

SYSTEMS THINKING DESIGN

Systems Engineering Work Group Based
Project Report

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ABSTRACT

The design team for Project Trojan designed a weapon system to neutralise a hostile communication system while limiting collateral damage. To satisfy the customer requirements to deliver a safe and reliable system, a concept design of a modular drone to target external antennas was developed.

The team used a systems engineering approach to aid in decision making and promote a collaborative working environment. Quality Functional Deployments (QFDs) and N² analysis enabled the design team to identify the weapon systems' critical subsystem and component. The initiation system of a High Voltage Exploding Bridgewire and its RDX pellet were selected due to their importance in ensuring a safe system that reliably delivers its terminal effect.

The manufacturing process of the critical component was also developed using the system engineering methodologies, primarily focusing on the making of the RDX pellet. By utilising QFDs, Parameter Diagrams and What/Why tables, the critical step was identified to be the weighing of the material. This was selected due to its influence on quality and producing a safe reliable component.

The importance of safety was ensured throughout the design process using Failure Effect Mode Analysis on the system's functionality and the manufacturing process to allow informed design decisions and mitigation strategies to be incorporated.

Overall, the systematic approach allowed the design team to make informed decisions to aid in the development of a safe and reliable weapon system.

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1 INTRODUCTION

Systems engineering is a systematic approach designed to support the engineering of complex systems [1]. It incorporates different toolsets and methodologies to guide the development of ideas with an emphasis on a collaborative approach across multiple disciplines.

Systems engineering facilitates informed decision-making by encouraging teams to consider different factors and potential consequences. It provides a series of processes and feedback loops to ensure all aspects are considered [2], including the safety implications of a system. The toolset highlights the importance of documenting design decisions, analysis and any assumptions made, ensuring traceability throughout the process [1, 2].

This report outlines how a systems engineering approach aided in the decision-making process of designing a weapon system, during a university Work Based Group Project, and how it aided in incorporating safety into the design. The Project Trojan Project Report [3] outlines how the design team worked together.

1.1 THE MISSION BRIEF

A mission brief was given for the design team to develop a weapon system capable of neutralising a hostile communications centre whilst causing minimal collateral damage to the building structure or potential occupants. Table 1-1 provides the key mission specifications.

Table 1-1 – Mission Brief Specifications

<i>Target Location</i>	Second Floor of an office building
<i>Target Specification</i>	Three terminals, manned by six operatives
<i>Access</i>	Three external 1x2m windows or two barricaded internal doors
<i>Range</i>	Target to be neutralised from at least 100m away

1.2 THE DESIGN TEAM

During the design phase of the system development, here after referred to as Project Trojan, each member of the design team, shown in Table 1-2, provided advice and guidance on their area of expertise.

Table 1-2 – Design Team Roles

ROLE	STUDENT
RESEARCH AND DEVELOPMENT LEAD	Leo Smith
PRODUCT SAFETY LEAD	Emalie Halifax
TESTING AND EVALUATION LEAD	Alex Lamdin
MANUFACTURING LEAD	Libbie Bush
PROCESS SAFETY LEAD	John Hamilton
BREAKDOWN AND DISPOSAL LEAD	Samual Hawkins

2 SYSTEM REQUIREMENTS

The mission brief provided expressed requirements for the system. To design a comprehensive weapon system, further requirements were gathered from the stakeholders. These were identified using the Stakeholder Boundary map in Figure 2-1 and a Stakeholder Influence map in Figure 2-2. Communicating with the key stakeholders for the project in Table 2-1, allowed further requirements to be identified through interviews, Use Cases and Affinity Diagrams. Appendix A Table A-1 provides the full list of system requirements.

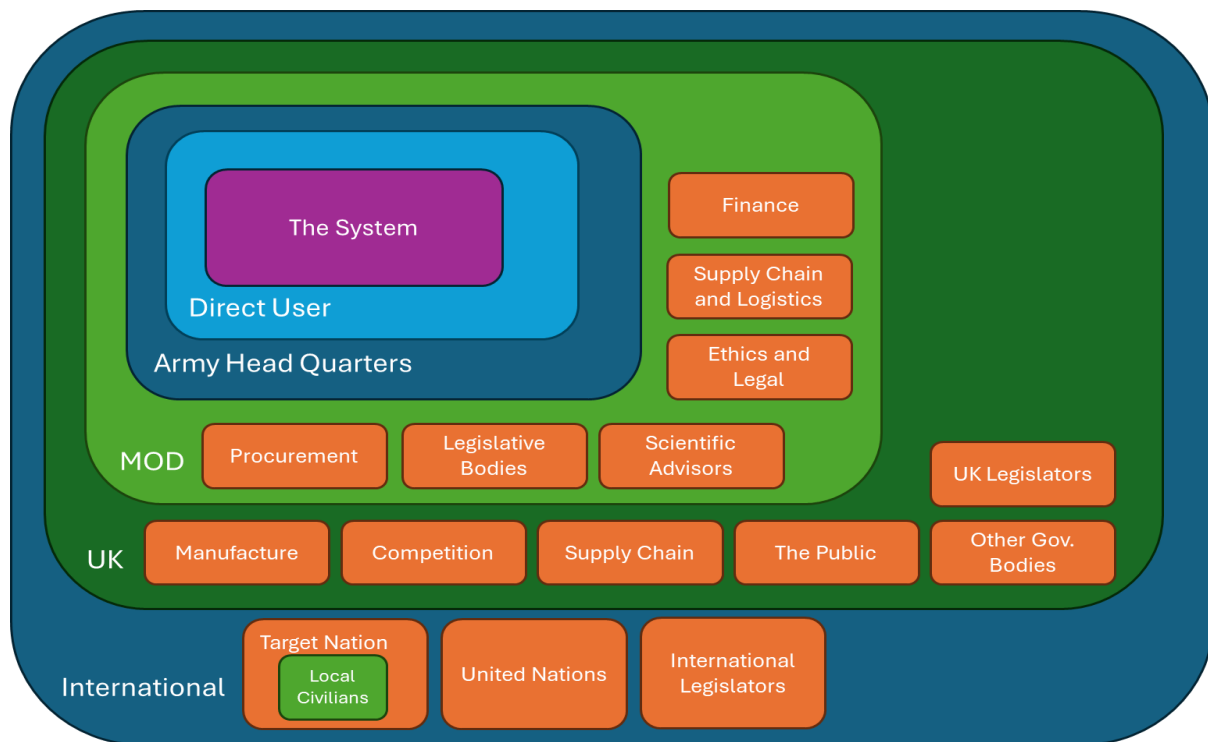


Figure 2-1 – Project Trojan Stakeholder Boundary Map

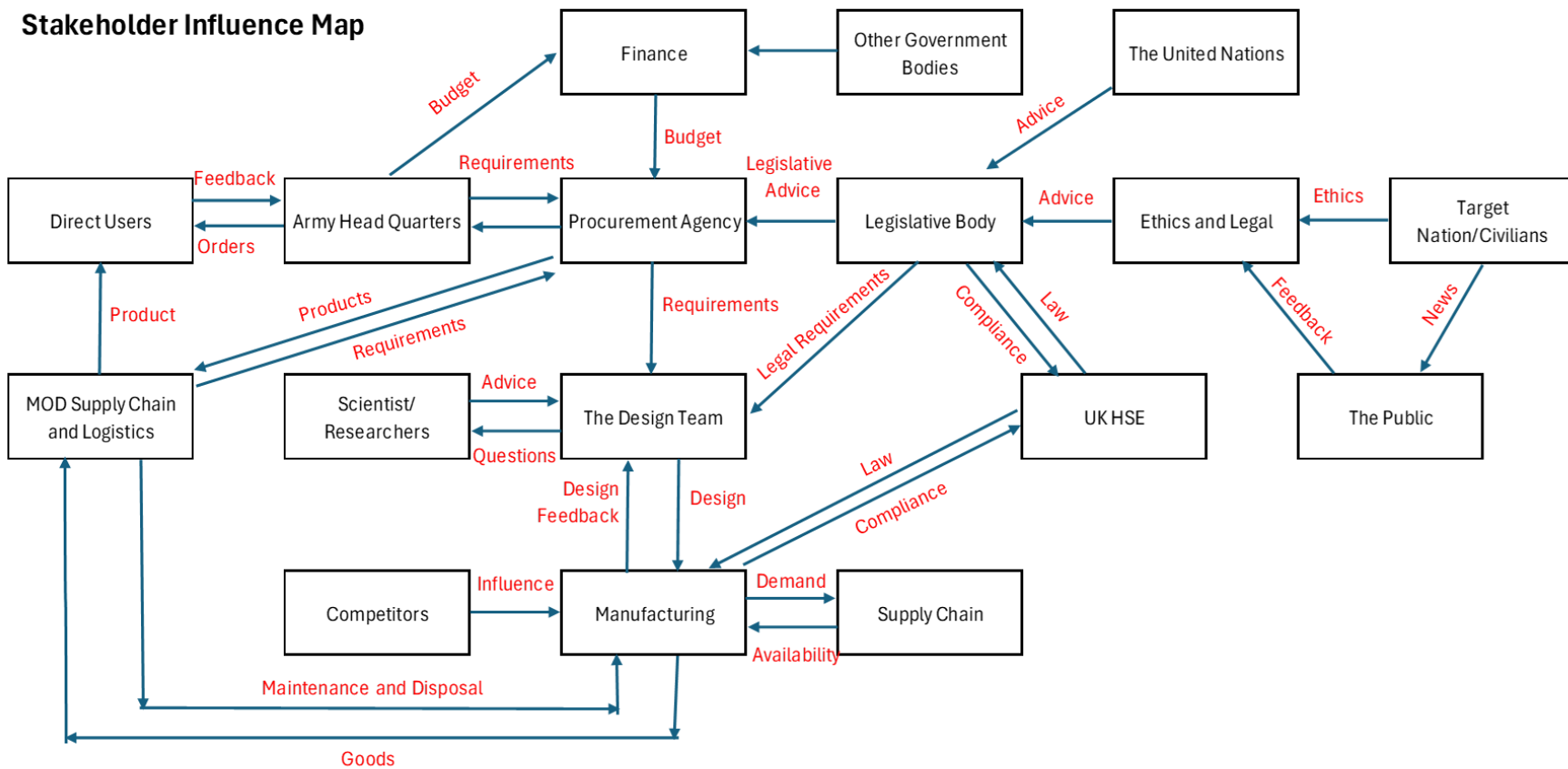


Figure 2-2 – Project Trojan Stakeholder Influence Map

Table 2-1 – Project Trojan Key Stakeholders

KEY STAKEHOLDERS	EXPLANATION
<i>Main Customer</i>	The person tasking the design team to develop the solution.
<i>User</i>	Final User Group assigned to use the system to complete the mission.
<i>Command/Tasking Authority</i>	Command Authority who has deemed the mission necessary and tasked the user.
<i>Procurement Body</i>	Procurement body who are responsible for purchasing systems and planning through-life support.
<i>Supply Chain & Logistics</i>	Logistics body responsible for storing, transporting & distributing in-service systems.
<i>Manufacturer(s)</i>	Single or multiple manufacturers tasked with manufacturing the final system.
<i>Legislative Bodies</i>	Authorities providing legislative oversight of the system's design, manufacture, through-life management and usage.

To direct the focus of the project, the customer requirements were prioritised using a Pairwise Comparison tool. This provided each requirement with an importance score to allow design decisions to be made based on the key requirements. It also provided means of traceability for any decisions made where a design trade-off may have been made. The Pairwise results for Project Trojan are shown in Figure 2-3 with Table 2-2 outlining how the top three requirements impact the design consideration. The overall safety and legislative requirements have not been included in the Pairwise as the system must always be safe and must always be legal, therefore these are always the highest priority when designing a system.

Project Trojan System Requirements Pairwise Comparison Results

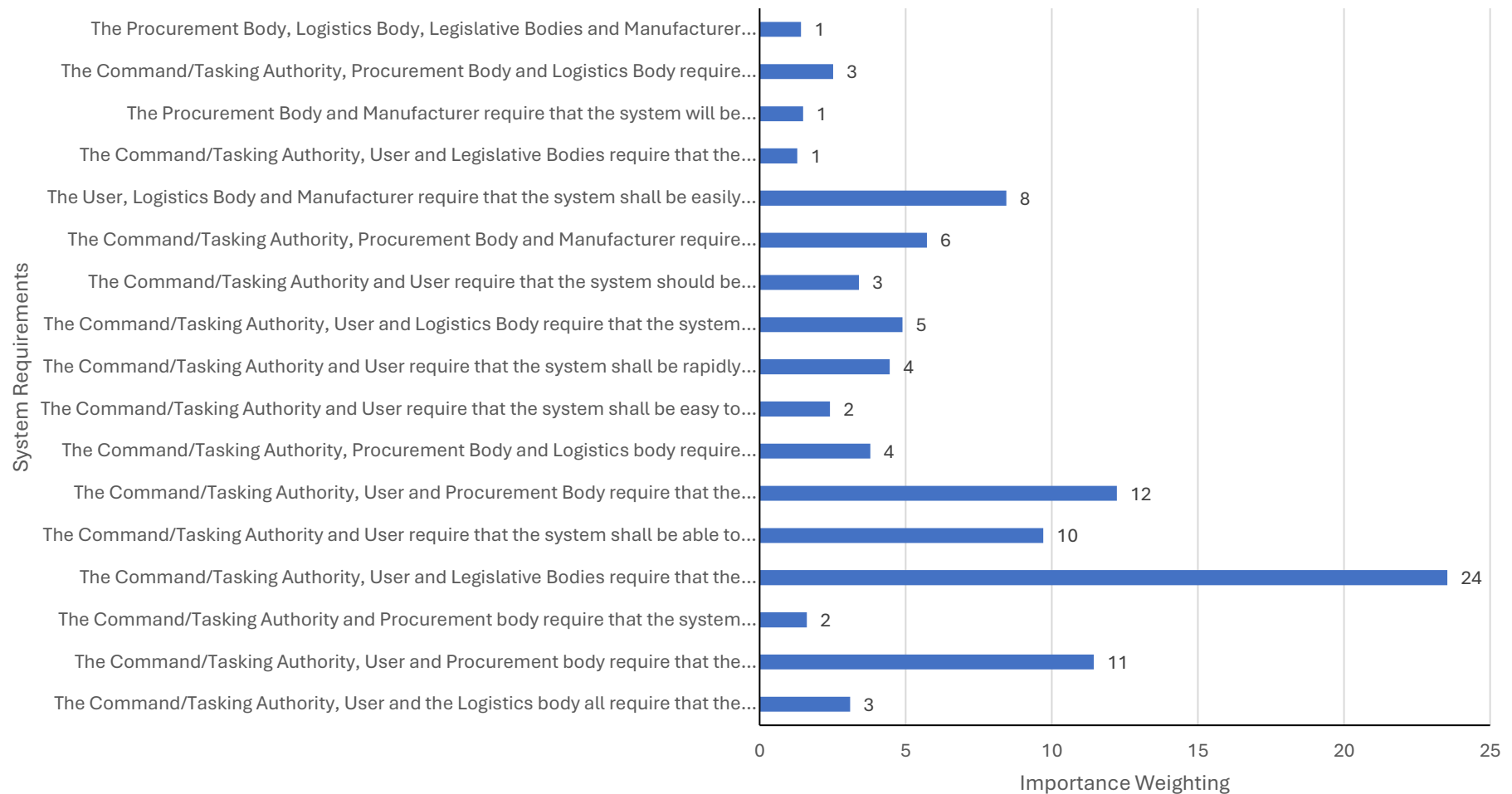


Figure 2-3 – Project Trojan System Requirements Pairwise Comparison Results

Table 2-2 – Project Trojan Key Customer Requirements

REQUIREMENT	IMPACT ON DESIGN CONSIDERATION
<i>The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effect(s) shall be contained within the target location specified in the mission brief.</i>	The terminal effect needs to be effective in neutralising the target, but the explosive power should not be excessive where it causes undue harm or damage. This will be measured in the trials and evaluation programme.
<i>The Command/Tasking Authority, User and Procurement Body require that the system shall function within its specified performance requirements (TBC) during TBC% of deployments.</i>	Design should be reliable and meet performance specifications. This would be met by the selection of materials and components and by the trials and evaluation programme.
<i>The Command/Tasking Authority, User and Procurement body require that the system shall successfully neutralise the target specified within the mission brief</i>	The system needs to be designed with the intended target in mind.

This analysis ensured that the system was designed as such that its effects are minimised to only neutralise the specified target while meeting the desired performance characteristics. It also ensured that the risks to health and the risk of an unsafe event during the Manufacture to Target or Disposal Sequence are as low as reasonably practicable and tolerable as outlined in the Defence Code of Practice (DCOP) 101: OME Design Requirements [4].

3 INITIAL SYSTEM FUNCTIONALITY

To ensure all essential design features are considered, the systems generic functionality needed to be identified and evaluated. The Use Case in Appendix B, served as the basis for the functional flow diagram in Figure 3-1. These aided in the identification of the initial generic functionality of the system.

The evaluation was performed by a Quality Functional Deployment (QFD) 1. The initial systems' generic functionality was rated against the system requirements to determine the critical system functionality. The results provided in Figure 3-2, identify the critical functionality to be:

- Deliver Terminal Effect
- Penetrate Target
- Move to Target.

3.1 FUNCTIONAL EFFECT FAILURE MODE ANALYSIS

Understanding how a system can fail is imperative to the design process [5], as it allows mitigations to be integrated into the system. A Function Failure Mode Effect Analysis (FFMEA) was conducted on four of the initial generic functions, with an example provided in Appendix C:

- Penetrate Target
- Deliver Terminal Effect
- Acquire Target
- Generate Motive Force

The FFMEA was an opportunity for recommendations to be made on additional functionality or features to be incorporated into the overall design. For the function *Penetrate Target*, a recommendation was made to consider means of redundancy and a robust testing and trials regime to ensure reliability in line with the system requirements. FFMEAs also provides an opportunity to identify any potential hazards to be designed out of the system or a mitigation designed in. A common effect identified across multiple FFMEAs was the system delivering the terminal effect in an unintended location. To mitigate this, an adequate safety isolation and prevention system was recommended. This resulted in a location-based proximity fuze being incorporated into the design.

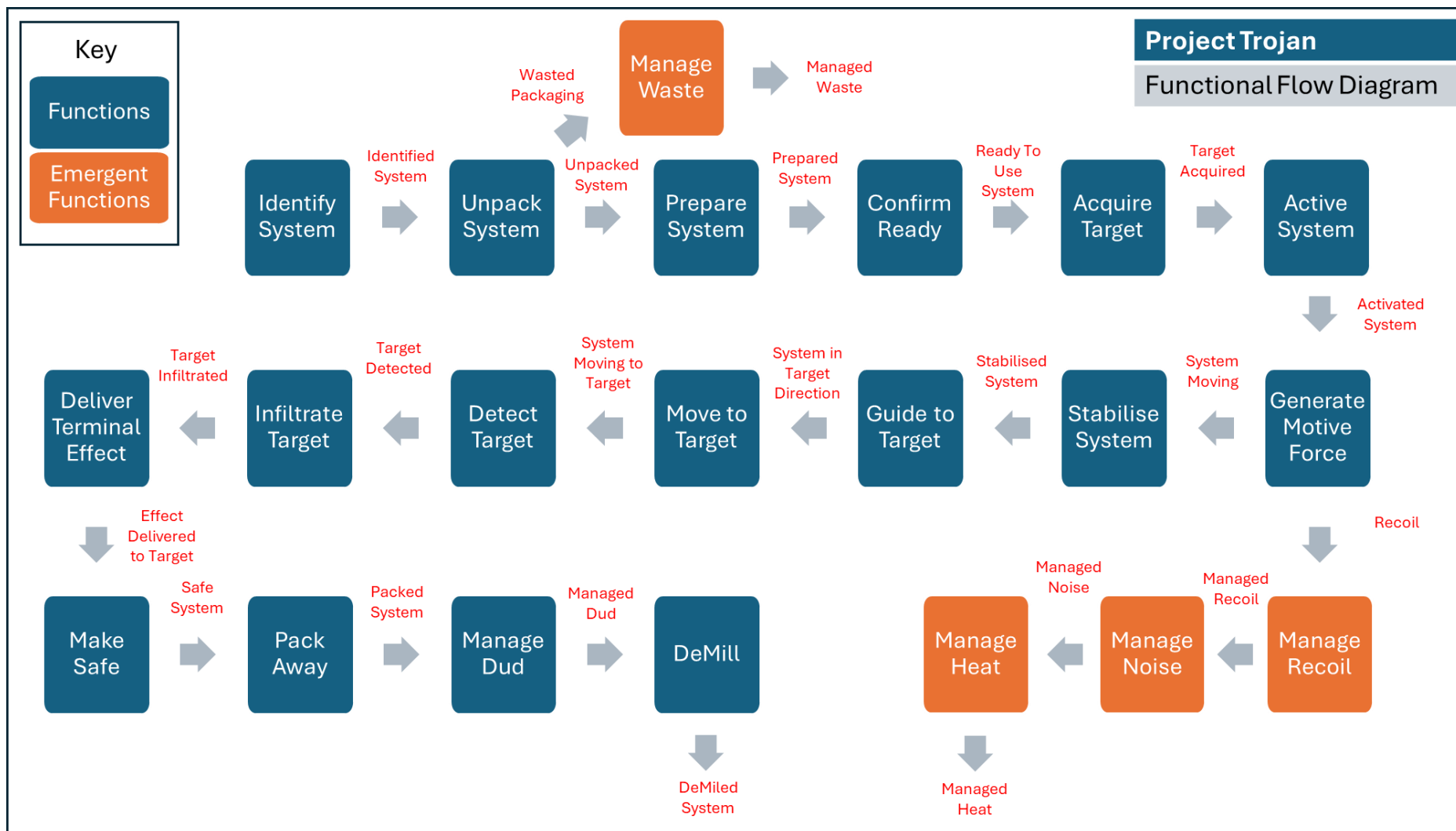


Figure 3-1 – Project Trojan Generic Functional Flow Diagram

QFD 1 Functional Importances

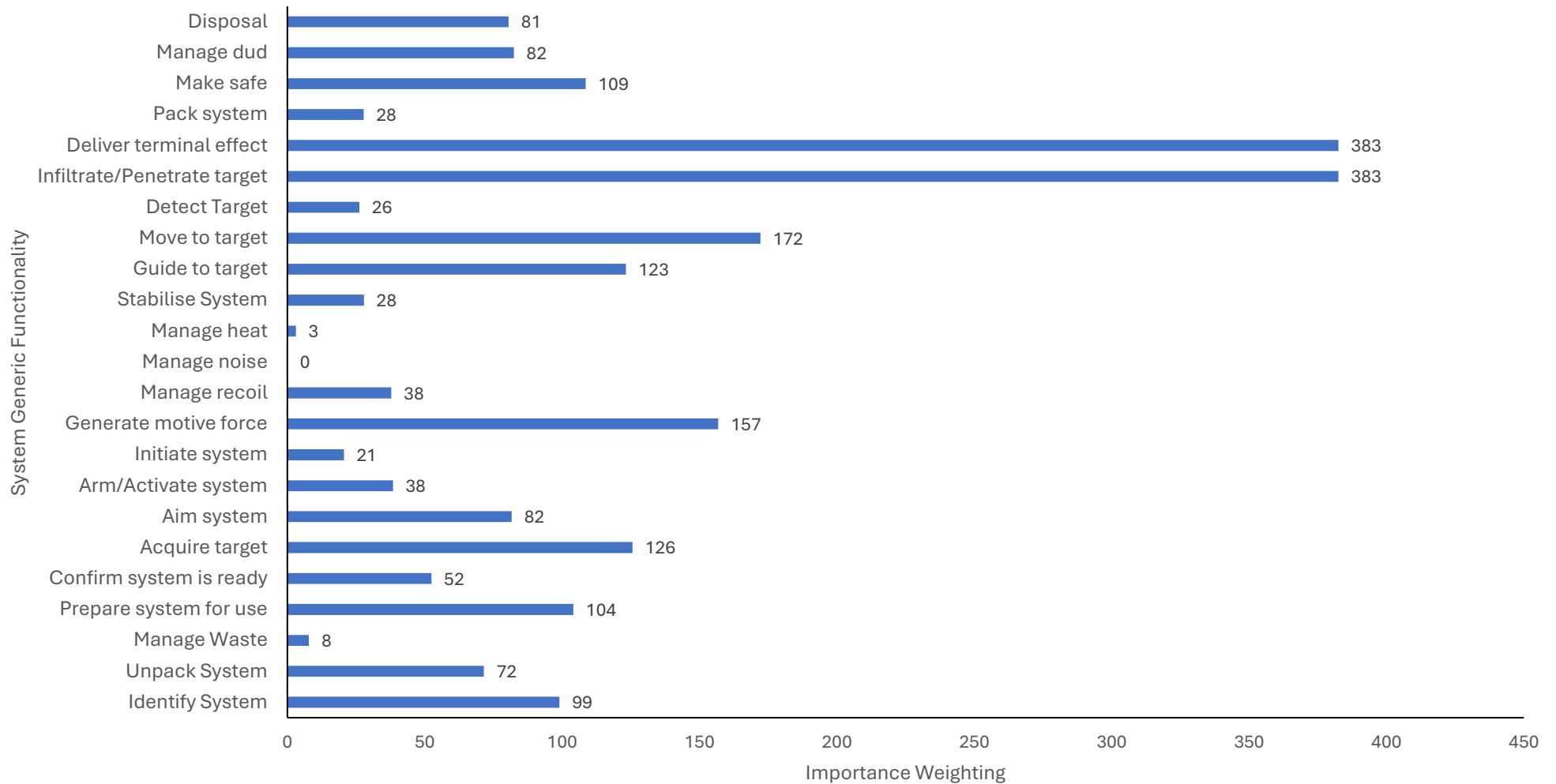


Figure 3-2 – Project Trojan QFD1 Results

4 DESIGN CONCEPT DERIVATION

Three design concepts were generated using a Function Means Analysis (FMA), which involved considering solutions to the generic functionality of the potential system. The three design concepts were:

- A Robot Dog
- A Drone
- A Loitering Munition

To evaluate which concept would best suit the customers' needs, a Pugh Matrix was used to compare each design against the customer's requirements. As the Mission Brief did not stipulate the exact desired method of neutralising the target, each design was assessed based on three potential attack scenarios. Table 4-1 summarises each scenario, outlining the advantages and disadvantages relating to the customer requirements. An Electronic Warfare Specialist was consulted after the team identified a lack of knowledge and understanding on how communication systems are design and can be defeated, their recommendations were integrated into the three potential attack scenarios. The results of the Pugh Matrices in Figure 4-1- Figure 4-3 are summarised in Table 4-2.

Table 4-1 – Summary of Attack Scenarios

SCENARIO	DESCRIPTION	ADVANTAGES	DISADVANTAGES
<i>Scenario One</i>	Disrupt external power supply to the office building.	Reduces collateral damage to the building and occupants in the intended room.	Easily rectifiable with backup generators and batteries. May also take out key systems for civilians putting them at undue risk.
<i>Scenario Two</i>	Target external antennas sending and receiving the communication signals.	Reduces collateral damage to the building and occupants.	Potential for secondary antenna system not identified. May take out civilian communication systems.
<i>Scenario Three</i>	Target the communication system inside the room.	Known location targeted.	Increased potential for collateral damage to building and occupants due to required magnitude of the terminal effect.

Project Trojan Pugh Matrix
Scenario 1: Disrupt External Electricity Supply

	Relative Importance Equal	Drone	Robot Dog	Loitering Munition
WHATs - Customer Requirements				
The Command/Tasking Authority, User and the Logistics body all require that the system shall be resistant to the environmental conditions specified within the mission brief (AOP 15A, specified as N. Europe)	3.1	0	2	1
The Command/Tasking Authority, User and Procurement body require that the system shall successfully neutralise the target specified within the mission brief	11	0	-1	-2
The Command/Tasking Authority and Procurement body require that the system may be capable of being used against a range of alternative targets	1.6	0	-2	2
The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effect(s) shall be contained within the target location specified in the mission brief.	24	0	2	-2
The Command/Tasking Authority and User require that the system shall be able to be deployed at a minimum distance of 100m from the intended target	9.7	0	-2	1
The Command/Tasking Authority, User and Procurement Body require that the system shall meet the specified performance and reliability criteria as specified within document TBC	12	0	-1	1
The Command/Tasking Authority, Procurement Body and Logistics body require that the system shall have a shelf life of X years (TBC)	3.8	0	1	0
The Command/Tasking Authority and User require that the system shall be easy to operate, requiring minimal training (X hours per annum)	2.4	0	1	-1
The Command/Tasking Authority and User require that the system shall be rapidly deployable within X minutes.	4.5	0	-2	0
The Command/Tasking Authority, User and Logistics Body require that the system shall be transportable to the specified firing location, without mechanical assistance, by the 5-man mission team.	4.9	0	-1	0
The Command/Tasking Authority and User require that the system should be capable of being set up, deployed and operated by the minimum number of personnel necessary.	3.4	0	0	0
The Command/Tasking Authority, Procurement Body and Manufacturer require that the system should be cost effective throughout the product life-cycle (Manufacture to Target or Disposal Sequence), approximately similar cost-per-shot to NLAW (£30-40k)	5.7	0	-1	-2
The User, Logistics Body and Manufacturer require that the system shall be easily identifiable throughout the product lifecycle (Manufacture to Target or Disposal Sequence)	8.4	0	0	0
The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effects should cause minimal harm to any occupants within the target location specified in the mission brief.	1.3	0	0	-1
The Procurement Body and Manufacturer require that the system will be constructed utilising technology and components manufacturable within the UK economy.	1.5	0	0	0
The Command/Tasking Authority, Procurement Body and Logistics Body require that the system should be interoperable with current UK and NATO military equipment and infrastructure.	2.5	0	0	0
The Procurement Body, Logistics Body, Legislative Bodies and Manufacturer require that the system shall, at end-of-life, be capable of being broken down to a point where the remaining components can be safely disposed of.	1.4	0	2	1
All key stakeholders require that the system must adhere to all relevant regulations & legislation (REACH, UK, International)	10	0	0	0
All key stakeholders require that the system must be safe throughout the product life cycle (Manufacture to Target or Disposal Sequence)	10	0	0	-1
Score:		0	-3.54752	-65.4373

Figure 4-1 – Project Trojan System Pugh Matrix Scenario One

Project Trojan Pugh Matrix
Scenario 2: External Mounted Antenna

	Relative Importance Equal	Drone	Robot Dog	Loitering Munition
WHATs - Customer Requirements				
The Command/Tasking Authority, User and the Logistics body all require that the system shall be resistant to the environmental conditions specified within the mission brief (AOP 15A, specified as N. Europe)	3.1	0	2	1
The Command/Tasking Authority, User and Procurement body require that the system shall successfully neutralise the target specified within the mission brief	11	0	-2	2
The Command/Tasking Authority and Procurement body require that the system may be capable of being used against a range of alternative targets	1.6	0	-2	2
The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effect(s) shall be contained within the target location specified in the mission brief.	24	0	-2	-2
The Command/Tasking Authority and User require that the system shall be able to be deployed at a minimum distance of 100m from the intended target	9.7	0	-2	1
The Command/Tasking Authority, User and Procurement Body require that the system shall meet the specified performance and reliability criteria as specified within document TBC	12	0	-2	1
The Command/Tasking Authority, Procurement Body and Logistics body require that the system shall have a shelf life of X years (TBC)	3.8	0	1	0
The Command/Tasking Authority and User require that the system shall be easy to operate, requiring minimal training (X hours per annum)	2.4	0	1	-1
The Command/Tasking Authority and User require that the system shall be rapidly deployable within X minutes.	4.5	0	-2	0
The Command/Tasking Authority, User and Logistics Body require that the system shall be transportable to the specified firing location, without mechanical assistance, by the 5-man mission team.	4.9	0	-1	0
The Command/Tasking Authority and User require that the system should be capable of being set up, deployed and operated by the minimum number of personnel necessary.	3.4	0	0	0
The Command/Tasking Authority, Procurement Body and Manufacturer require that the system should be cost effective throughout the product life-cycle (Manufacture to Target or Disposal Sequence), approximately similar cost-per-shot to NLAW (£30-40k)	5.7	0	-1	-2
The User, Logistics Body and Manufacturer require that the system shall be easily identifiable throughout the product lifecycle (Manufacture to Target or Disposal Sequence)	8.4	0	0	0
The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effects should cause minimal harm to any occupants within the target location specified in the mission brief.	1.3	0	0	-1
The Procurement Body and Manufacturer require that the system will be constructed utilising technology and components manufacturable within the UK economy.	1.5	0	0	0
The Command/Tasking Authority, Procurement Body and Logistics Body require that the system should be interoperable with current UK and NATO military equipment and infrastructure.	2.5	0	0	0
The Procurement Body, Logistics Body, Legislative Bodies and Manufacturer require that the system shall, at end-of-life, be capable of being broken down to a point where the remaining components can be safely disposed of.	1.4	0	2	1
All key stakeholders require that the system must adhere to all relevant regulations & legislation (REACH, UK, International)	10	0	0	0
All key stakeholders require that the system must be safe throughout the product life cycle (Manufacture to Target or Disposal Sequence)	10	0	0	-1
Score:		0	-121.361	-19.6817

Figure 4-2 – Project Trojan System Pugh Matrix Scenario Two

Project Trojan Pugh Matrix
Scenario 3: Internal Communication System

	Relative Importance Equal	Drone	Robot Dog	Loitering Munition
WHATs - Customer Requirements				
The Command/Tasking Authority, User and the Logistics body all require that the system shall be resistant to the environmental conditions specified within the mission brief (AOP 15A, specified as N. Europe)	3.1	0	2	1
The Command/Tasking Authority, User and Procurement body require that the system shall successfully neutralise the target specified within the mission brief	11	0	-2	2
The Command/Tasking Authority and Procurement body require that the system may be capable of being used against a range of alternative targets	1.6	0	-2	2
The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effect(s) shall be contained within the target location specified in the mission brief.	24	0	-2	0
The Command/Tasking Authority and User require that the system shall be able to be deployed at a minimum distance of 100m from the intended target	9.7	0	-2	1
The Command/Tasking Authority, User and Procurement Body require that the system shall meet the specified performance and reliability criteria as specified within document TBC	12	0	-2	1
The Command/Tasking Authority, Procurement Body and Logistics body require that the system shall have a shelf life of X years (TBC)	3.8	0	1	0
The Command/Tasking Authority and User require that the system shall be easy to operate, requiring minimal training (X hours per annum)	2.4	0	1	-1
The Command/Tasking Authority and User require that the system shall be rapidly deployable within X minutes.	4.5	0	-2	0
The Command/Tasking Authority, User and Logistics Body require that the system shall be transportable to the specified firing location, without mechanical assistance, by the 5-man mission team.	4.9	0	-1	0
The Command/Tasking Authority and User require that the system should be capable of being set up, deployed and operated by the minimum number of personnel necessary.	3.4	0	0	0
The Command/Tasking Authority, Procurement Body and Manufacturer require that the system should be cost effective throughout the product life-cycle (Manufacture to Target or Disposal Sequence), approximately similar cost-per-shot to NLAW (£30-40k)	5.7	0	-1	-2
The User, Logistics Body and Manufacturer require that the system shall be easily identifiable throughout the product lifecycle (Manufacture to Target or Disposal Sequence)	8.4	0	0	0
The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effects should cause minimal harm to any occupants within the target location specified in the mission brief.	1.3	0	0	-2
The Procurement Body and Manufacturer require that the system will be constructed utilising technology and components manufacturable within the UK economy.	1.5	0	0	0
The Command/Tasking Authority, Procurement Body and Logistics Body require that the system should be interoperable with current UK and NATO military equipment and infrastructure.	2.5	0	0	0
The Procurement Body, Logistics Body, Legislative Bodies and Manufacturer require that the system shall, at end-of-life, be capable of being broken down to a point where the remaining components can be safely disposed of.	1.4	0	2	1
All key stakeholders require that the system must adhere to all relevant regulations & legislation (REACH, UK, International)	10	0	0	0
All key stakeholders require that the system must be safe throughout the product life cycle (Manufacture to Target or Disposal Sequence)	10	0	0	-1
Score:		0	-121.361	26.1057

Figure 4-3 – Project Trojan System Pugh Matrix Scenario Three

Table 4-2 – Initial Design Comparison Results

SCENARIO	SOLUTION	PUGH SCORE	RANKING
<i>Scenario One</i>	Drone	0	1st
	Robot Dog	-3.5	2nd
	Loitering Munition	-65.4	3rd
<i>Scenario Two</i>	Drone	0	1st
	Robot Dog	-121.4	3rd
	Loitering Munition	-19.7	2nd
<i>Scenario Three</i>	Drone	0	2nd
	Robot Dog	-121.4	3rd
	Loitering Munition	26.1	1st

These results were taken forward into a Design Review with the Customer to determine which solution to progress with. Due to the reduced collateral damage and the increased impact on the hostile communication system, the customer decided to proceed with attack Scenario Two, focusing on targeting the external antenna arrays using the drone-based solution.

4.1 PROGRESSION OF CONCEPT GENERATION

Based on the more precise design specification from the Customer, improved system functionality needed to be developed, and new critical functionality determined. This required the QFD1 to be repeated using the new functional flow provided in Figure 4-4. The results for the repeated QFD1 are provided in Figure 4-5, highlighting the new critical functions to be:

1. Identify Target Location
2. Deliver Terminal Effect
3. Communicate with Drone System
4. Move to Target

A secondary FMA was also conducted using the improved generic functionality to allow a more refined concept to be developed. This resulted in two drone-based solutions, a suicide drone with a built-in warhead and an option which contained a modular warhead. The secondary Pugh comparison, Figure 4-6, highlighted that the modular warhead met the customer requirements more effectively by providing increased capability and a safer system.

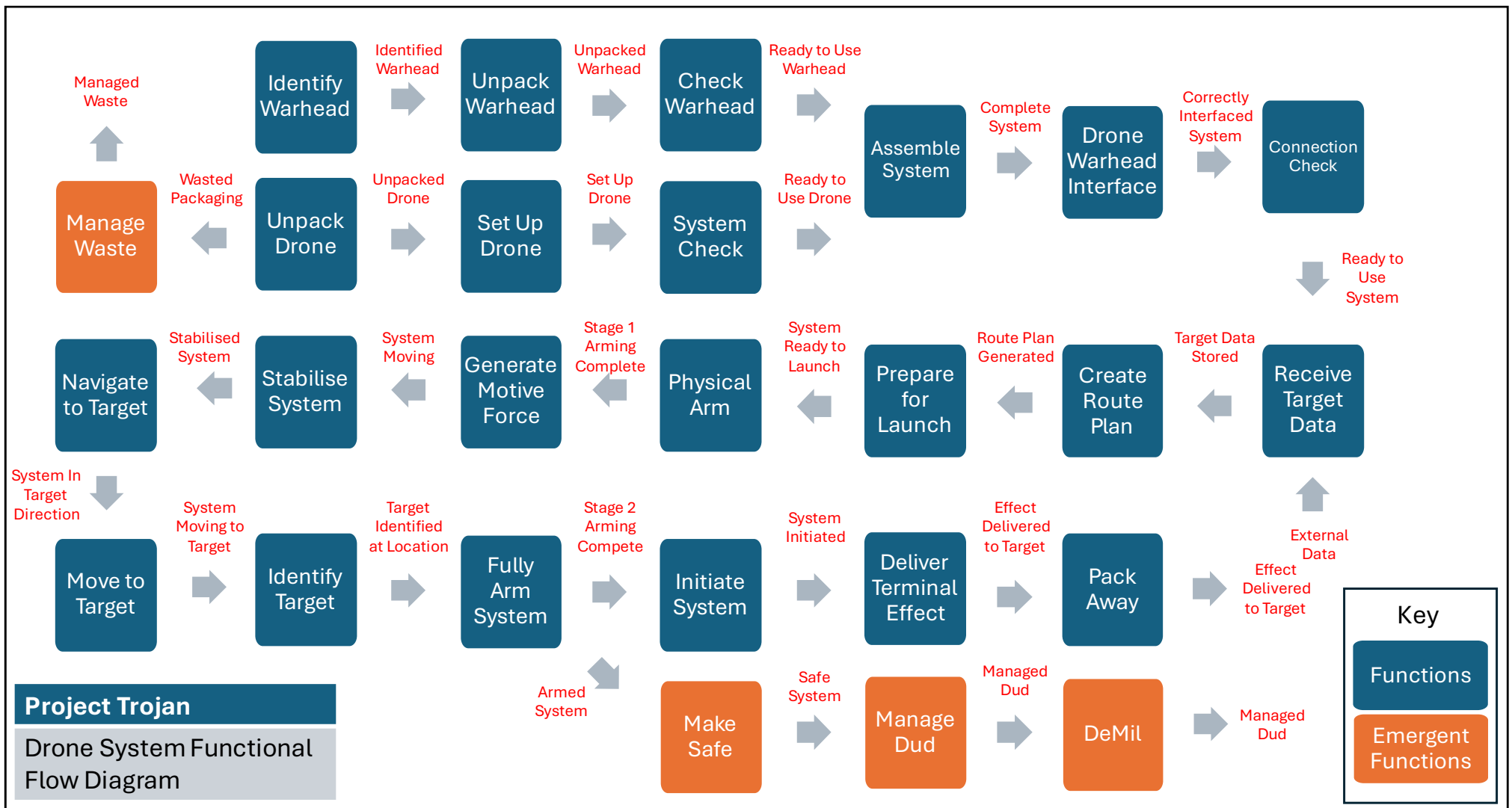


Figure 4-4 – Project Trojan Drone-based System Functional Flow Diagram

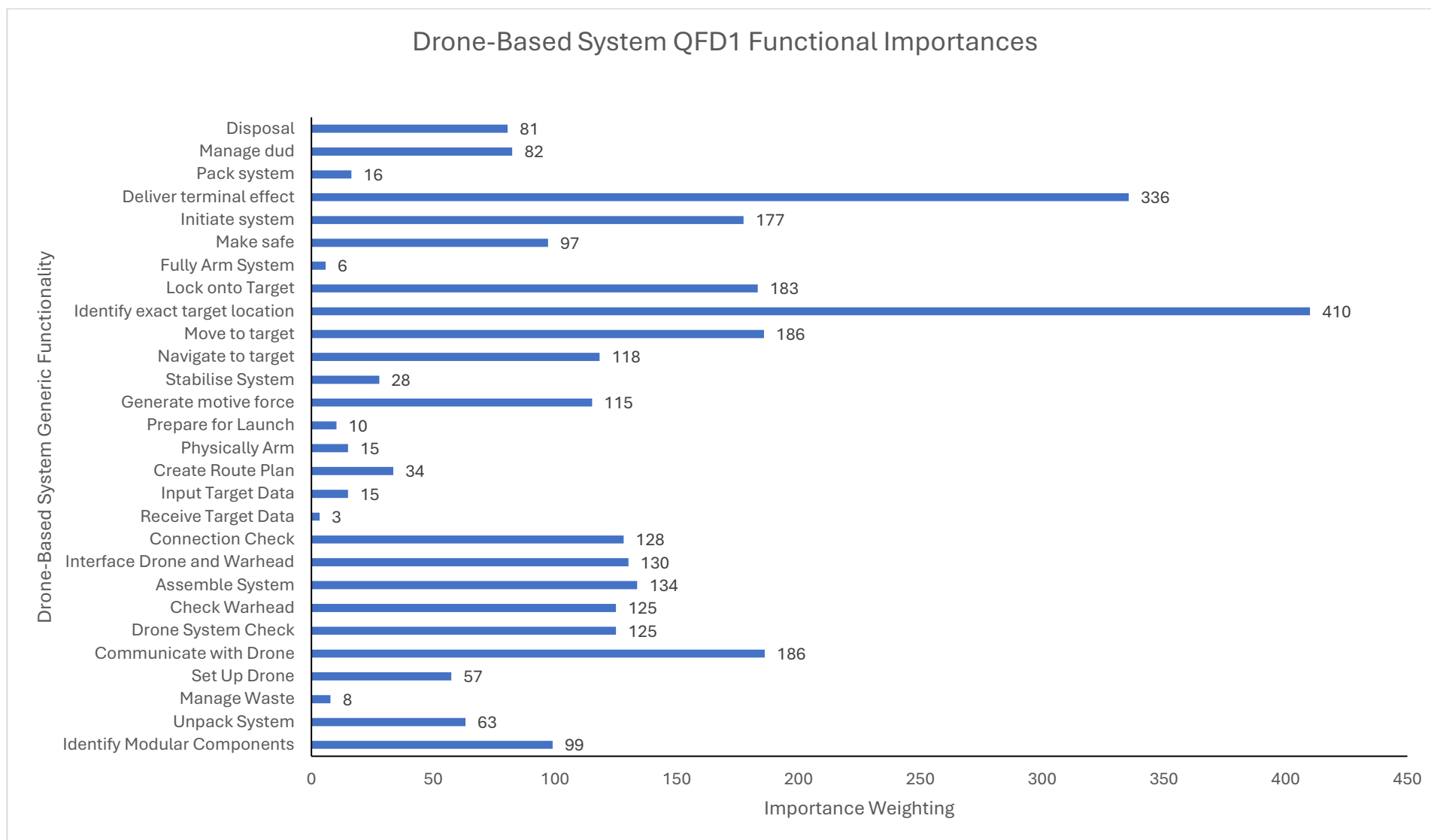


Figure 4-5 – Project Trojan Drone-Based System QFD1 Results

Project Trojan Pugh Matrix
Scenario 2: External Mounted Antenna

	Relative Importance Equal	Drone	Modular Drone
WHATs - Customer Requirements			
The Command/Tasking Authority, User and the Logistics body all require that the system shall be resistant to the environmental conditions specified within the mission brief (AOP 15A, specified as N. Europe)	3.1	0	0
The Command/Tasking Authority, User and Procurement body require that the system shall successfully neutralise the target specified within the mission brief	11	0	2
The Command/Tasking Authority and Procurement body require that the system may be capable of being used against a range of alternative targets	1.6	0	2
The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effect(s) shall be contained within the target location specified in the mission brief.	24	0	0
The Command/Tasking Authority and User require that the system shall be able to be deployed at a minimum distance of 100m from the intended target	9.7	0	0
The Command/Tasking Authority, User and Procurement Body require that the system shall meet the specified performance and reliability criteria as specified within document TBC	12	0	1
The Command/Tasking Authority, Procurement Body and Logistics body require that the system shall have a shelf life of X years (TBC)	3.8	0	2
The Command/Tasking Authority and User require that the system shall be easy to operate, requiring minimal training (X hours per annum)	2.4	0	-1
The Command/Tasking Authority and User require that the system shall be rapidly deployable within X minutes.	4.5	0	-1
The Command/Tasking Authority, User and Logistics Body require that the system shall be transportable to the specified firing location, without mechanical assistance, by the 5-man mission team.	4.9	0	0
The Command/Tasking Authority and User require that the system should be capable of being set up, deployed and operated by the minimum number of personnel necessary.	3.4	0	0
The Command/Tasking Authority, Procurement Body and Manufacturer require that the system should be cost effective throughout the product life-cycle (Manufacture to Target or Disposal Sequence), approximately similar cost-per-shot to NLAW (£30-40k)	5.7	0	-1
The User, Logistics Body and Manufacturer require that the system shall be easily identifiable throughout the product lifecycle (Manufacture to Target or Disposal Sequence)	8.4	0	0
The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effects should cause minimal harm to any occupants within the target location specified in the mission brief.	1.3	0	0
The Procurement Body and Manufacturer require that the system will be constructed utilising technology and components manufacturable within the UK economy.	1.5	0	0
The Command/Tasking Authority, Procurement Body and Logistics Body require that the system should be interoperable with current UK and NATO military equipment and infrastructure.	2.5	0	2
The Procurement Body, Logistics Body, Legislative Bodies and Manufacturer require that the system shall, at end-of-life, be capable of being broken down to a point where the remaining components can be safely disposed of.	1.4	0	2
All key stakeholders require that the system must adhere to all relevant regulations & legislation (REACH, UK, International)	10	0	0
All key stakeholders require that the system must be safe throughout the product life cycle (Manufacture to Target or Disposal Sequence)	10	0	1
Score:		0	51.1634

Figure 4-6 – Project Trojan Drone-Based System Pugh Matrix

5 CRITICAL DESIGN FEATURES

The critical design features are the systems, subsystems, and components that have the most impact on meeting the design requirements and system functionality [6]. These have been identified using a QFD2 and a N² Analysis, with the critical component of the critical subsystem taken forward to explore potential manufacturing processes.

5.1 CRITICAL SUBSYSTEM

As shown in Figure 5-1 and Figure 5-2, the system level QFD2 and N² Analysis identified the Interactive Control Module (ICM) as the critical subsystem. This system would contain complex software and electrical components, and it was decided by the design team that software and electrical Subject Matter Experts (SMEs) would be better placed to enhance the design of this subsystem.

A second N² Analysis was conducted specifically isolating the features relating to the warhead module, the subsequent smaller N² matrix is presented in Figure 5-3. This concluded that the Bespoke Interface Subsystem, designed to send signals to and from the ICM, main drone body and the warhead module, was the next critical subsystem. It was decided that this would be better suited as a focus for the software and electrical SMEs. Further analysis of **Error! Reference source not found.** highlighted the Initiation Subsystem, in the form of a High Voltage Exploding Bridgewire (HVEBW), as another critical subsystem. As this is essential to delivering the terminal effect and therefore crucial to satisfying the customer requirements, the Initiation Subsystem was selected to identify the critical component.

5.2 CRITICAL COMPONENT

The Initiation Subsystem incorporated into the warhead module is a HVEBW Detonator containing a low density PETN (pentaerythritol tetranitrate) pellet and a RDX (1,3,5-trinitroperhydro-1,3,5-triazine) pellet. To determine its critical component, QFD1, QFD2 and N² Analysis were repeated using the subsystem requirements in Table A-2, which were derived from the customer requirements and the system architecture. The results of the QFD1 in Figure 5-4, highlighted the generic function of *Receive Shockwave* as the critical function of the subsystem. RDX was identified as the critical component in the QFD2 results in Figure 5-5 whereas, the N² Analysis in Figure 5-6 identified both the low density PETN and RDX. Due to the greater difference in importance between the two materials shown in the QFD2, the design team decided to explore manufacturing processes with the RDX Pellet.

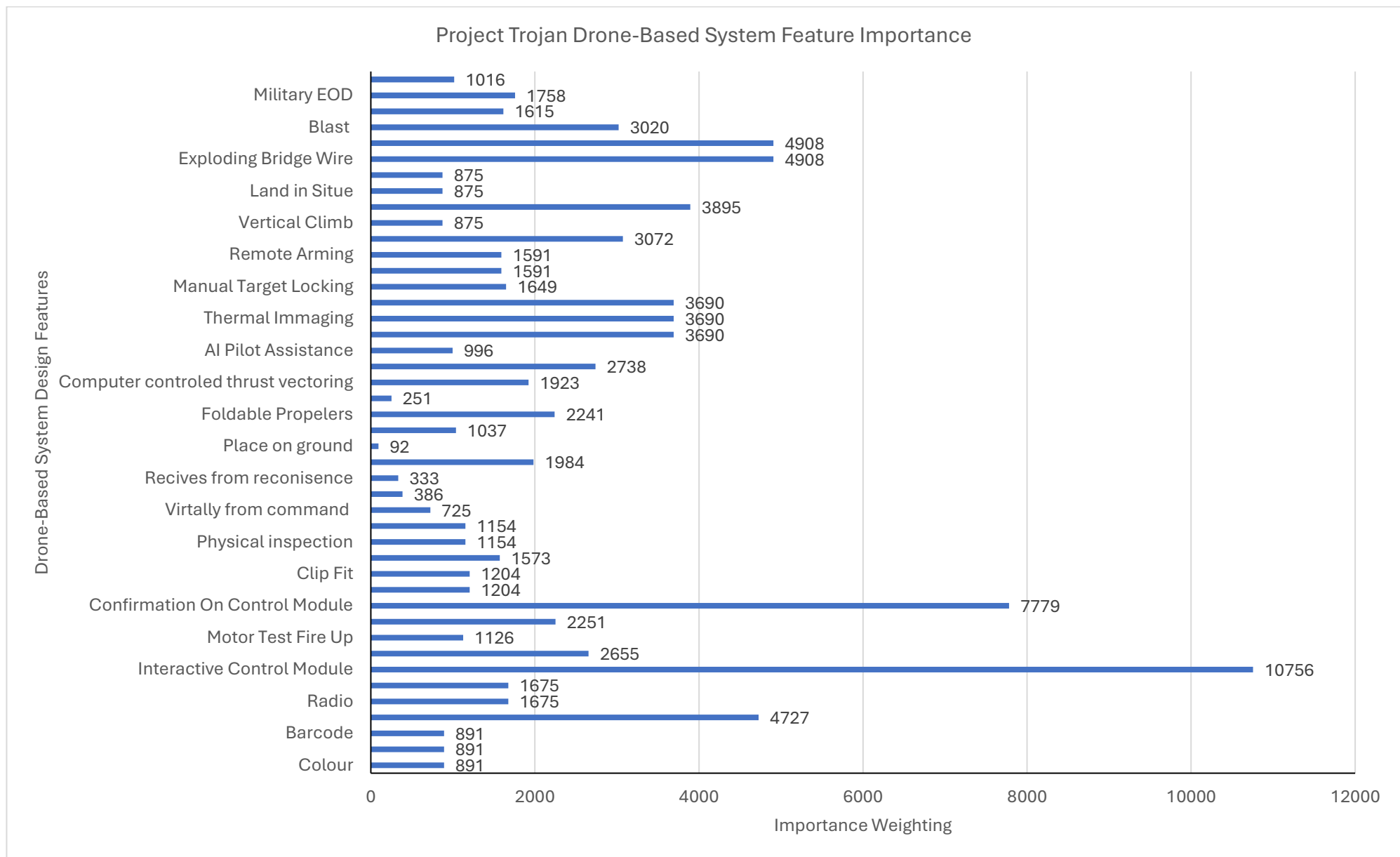


Figure 5-1 – Project Trojan Drone-Based System QFD2 Results

Project Trojan Whole System Solution N ² Analysis							
System	Project Trojan	Author	E Halifax, J Hamilton, L Smith, A Jones, A Lamsdin, S Hawkins	Date	13/03/2025	Issue	1

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Project Trojan Warhead Subsystem Solution N ² Analysis																					
System			Project Trojan				Author	E Halifax, J Hamilton, L Smith, L Jones, A Lamdin, S Hawkins							Date	13/03/2025		Issue	1		
External Input										External Input											
Barcode																					0
	Colour		1																		1
		Label	1																		1
			Manual	1	1	1				1								1			5
				Visual Inspection				1													1
					Mechanical Latch		1														1
						QipFit	1														1
							Bespoke Interface		1		1	1	1		1	1					6
								Physical Inspection													0
							1			Circuit R Check											1
											Arming Pins					1					1
												Software Arming				1					1
							1						Remote Arming			1					2
														Proximity Fuze		1					1
															Detonate		1			1	2
											1	1					Undo Arming				2
														1			HVEBW				1
																		Blast			0
																			Dis Assemble		0
																		1	EOD		1
																				Self Distruct	0
External Output			External Output																		
0	0	0	2	1	1	1	4	1	1	1	2	2	1	1	1	5	1	2	0	1	

Figure 5-3 - Project Trojan Warhead Subsystem N² Analysis

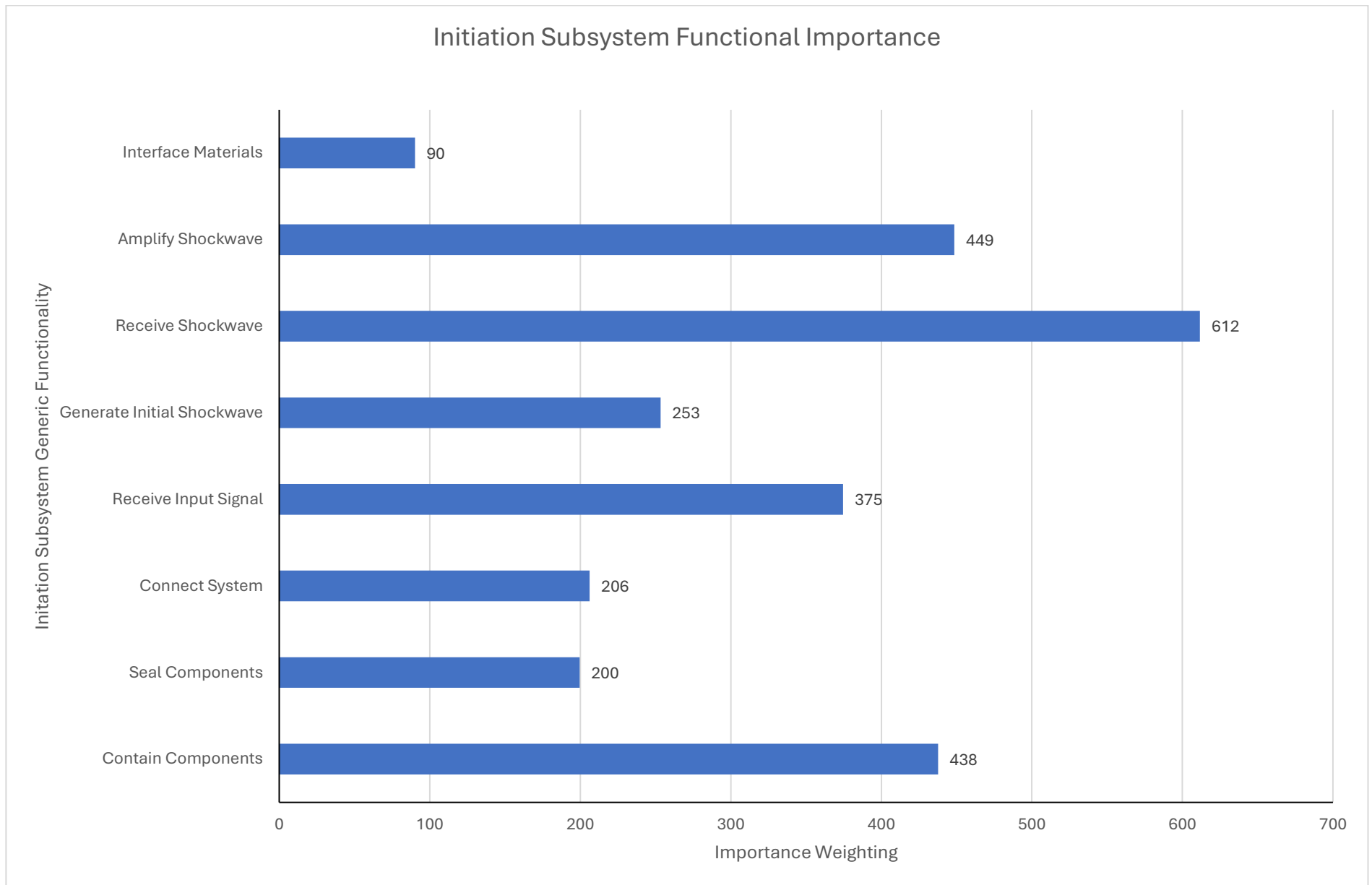


Figure 5-4 – Project Trojan Initiation Subsystem QFD1 Results

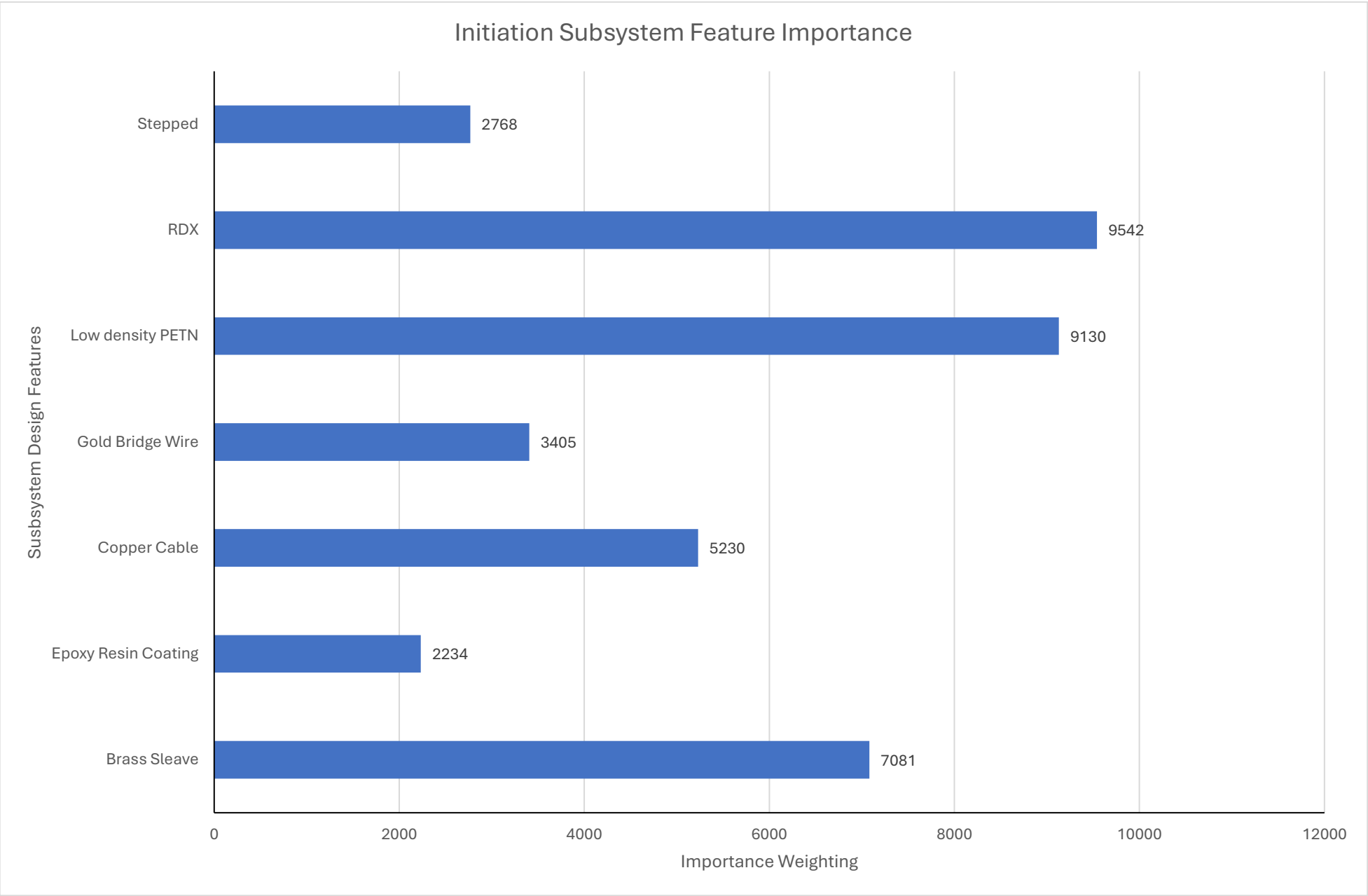


Figure 5-5 – Project Trojan Initiation Subsystem QFD2 Results

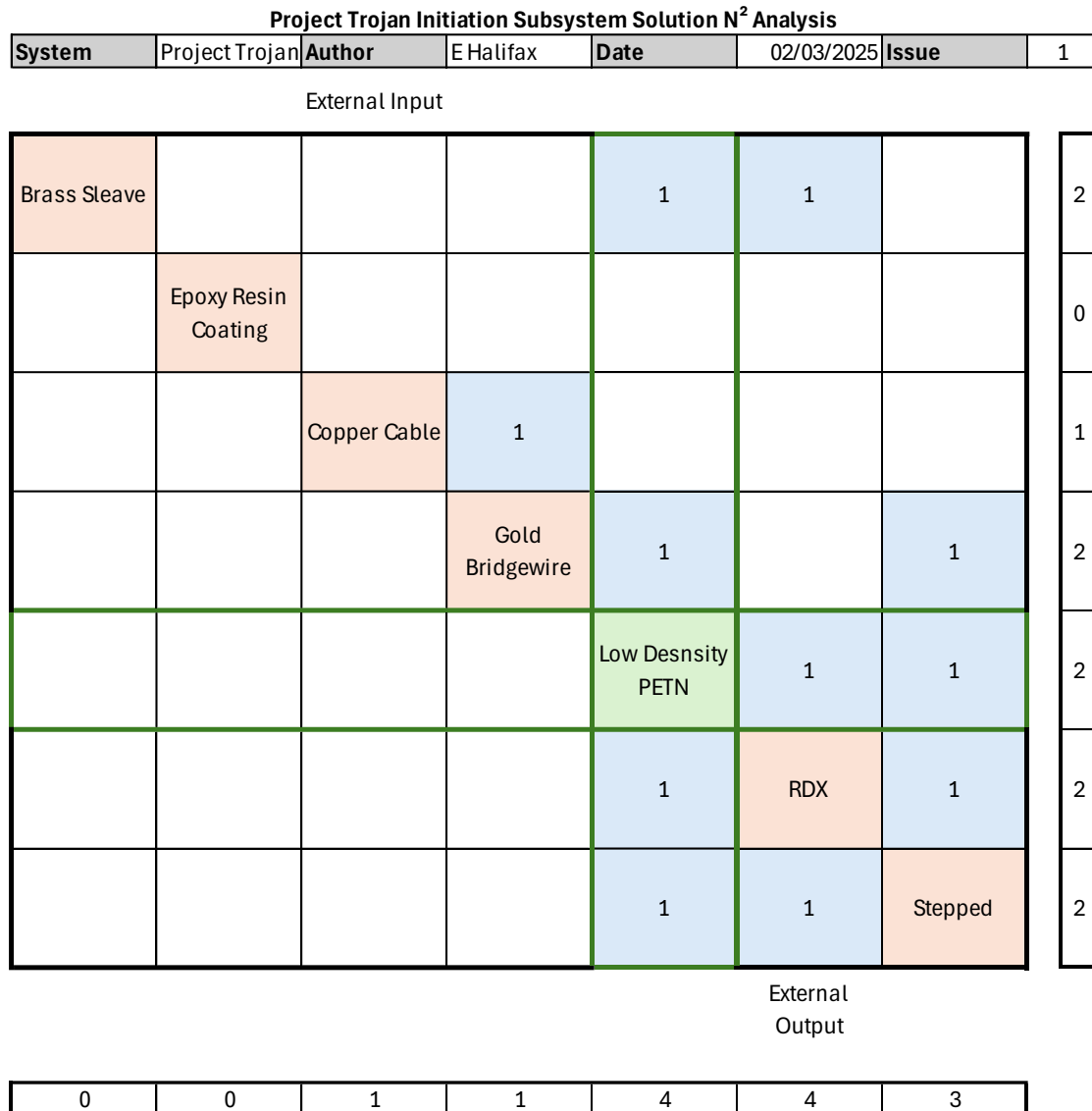


Figure 5-6 – Project Trojan Initiation Subsystem Solution N² Analysis

6 MANUFACTURING PROCESS

When designing a system, consideration of how the system will be manufactured is important to ensure the desired specifications in design, reliability and safety can be met [2]. Due to their increasing complexity and the requirement for flexibility [7], focusing on the whole process ensures the range of sub-processes and components work together cohesively. The design team used a systems engineering approach to develop the manufacturing process of the RDX pellet in order to identify the critical step in the process.

6.1 MANUFACTURING REQUIREMENTS

Using the same system design toolset, the key stakeholders in Table 6-1 and manufacturing requirements in Table A-3 were established. The subsequent Pairwise comparison results presented in Figure 6-1 identified the top three manufacturing requirements, excluding the legal and safety requirements, in Table 6-2.

Table 6-1 – Project Trojan Manufacturing Stakeholders

KEY STAKEHOLDERS:	EXPLANATION
<i>Operators</i>	The group who works on the shop floor conducting processes.
<i>Quality Assurance</i>	The quality department is responsible for overseeing the standard of the product and the overall production outputs and inputs.
<i>Planning and Logistics</i>	The planning and logistic team who are responsible for the movement of all the individual materials and components as well as the final product. They are also responsible for all the resource scheduling required for the process.
<i>Safety</i>	The safety department is responsible for assessing and minimising the risk of the process in all areas including explosive, non-explosive, and final product. They also assure compliance with any legislation required by internal and external bodies.
<i>Manufacturing Engineers</i>	The Manufacturing Engineers are responsible for day to day managing and maintaining of the process and its people.
<i>Process Engineers</i>	The Process Engineers are responsible for designing and implementing the process as well as any major upgrades and changes that may be introduced after implementation.

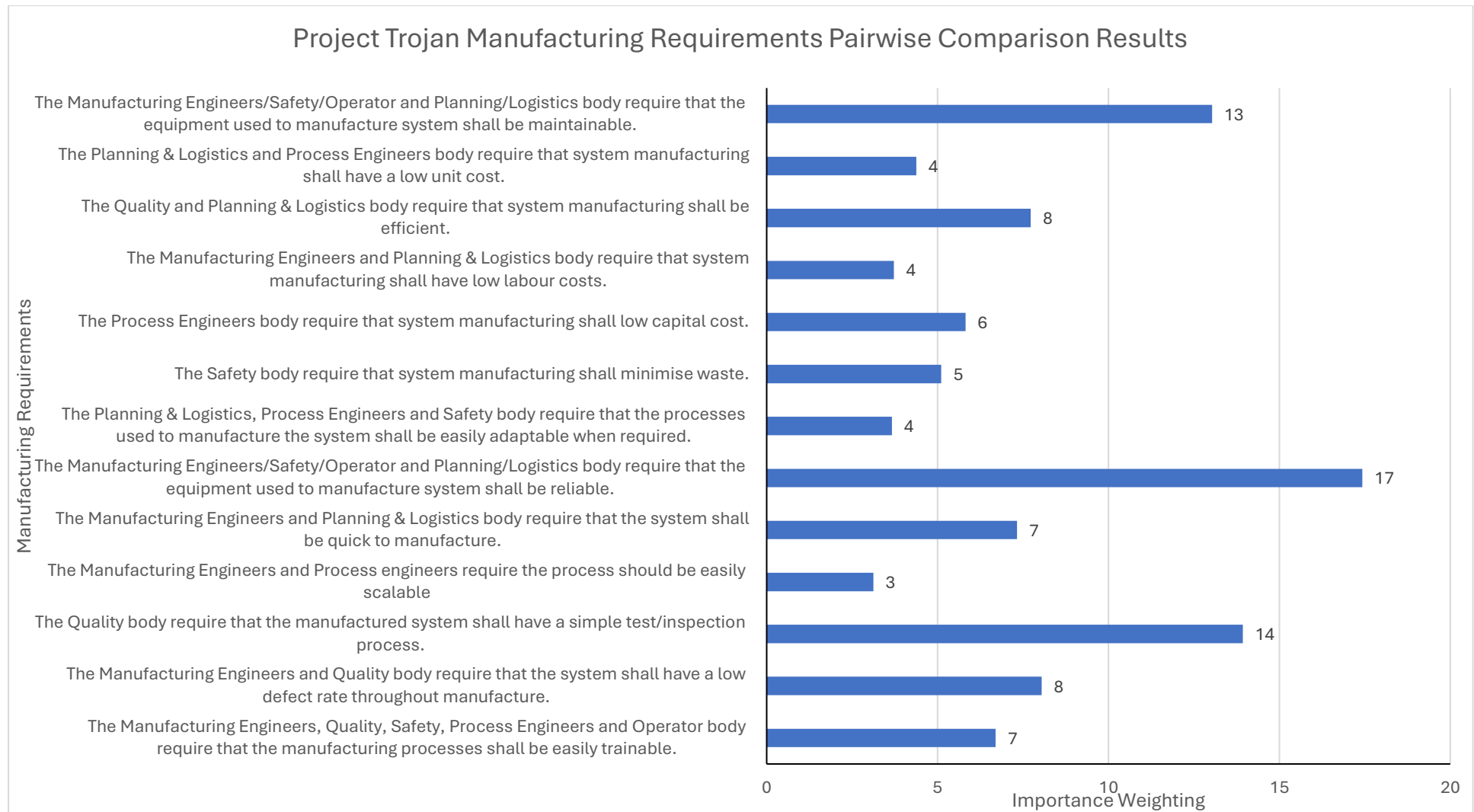


Figure 6-1 – Project Trojan Manufacturing Requirements Pairwise Comparison Results

Table 6-2 – Project Trojan Manufacturing Key Requirements

REQUIREMENT	IMPACT ON DESIGN CONSIDERATION
<i>The Manufacturing Engineers, Safety Engineers, Operators and Planning and Logistics body require that the manufacturing equipment shall be reliable.</i>	Any equipment used needs to have a low defect rate and perform to its required specification for a minimum period.
<i>The Quality Assurance require that the manufactured system shall have a simple verification process.</i>	The process required to assure the manufactured system meets the requirements specifications should not require complex processes or equipment.
<i>The Manufacturing Engineers, Safety Engineers, Operators and Planning and Logistics body require that the manufacturing equipment shall be maintainable.</i>	Any equipment used needs be able to have a maintenance schedule with accessible replacement parts.

6.2 MANUFACTURING FUNCTIONALITY

Once the critical component was identified, the manufacturing team started to develop its manufacturing process. Initially a Sequence Diagram was produced to define the sequence of activities or process steps which convert inputs into outputs. This aided in understanding the required components and materials, along with the assessment of any emergent behaviour. The Sequence Diagram in Figure 6-2 provided an insight to the generic manufacturing process of a HVEBW, with a focus on the steps required to manufacture the RDX pellet.

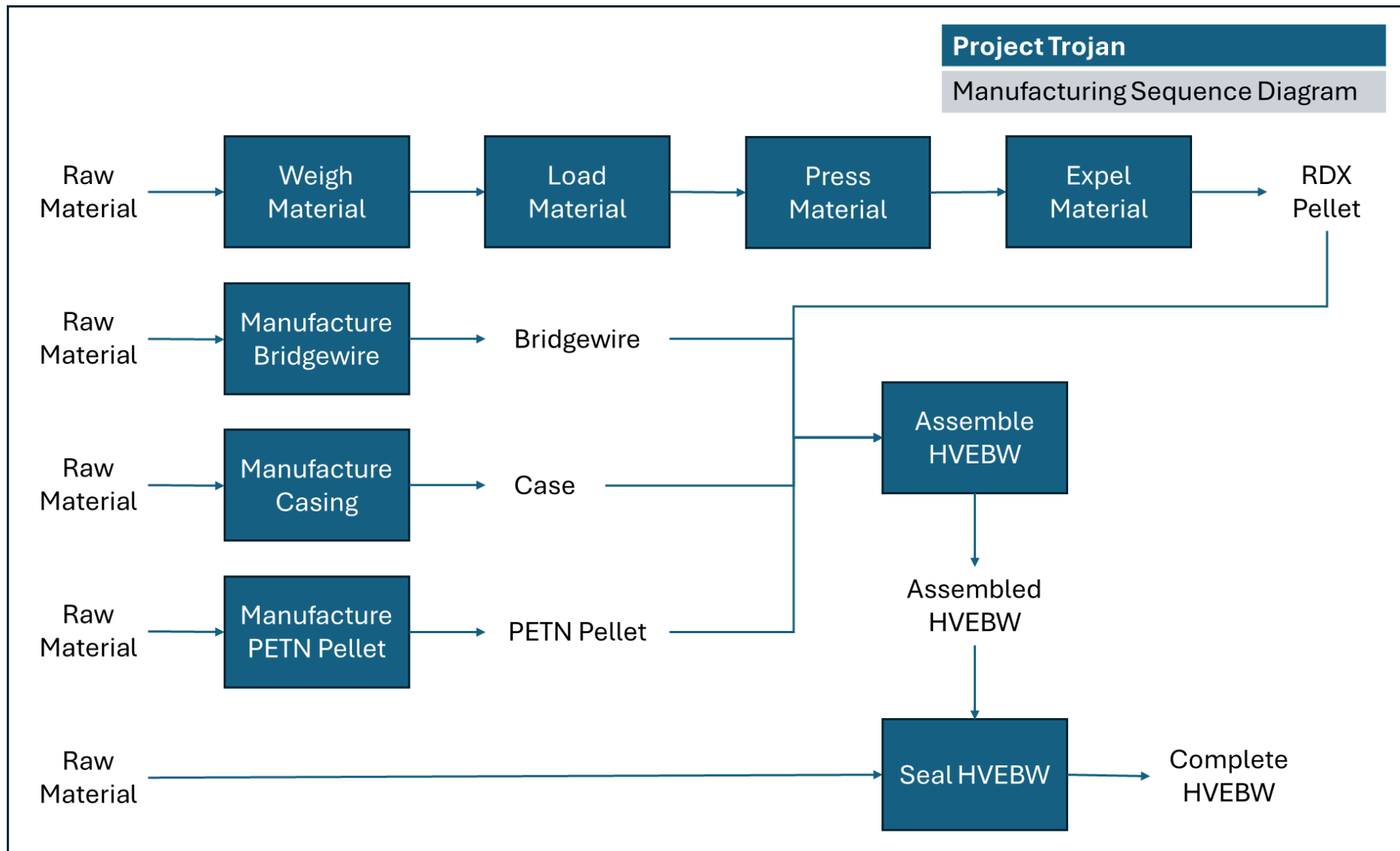


Figure 6-2 – Project Trojan Initiation Subsystem Manufacturing Sequence Diagram

6.3 PROPOSED PROCESS DESIGNS

Using the Sequence Diagram and an FMA, three process designs were developed:

- A Fully Manual Press
- An Automated Vacuum Assisted Press
- An Automated Robotic Assisted Press

The designs were assessed in a Pugh Comparison provided in Figure 6-3, with the results summarised in Table 6-3.

Table 6-3 – RDX Manufacturing Process Design Comparison Results

Process	Pugh Score
<i>Fully Manual Press</i>	-43.3
<i>Automated Vacuum Assisted Press</i>	43.9
<i>Automated Robotic Assisted Press</i>	0

The manual process would have been cheaper for the manufacturing company with a low maintenance requirement; however, the automated process would be significantly safer for the operators, reducing their exposure to highly hazardous materials. With this consideration the design team developed an automated vacuum assisted press process.

6.4 CRITICAL COMPONENT NOISE FACTORS

Noise factors are things that can impact the quality and/or use of a component. Understanding what can impact this is imperative to implementing control factors and safety measures, either in the design or during processes [1]. To support the development of the manufacturing process for the RDX pellet, the Safety Team analysed the potential noise and control factors. This was supported by the development of a What/Why Table using the information in the Parameter Diagram (P-Diagram) provided in Figure 6-4. The resulting Noise Importance Graph in Figure 6-5 highlighted that *Deterioration in manufacturing equipment* followed by the *Density of the RDX* are the two most important noise factors to control; whereas, the Control Factors Importance Graph in Figure 6-6, highlighted *Material quality* as the most important control factor.

Project Trojan - Manufacturing Process Press Material Pugh Matrix

	Relative Importance Equal	Option One - Robotic	Option Two - Vacuum Assist	Option Three - Everything Manual
WHATs - Customer Requirements				
The Manufacturing Engineers, Quality, Safety, Process Engineers and Operator body require that the manufacturing processes shall be easily trainable.	6.7	0	1	-2
The Manufacturing Engineers and Quality body require that the system shall have a low defect rate throughout manufacture.	8	0	0	-1
The Quality body require that the manufactured system shall have a simple test/inspection process.	14	0	1	2
The Manufacturing Engineers and Process engineers require the process should be easily scalable	3.1	0	0	-2
The Manufacturing Engineers and Planning & Logistics body require that the system shall be quick to manufacture.	7.3	0	-1	-2
The Manufacturing Engineers/Safety/Operator and Planning/Logistics body require that the equipment used to manufacture system shall be reliable.	17	0	2	-1
The Planning & Logistics, Process Engineers and Safety body require that the processes used to manufacture the system shall be easily adaptable when required.	3.7	0	1	2
The Safety body require that system manufacturing shall minimise waste.	5.1	0	0	-2
The Process Engineers body require that system manufacturing shall low capital cost.	5.8	0	1	2
The Manufacturing Engineers and Planning & Logistics body require that system manufacturing shall have low labour costs.	3.7	0	-1	-2
The Quality and Planning & Logistics body require that system manufacturing shall be efficient.	7.7	0	-1	-2
The Planning & Logistics and Process Engineers body require that system manufacturing shall have a low unit cost.	4.4	0	1	-2
All key stakeholders require that the system must adhere to all relevant regulations & legislation (REACH, UK, International)	13	0	0	0
The Manufacturing Engineers, Safety, Operator and Planning & Logistics body require that the energetics shall be safe throughout the manufacturing process.	10	0	1	-2
The Manufacturing Engineers, Safety, Operator and Planning & Logistics body require that the non-energetics shall be safe throughout the manufacturing process.	10	0	-2	-1
The Manufacturing Engineers/Safety/Operator and Planning/Logistics body require that the equipment used to manufacture system shall be maintainable.	10	0	1	2
Score:		0	50.5813	-64.8055

Figure 6-3 – Project Trojan Manufacturing Process - Press Material Pugh Matrix

Initiation Sub-System Critical Component P- Diagram							
System	Project Trojan	Author	E Halifax, J Hamilton	Date	13/03/2025	Issue	1

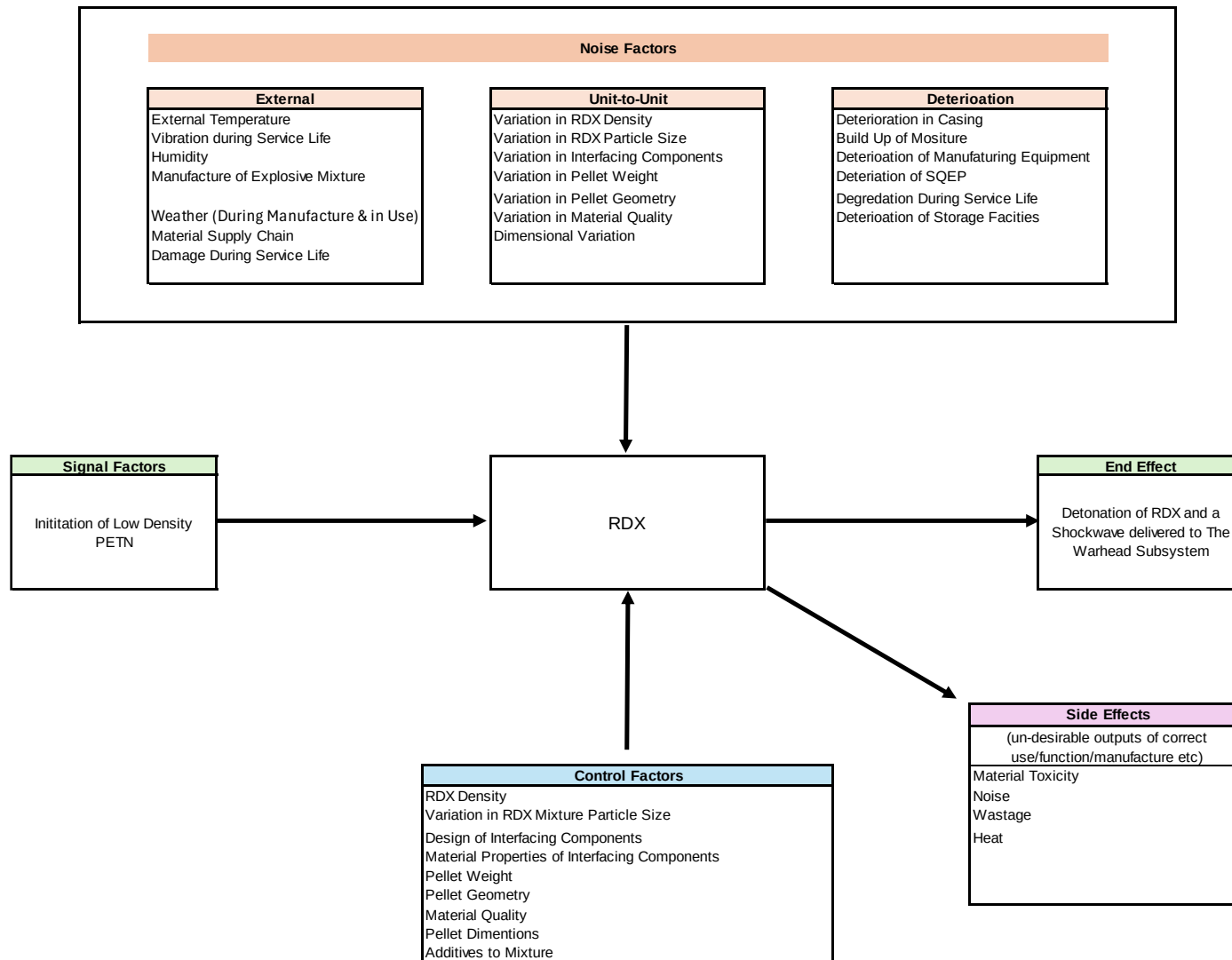


Figure 6-4 – Project Trojan Initiation Subsystem Critical Component P-Diagram

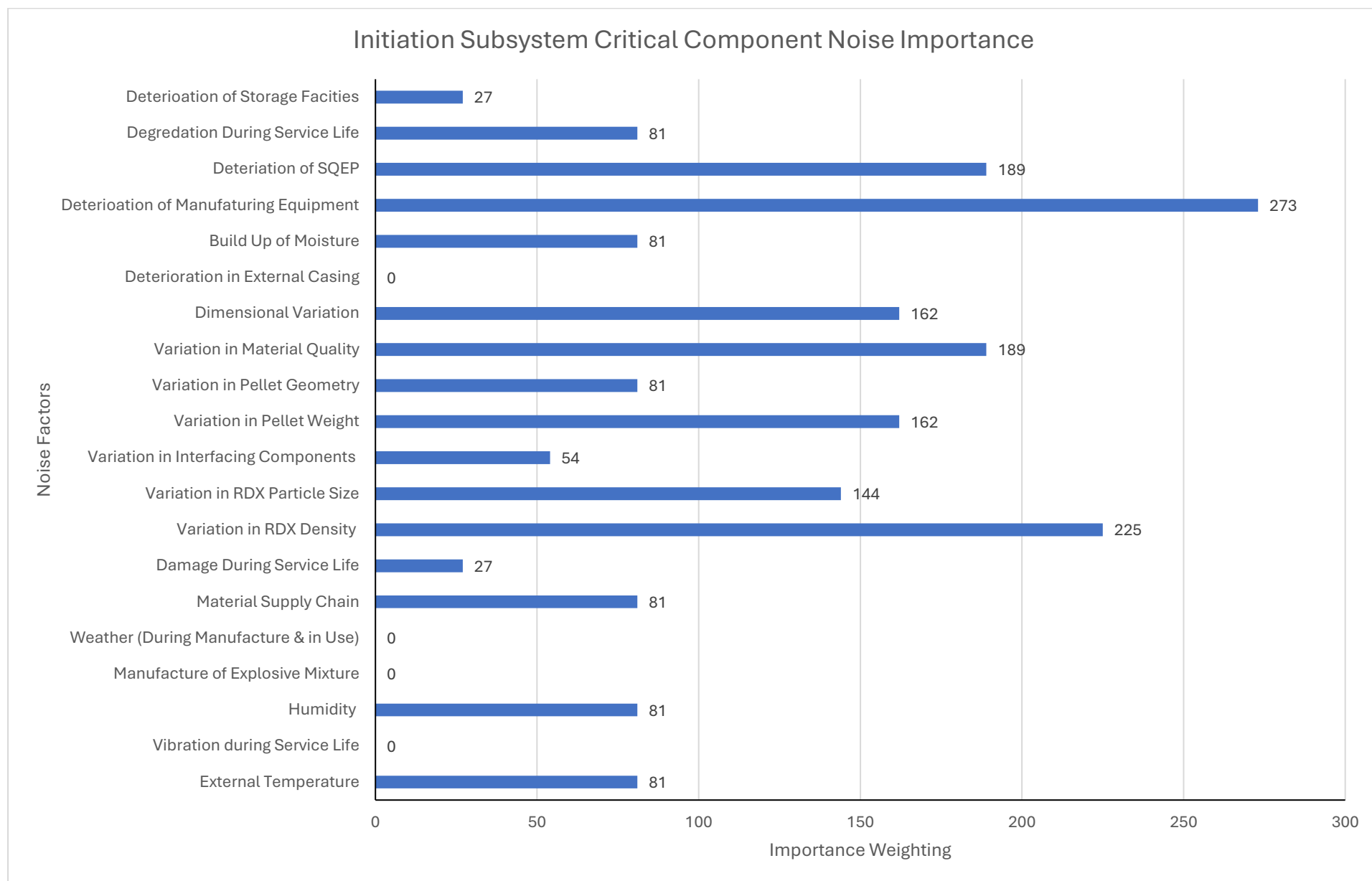


Figure 6-5 – Project Trojan Critical Component Noise Importance Graph

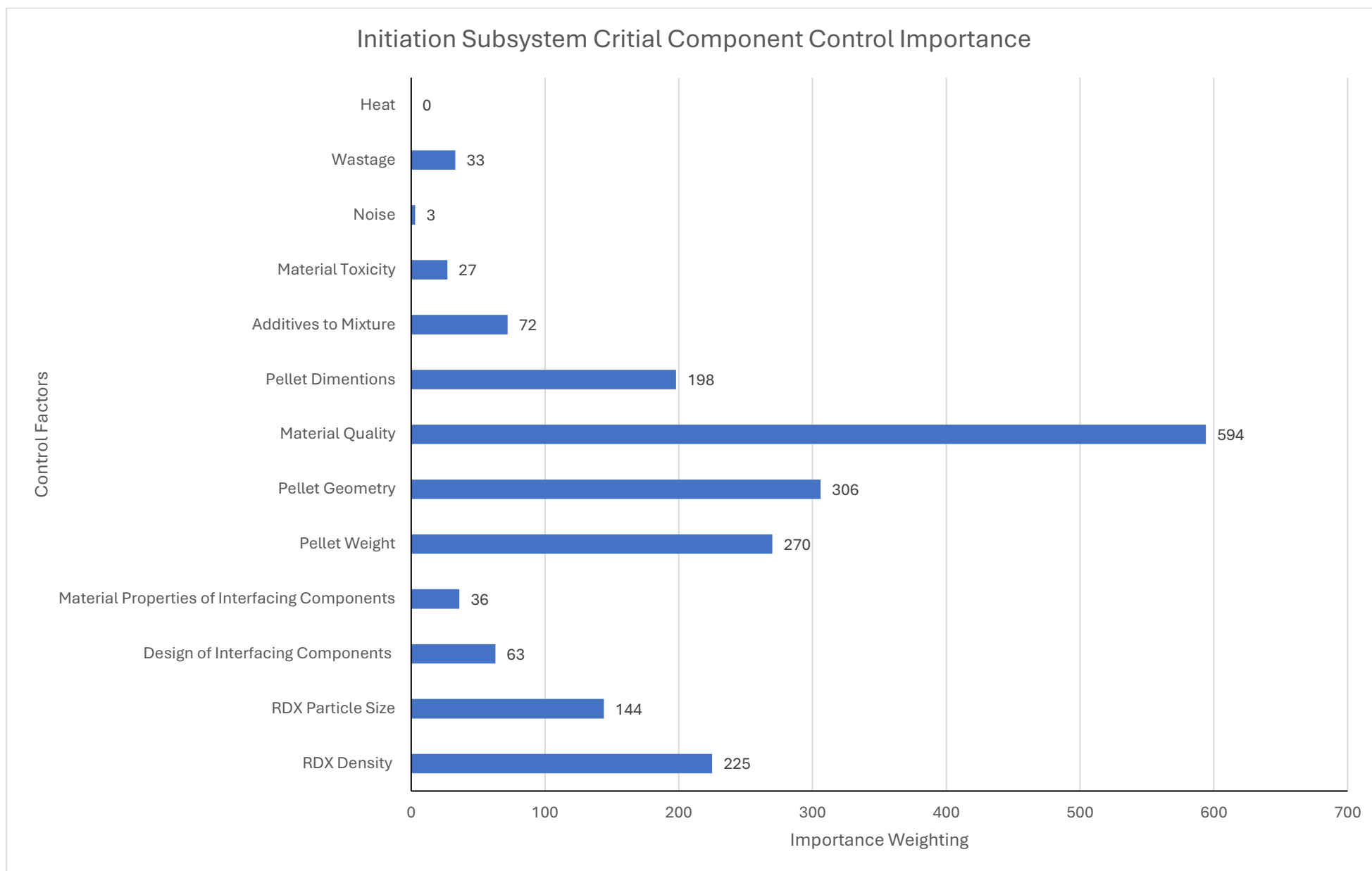


Figure 6-6 – Project Trojan Critical Component Control Importance Graph

6.5 CRITICAL MANUFACTURING STEP

The critical steps in a manufacturing process are essential to providing a quality product [6]. The critical step for producing an RDX pellet has been determined by a QDF3. This involved assessing the manufacturing steps against the critical component parameters provided by the manufacturing QFD2 results (Figure 6-7) along with the P-Diagram (Figure 6-4) and What/Why results (Figure 6-5 and Figure 6-6) of the RDX Pellet. As shown by the results in Figure 6-8 and the importance of the digital scales, the critical manufacturing step is *Weighing the Material*. The weight of the material is highly influential on the pellet weight, pellet geometry and potential variation in the pellet's dimensions, which can ultimately affect the reliability, performance and safety of the HVEBW.

6.6 PROCESS FAILURE EFFECT MODE ANALYSIS

Understanding how a process can fail is just as important as understanding how a system can fail. A Process Failure Effect Mode Analysis (PFEMA) enables identification of hazards in a process and supports design change recommendations [8]. The PFEMA on the critical process identified the potential design and procedural considerations in Table 6-4.

Table 6-4 – Design and Procedural Considerations for Weighing the Material

DESIGN CONSIDERATIONS	PROCESS CONSIDERATIONS
Incorporation of redundancy in the design for the scale sensor.	Implementation of an adequate maintenance schedule .
Incorporation of a system cut off to stop the filling of material when the sensor detects the correct weight or a system failure.	Implementation of adequate pre-start checks on all equipment.
Incorporation of an emergency stop function.	

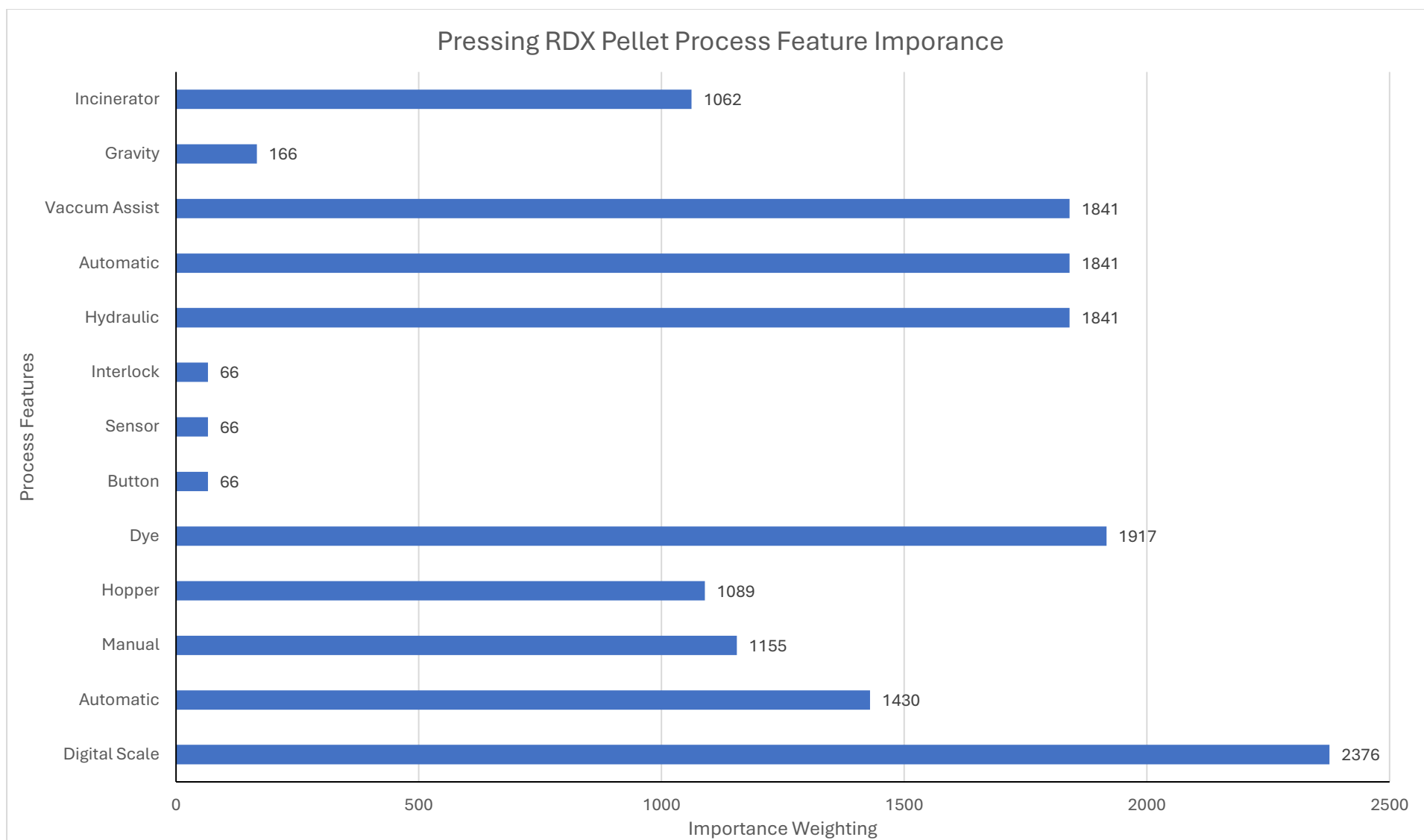


Figure 6-7 – Project Trojan Manufacturing RDX Pellet QFD2 Results

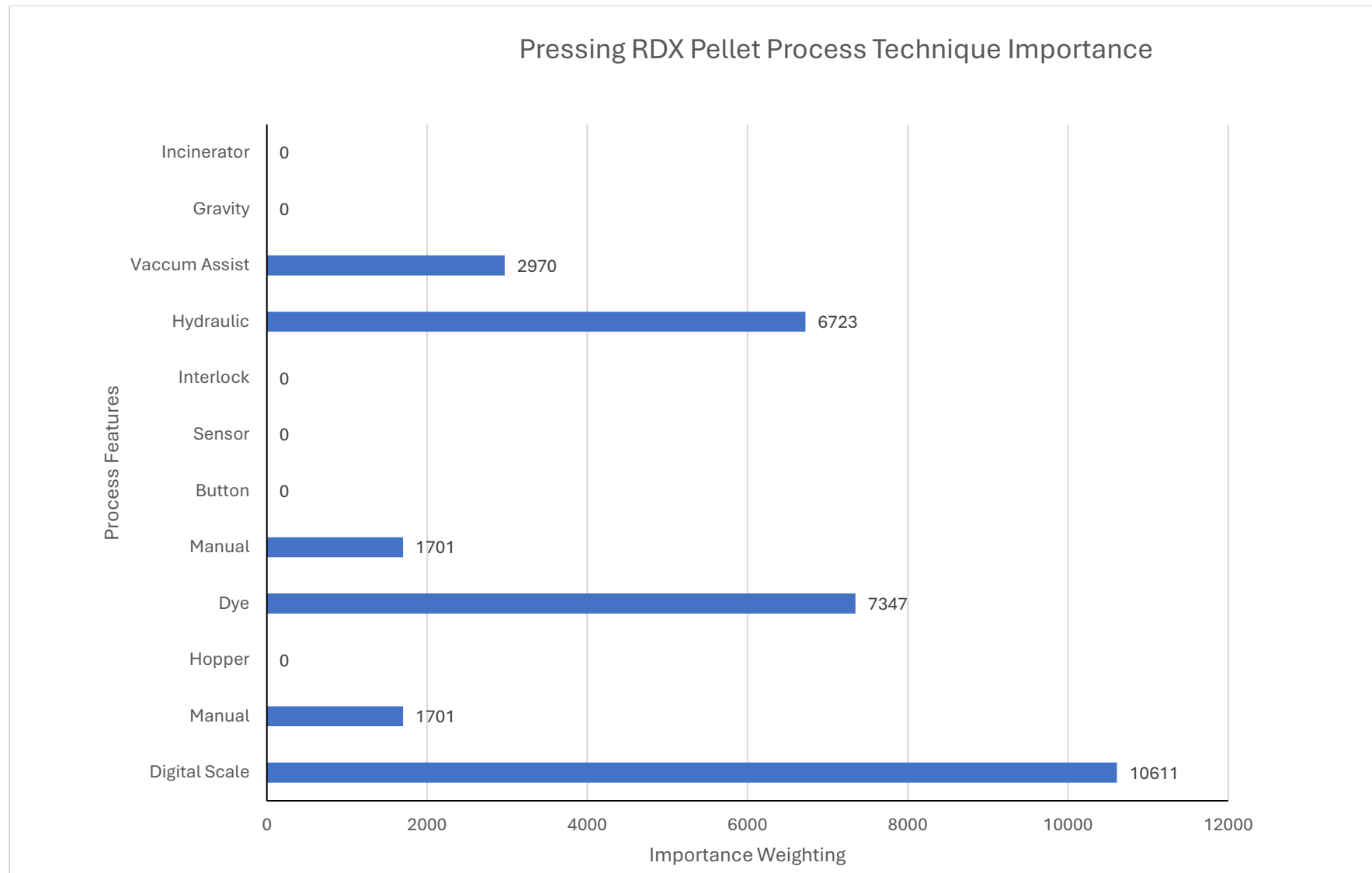


Figure 6-8 – Project Trojan Manufacturing RDX Pellet QFD3 Results

6.7 CRITICAL CONTROL PROCESSES

To reduce the impact of noises, manufacturers should develop control measures. Project Trojan utilised QFD4, which incorporated the process parameters in Table 6-5 and the potential control measures in Table 6-6, to assess suitable control measures for the weighing of material.

Table 6-5 – Weigh Material Process Parameters

PROCESS PARAMETERS
Calibration of Scales
Degradation of Equipment
Material Wastage
Accuracy of Scales
Operator Competence

Table 6-6 – Weigh Material Process Controls

PROCESS CONTROLS
Training
Work Instruction
Maintenance Schedule
In process Inspections
Worker Traceability
Calibration Test
Pre-Start Inspections
Shift Handover
Defect Reporting
Segregation of Materials
Receipt Inspections
Post Process Inspection
Incineration

It was determined by the results of the QFD4 in Figure 6-9, that the maintenance schedule and the subsequent maintenance of equipment was the most important control factor for mitigating variance in the RDX pellet. These results supported the creation of the Process Control Plan by the Manufacturing Lead.

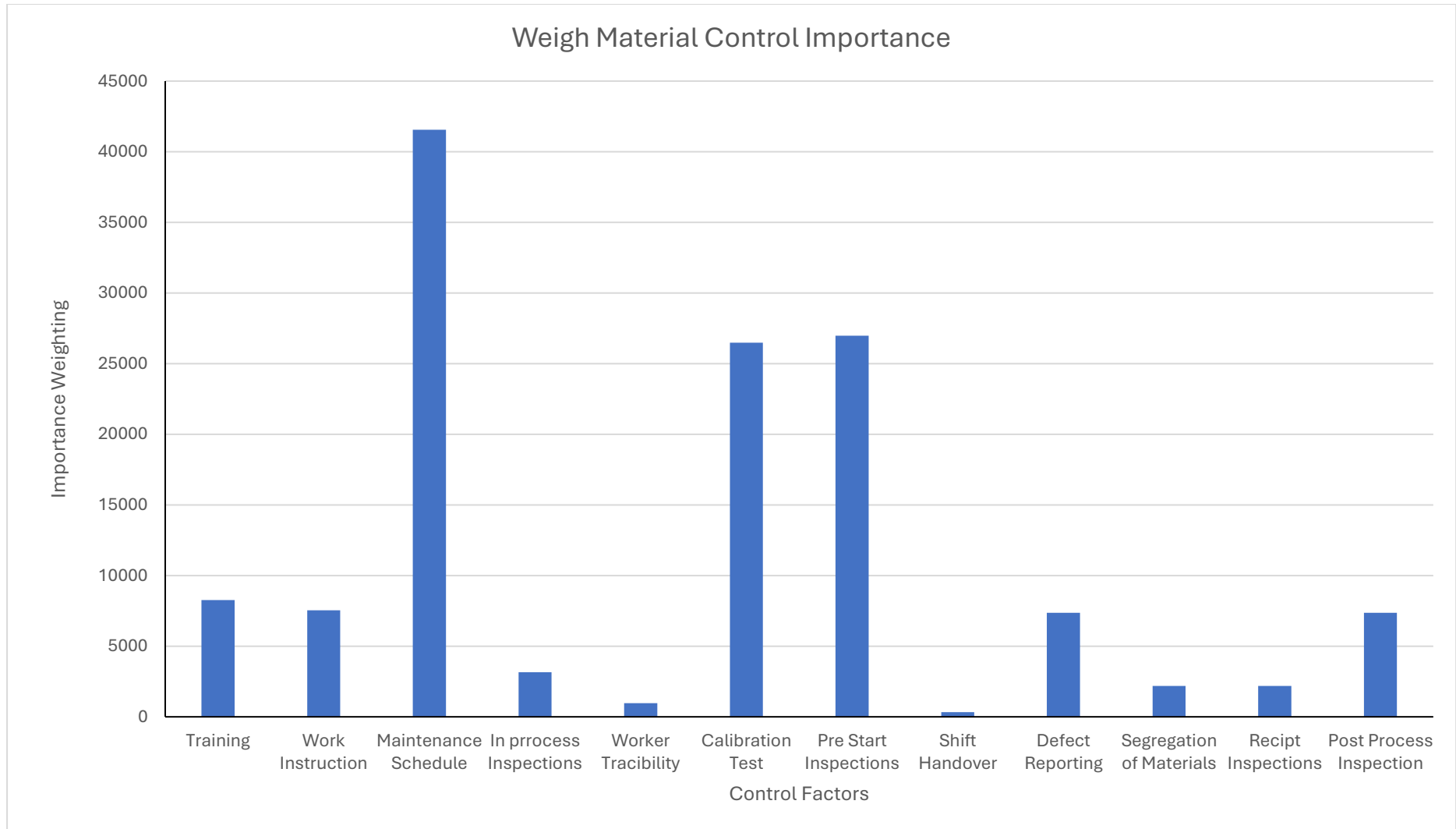


Figure 6-9 – Project Trojan Weigh Material Control Importance

7 TESTING AND EVALUATION PROGRAMME

A Testing and Evaluation programme is required to be in place during the development of a system to determine:

- Critical Functionality
- Safety Requirements
- Capability and Limitation Definition
- Compatibility

Throughout the concept development, the Testing and Evaluation Lead conducted Functional Metrics Analysis which provided target specifications for the QFDs and advised on the required performance characteristics to meet relevant regulatory and NATO standards such as Allied Ordnance Publication-39: Assessment of Insensitive Munitions [9] and DCOP 107: Explosive Material Qualification [10]. An example is provided in Figure 7-1.

This allowed a testing regime to be developed, highlighting the importance of testing each component and subsystem individually before combining them into the main system. This would provide assurance on the reliability and safety of the system.

8 END OF LIFE MANAGEMENT

The design team have a responsibility to have a Waste and Disposal Management Plan in place, to ensure the safe disposal of any hazardous material associated with their design through all lifecycle phases. This is set out in the Controlled Waste (England and Wales) Regulations 2014 [11, 12] and Defence Standard 00-051 [13]. To ensure this was considered during the design process of the system and the manufacturing process, the Breakdown and Disposal Lead developed a disposal P-Diagram and a What/Why Table to produce a Waste and Disposal Management Plan. This outlined the associated risks with disposing of the system and the proposed disposal methods.

Function:- (Insert Specific function here)		Test method and relationship to requirements		How									
		Importance		Overall Weight Measurement	Physical Dimension and Interfacing Tests	Completed Initiation Sub-System reliability testing	Completed Initiation Sub-system Time-to-function Testing	Completed Initiation Sub-system Energetic Output Testing	Physical Component options comparison Function Testing	Electrical Component options comparison Function Testing	Energetic Component options comparison function testing	Energetic Components SSHT (Sensitivity) Testing	Environmental (& Simulated Aging) Testing
What	Customer Requirements												Add requirements detail and definition in here.
	Contain Components	438	3					9					Initiator must remain in tact during 100% of standards deployments.
	Seal Components	200						9				9	Moisture incress must be kept bellow 0.01ml when exposed to the environmental conditions defined in AOP-15A
	Connect System	206							9				The initiation sub system must connect with the saftey and arming ssub-system without loosing connection during TBC% of deployments.
	Receive Input Signal	375		9	9				9				A correctly conencted unit should be capable of receving a firing signal during TBC% of deployments
	Generate Initial Shockwave	253		9	9					9	9		During TBC% of initiations a shock of TBC M/s2 must be achieved
	Receive Shockwave	612		9	3					9	9		Upon receiving a shock wave of TBC m/s2 detonation must occure in TBC% of occurrences
	Amplify Shockwave	449		9	3	9				9	9		Upon receiving a shock wave of TBC m/s2 a shock of TBC m/s2 must be produced
	Interface Materials	90		9				3			3		Detonation must transfer across the material interface in TBC% of initiations
			1313	811	15196	8835	4037			5230	12092	11821	1796
		Overall weight should be ALARP, since increased weight will reduce performance of UAS platform. Overall Dimesnions should commensurate with the rest of the payload Sub-System(s) The initiation system should function reliably 99% of the time. The TTF of the initiation sub-system should be ALARP, and the TTF should be reliable & predictable. The output (Shockwave) of the Initiation sub-system should be sufficient to initiate the warhead sub-system reliably. Comparative testing of physical component materials and sizes to ensure good performance with minimal cost and easy availability/manufacturability Comparative testing of electric component materials and sizes to ensure good performance with minimal cost and easy availability/manufacturability Comparative testing of energetic component materials and sizes to ensure good performance with minimal cost and easy availability/manufacturability The Munition's initiation system should be in accordance with MoD & NATO insensitve munitions policies (DSA 03 OME Pt.1 (JSP520)) The munition (and packaging) should meet the standards specified in DSA 03 OME Pt.1 (JSP520). Moisture incress must be kept below 0.01ml when exposed to the environmental conditions defined in AOP-15A											
How Much													

Figure 7-1 – Project Trojan Initiation Subsystem Functional Metrics Analysis

9 CONCLUSION

The design team benefited from taking a systems engineering approach to the design of a weapon system to neutralise a hostile communication system consisting of a modular drone design to target external antennas. Early analysis of customer requirements ensured key design decisions were made to ensure safety was incorporated into the design. The toolset and methodologies promoted multidisciplinary collaboration to ensure each subject area was considered, allowing safety to be evaluated at every stage.

The use of QFDs and N² Analysis allowed identification of the Initiation Subsystem and the RDX pellet as being critical to the system. This was due to their direct impact on delivering the terminal effect safely and reliably to meet key customer requirements. Through FFMEA, potential hazards were identified and recommendations made on how to mitigate them.

The design of the manufacturing process for the critical component also benefited from the systematic approach. The critical manufacturing process was identified as being the weighing of the material due to its influence on the quality and safety of the RDX pellet. Further use of QFDs, P-diagrams and What/Why tables enabled noises and controls to be evaluated and mitigated in a Control Plan.

Overall, the systems engineering approach allowed the design team to make informed decisions to aid in the development of a safe and reliable weapon system.

10 REFERENCES

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APPENDIX A – PROJECT TROJAN CUSTOMER REQUIREMENTS

Table A-1 - Project Trojan System Requirements

ORIGINATOR	REQUIREMENT	TYPE
User, Command/Tasking Authority, Procurement Body, Logistics/Supply Chain, Manufacturer(s), Legislative Bodies	All key stakeholders require that the system must adhere to all relevant regulations & legislation (REACH, UK, International)	Non -Functional System
User, Command/Tasking Authority, Procurement Body, Logistics/Supply Chain, Manufacturer(s), Legislative Bodies	All key stakeholders require that the system must be safe throughout the product life cycle (Manufacture to Target or Disposal Sequence)	Non -Functional System
User, Command/Tasking Authority, Logistics/Supply Chain	The Command/Tasking Authority, User and the Logistics body all require that the system shall be resistant to the environmental conditions specified within the mission brief (AOP 15A, specified as N. Europe)	Non -Functional System
User, Command/Tasking Authority, Procurement Body	The Command/Tasking Authority, User and Procurement body require that the system shall successfully neutralise the target specified within the mission brief	Non-Functional Performance
Command/Tasking Authority, Procurement Body	The Command/Tasking Authority and Procurement body require that the system may be capable of being used against a range of alternative targets	Non-Functional Performance

ORIGINATOR	REQUIREMENT	TYPE
<i>User, Command/Tasking Authority, Legislative Bodies</i>	The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effect(s) shall be contained within the target location specified in the mission brief.	Non-Functional Performance
<i>User, Command/Tasking Authority</i>	The Command/Tasking Authority and User require that the system shall be able to be deployed at a minimum distance of 100m from the intended target	Non-Functional Performance
<i>User, Command/Tasking Authority, Procurement Body</i>	The Command/Tasking Authority, User and Procurement Body require that the system shall function within its specified performance requirements (TBC) during TBC% of deployments.	Non-Functional Performance
<i>Command/Tasking Authority, Procurement Body, Logistics/Supply Chain</i>	The Command/Tasking Authority, Procurement Body and Logistics body require that the system shall have a shelf life of X years (TBC)	Non -Functional System
<i>User, Command/Tasking Authority</i>	The Command/Tasking Authority and User require that the system shall be easy to operate, requiring minimal training (X hours per annum)	Non -Functional System
<i>User, Command/Tasking Authority</i>	The Command/Tasking Authority and User require that the system shall be rapidly deployable within X minutes.	Non -Functional System
<i>User, Command/Tasking Authority, Logistics/Supply Chain</i>	The Command/Tasking Authority, User and Logistics Body require that the system shall be transportable to the specified firing location, without mechanical assistance, by the 5-man mission team.	Non -Functional System
<i>User, Command/Tasking Authority</i>	The Command/Tasking Authority and User require that the system should be capable of being utilised operationally by the minimum	Non -Functional System

ORIGINATOR	REQUIREMENT	TYPE
	number of personnel necessary.	
<i>Command/Tasking Authority, Procurement Body, Manufacturer(s)</i>	The Command/Tasking Authority, Procurement Body and Manufacturer require that the system should be cost effective throughout the product life cycle (Manufacture to Target or Disposal Sequence), approximately similar cost-per-shot to NLAW (£30-40k)	Non -Functional System
<i>User, Logistics/Supply Chain, Manufacturer(s)</i>	The User, Logistics Body and Manufacturer require that the system shall be easily identifiable throughout the product lifecycle (Manufacture to Target or Disposal Sequence)	Non -Functional System
<i>User, Command/Tasking Authority, Legislative Bodies</i>	The Command/Tasking Authority, User and Legislative Bodies require that the system's terminal effects should cause minimal harm to any occupants within the target location specified in the mission brief.	Non-Functional Performance
<i>Procurement Body, Manufacturer(s)</i>	The Procurement Body and Manufacturer require that the system will be constructed utilising technology and components manufacturable within the UK economy.	Non -Functional System
<i>Command/Tasking Authority, Procurement Body, Logistics/Supply Chain</i>	The Command/Tasking Authority, Procurement Body and Logistics Body require that the system should be interoperable with current UK and NATO military equipment and infrastructure.	Non -Functional System
<i>Procurement Body, Logistics/Supply Chain, Manufacturer(s), Legislative Bodies</i>	The Procurement Body, Logistics Body, Legislative Bodies and Manufacturer require that the system shall, at end-of-life, be capable of being broken down to a point where the remaining components can be safely disposed of.	Non -Functional System

Table A-2 - Project Trojan Initiation Subsystem Requirements

ORIGINATOR	REQUIREMENT	TYPE
User, Command/Tasking Authority, Procurement Body, Logistics/Supply Chain, Manufacturer(s), Legislative Bodies	All key stakeholders require that the initiation sub-system must adhere to all relevant regulations & legislation (REACH, UK, International)	Non -Functional System
User, Command/Tasking Authority, Procurement Body, Logistics/Supply Chain, Manufacturer(s), Legislative Bodies	All key stakeholders require that the initiation sub-system must be safe throughout the product life cycle (Manufacture to Target or Disposal Sequence)	Non -Functional System
User, Command/Tasking Authority, Legislative Bodies	The Command/Tasking Authority, User and Legislative Bodies require that the initiation sub-system should only function when the delivery of the terminal effect is requested by the operator.	Non -Functional Performance
Procurement Body, Logistics/Supply Chain, Manufacturer(s), Legislative Bodies	The Procurement Body, Logistics Body, Legislative Bodies and Manufacturer require that the initiation sub-system shall, at end-of-life, be capable of being removed from the warhead sub-system to enable safe disposal	Non -Functional System

ORIGINATOR	REQUIREMENT	TYPE
<i>User, Command/Tasking Authority, Logistics/Supply Chain</i>	The Command/Tasking Authority, User and the Logistics body all require that the initiation sub-system shall be resistant to the environmental conditions specified within the mission brief (AOP 15A, specified as N. Europe)	Non -Functional System
<i>User, Command/Tasking Authority, Procurement Body</i>	The Command/Tasking Authority, User and Procurement Body require that the initiation sub-system shall function within its specified performance requirements (TBC) during TBC% of deployments.	Non -Functional Performance
<i>Command/Tasking Authority, Procurement Body, Logistics/Supply Chain</i>	The Command/Tasking Authority, Procurement Body and Logistics body require that the initiation sub-system shall have a shelf life of X years (TBC)	Non -Functional System
<i>Command/Tasking Authority, Procurement Body, Manufacturer(s)</i>	The Command/Tasking Authority, Procurement Body and Manufacturer require that the initiation sub-system should be cost effective throughout the product life cycle (Manufacture to Target or Disposal Sequence).	Non -Functional System
<i>Procurement Body, Manufacturer(s)</i>	The Procurement Body and Manufacturer require that the initiation sub-system will be constructed utilising technology and components manufacturable within the UK economy.	Non -Functional System
<i>Design Engineers</i>	The Design Engineers require the initiation sub-system shall be activated via an electronic signal (Specification TBD) to allow integration into the system.	Non-Functional Interoperability Requirement
<i>Design Engineers</i>	The Design Engineers require the initiation sub-system should be compact (Specification TBD) to allow integration into the system.	Non-Functional Interoperability Requirement

Table A-3 - Project Trojan Manufacturing Requirements

ORIGINATOR	REQUIREMENT
<i>All</i>	All key stakeholders require that the system must adhere to all relevant regulations & legislation (REACH, UK, International)
<i>Manufacturing Engineers, Safety, Operators, Planning and Logistics</i>	The Manufacturing Engineers, Safety, Operator and Planning & Logistics body require that the energetics shall be safe throughout the manufacturing process.
<i>Manufacturing Engineers, Safety, Operators, Planning and Logistics</i>	The Manufacturing Engineers, Safety, Operator and Planning & Logistics body require that the non-energetics shall be safe throughout the manufacturing process.
<i>Manufacturing Engineers, Quality, Safety, Process Engineers, Operators</i>	The Manufacturing Engineers, Quality, Safety, Process Engineers and Operator body require that the manufacturing processes shall be easily trainable.
<i>Manufacturing Engineers, Quality</i>	The Manufacturing Engineers and Quality body require that the system shall have a low defect rate throughout manufacture.
<i>Quality</i>	The Quality body require that the manufactured system shall have a simple test/inspection process.
<i>Manufacturing Engineers, Process Engineers</i>	The Manufacturing Engineers and Process engineers require the process should be easily scalable
<i>Manufacturing Engineers, Planning and Logistics</i>	The Manufacturing Engineers and Planning & Logistics body require that the system shall be quick to manufacture.
<i>Manufacturing Engineers, Safety, Process Engineers, Operators, Planning and Logistics</i>	The Manufacturing Engineers/Safety/Operator and Planning/Logistics body require that the equipment used to manufacture system shall be reliable.

ORIGINATOR	REQUIREMENT
<i>Process Engineers, Planning and Logistics, Safety, Safety</i>	The Planning & Logistics, Process Engineers and Safety body require that the processes used to manufacture the system shall be easily adaptable when required.
<i>Process Engineers</i>	The Safety body require that system manufacturing shall minimise waste.
<i>Manufacturing Engineers. Planning and Logistics</i>	The Process Engineers body require that system manufacturing shall low capital cost.
<i>Quality, Planning and Logistics</i>	The Manufacturing Engineers and Planning & Logistics body require that system manufacturing shall have low labour costs.
<i>Planning and Logistics, Process Engineers</i>	The Quality and Planning & Logistics body require that system manufacturing shall be efficient.
<i>Manufacturing Engineers, Safety, Process Engineers, Operators, Planning and Logistics</i>	The Planning & Logistics and Process Engineers body require that system manufacturing shall have a low unit cost.
	The Manufacturing Engineers/Safety/Operator and Planning/Logistics body require that the equipment used to manufacture system shall be maintainable.

APPENDIX B – PROJECT TROJAN USE CASE

Use Case: A clear verb/noun or actor/verb/noun that communicates the scope of the use Case Use case for: Neutralizing a hostile communications centre whilst causing minimal collateral damage to the rest of the building and potential occupants.
Scenario: - A single-room clandestine hostile communications centre embedded within a larger building containing other occupants, roles unknown (could be civilian). Located in an urban centre within northern Europe with temperate climate. Mission parameters require an intervention to be affected from a minimum of 100m distance, unless other mitigating factors are at play. Such mission can be undertaken during the day and night.
Actors: - A list of actors who can engage in the activities described in the use case. - Non-Commissioned Officer (In control of executing the mission, leading the action team) 4x Supporting Soldiers (Conducting actions to execute the mission)
Pre-conditions: - Anything that can be assumed to be true when the use case begins. - Assuming all users are suitably trained and fully equip to execute the mission. - We know the exact location of the room. - We know the content of the room and the number of personnel (3 computers, 6 people). - We know the construction of the room (Bar ceiling and roof). - In an appropriate firing position.
Post-Conditions: - Anything that must be true when the use case is complete. - All hostile equipment is neutralised. - No structural damage to the rest of the building. - No weapons effect outside the target room. - No civilian casualties.
Basic Flow: - The set of steps the actors take to accomplish the goal of the Use Case. A clear description of what the system does in response to each user action. - Fire Team reach mission area - Team undertake confirmatory reconnaissance - System is unpacked - System is prepared for use - Target is acquired - Permission to proceed is granted - System is deployed - Effect is achieved - Remaining system is made safe and packed up.

10. Fire team leave area.

Alternative Flow: - Captures alternative user/system interactions, such as what happens if data is entered incorrectly.

1. Fire Team reach mission area
2. Team undertake confirmatory reconnaissance
3. System is unpacked
4. System is prepared for use
5. Target is acquired
- 6. Permission to proceed is denied/rescinded**
7. System is made safe
8. Unused system is repacked
9. Fire team leave area

Exception Flow: - The things that can happen to prevent the user from reaching their goal.

- Civilian interference
- Enemy interference
- Target already eliminated
- Target is incorrect
- System Malfunction
- Misfire
- System is damaged during transport
- Loss of fire team personnel
- Used incorrectly
- Adverse Weather

APPENDIX C – PENETRATE TARGET FUNCTIONAL FAILURE MODE EFFECT ANALYSIS

Functional Failure Mode Effect Analysis											
System	Project Trojan	O - Probability of Occurrence		1: Very Rare → 10: Frequent			Date		17 February 2025	No	1
		S - Severity of Occurrence		1: No Effect → 10: Most Severe			Author		E. Halifax	Issue	1
		D - Probability of Detection		1: Certain Detection → 10: No Detection							
Function	Functional Failure Mode	Effects		S	Causes	O	Detection/Prevention		RPN	Design Suggestions/Comments	
		On System	Seen by Customer				Current Method	D			
Penetrate Target	No Penetration	System not in desired target location (external to location) and unable to deliver effect as intended	Target not neutralised, risk of terminal effect being delivered in an undesirable location with additional risk/harm to civilians and local infrastructure	10	Failure in the penetration mechanism (exact cause solution dependant)	5	None in place	9	450	Incorporate a redundancy penetration method and substantiate methods with a robust testing and evaluation regime to ensure efficiency. Incorporate a safety isolation and prevention system (Safety and Arming Unit) to prevent the terminal effect being delivered in an unintended location.	
			Mission Failure - requirement to demol munition	5			None in place	9	225		

Function	Functional Failure Mode	Effects		S	Causes	O	Detection/Prevention		RPN	Design Suggestions/Comments
		On System	Seen By Customer				Current Method	D		
Penetrate Target	Penetrates Too Much	System not in desired target location (internal to location/or through to other external side) and unable to deliver effect as intended	Target not neutralised, risk of terminal effect being delivered in an undesirable location with additional risk/harm to civilians and local infrastructure	10	Failure in the penetration mechanism (exact cause solution dependant)	5	None in place	9	450	Incorporate a redundancy penetration method and substantiate methods with a robust testing and evaluation regime to ensure efficiency. Incorporate a safety isolation and prevention system (Safety and Arming Unit) to prevent the terminal effect being delivered in an unintended location.
			Mission Failure - requirement to demil munition	5			None in place	9	225	
	Penetrates Too Little	System only partially penetrates desired target, resulting in system not being in desired location	Target not neutralised, risk of terminal effect being delivered in an undesirable location with additional risk/harm to civilians and local infrastructure	10	Failure in the penetration mechanism (exact cause solution dependant)	5	None in place	9	450	Incorporate a redundancy penetration method and substantiate methods with a robust testing and evaluation regime to ensure efficiency. Incorporate a safety isolation and prevention system (Safety and Arming Unit) to prevent the terminal effect being delivered in an unintended location.
			Mission Failure - requirement to demil munition	5			None in place	9	225	

Function	Functional Failure Mode	Effects		S	Causes	O	Detection/Prevention		RPN	Design Suggestions/Comments
		On System	Seen By Customer				Current Method	D		
Penetrate Target	Intermittent Penetration	The system does not consistently deliver desired penetration effect, resulting in a combination of effects from all other failure modes	Unreliability, unable to have confidence in the system	10	Failure in the penetration mechanism (exact cause solution dependant)	5	None in place	9	450	Incorporate a redundancy penetration method and substantiate methods with a robust testing and evaluation regime to ensure efficiency. Incorporate a safety isolation and prevention system (Safety and Arming Unit) to prevent the terminal effect being delivered in an unintended location.
	Incorrect Penetration	The system delivers the incorrect penetration method resulting in potential adverse effects on the overall system and unable to deliver desired effect	Target not neutralised, risk of terminal effect being delivered in an undesirable location with additional risk/harm to civilians and local infrastructure	10	Failure in the penetration mechanism (exact cause solution dependant)	5	None in place	9	450	Incorporate a redundancy penetration method and substantiate methods with a robust testing and evaluation regime to ensure efficiency. Incorporate a safety isolation and prevention system (Safety and Arming Unit) to prevent the terminal effect being delivered in an unintended location.
			Mission Failure - requirement to demol munition	5			None in place	9	225	