

# Systems Thinking Design Report

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# Introduction

This report details the design process undertaken by the TruePath Team, outlining how design solutions were developed from the mission objectives, defined in the design brief. It also documents the tools and methods used to create critical design and process decisions, ensuring the system was developed with a safe by design approach.

# 1. Design brief and mission objective

## Mission objective

“The teams will be required to design a portable (Land Rover or Toyota 4x4) mine detection, clearing and marking system to ensure safe passage for this and future convoys.” [1]

## 1.1 Design Requirements

The requirements were derived from the design brief mission object and was broken down into:

- Their base level requirements (level 1)
- The originator (The stake holder who creates the requirements)
- The requirements Tailored to the stakeholder (level 2)

*Table 1 Design requirements set*

| <u>Level 1</u>                             | <u>Originator</u> | <u>Level 2</u>                                                                           |
|--------------------------------------------|-------------------|------------------------------------------------------------------------------------------|
| Easily deployable                          | MoD/User          | The deployment vehicle must be lightweight (<3 tonne).                                   |
|                                            | MoD/User          | The system could be easily transportable by a Land rover or similar vehicle.             |
|                                            | Logistics         | The system should not put a large strain on the existing transport capacity.             |
| Fast implementation and budget constraints | Manufacture       | The system should be manufactured rapidly.                                               |
|                                            | MoD/Manufacturing | The cost of the program should be ALARP.                                                 |
|                                            | User/Civilians    | There must be minimal time spent in clearing the mined area.                             |
| Surface level, quality operation           | User              | The system must not include a helicopter.                                                |
|                                            | MoD               | Minimal explosives must be used.                                                         |
|                                            | MoD/Manufacturing | All regulations and laws must be adhered to.                                             |
| Very survivable                            | Users             | There must be maximum safety from the mines while operating the device.                  |
|                                            | MoD/User          | The road must be passable by convoys after the process                                   |
|                                            | T&E/MoD           | The operational data should be known to simulate the threat environment.                 |
|                                            | T&E/MoD           | The prequalification trials must have sign off from MoD/safety bodies.                   |
|                                            | Logistics/User    | Spare parts should be easily accessible and cheap.                                       |
|                                            | Logistics/User    | The system design should be able to be repaired in the field or disposed/made safe.      |
| MTDS safe and easy                         | R&D/manufacturing | The system should be made by COTS items.                                                 |
|                                            | R&D               | The system should be easy to prototype.                                                  |
|                                            | Disposal          | Conventional disposal techniques should be applicable.                                   |
|                                            | Disposal          | The system should not be overly hazardous to health during the disposal process.         |
| Safe route created and indicated           | MoD/Civilians     | The system must clear all mines from the pathway ensuring a large safety margin.         |
|                                            | MoD/Civilians     | The de-mined section must be clearly marked out for the following convoys and civilians. |

From the requirements set a pairwise comparison is used to evaluate each requirements perceived importance, compared to each other.

Table 2 Design requirements Pairwise comparison

|   |                                                                                                                                                                                             | 1                 | 2                                          | 3                       | 4               | 5                  | 6                                | Calc        |                         | Calc             |
|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|--------------------------------------------|-------------------------|-----------------|--------------------|----------------------------------|-------------|-------------------------|------------------|
|   | Pairwise comparison of requirements<br><br>1 = No Preference, Reciprocal = 1<br>2 = Slight Preference, Reciprocal = 0.5<br>5 = Preference, Reciprocal = 0.2<br>9 = Strong preference = 0.11 | Easily deployable | Fast implementation and budget constraints | Surface level operation | Very survivable | MTDS safe and easy | Safe route created and indicated | Row Product | nth root of row product | Total Normalised |
| 1 | Easily deployable                                                                                                                                                                           | 1                 | 2                                          | 0.5                     | 0.11            | 2                  | 0.2                              | 0.044       | 0.9                     | 14               |
| 2 | Fast implementation and budget constraints                                                                                                                                                  | 0.5               | 1                                          | 0.2                     | 0.11            | 2                  | 0.2                              | 0.004       | 0.8                     | 12               |
| 3 | Surface level operation                                                                                                                                                                     | 2                 | 5                                          | 1                       | 0.5             | 5                  | 1                                | 25          | 1.2                     | 19               |
| 4 | Very survivable                                                                                                                                                                             | 9                 | 9                                          | 2                       | 1               | 9                  | 2                                | 2916        | 1.5                     | 24               |
| 5 | MTDS safe and easy                                                                                                                                                                          | 0.5               | 0.5                                        | 0.2                     | 0.11            | 1                  | 5                                | 0.028       | 0.8                     | 14               |
| 6 | Safe route created and indicated                                                                                                                                                            | 5                 | 5                                          | 1                       | 0.5             | 0.2                | 1                                | 2.5         | 1                       | 17               |
|   |                                                                                                                                                                                             |                   |                                            |                         |                 |                    |                                  | 2943.576    | 6.17                    | 100              |

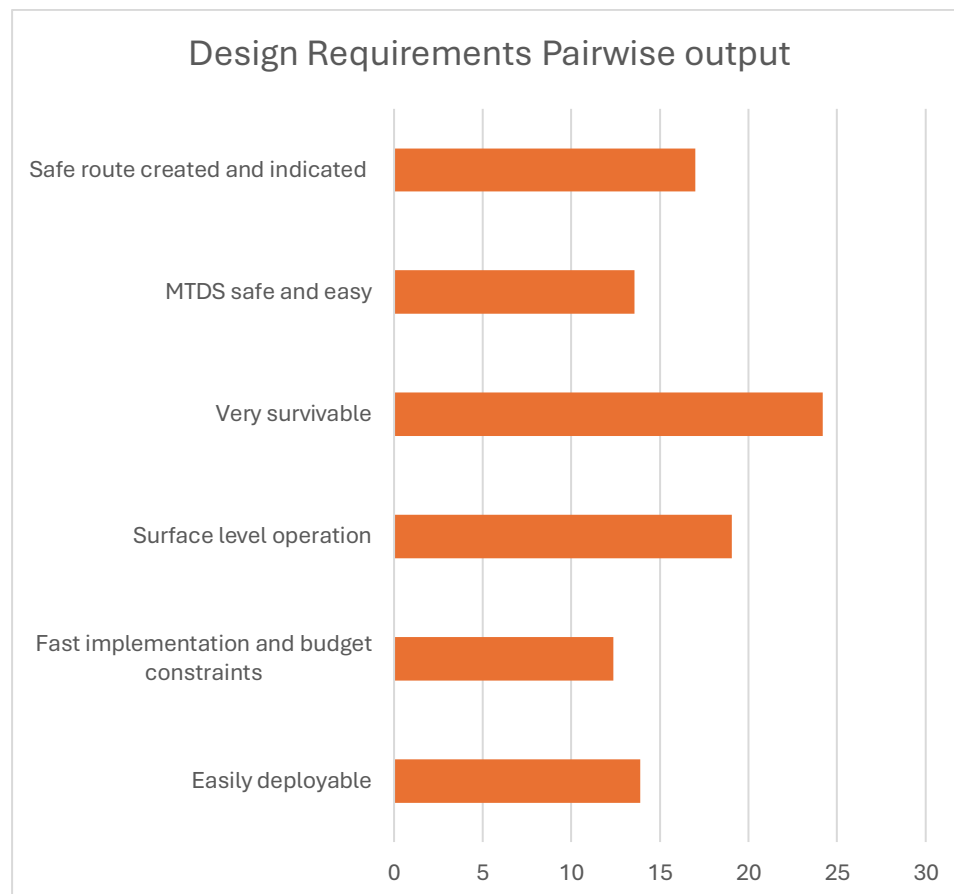


Figure 1 Design Requirements Pairwise output

## 1.2 Required Functionality

The required functionality uses the requirements made by the customer. Turing those requirements into “what needs to be done” to meet the requirements?

| Level 1 (required functionality)     | How Much                                                |
|--------------------------------------|---------------------------------------------------------|
| Technique for manufacture            | Off the shelf equipment used                            |
| Deploy system                        | transportable by pickup truck, under 3 tonnes           |
| Detect surface mines                 | Detect mines within top 0.5m                            |
| Neutralise mines                     | No more than 50kg of explosives used                    |
| Create cleared lane                  | Clear 10m in 30mins                                     |
| Mark cleared route                   | Produce 10m wide marked pathway                         |
| Protect personnel                    | Limited blast/frag risk to operators                    |
| Operate in air contested environment | No higher than 100m                                     |
| Comply with regulations              | Meet HSE, JSP, DEFSTAN, STANAG                          |
| Survive environment                  | Sand/dust, temperature, impact, vibration, UV tolerable |
| Technique for field repair           | Easily sourced parts and minimal training               |
| Dispose system                       | Conventional disposal methods are effective             |

A Quality Function Deployment (QFD) matrix is then used to calculate the functional importance of the functionality against the requirements, this is scored 1,3,9 lowest to highest with nothing representing no relation.

To be able to do this the requirements are first ranked by their perceived importance score, this being the output from the pairwise comparison. [2]

Table 3 Design QFD 1

[illegible]

### 1.2.1 Critical functionality/Functional Importance

The output of QFD1 identified survive the environment (492) and protect personnel (482) as the most important functions.

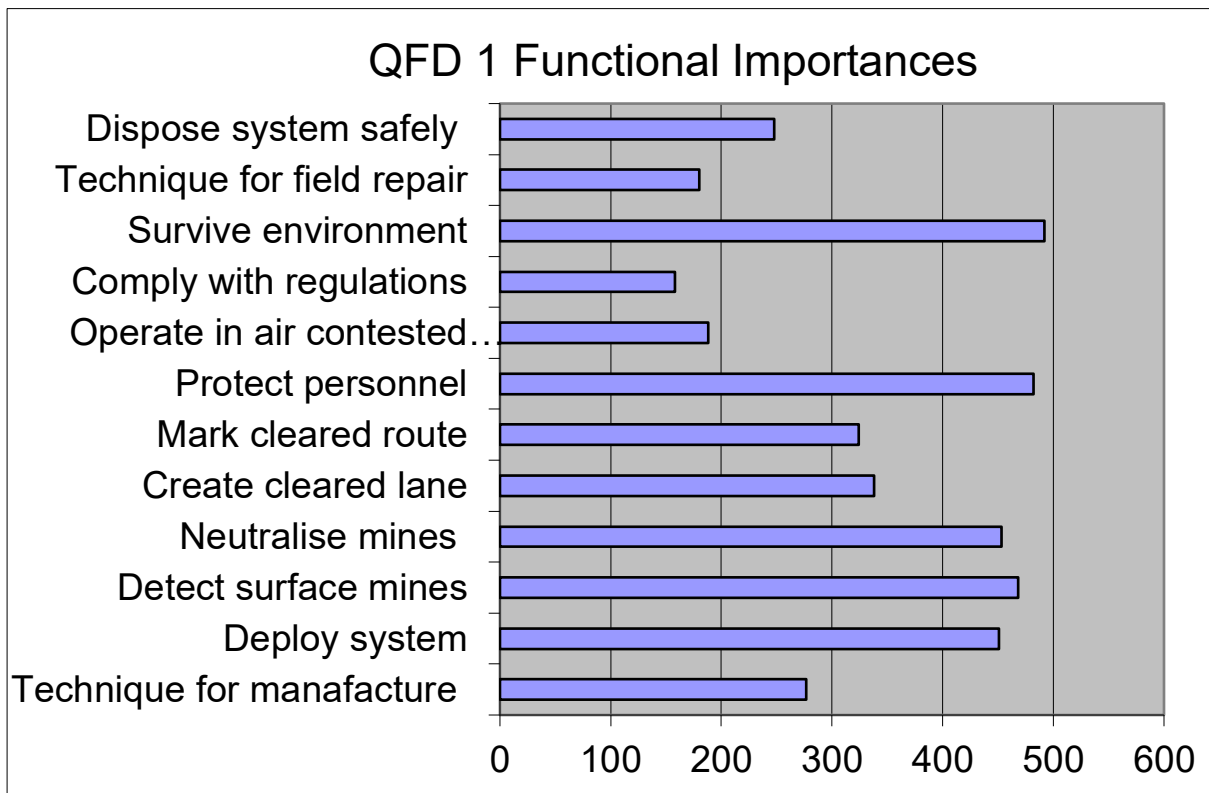


Figure 2 QFD 1 Functional Importance

The Score calculated by the QFD will later be used as a functionality importance score.

## 1.3 Function Means analysis

The concept derivation and design choices phase uses the identified critical functionality and considers how the function can be performed. This was done by conducting function means analysis, where the members of the TruePath team suggested means in which the function could be performed.

The output of their shared knowledge and expertise was added to a table, where the feasibility of each means was ranked, With Green being overall agreement, yellow being to be considered and red being ruled out.

| Function                             | Means                        |                           |                                     |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |             |  |
|--------------------------------------|------------------------------|---------------------------|-------------------------------------|----------------------------|----------------------------------|------------------------------------|-----------------|-------------------------|-----------------------|------------------|------------------------------|----------------------------|-------------|--|
| Deploy system                        | In pickup truck bed          | Towed by pickup truck     | Hard-mounted on pickup truck        | Self-propelled to location | Man carried                      | Air dropped                        | Horseback       | Helicopter              |                       |                  |                              |                            |             |  |
| Detect surface mines                 | Kinetic (Poking or Brushing) | Sonar                     | Radar                               | Lidar                      | Don't                            | Sniffer dog                        | Magnetic field  | Seismic                 | Thermal               | Visual           | Nuclear Quadrupole resonance | Nuclear Magnetic Resonance | Excavation  |  |
| Neutralise mines                     | Don't                        | Controlled EOD Detonation | Uncontrolled Detonation (e.g. fail) | Mechanical Defusal         | Electro magnetically defuse      | Flood it                           | Insulate        | Controlled deflagration | Pirate control signal |                  |                              |                            |             |  |
| Create cleared lane                  | Don't                        | Move mines                | Destroy mines                       |                            |                                  |                                    |                 |                         |                       |                  |                              | Sacrificial panels         |             |  |
| Mark cleared route                   | Flags                        | Digitally                 | Paint                               | Grid reference             | Human wall                       | Netting                            | GPS             |                         |                       |                  | GPS                          |                            |             |  |
| Protect personnel                    | Hardened Armour              | Distance                  | Training                            | Don't                      | Sacrificial panels               | Autonomous human controlled or not | ERA             |                         |                       |                  |                              |                            |             |  |
| Operate in air contested environment | Fly                          | Hover                     | Ground operate (Wheels/Tracks)      | Legs                       | Accept Loss Rate/cheap           |                                    |                 |                         |                       |                  |                              |                            |             |  |
| Comply with regulations              | Don't comply                 | Comply                    | Partial compliance                  | Waiver                     | Limit operability                |                                    |                 |                         |                       |                  |                              |                            |             |  |
| Survive environment                  | Don't                        | Dust filters              | Heating/Cooling System              | Environmental Shielding    | Environmental Seals              | Suspension                         | Tracked         | Tyres                   | Unditching Log        | Impact Resistant | Winch                        | EMR shielding              |             |  |
| Technique for field repair           | Spare Parts                  | Serviceable               | Modular                             | Simple                     | COTS items                       | Poka-yoke                          | Manuals         | People training         |                       |                  |                              |                            |             |  |
| Dispose system                       | Send to Allies               | Non-Bespoke Materials     | Non-Hazardous Materials             | Non-TAR/EAR                | Breakdownable (Screws Not Welds) | Ocean/ bury                        | Training Target | Leave in Storage        | Museum                | Sell for Scrap   | Burn                         | detonate                   | Disassemble |  |

Figure 3 FMA Solutions

With a list of credible Means, Concept derivation and design choices could be made, this was done by selecting means for each function and theorizing what the combined functions would culminate as a design.

From the function means table the TruePath team came up with 4 concepts Core concepts:

### Flail

| Function                                                                                                                                       | Means                        |                           |                                     |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |             |  |
|------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|---------------------------|-------------------------------------|----------------------------|----------------------------------|------------------------------------|-----------------|-------------------------|-----------------------|------------------|------------------------------|----------------------------|-------------|--|
| Deploy system                                                                                                                                  | In pickup truck bed          | Towed by pickup truck     | Hard-mounted on pickup truck        | Self-propelled to location | Man carried                      | Air dropped                        | Horseback       | Helicopter              |                       |                  |                              |                            |             |  |
| Detect surface mines                                                                                                                           | Kinetic (Poking or Brushing) | Sonar                     | Radar                               | Lidar                      | Don't                            | Sniffer dog                        | Magnetic field  | Seismic                 | Thermal               | Visual           | Nuclear Quadrupole resonance | Nuclear Magnetic Resonance | Excavation  |  |
| Neutralise mines                                                                                                                               | Don't                        | Controlled EOD Detonation | Uncontrolled Detonation (e.g. fail) | Mechanical Defusal         | Electro magnetically defuse      | Flood it                           | Insulate        | Controlled deflagration | Pirate control signal |                  |                              |                            |             |  |
| Create cleared lane                                                                                                                            | Don't                        | Move mines                | Destroy mines                       |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |             |  |
| Mark cleared route                                                                                                                             | Flags                        | Digitally                 | Paint                               | Grid reference             | Human wall                       | Netting                            | GPS             | rope it off             |                       |                  |                              |                            |             |  |
| Protect personnel                                                                                                                              | Hardened Armour              | Distance                  | Training                            | Don't                      | Sacrificial panels               | Autonomous human controlled or not | ERA             |                         |                       |                  |                              |                            |             |  |
| Operate in air contested environment                                                                                                           | Fly                          | Hover                     | Ground operate (Wheels/Tracks)      | Legs                       | Accept Loss Rate/cheap           |                                    |                 |                         |                       |                  |                              |                            |             |  |
| Comply with regulations                                                                                                                        | Don't comply                 | Comply                    | Partial compliance                  | Waiver                     | Limit operability                |                                    |                 |                         |                       |                  |                              |                            |             |  |
| Survive environment                                                                                                                            | Don't                        | Dust filters              | Heating/Cooling System              | Environmental Shielding    | Environmental Seals              | Suspension                         | Tracked         | Tyres                   | Unditching Log        | Impact Resistant | Winch                        | EMR shielding              |             |  |
| Technique for field repair                                                                                                                     | Spare Parts                  | Serviceable               | Modular                             | Simple                     | COTS items                       | Poka-yoke                          | Manuals         | People training         |                       |                  |                              |                            |             |  |
| Dispose system                                                                                                                                 | Send to Allies               | Non-Bespoke Materials     | Non-Hazardous Materials             | Non-TAR/EAR                | Breakdownable (Screws Not Welds) | Ocean/ bury                        | Training Target | Leave in Storage        | Museum                | Sell for Scrap   | Burn                         | detonate                   | Disassemble |  |
| Flail either attached to pickup truck (weight issue) or smaller and remotely operated machine (would be destroyed more often so a cost issue). |                              |                           |                                     |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |             |  |

Figure 4 Flail FMA concept

### Plow

| Function                                                                                                                                                                            | Means                        |                           |                                      |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |            |  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|---------------------------|--------------------------------------|----------------------------|----------------------------------|------------------------------------|-----------------|-------------------------|-----------------------|------------------|------------------------------|----------------------------|------------|--|
| Deploy system                                                                                                                                                                       | In pickup truck bed          | Towed by pickup truck     | Hand-mounted on pickup truck         | Self-propelled to location | Man carried                      | Air dropped                        | Horseback       | Helicopter              |                       |                  |                              |                            |            |  |
| Detect surface mines                                                                                                                                                                | Kinetic (Poking or Brushing) | Sonar                     | Radar                                | Lidar                      | Don't                            | Sniffer dog                        | Magnetic field  | Seismic                 | Thermal               | Visual           | Nuclear Quadrupole resonance | Nuclear Magnetic Resonance | Excavation |  |
| Neutralise mines                                                                                                                                                                    | Don't                        | Controlled EOD Detonation | Uncontrolled Detonation (e.g. flail) | Mechanical Defusal         | Electro magnetically defuse      | Flood it                           | Insulate        | Controlled deflagration | Pirate control signal |                  |                              |                            |            |  |
| Create cleared lane                                                                                                                                                                 | Don't                        | Move mines                | Destroy mines                        |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |            |  |
| Mark cleared route                                                                                                                                                                  | Flags                        | Digitally                 | Paint                                | Grid reference             | Human wall                       | Netting                            | GPS             | rope it off             |                       |                  |                              |                            |            |  |
| Protect personnel                                                                                                                                                                   | Hardened Armour              | Distance                  | Training                             | Don't                      | Sacrificial panels               | Autonomous human controlled or not | ERA             |                         |                       |                  |                              |                            |            |  |
| Operate in air contested environment                                                                                                                                                | Fly                          | Hover                     | Ground operate (Wheels/tracks)       | Legs                       | Accept Loss Rate/cheap           |                                    |                 |                         |                       |                  |                              |                            |            |  |
| Comply with regulations                                                                                                                                                             | Don't comply                 | Comply                    | Partial compliance                   | Waiver                     | Limit operationally              |                                    |                 |                         |                       |                  |                              |                            |            |  |
| Survive environment                                                                                                                                                                 | Don't                        | Dust filters              | Heating/Cooling System               | Environmental Shielding    | Environmental Seals              | Suspension                         | Tracked         | Tyres                   | Unditching Log        | Impact Resistant | Winch                        | EMR shielding              |            |  |
| Technique for field repair                                                                                                                                                          | Spare Parts                  | Serviceable               | Modular                              | Simple                     | COTS items                       | Poka-yoke                          | Manuals         | People training         |                       |                  |                              |                            |            |  |
| Dispose system                                                                                                                                                                      | Send to "Alber"              | Non-Hazardous Materials   | Non-Hazardous Materials              | Non-ITAR/EAR               | Breakdownable (Screws Not Welds) | Ocean/ bury                        | Training Target | Leave in Storage        | Museum                | Sell for Scrap   | Burn                         | Detonate                   |            |  |
| Plow either attached to pickup truck (weight issue) or smaller and remotely operated machine (would be destroyed more often so a cost issue). Less chance of detonation than flail. |                              |                           |                                      |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |            |  |

Figure 5 Plow FMA concept

## Tumbleweed

| Function                                                                                                                                                                            | Means                        |                           |                                      |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |            |  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|---------------------------|--------------------------------------|----------------------------|----------------------------------|------------------------------------|-----------------|-------------------------|-----------------------|------------------|------------------------------|----------------------------|------------|--|
| Deploy system                                                                                                                                                                       | In pickup truck bed          | Towed by pickup truck     | Hand-mounted on pickup truck         | Self-propelled to location | Man carried                      | Air dropped                        | Horseback       | Helicopter              |                       |                  |                              |                            |            |  |
| Detect surface mines                                                                                                                                                                | Kinetic (Poking or Brushing) | Sonar                     | Radar                                | Lidar                      | Don't                            | Sniffer dog                        | Magnetic field  | Seismic                 | Thermal               | Visual           | Nuclear Quadrupole resonance | Nuclear Magnetic Resonance | Excavation |  |
| Neutralise mines                                                                                                                                                                    | Don't                        | Controlled EOD Detonation | Uncontrolled Detonation (e.g. flail) | Mechanical Defusal         | Electro magnetically defuse      | Flood it                           | Insulate        | Controlled deflagration | Pirate control signal |                  |                              |                            |            |  |
| Create cleared lane                                                                                                                                                                 | Don't                        | Move mines                | Destroy mines                        |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |            |  |
| Mark cleared route                                                                                                                                                                  | Flags                        | Digitally                 | Paint                                | Grid reference             | Human wall                       | Netting                            | GPS             | rope it off             |                       |                  |                              |                            |            |  |
| Protect personnel                                                                                                                                                                   | Hardened Armour              | Distance                  | Training                             | Don't                      | Sacrificial panels               | Autonomous human controlled or not | ERA             |                         |                       |                  |                              |                            |            |  |
| Operate in air contested environment                                                                                                                                                | Fly                          | Hover                     | Ground operate (Wheels/tracks)       | Legs                       | Accept Loss Rate/cheap           |                                    |                 |                         |                       |                  |                              |                            |            |  |
| Comply with regulations                                                                                                                                                             | Don't comply                 | Comply                    | Partial compliance                   | Waiver                     | Limit operationally              |                                    |                 |                         |                       |                  |                              |                            |            |  |
| Survive environment                                                                                                                                                                 | Don't                        | Dust filters              | Heating/Cooling System               | Environmental Shielding    | Environmental Seals              | Suspension                         | Tracked         | Tyres                   | Unditching Log        | Impact Resistant | Winch                        | EMR shielding              |            |  |
| Technique for field repair                                                                                                                                                          | Spare Parts                  | Serviceable               | Modular                              | Simple                     | COTS items                       | Poka-yoke                          | Manuals         | People training         |                       |                  |                              |                            |            |  |
| Dispose system                                                                                                                                                                      | Send to "Alber"              | Non-Hazardous Materials   | Non-Hazardous Materials              | Non-ITAR/EAR               | Breakdownable (Screws Not Welds) | Ocean/ bury                        | Training Target | Leave in Storage        | Museum                | Sell for Scrap   | Burn                         | Detonate                   |            |  |
| Multiple cheap tumbleweed released onto minefield. Would need other means to ensure all mines are cleared and mapped as movement is random. Will not work on heavy anti tank mines. |                              |                           |                                      |                            |                                  |                                    |                 |                         |                       |                  |                              |                            |            |  |

Figure 6 Tumbleweed FMA concept

## Drone

| Function                             | Means                        |                           |                                      |                            |                                  |                                    |                 |                         |                       |                  |                              |               |  |  |
|--------------------------------------|------------------------------|---------------------------|--------------------------------------|----------------------------|----------------------------------|------------------------------------|-----------------|-------------------------|-----------------------|------------------|------------------------------|---------------|--|--|
| Deploy system                        | In pickup truck bed          | Towed by pickup truck     | Hand-mounted on pickup truck         | Self-propelled to location | Man carried                      | Air dropped                        | Horseback       | Helicopter              |                       |                  |                              |               |  |  |
| Detect surface mines                 | Kinetic (Poking or Brushing) | Sonar                     | Radar                                | Lidar                      | Don't                            | Sniffer dog                        | Magnetic field  | Seismic                 | Thermal               | Visual           | Nuclear Quadrupole resonance |               |  |  |
| Neutralise mines                     | Don't                        | Controlled EOD Detonation | Uncontrolled Detonation (e.g. flail) | Mechanical Defusal         | Electro magnetically defuse      | Flood it                           | Insulate        | Controlled deflagration | Pirate control signal |                  |                              |               |  |  |
| Create cleared lane                  | Don't                        | Move mines                | Destroy mines                        |                            |                                  |                                    |                 |                         |                       |                  |                              |               |  |  |
| Mark cleared route                   | Flags                        | Digitally                 | Paint                                | Grid reference             | Human wall                       | Netting                            | GPS             | rope it off             | Painted rock          |                  |                              |               |  |  |
| Protect personnel                    | Hardened Armour              | Distance                  | Training                             | Don't                      | Sacrificial panels               | Autonomous human controlled or not | ERA             |                         |                       |                  |                              |               |  |  |
| Operate in air contested environment | Fixed Wings                  | Rotary Wing               | Ground operate (Wheels/tracks)       | Legs                       | Accept Loss Rate/cheap           |                                    |                 |                         |                       |                  |                              |               |  |  |
| Comply with regulations              | Don't comply                 | Comply                    | Partial compliance                   | Waiver                     | Limit operationally              |                                    |                 |                         |                       |                  |                              |               |  |  |
| Survive environment                  | Don't                        | Dust filters              | Heating/Cooling System               | Environmental Shielding    | Environmental Seals              | Suspension                         | Tracked         | Tyres                   | Unditching Log        | Impact Resistant | Winch                        | EMR shielding |  |  |
| Technique for field repair           | Spare Parts                  | Serviceable               | Modular                              | Simple                     | COTS items                       | Poka-yoke                          | Manuals         | People training         |                       |                  |                              |               |  |  |
| Dispose system                       | Send to Alber                | Non-Hazardous Materials   | Non-Hazardous Materials              | Non-ITAR/EAR               | Breakdownable (Screws Not Welds) | Ocean/ bury                        | Training Target | Leave in Storage        | Museum                | Sell for Scrap   | Burn                         | Detonate      |  |  |

Figure 7 Drone FMA concept

As concepts developed more means were added to enable the cohesion of the different functions.

Following the creation of the concepts a system Pugh was used, enabling the TruePath team to select a design solution. This was achieved by ranking the design concepts against the weighted requirements, selecting the concept that scored highest. An in-service solution (EOD specialist with mine detector) was also added as a means of comparison.

Table 4 System Pugh

|                                            |                              | Relative Importance<br>Equal | Relative Importance<br>Weighted | EoD specialist with<br>mine detector | Flail | Plow | Tumbleweed | DRONE |
|--------------------------------------------|------------------------------|------------------------------|---------------------------------|--------------------------------------|-------|------|------------|-------|
| <b>WHATs - Customer Requirements</b>       | <b>How much:- From QFD 1</b> |                              |                                 |                                      |       |      |            |       |
| Easily deployable                          |                              | 5                            | 14                              | 0                                    | -1    | -1   | 0          | 0     |
| Fast implementation and budget constraints |                              | 5                            | 12                              | 0                                    | -1    | -1   | 1          | 0     |
| Surface level operation                    |                              | 5                            | 19                              | 0                                    | 0     | 0    | 0          | 0     |
| Very survivable                            |                              | 5                            | 24                              | 0                                    | 1     | 1    | 2          | 3     |
| MTDS safe and easy                         |                              | 5                            | 14                              | 0                                    | -1    | -1   | 0          | 0     |
| Safe route created and indicated           |                              | 5                            | 17                              | 0                                    | 0     | 0    | -2         | 0     |

The outcome was that the Drone concept was chosen, as it had the highest score for the customers weighted requirements.

### 1.3.1 Design overview

#### Overview

Two-drone system for mine detection and neutralisation

- Detection drone surveys terrain for mines
- Defeat drone deploys shaped charges to neutralise mines

#### Mine Detection Mechanism

Dual Sensor Array that uses electromagnetic and Radio frequency waves that can detect subsurface density and conductive discrepancies.

- Nuclear Quadrupole Resonance (NQR)
- Ground Penetrating Radar (GPR)

#### Detector Drone Platform

A large Drone platform is used that has a High payload capacity being able to carry the dual sensor system while remaining stable in air.

#### Mine Defeat Mechanism

Small Shaped charges placed atop detected mines and can be remotely detonated using a firing wire that unravels as drone moves away for safe detonation distance.

#### Shaped Charge Deployment Drone Platform

The Small Drone platform transports shaped charges with precision to the mine, the charge is held in a spring-loaded mechanism that releases once positioned above the mine

## 1.4 TruePath function means (safety)

With personal safety being the second highest functional importance, the safety team of TruePath engaged in ensuring that the requirement of safety would be met.

Example rational given for the Mean selected from a Safety perspective.

Means selected:

- Radar
- Nuclear Quadruple resonance

Safety rational:

Both methods were selected based on their proven reliability demonstrated in service within other mine detection devices [3] [4]. Two distinct detection methods were implemented to provide redundancy in the event that one device fails to detect a mine. Although this increases the cost per unit, the justification for this approach is supported by the functional importance scores shown in Figure 2, which were derived directly from the customer requirements for safety.

## 1.5 Potential failure modes

### 1.5.1 Failure mode analysis P-Diagram

To Identify the possible failure modes a Failure Mode and Effects Analysis (FMEA) Tool was used.

Parameter Diagram (P-Diagram):

A P-Diagram is a Design FMEA tool that is used to identify Inputs, outputs, control factors and noise factors that would affect the system's performance. [5]

*Table 5 Parameter Diagram Definitions*

|                     |                                                                              |
|---------------------|------------------------------------------------------------------------------|
| Input/Signal Factor | The intended act of the system                                               |
| Output              | The Intended outcome of successful operation.                                |
| Noise Factors       | The Factors that reduce the system's ability to achieve its intended output. |
| Control Factors     | The Factors that can be changed by design modifications.                     |

The TruePath team implemented this tool to mitigate the possible failure modes prior to production, to ensure that the TruePath system is fit for purpose per user requirements.

Figure 8 Illustrates how the tool was used by the TruePath team for the Drone mine detector.

The noise factors identified were grouped by:

- External: Environmental factors
- Unit to unit: The variation that can occur within Units
- Deterioration: Wear over time

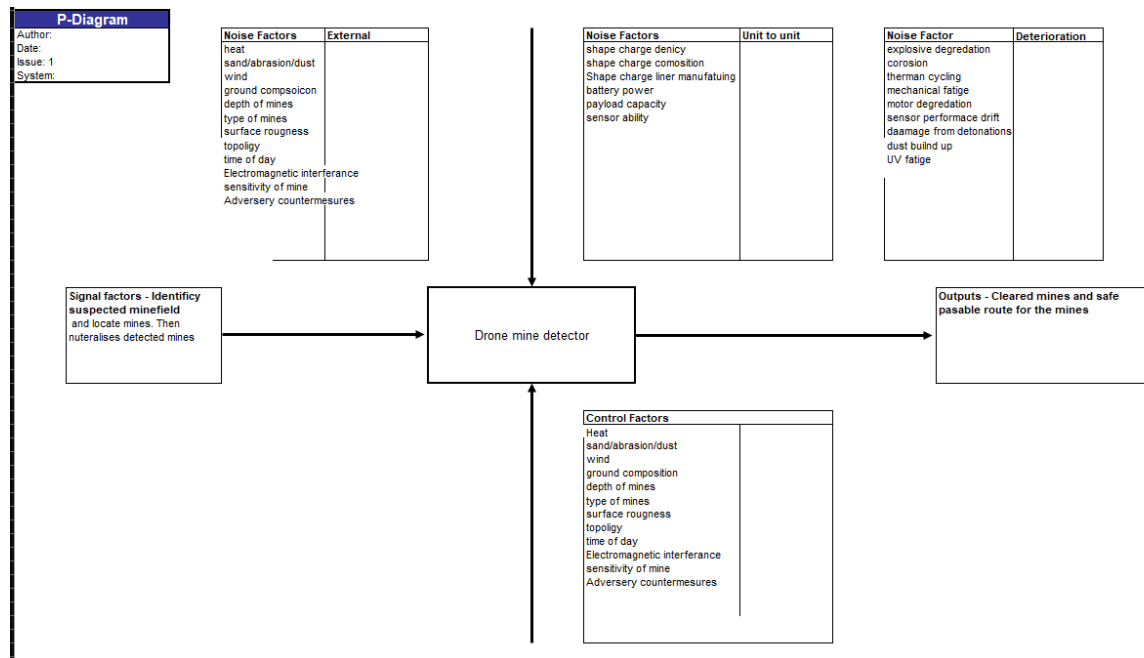


Figure 8 P-Diagram Drone mine detector

### 1.5.2 TruePath Clarification for P-Diagram

With later retrospection, the TruePath team acknowledges that an error occurred during this process. On initial use the team incorrectly put the Noise factors, that should be controlled for, within the control factors section, misinterpreting the sections use. This later effected the use of what why table see Table 7.

The table below shows what the correct use of the control factors section should be.

Table 6 P-Diagram correct control factors correction

| Control Factors                          |
|------------------------------------------|
| Materials                                |
| Detection equipment fitted to system     |
| Operator training                        |
| Motors used                              |
| Communication method (Drone to operator) |
| Shape Charge used                        |
| Environmental shielding used             |
| Adversary countermeasures systems used   |

### 1.5.1 Error Identification and Takeaway

Although the implementation of the P-Diagram was incorrect, the process still enabled the TruePath team to mitigate the failure modes. This was because the process considered both the system function (output) and the factors associated with the failure mechanisms that generate failure modes. Consequently, the effects of these failure modes would have resulted in the system failing to meet the customer requirements.

#### Application of P-Diagram

With the identification of the noise factors and the (incorrect) Controls a what why table was used to map design parameters and performance characteristics This being what control factors will change and why (Noise factors).

#### **Correct example**

Control factor: Material used for drone frame

Noise factor external: Heat (High temperature)

#### **Application of What Why.**

What might have to change? The material used for drone frame. Why? Because the Heat could cause the drone frame to melt if the material used has a low melting point.

This example illustrates the tools' ability to identify control factors that require adjusting in order to control for the impact of uncontrollable noise factors

If insert rows/columns, copy formulae in purple cells

[illegible]

The What Why output for the control factors was intended to show which control factors were most affected by the different noise factors. However, due to the error in the process, the output instead highlighted the noise factors with the greatest impact on the system and therefore requiring control solutions to minimize their effects the most. Although the process was incorrect, the results still provided useful insights.

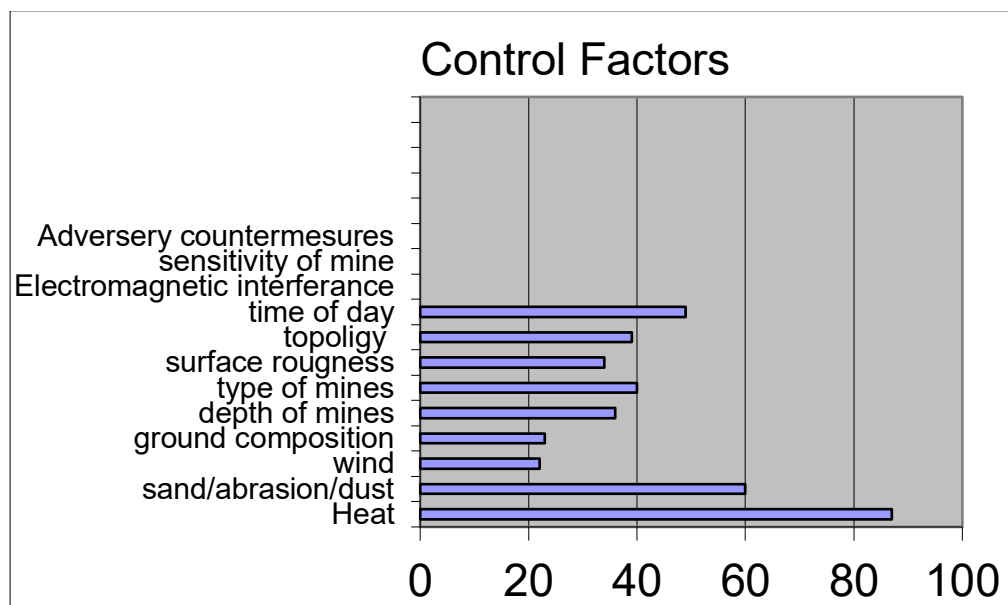


Figure 9 Incorrect output of What why Control Factors

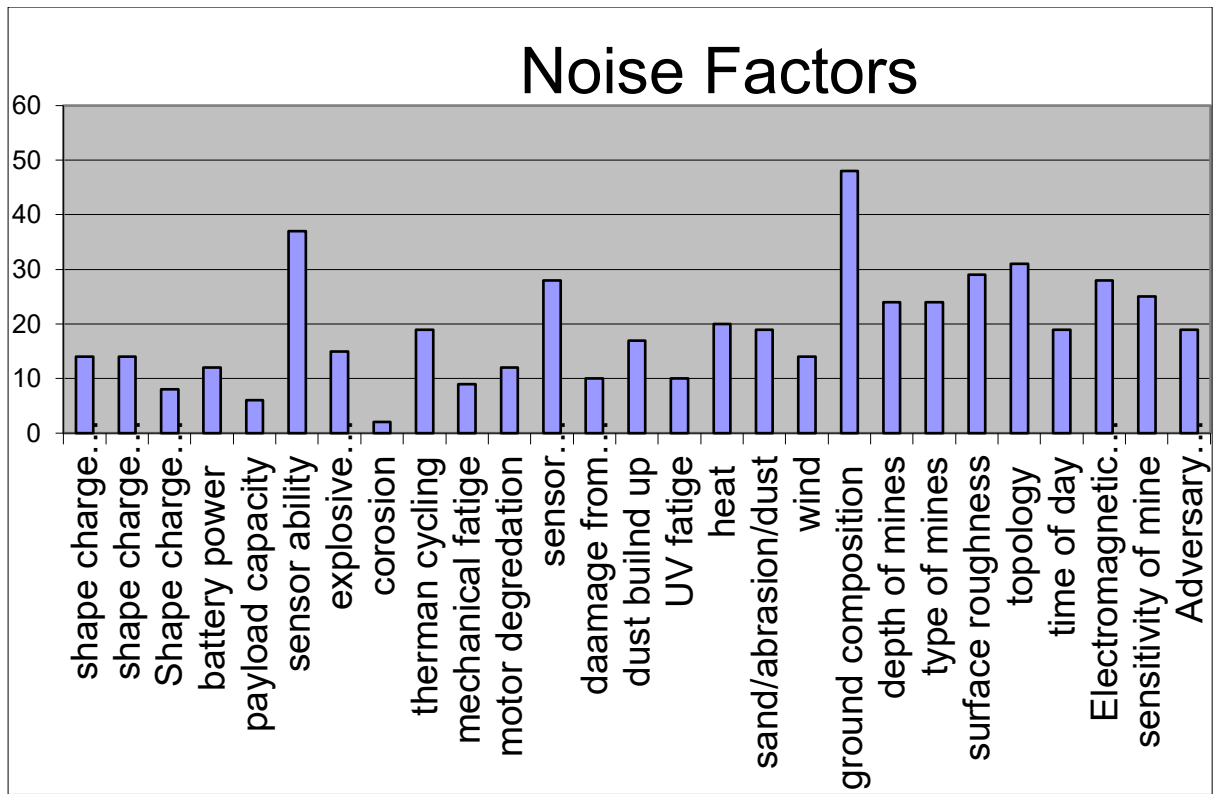


Figure 10 Incorrect output of What why Noise Factors

## 1.6 Critical design features

To identify the critical design features QFD 2 was used to calculate relationships between the functionality and the Means from the design solution as seen Table 8

Table 8 Design QFD 2

| Design feature                       | Importance |    | Importance | Transported and deployed from pickup truck bed | Drone utilises multi sensor imaging | Second shaped charge carrying drone | Mines destroyed and no longer a threat | Painted rock placed to mark pathway | Personnel far from minefield threat | Drone hovers over minefield, below MANPAD threat | Systsem complys with legal regulations and defence standards | Environmentally and EMC shielded system | Spare parts and modular design | Recycle drone/ detonate explosives |
|--------------------------------------|------------|----|------------|------------------------------------------------|-------------------------------------|-------------------------------------|----------------------------------------|-------------------------------------|-------------------------------------|--------------------------------------------------|--------------------------------------------------------------|-----------------------------------------|--------------------------------|------------------------------------|
| <b>Functionality</b>                 |            |    |            |                                                |                                     |                                     |                                        |                                     |                                     |                                                  |                                                              |                                         |                                |                                    |
| Deploy system                        | 451        | 12 | 37.5833333 | 9                                              | 3                                   | 3                                   | 3                                      | 1                                   | 1                                   |                                                  | 1                                                            | 3                                       | 3                              |                                    |
| Detect surface mines                 | 468        | 12 | 39         |                                                | 9                                   |                                     | 3                                      |                                     |                                     | 9                                                | 3                                                            | 3                                       | 1                              |                                    |
| Neutralise mines                     | 425        | 12 | 35.4166667 |                                                |                                     | 9                                   | 9                                      |                                     | 1                                   | 9                                                | 1                                                            | 1                                       | 1                              |                                    |
| Create cleared lane                  | 338        | 12 | 28.1666667 |                                                | 3                                   | 9                                   | 9                                      |                                     |                                     | 3                                                | 1                                                            |                                         |                                |                                    |
| Mark cleared route                   | 324        | 12 | 27         |                                                | 3                                   |                                     |                                        | 9                                   |                                     |                                                  | 1                                                            |                                         |                                |                                    |
| Protect personnel                    | 484        | 12 | 40.3333333 |                                                | 3                                   | 3                                   | 3                                      | 9                                   | 9                                   | 1                                                | 1                                                            | 3                                       | 1                              | 9                                  |
| Operate in air contested environment | 188        | 12 | 15.6666667 | 3                                              |                                     |                                     |                                        |                                     |                                     | 9                                                | 1                                                            | 1                                       |                                |                                    |
| Comply with regulations              | 500        | 12 | 41.6666667 |                                                |                                     | 3                                   | 3                                      | 3                                   | 9                                   | 1                                                | 9                                                            | 1                                       | 1                              | 3                                  |
| Survive environment                  | 492        | 12 | 41         |                                                | 3                                   |                                     | 3                                      | 1                                   |                                     | 1                                                | 3                                                            | 9                                       | 3                              | 1                                  |
| Technique for field repair           | 180        | 12 | 15         | 1                                              | 3                                   | 1                                   |                                        |                                     |                                     |                                                  | 1                                                            | 3                                       | 9                              | 3                                  |
| Dispose system safely                | 248        | 12 | 20.6666667 |                                                |                                     | 3                                   |                                        |                                     |                                     |                                                  | 1                                                            |                                         |                                | 9                                  |
|                                      |            |    |            | 400                                            | 918                                 | 1008                                | 1171                                   | 810                                 | 811                                 | 1018                                             | 835                                                          | 858                                     | 527                            | 760                                |

The output of QFD 2 identifies critical design features that can then be compared with the output of QFD 1 to ensure the critical features align with the required functional importance. This helps control potential design creep that may occur during development.

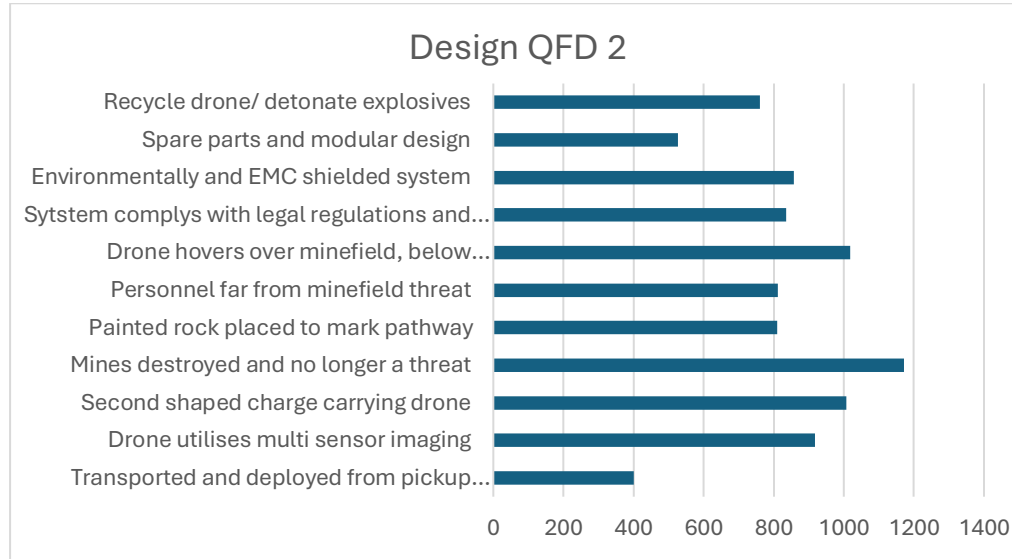


Figure 11 Design QFD 2 Results

Table 9 Design QFD 1 and QFD 2 comparison

| Functionality                               | Functionality Score | Critical design feature                                      | Critical design feature score | % Change |
|---------------------------------------------|---------------------|--------------------------------------------------------------|-------------------------------|----------|
| <b>Dispose system safely</b>                | 451                 | Recycle drone/ detonate explosives                           | 400                           | -11.31%  |
| <b>Technique for field repair</b>           | 468                 | Spare parts and modular design                               | 918                           | +96.15%  |
| <b>Survive environment</b>                  | 453                 | Environmentally and EMC shielded system                      | 1008                          | +122.52% |
| <b>comply with regulations</b>              | 338                 | System complies with legal regulations and defence standards | 1171                          | +246.45% |
| <b>Operate in air contested environment</b> | 324                 | Drone hovers over minefield, below MANPAD threat             | 810                           | +150.00% |
| <b>Protect personnel</b>                    | 482                 | Personnel far from minefield threat                          | 811                           | +68.26%  |
| <b>Mark cleared route</b>                   | 188                 | Painted rock placed to mark pathway                          | 1018                          | +441.49% |
| <b>Create cleared lane</b>                  | 158                 | Mines destroyed and no longer a threat                       | 835                           | +428.48% |
| <b>Neutralise mines</b>                     | 492                 | Second shaped charge carrying drone                          | 858                           | +74.39%  |
| <b>Detect surface mines</b>                 | 180                 | Drone utilizes multi sensor imaging                          | 527                           | +192.78% |
| <b>Deploy system</b>                        | 248                 | Transported and deployed from pickup truck bed               | 760                           | +206.45% |
| <b>Technique for manufacture</b>            |                     | (not required functionality)                                 |                               |          |

## 2. Manufacturing

### 2.1 Manufacturing processes

Manufacturing used the same tools used within the design process.

The requirements set were a combination of the customers' requirements and general manufacturing requirements.

| Level 1                   | Originator             | Level 2                                                                                               |
|---------------------------|------------------------|-------------------------------------------------------------------------------------------------------|
| Low cost Manufacture      | MoD/Manufacturer       | The system shall be manufacturable using predominantly off-the-shelf (COTS) components                |
|                           | Manufacturer           | The unit manufacturing cost shall be minimised to ensure programme affordability                      |
| Rapid Manufacture         | User/Mod               | The system shall be capable of being manufactured and assembled within short lead times               |
|                           | Manufacturer           | The design shall minimise part count to reduce assembly time                                          |
| Simple assembly           | Manufacturer           | The system shall be designed for assembly using basic workshop tools                                  |
|                           | Manufacturer/R&D       | The design shall not require highly specialised labour or facilities                                  |
| Scalable production       | MoD                    | The manufacturing process shall be scaleable from low rate initial production to full rate production |
|                           | Manufacturer           | The design shall support batch manufacturing                                                          |
| Quality and repeatability | MoD/Manufacturer       | The system shall be manufacturable quality and performance between units                              |
|                           | Manufacturer           | Manufacturing shall be achievable using conventional processes                                        |
| Supply Chain robustness   | Logistics/Manufacturer | Components shall be sourced widely available                                                          |
|                           | Logistics              | Single source components shall be avoided where possible                                              |
| Safe Manufacture          | Manufacturer           | The manufacturing process shall minimise handling of energetic materials                              |
|                           | HSE/MoD                | Manufacturing shall comply with HSE and JSI regulations                                               |
| Ease of modification      | R&D/Manufacturer       | The design shall allow rapid design iteration without major tooling changes                           |

Figure 12 Manufacturing Requirements set

Derived from these requirements, process functionality for manufacturing was created.

Table 10 Manufacturing processes functionality

| <b><u>Manufacturing processes functionality</u></b> |
|-----------------------------------------------------|
| Select manufacturing approach                       |
| Fabricate structural components                     |
| Assemble system                                     |
| Integrate Sub-systems                               |
| Integrate explosive components                      |
| Quality assurance                                   |
| Manufacture at scale                                |
| Control manufacturing cost                          |
| Enable field repair manufacture                     |
| Package for transport                               |
| Dispose of manufacturing waste                      |

A functional Importance for manufacturing was also generated, later being used to compare against QFD 2 of manufacturing.

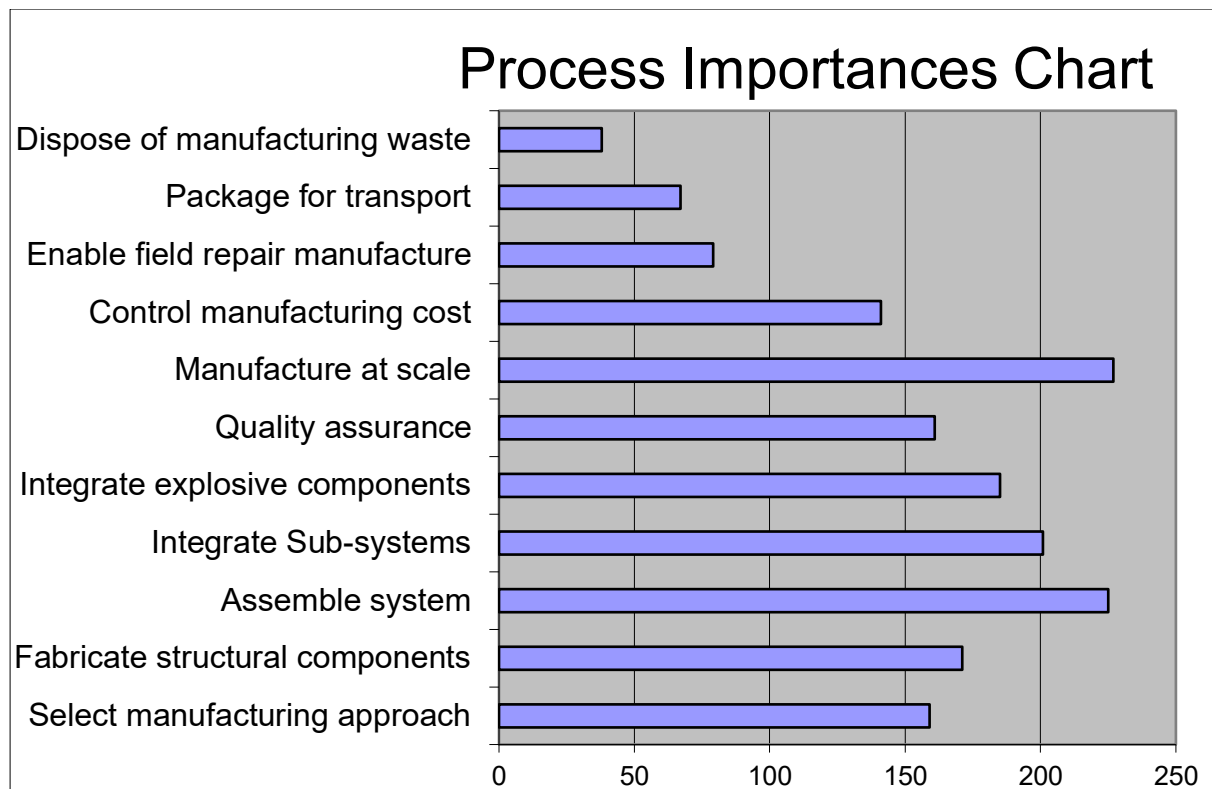


Figure 13 Manufacturing Process Importances Chart

Function means analysis was performed to select the means to perform the required functions.

| Function                        | Means               |                      |                      |                      |                             |                      |                |
|---------------------------------|---------------------|----------------------|----------------------|----------------------|-----------------------------|----------------------|----------------|
| Fabricate structural Components | 3D Print Plastic    | 3D Print Metal       | Laser Cut            | Welded               | Machined                    |                      |                |
| Select manufacturing approach   | Purchase COTS items | Bespoke manufactured | Hybrid               | Don't make it        |                             |                      |                |
| Assemble system                 | Human assembly      | Machine assembly     | Cobot                | Hybrid assembly      |                             |                      |                |
| Integrate Sub-systems           | Mounts              | Glue                 | Weld/Soldered        | Bolts                | Don't                       | Rope                 | Magnets        |
| Integrate explosive components  | Claw machine        | electromagnet        | electronically       | kamikaze             |                             |                      |                |
| Quality assurance               | don't               | Visually             | Physically           | X-Ray                | T&E                         | Compliance with regs |                |
| Manufacture at scale            | Batch create        | Automation           | don't                | Overseas manufacture | supply chain Sub-assemblies |                      |                |
| Control manufacturing cost      | Cheap parts         | Expensive parts      | Cheap labour         | In-house manufacture | Sub-Contract                | Subsidies            | COTS           |
| Enable field repair manufacture | don't               | Modular              | Conventional tooling | Trained staff        | repair guides               | Spare parts          |                |
| Package for transport           | Metal               | containers           | don't                | cardboard            | Felt                        | foam                 | polystyrene    |
| Dispose of manufacturing waste  | don't               | Non-toxic            | Toxic                | Burn it              | Recycle                     | Explode              | Minimise waste |
|                                 |                     |                      |                      |                      |                             |                      |                |
|                                 |                     |                      |                      |                      |                             |                      |                |

Figure 14 Manufacturing FMA

The function means analysis created 3 Manufacturing processes:

- Bespoke parts
- Commercial Off-The-Shelf (COTS)
- Hybrid (combination of both COTS and Bespoke parts)

The Hybrid manufacturing process was selected using a Process Pugh, this is because the process achieved the highest score in relation to the requirements.

|                                      |                              | Relative Importance<br>Equal | Relative Importance<br>Weighted | COTS      | Hybrid     | Bespoke   |
|--------------------------------------|------------------------------|------------------------------|---------------------------------|-----------|------------|-----------|
| <b>WHATs - Customer Requirements</b> | <b>How much:- From QFD 1</b> |                              |                                 |           |            |           |
| Low cost Manufacture                 |                              | 5                            | 1                               | 5         | 2          | -3        |
| Rapid Manufacture                    |                              | 5                            | 4                               | 5         | 3          | -3        |
| Simple assembly                      |                              | 5                            | 3                               | -3        | 3          | 2         |
| Scalable production                  |                              | 5                            | 3                               | -1        | 4          | 1         |
| Quality and repeatability            |                              | 5                            | 5                               | 3         | 4          | 4         |
| Supply Chain robustness              |                              | 5                            | 4                               | 0         | 0          | 5         |
| Safe Manufacture                     |                              | 5                            | 5                               | 5         | 2          | -2        |
| Ease of modification                 |                              | 5                            | 2                               | -2        | 5          | 5         |
| <b>Ranking</b>                       |                              | Un Weighted                  |                                 | <b>60</b> | <b>115</b> | <b>45</b> |
|                                      |                              | Weighted                     |                                 | <b>49</b> | <b>75</b>  | <b>34</b> |
|                                      |                              | 100                          |                                 | <b>11</b> | <b>40</b>  | <b>11</b> |

Table 12 Manufacturing QFD 2

| Design feature                  | Performance |        |       | Cost                |                 |                  |                                 | Quality                        |             |                 |                      | Safety      |              |                      |               | Sustainability |             |                 |                         |                           |           |               |                |
|---------------------------------|-------------|--------|-------|---------------------|-----------------|------------------|---------------------------------|--------------------------------|-------------|-----------------|----------------------|-------------|--------------|----------------------|---------------|----------------|-------------|-----------------|-------------------------|---------------------------|-----------|---------------|----------------|
|                                 | Importance  | Weight | Score | Purchase COTS items | Hybrid assembly | Mounts for drone | Weld/Soldered drone electronics | electronically (shaped charge) | Visually QA | Physically (QA) | Compliance with regs | Cheap parts | Cheap labour | Conventional tooling | Trained staff | repair guides  | Spare parts | Metal PACKAGING | container FOR PACKAGING | polystyrene for packaging | Non-toxic | Recycle parts | Minimise waste |
| Functionality                   |             |        |       |                     |                 |                  |                                 |                                |             |                 |                      |             |              |                      |               |                |             |                 |                         |                           |           |               |                |
| Select Manufacturing approach   | 159         | 10     | 15.9  | 9                   | 9               | 3                | 3                               |                                |             |                 | 9                    | 3           | 3            | 3                    | 9             | 3              | 3           |                 |                         |                           | 9         | 9             | 9              |
| Fabricate structural components | 171         | 10     | 17.1  | 9                   |                 | 3                |                                 |                                |             |                 | 9                    | 3           | 3            | 1                    | 9             | 1              | 1           |                 |                         |                           | 3         | 1             | 1              |
| Assemble system                 | 225         | 10     | 22.5  | 9                   | 9               | 9                | 9                               | 9                              | 9           | 9               | 9                    | 3           | 3            | 9                    | 9             |                | 3           |                 |                         |                           | 3         | 3             | 3              |
| Integrate Sub-systems           | 201         | 10     | 20.1  | 9                   | 9               | 9                | 9                               | 9                              | 9           | 9               | 9                    | 3           | 3            | 9                    | 9             |                | 3           |                 |                         |                           | 1         | 3             | 3              |
| Integrate explosive components  | 185         | 10     | 18.5  |                     | 9               | 9                |                                 | 9                              | 9           | 9               | 9                    | 3           | 3            | 1                    | 9             |                |             |                 |                         |                           | 9         |               | 9              |
| Quality assurance               | 161         | 10     | 16.1  | 3                   | 3               |                  |                                 |                                | 9           | 9               | 9                    | 1           | 1            |                      | 3             |                |             |                 |                         |                           |           |               |                |
| Manufacture at scale            | 227         | 10     | 22.7  | 9                   | 9               |                  | 9                               | 3                              | 1           | 1               |                      | 1           | 1            | 1                    | 3             |                | 3           |                 |                         |                           |           |               | 9              |
| Control manufacturing cost      | 141         | 10     | 14.1  | 9                   | 3               |                  |                                 |                                |             |                 |                      | 9           | 9            | 3                    | 3             |                | 3           | 3               | 3                       | 3                         |           | 3             | 3              |
| Package for transport           | 79          | 10     | 7.9   |                     |                 |                  |                                 |                                |             |                 | 9                    |             |              |                      |               |                |             | 9               | 9                       | 9                         | 3         |               |                |
| Dispose of manufacturing waste  | 67          | 10     | 6.7   | 3                   |                 | 1                | 1                               |                                |             |                 | 9                    |             |              |                      |               |                | 3           |                 |                         |                           |           | 9             | 9              |
| Enable field repair manufacture | 38          | 10     | 3.8   | 3                   |                 | 3                | 3                               | 3                              |             |                 |                      |             |              | 9                    |               | 9              | 9           |                 |                         |                           | 3         |               |                |
|                                 |             |        |       |                     |                 |                  |                                 |                                |             |                 |                      |             |              |                      |               |                |             |                 |                         |                           |           |               |                |
|                                 |             |        |       | 1091                | 988             | 667              | 654                             | 629                            | 718         | 718             | 1123                 | 448         | 448          | 566                  | 1006          | 99             | 357         | 113             | 113                     | 113                       | 484       | 391           | 761            |

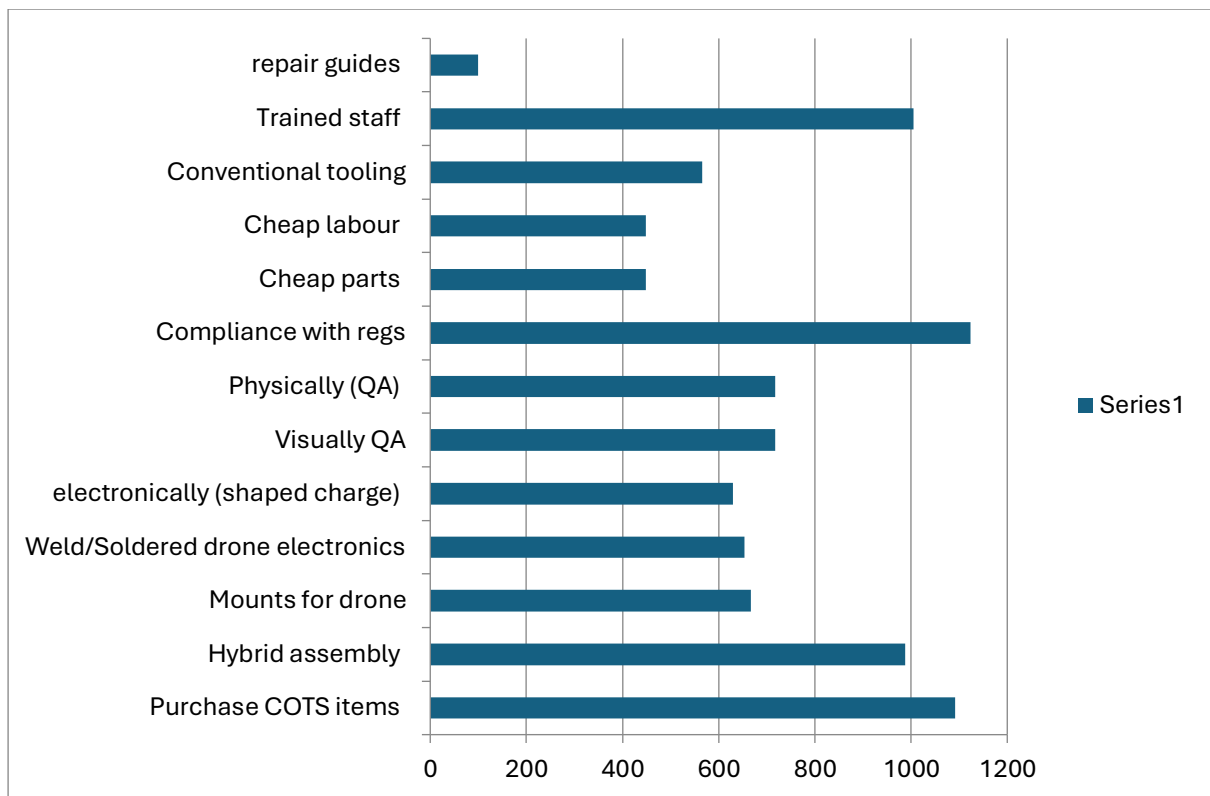


Figure 15 Manufacturing QFD 2 Output

The TruePath team agreed alignment was met and that Process steps could be considered.

## 2.2 Manufacturing Critical Process steps

QFD 3 was used to determine the technique importance for the identified design features, that the design solution would have, using the output of QFD 2's output to guide the rankings.

Table 13 Manufacturing QFD 3

| Process Features          | Importance | Laser cut | CNC machine | Stamp | Meltcast | Mechanical assembly | Electrical assembly | Integration |
|---------------------------|------------|-----------|-------------|-------|----------|---------------------|---------------------|-------------|
| Important design features |            |           |             |       |          |                     |                     |             |
| Radar Mount               | 5          | 9         |             |       |          | 3                   |                     | 3           |
| Charge Casing             | 5          |           | 9           |       |          | 3                   |                     |             |
| Copper Liner              | 5          |           |             | 9     |          | 3                   |                     |             |
| Explosive fill            | 5          |           |             |       | 9        | 3                   |                     |             |
| Solenoid release          | 5          |           |             |       |          | 9                   | 3                   |             |
| RF Detonation System      | 5          |           |             |       |          | 3                   | 9                   | 3           |
| Payload Mount interface   | 5          | 3         | 3           |       |          | 9                   |                     | 9           |
|                           |            | 60        | 60          | 45    | 45       | 165                 | 60                  | 75          |

The Output of QFD 3 shows the influence that QFD 2 had as mechanical assembly, the joining of multiple COTS parts, had the highest score.

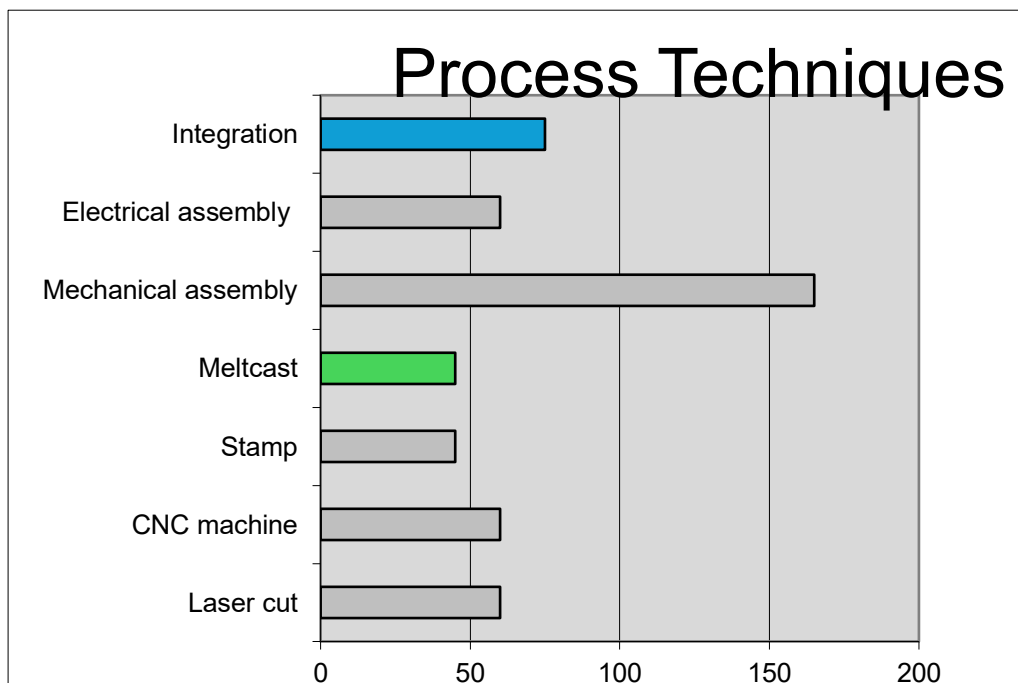


Figure 16 Manufacturing QFD 3 Output

## 2.1 Manufacturing process control measures

Control measures were created to ensure that the requirement of “quality and repeatability could be met.

This was done by taking critical design features and creating process parameters for the manufacturing of the features, The creation of Target values that would set out the manufactured “quality” of the feature (e.g. tolerances). And the Manufacturing controls and Aids that would make the quality of the manufactured feature “repeatable”. Process controls were also created to assure quality.

*Table 14 Manufacturing Controls*

| <b><u>Process parameters</u></b>        | <b><u>Target Values</u></b>                         | <b><u>Manufacturing controls and Aids</u></b>                   | <b><u>Process controls</u></b>                                  |
|-----------------------------------------|-----------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------|
| Charge casing dimensions                | Within Drawing tolerance                            | CNC machining process control and dimensional measurement tools | Dimensional inspection of machined casing before assembly       |
| Copper Liner Geometry                   | Correct Cone Angle and Thickness                    | Precision stamping die and inspection gauge                     | Go / no-go gauge inspection of liner geometry                   |
| Explosive fill mass and density         | Correct TNT fill mass and uniform melt-cast fill    | Controlled melt-cast process and weighing equipment             | Mass verification and visual inspection of explosive fil        |
| Liner alignment within charge casing    | Correct concentric alignment with casing            | Assembly alignment fixture                                      | Fixture-guided assembly and visual inspection                   |
| Solenoid release mechanism operation    | Reliable release when activated                     | Bench test equipment                                            | Solenoid actuation test prior to system integration             |
| RF detonation signal and firing circuit | Reliable RF signal reception and circuit activation | RF testing equipment and electrical continuity tester           | RF signal reception test and electrical continuity verification |

These were then incorporated into QFD 4. However, QFD 4 focuses on overall quality assurance, where process controls are designed for entire processes rather than specific process parameters. In contrast, the process controls conducted by TruePath were tailored to specific process parameters.

Table 15 Manufacturing QFD 4

|                                         |                                                     |                                         | Operational assessment          |            |           |          |               |  | Process Controls |                                                           |                                               |                                                           |                                               |                                                     |                                                                 |
|-----------------------------------------|-----------------------------------------------------|-----------------------------------------|---------------------------------|------------|-----------|----------|---------------|--|------------------|-----------------------------------------------------------|-----------------------------------------------|-----------------------------------------------------------|-----------------------------------------------|-----------------------------------------------------|-----------------------------------------------------------------|
|                                         |                                                     |                                         | manufacturing controls and Aids | Difficulty | Frequency | Severity | Detectability |  | RPN              | Dimensional inspection of machined casing before assembly | Go / no-go gauge inspection of liner geometry | Mass verification and visual inspection of explosive fill | Fixture-guided assembly and visual inspection | Solenoid actuation test prior to system integration | RF signal reception test and electrical continuity verification |
|                                         |                                                     |                                         |                                 |            |           |          |               |  |                  |                                                           |                                               |                                                           |                                               |                                                     |                                                                 |
|                                         |                                                     |                                         |                                 |            |           |          |               |  |                  |                                                           |                                               |                                                           |                                               |                                                     |                                                                 |
|                                         |                                                     |                                         |                                 |            |           |          |               |  |                  |                                                           |                                               |                                                           |                                               |                                                     |                                                                 |
| Process parameters                      | Target Values                                       |                                         |                                 |            |           |          |               |  |                  |                                                           |                                               |                                                           |                                               |                                                     |                                                                 |
| Charge casing dimensions                | Within Drawing tolerance                            | CNC machining process control and       | 2                               | 2          | 4         | 2        | 32            |  | 9                |                                                           |                                               |                                                           |                                               |                                                     |                                                                 |
| Copper Liner Geometry                   | Correct Cone Angle and Thickness                    | Precision stamping die and inspection   | 3                               | 2          | 5         | 3        | 90            |  |                  | 9                                                         |                                               |                                                           |                                               |                                                     |                                                                 |
| Explosive fill mass and density         | Correct TNT fill mass and uniform melt-cast fill    | Controlled melt-cast process and weight | 4                               | 2          | 5         | 3        | 120           |  |                  |                                                           | 9                                             |                                                           |                                               |                                                     |                                                                 |
| Liner alignment within charge casing    | Correct concentric alignment with casing            | Assembly alignment fixture              | 3                               | 2          | 5         | 3        | 90            |  |                  |                                                           |                                               | 9                                                         |                                               |                                                     |                                                                 |
| Solenoid release mechanism operation    | Reliable release when activated                     | Bench test equipment                    | 2                               | 3          | 4         | 2        | 48            |  |                  |                                                           |                                               |                                                           | 9                                             |                                                     |                                                                 |
| RF detonation signal and firing circuit | Reliable RF signal reception and circuit activation | RF testing equipment and electrical c   | 3                               | 3          | 5         | 2        | 90            |  |                  |                                                           |                                               |                                                           |                                               | 9                                                   |                                                                 |
|                                         |                                                     |                                         |                                 |            |           |          | 0             |  |                  |                                                           |                                               |                                                           |                                               |                                                     |                                                                 |
|                                         |                                                     |                                         |                                 |            |           |          |               |  | 288              | 810                                                       | 1080                                          | 810                                                       | 432                                           | 810                                                 |                                                                 |

As a result, TruePath's QFD4's output is not useable by its deigned purpose.

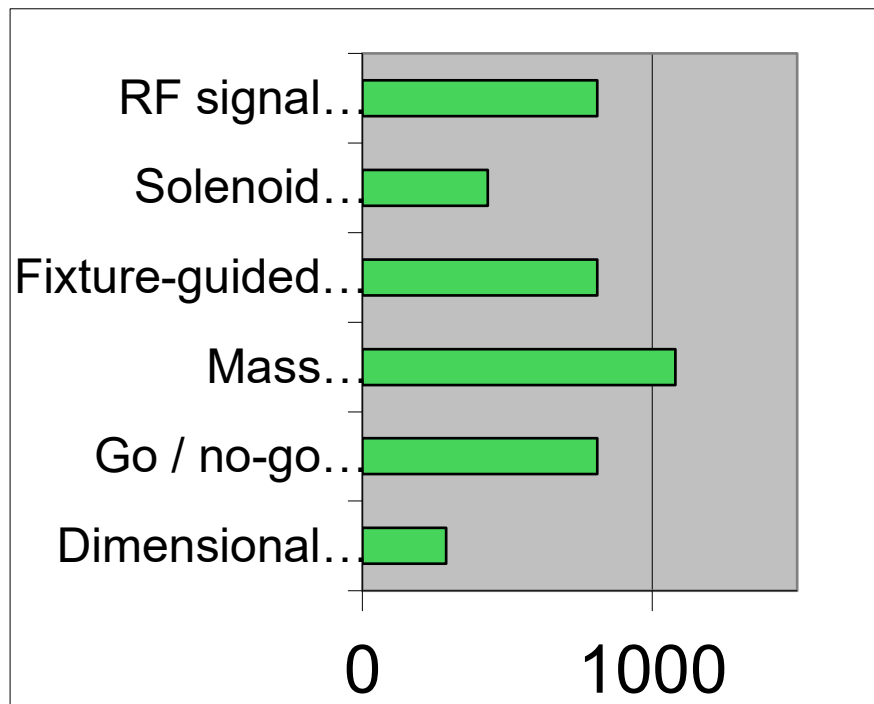


Figure 17 Manufacturing QFD 4 Output

### 3. Disposal and safety

This section demonstrates the impact of safety considerations on disposal and how they were applied throughout the design toolset.

Manufacture to target disposal sequence (MTDS) is among the list of requirements see Table 1. This requirement was mandated by TruePath safety to ensure compliance with Defence safety authority regulation DSA02. The regulation requires that an Accountable Person defines the MTDS of the OME within the system.

The accountable Person for disposal was the Role Lead of TruePath Disposal, TruePath safety provided guidance on the required processes outlined in DSA03. OME Defence Code of Practice (DCOP) 104. Where the creation of a Safety and Environmental Management Plan (SEMP) is outlined, requiring evidence for demonstrating how safety risks and environmental impacts are managed. The toolset used within this report contributes to provide evidence of a safety rationale required to prove compliance.

Additionally, the Means of disposal were chosen based on the safety requirements imposed by the regulatory environment in which TruePath operates. TruePath safety also impacted the processes conducted by each selected Means. For example, burning of the OME was selected as a means of disposal and the process used to conduct this was determined in accordance with DSA02. OME guidance. With its supporting documentation specifying how to conduct a safe burn, including safety distances and net explosive quantity restrictions.[6][7]

Figure 20 Shows a Bowtie diagram as a visual representee of a risk assessment process required by the DSA.

### 3.1 Safe by Design

The process control of safe by design was considered throughout each stage of the design process because all system functions can influence overall system safety. For example, in Figure 3 FMA Solutions the requirements “Protect Personnel” and “Survive Environment” can be clearly identified as safety requirements. However, all functions remain critical to achieving a safe by design system.

For example, a selected method for detecting surface mines may successfully achieve the detection function, but if it Means selected requires an EOD technician to place themselves in harm’s way, the “Protect Personnel” requirement would be negatively impacted. The solutions could still be considered, however the associated risks would need to be assessed to determine whether they are tolerable and whether no practicable alternative exists. [8] [9]

## 4. Conclusion

This report demonstrated the application of the selected design toolset that enabled TruePath to validate each completed process against the established requirements before allowing progression to the next stage. This created an environment in which verification and validation were necessary throughout the development process. With the final design solution being selected adhering to the requirements set by both the customer and the regulatory environment. Furthermore, the toolset used also functioned as a safety management control tool that could provide evidence of regulatory compliance demonstrating the safe by design process.

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## 6. Annex A

### 6.1 Safety Outputs

Bow tie diagram examples Illustrates a risk Assessment process by identifying Treats that cause the event, controls to reduce the likelihood of the event occurring, mitigations to reduce the impact and the outcome of the event with the hierarchy of control implemented.

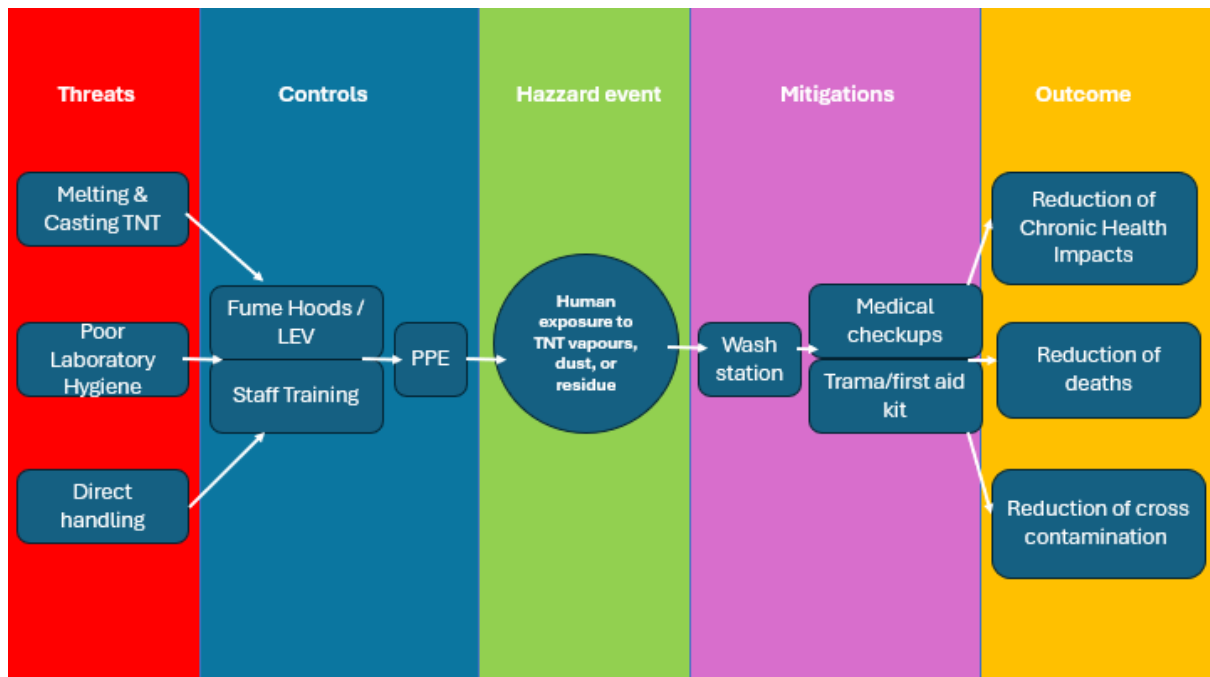


Figure 18 Bow tie R&D example

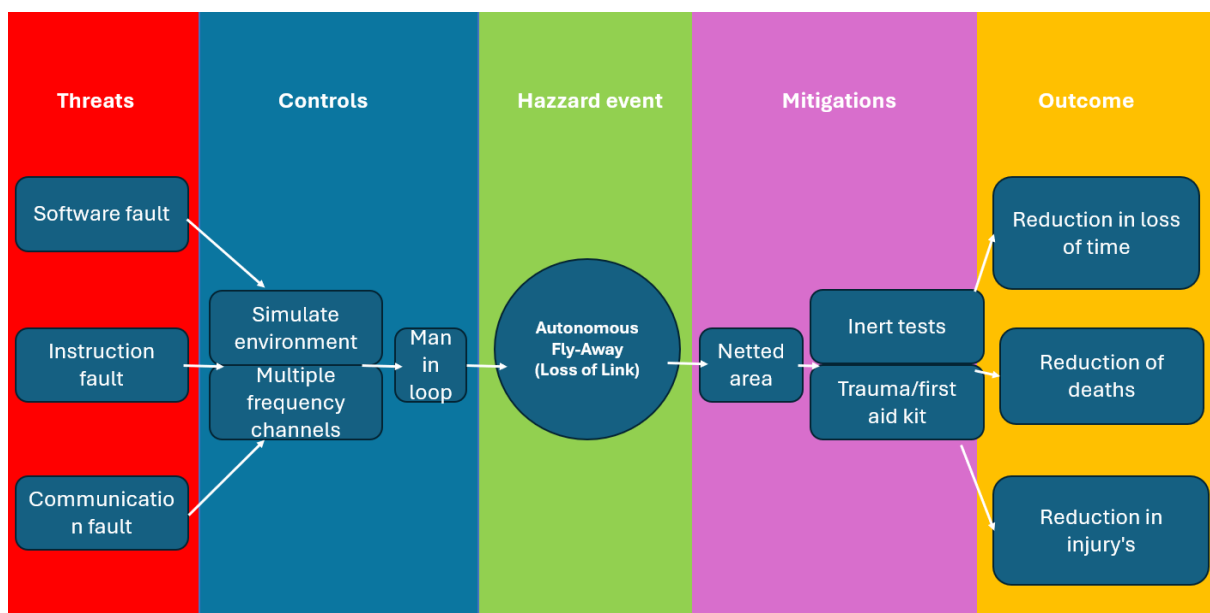


Figure 19 Bow tie T&E example

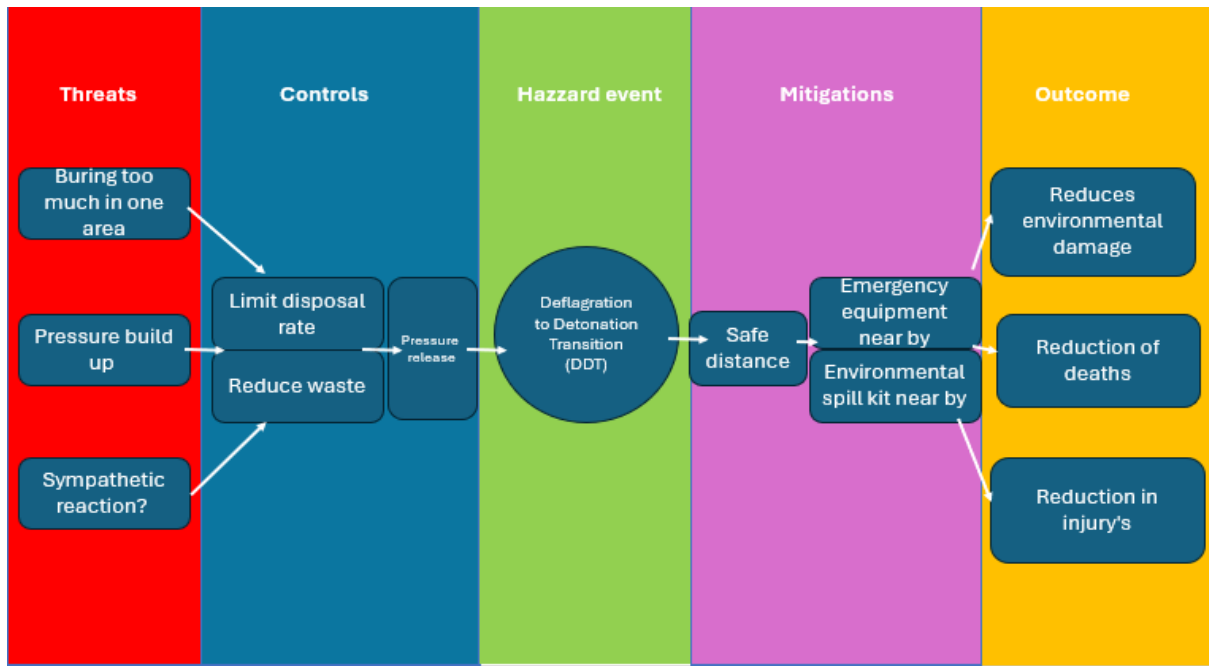


Figure 20 Bow tie Disposal example

## 6.2 Safety Integration with T&E

Safety's importance can be seen within the original requirements set and all thought all requirements set by for each role (R&D, T&E, Manufacturing, MTDS)

This came in the form of the safety team working directly with each role to ensure safety a key requirement and adequately considered for the start of their process. An example of this can be seen in Table 16 Illustrating safety's integration within all roles

Table 16 Requirements Set T&E

| <u>Level 1</u>                               | <u>Originator</u> | <u>Level 2</u>                                                                                                               |
|----------------------------------------------|-------------------|------------------------------------------------------------------------------------------------------------------------------|
| General testability                          | T&E               | There must be a verification plan (verify performance requirements by test, inspection and analysis).                        |
|                                              | T&E               | There must be a trial readiness review (TRR) completed prior to operational trials.                                          |
|                                              | T&E               | There must be instrumentation compatibility (the system needs to be capable of integration with standard instrumentation).   |
| Compliance and regulatory                    | T&E               | There must be standards compliance (HSE, DEFSTAN, STANAG, JSP, etc).                                                         |
|                                              | T&E               | There must be an explosive safety certification.                                                                             |
| Deployment and setup assessment              | T&E               | There should be deployment time trials (transition from transport to operational readiness). Time<30 mins.                   |
|                                              | T&E               | There could be crew size trials (determine the number of trained personnel needed). Crew<5 people.                           |
|                                              | T&E               | There should be transportability verification (verify equipment can be fitted to a suitable vehicle). Time to fit<30 mins.   |
| Mine detection and neutralisation assessment | T&E               | There must be surface mine detection trials. Distance under sand detected>0.1m. Detection probability>0.99.                  |
|                                              | T&E               | There must be mine neutralisation effectiveness trials. Neutralisation probability>0.99.                                     |
| Route clearance assessment                   | T&E               | There should be clearance rate trials (speed of mine clearance). Time taken to clear 5m <sup>2</sup> <1 hour. Lane width=5m. |
|                                              | T&E               | There should be route marking trials. Amount of time it is visible>48 hours. Distance it is visible from>20m.                |
| Safety and survivability assessment          | T&E               | There must be operator safety trials. Operator survival rate probability after a blast>0.99.                                 |
|                                              | T&E               | There should be blast survivability trials. System functionality after a blast>0.9.                                          |
|                                              | T&E               | There must be emergency shutdown trials. Emergency stop functional probability>0.95.                                         |
| Environmental testing assessment             | T&E               | There should be temperature and humidity trials. System survives probability>0.95.                                           |
|                                              | T&E               | There should be vibration and shock trials. System survives probability>0.95.                                                |
|                                              | T&E               | There should be sand and dust trials. System survives probability>0.95.                                                      |
|                                              | T&E               | There should be electromagnetic compatibility (EMC) trials. System survives probability>0.95.                                |
| Operational field test assessment            | T&E               | There should be operational demonstration trials simulating a complete mission. Success probability>0.9.                     |
|                                              | T&E               | There must be user acceptance testing.                                                                                       |
|                                              | T&E               | There must be a post-trial assessment (performance, lessons learned etc).                                                    |