detonation on several different trials, meaning that personnel may not have retreated to a safe distance.	300	- Anti-static measures in place. - First aiders on site. - Other instances of the culprit munition treated as if very sensitive. - Minimum required personnel in the area to conduct the work safely. - Robust, clear emergency plan in place.
Misfire or partial fire of shaped charge leading to two UXO profiles in the field during explosive defeat testing.	250	- Damaged mine dealt with by range UXO procedures. - Area considered dangerous until declared free from UXO.

Table 3: Significant safety critical risks identified in trials from FMEA along with mitigations to assure safety and lessen impact.

Carrying out the FMEA process allowed for a clear understanding of the key risk areas, meaning that focus could be dedicated to safety specific areas, prioritising reduction of risk where it is greatest needed and maximising the chances of success at a trials level.

Feedback

As a result of the T&E process, delivering qualification in line with key functionality including all risk and failure analysis, it was possible to provide insight to the design and manufacturing teams about operational risks, and the best components to use to alleviate risks and increase the chances of success.

Figure 19 demonstrates the feedback loop utilised during the qualification process.



Figure 19: Feedback regime for T&E process between stakeholders.

Through utilisation of the systems engineering tools, and a clear line of communication through feedback, the following decisions on components were made:

- Commercial Drone

- GPR: Zond Aero 1000 GPR [11]
- UGV: Rheinmetall Mission Master Series [12]
- Shaped Charge: In-house manufacture, inspired by Alfords' Vulcan [13]

Manufacturing

Process Conceptualisation

The first step within the manufacturing domain was to identify the process map for all manufactured components. A large portion of the solution consists of commercially purchased products, but some parts of the concept require manufacturing, such as the mounts to safely attach the drone and GPR to the beds of the 4x4 trucks, and, crucially, the shaped charge for destroying the mine.

Figure 20 shows the process map for the manufacturing stage of the design, including all manufacturing processes from start to finish.

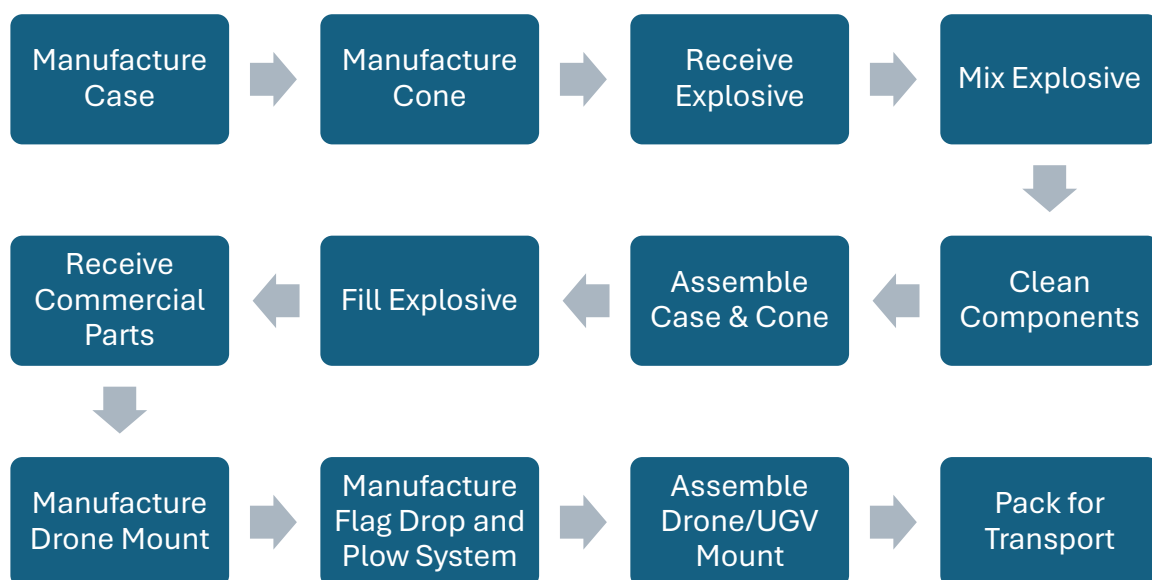


Figure 20: Process Map for manufacturing stage.

Finding Critical Processes

With a completed process map, the next stage was the process of completing a QFD 1 from a manufacturing perspective. In this matrix, manufacturing requirements are paired against the manufacturing processes from the process map in order to determine the critical processes.

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Figure 21 shows a snapshot of the QFD 1 matrix for this process, and figure 22 shows the graph relating the process importances from manufacturing.

Manufacturing Functionality	Importance	Manufacture Case		Receive	Mix	Clean	Assemble	Fill	Pack Shaped	Receive	Receive	Receive	Receive	Manufacture	Manufacture	Assemble	Assemble	Pack
		Case	Cone	Explosive	Explosive	Case / Cone	Case / Cone	Explosive	Charage	Drone	Radar	UGV	Plow	Drone	UGV	UGV	Drone	For Transport
Manufacturing Requirements																		
Manufacturing Costs																		
Labour	5	3	3	1	9	3	3	9	3	1	1	1	1	9	9	9	9	3
Equipment capital cost	5	9	9		9		3	9	1					9	9	3	3	3
Service / Operating Cost	5	3	3	1	9	1	1	9	1	1	1	1	1	9	9	3	3	1
Set up cost	5	9	9	1	9	1	3	9	1	1	1	1	1	9	9	3	3	3
Material Cost - Metal Bits	5	9	9						1				9	9	9	1	1	1
Material Cost - Energetic Bits	5			9	9					9	9	9						
Material Cost - other	5					1				9	9	9						
Maintenance Cost		9	9		9	3	3	9	1					3	3	3	3	1
Manufacturing Capacity	5																	
Target production rate XX per	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Reliable Manufacture	5																	
Repeatable performance	5	9	9	9	3	9	9	3	9	3	3	3	3	3	3	3	3	9
Effective Maintenance	5	9	9		9	1	3	9	3					3	3	3	3	1
Low system outage	5	3	3	1	1	9	3	1	9	1	1	1	1	3	3	3	3	9
Quality	5																	
Defect Free	5	3	3	9	9	9	9	9	9	9	9	9	9	3	3	9	9	9
Effective test and inspection	5	3	3	9	9	3	3	9	3	9	9	9	9	9	9	9	9	3
Safety	5																	
Explosive	5			9	9			9	9							9	9	9
Non-Explosive	5	9	9			9	9			9	9	9	9	9	9			
	5																	
	5																	
	5																	
	5																	
		360	360	260	440	245	245	395	260	230	230	230	230	390	390	290	290	270

Figure 21: QFD 1 matrix in full for manufacturing processes.

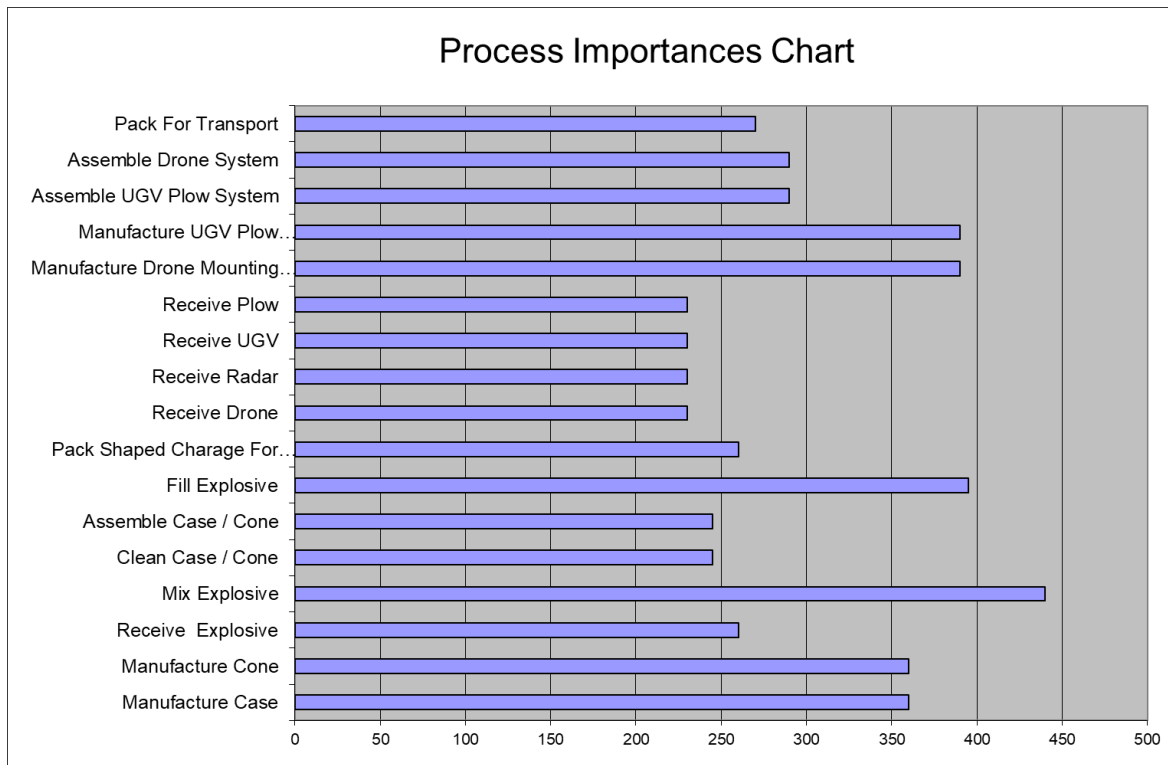


Figure 22: Process Importance Chart generated from manufacturing QFD 1 matrix.

Figure 22 shows clearly that the two most important processes are the filling and mixing of the explosive for the in-house shaped charge. As a result, and factoring in the obvious safety considerations associated, the full explosive side of the manufacturing process was selected for a more detailed analysis – to identify risks and noises and implement controls.

Process Control

In order to identify areas requiring extra controls during manufacture, it's important to first identify the areas of potential noise and variation in the process. To complete this process, P-diagrams and what-why tables are utilised.

P-diagrams are a tool used to understand where noise can enter the system. These noises are categorised into three categories: external noise (noises from outside factors), unit-to-unit variation (differences in manufacturing quality caused by differences between manufacturing units) and deterioration (noises caused by the aging of certain components in the process).

There is also a section for controls to be suggested to counter the noises.

Figure 23 shows the P-diagram constructed on the process of manufacturing the explosive fill for the shaped charge.

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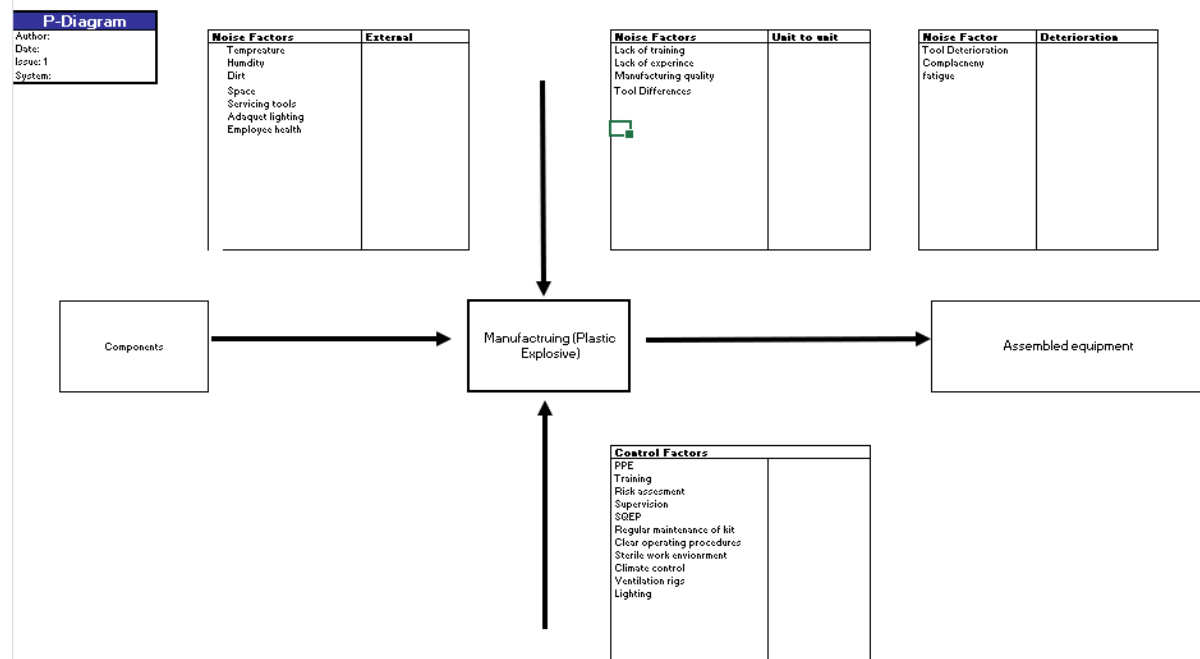


Figure 23: P-Diagram analysis for the manufacture of plastic explosive for the shaped charge.

Once the different sections of the P-diagram were filled, a What-Why table could then be produced, comparing the identified noises with the identified controls, to see which controls are the most effective at stopping noises, and also identifying which noises have the potential to cause the most issues. Figure 24 shows the chart relating the importance of controls and Figure 25 relates the most significant noises.

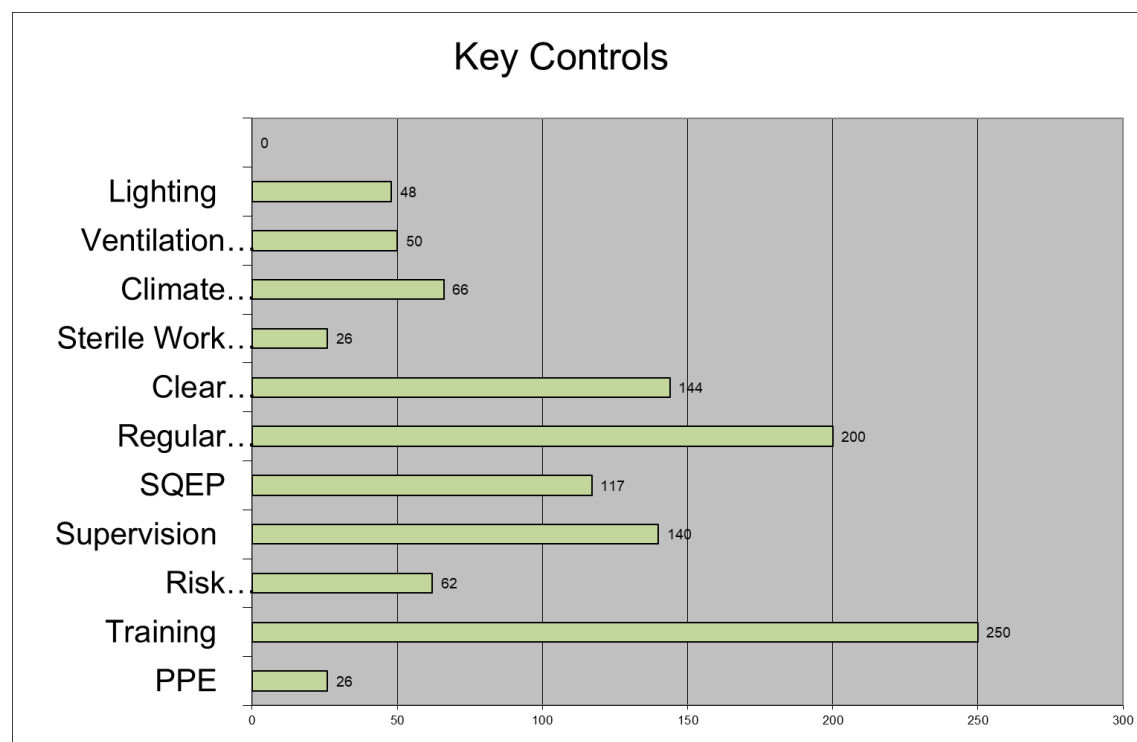


Figure 24: Key controls as identified through the what-why comparison matrix.

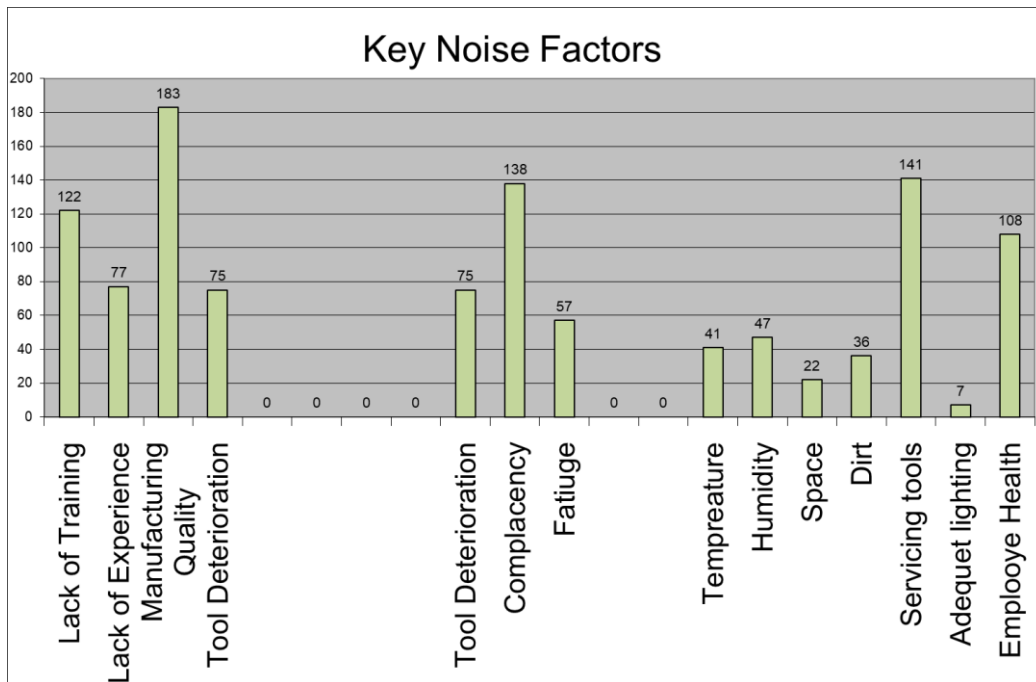


Figure 25: Chart showing the noises related by significance from what-why analysis.

The key noises identified from the P-diagram and What-Why table analysis were found to be:

- Complacency – where user familiarity leads to corners being cut and quality declining.
- Lack of training – where manufacturers lack the competence, experience or skill to create the product successfully.
- Tool differences – Differences in service schedule, lot, or age driving unit-to-unit or deterioration linked decline in quality.

The key controls identified from the same analysis were found to be:

- Training – Regular and continuous training schedules ensuring competence and compliance to keep standards high.
- Regular maintenance – A regular routine and reactive maintenance schedule for tools and equipment to ensure the highest quality and decrease the effects of aging.
- Clear process – A clear, understandable and easy to read set of processes, procedures and instructions to ensure absolute clarity on the manufacturing process.

The use of the systems engineering toolset allowed for a full analysis of the manufacturing process, designing a process flow and then analysing the process to find the key parts of the process, the largest areas of risk and the most essential controls to ensure that the manufacturing process is smooth and high-quality.

Conclusion

The systems engineering toolset played a valuable role in the creation of this solution. At each stage, a systems analysis tool could be used to provide a key insight into the system and how it may, or indeed may not, work. Using the matrices provided meant that clusters could be found that may indicate the existence of a subsystem, and that relationships could emerge, sometimes ones that may have been overlooked, meaning that considerations could be made early on in the design process.

The later that issues are discovered, the harder and costlier they are to fix. Using the systems engineering toolset wherever possible to their full extent means that any issues or possible failures can be captured early, at minimal cost.

The adaptation of the toolset into projects has the ability to bring down time and cost, ensuring that the system as a whole is given priority over individual department wishes, and this is a huge benefit to any complex project or complex system.

In this instance, the systems engineering toolset allowed for the creation of a viable solution that was presented to a panel of subject experts and was acknowledged as a viable solution – with recognition that the analysis done to come to the concept was thorough and had considered a large number of possible scenarios and issues to come to the concept.

References

- [1] A. Kossiakoff, S. Seymour, D. Flanigan and S. Biemer, “Systems Engineering and the World of Modern Systems,” in *Systems Engineering Principles and Practice*, John Wiley & Sons, 2020, pp. 3-33.
- [2] US Army, “Installation and Removal of US Mines (Section II: M15 Anti-Tank Mine),” in *Mine and Countermine Operations*, Washington DC, Department of the Army, 2005, pp. 365-378.
- [3] B. Seddon and N. Lainer, *Explosive Ordnance Guide for Ukraine*, Geneva: Geneva International Centre for Humanitarian Demining, 2025.
- [4] V. Jokic, “OZM-72 anti-personnel fragmentation mine,” 2011.
- [5] J. Pike and R. Sherman, “M15, M19 and M21 Anti-Tank Mines,” FAS Military Analysis Network, 1998.

- [6] R. Singh and H. Nachtnebel, “Analytical hierarchy process (AHP) application for reinforcement of hydropower strategy in Nepal,” *Renewable and Sustainable Energy Reviews*, no. 55, pp. 43-58, 2016.
- [7] T. Zink and I. Alexander, “Introduction to Systems Engineering with Use Cases,” *Computing and Control Engineering*, vol. 13, no. 6, 2002.
- [8] ASQ, “Quality Function Deployment (QFD),” [Online]. Available: https://asq.org/quality-resources/qfd-quality-function-deployment?srsId=AfmBOoo0DVohofUQz7Ql7APNND55eunaNmoApKz3mc0Lxzf_hsufBfqp. [Accessed 24 04 2026].
- [9] United Nations , “Classification Procedures, Test Methods and Criteria Relating to Explosives,” in *Manual of Tests and Criteria*, New York, United Nations, 2019, pp. 15-231.
- [10] International Mine Action Standards (IMAS), “IMAS 08.40 - Marking Explosive Ordnance Hazards,” United Nations Mine Action Service, New York, 2023.
- [11] Rheinmetall, “Rheinmetall Mission Master Series,” [Online]. Available: <https://www.rheinmetall.com/en/products/uncrewed-systems-and-autonomous-navigation-technology/mission-master-a-ugs>. [Accessed 24 04 2026].
- [12] A. Technologies, “Vulcan,” [Online]. Available: <https://www.explosives.net/products/vulcan/>. [Accessed 24 04 2026].
- [13] AlphaGeo, “Zond Aero 1000GPR,” AlphaGeo, [Online]. Available: <https://alphageo.uk.com/products/sph-engineering-gpr-system-radar-systems-zond-aero-1000-ng?srsId=AfmBOoqpawJUAWToWCNcKR-lxtYi6HXWIWkj3MHXzk5roBlzZABKFr4k>. [Accessed 24 04 2026].
- [14] Army Technology, “Bruntingthorpe Proving Ground,” Army Technology, [Online]. Available: <https://www.army-technology.com/contractors/training/bruntingthorpe/>. [Accessed 24 April 2026].
- [15] UTAC, “UTAC Millbrook,” UTAC, [Online]. Available: <https://www.utac.com/our-sites/europe/millbrook>. [Accessed 24 4 2026].
- [16] QinetiQ, “Hurn Proving Ground,” QinetiQ, [Online]. Available: <https://www.qinetiq.com/en/what-we-do/test-and-training/test-and-evaluation/facilities/hurn-proving-ground>. [Accessed 24 4 2026].

[17 QinetiQ, “Environmental Test Centre,” QinetiQ, [Online]. Available:
] <https://www.qinetiq.com/en/what-we-do/test-and-training/test-and-evaluation/facilities/environmental-test-centre>. [Accessed 24 4 2026].