

Systems Engineering

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Systems thinking and risk mitigation are key in the delivery of a trial requirement; each stage of assessment must retain analytical assessment and justification. Application of systems engineering tools can enable efficient effective and safe delivery of OME related trials, tests and evaluation in addition to all remnant lifecycle requirements; be it procurement, logistics, operation or disposal. Each application was suggested to compliment a different process demonstrating the interrelated nature of the systems engineering conceptual ideology and its holistic integration to OME lifecycle management.

Content

1	INTRODUCTION	3
1.1	SCOPE	3
1.2	CONTEXT	3
1.3	METHODOLOGY	3
1.4	LIMITATIONS	3
2	PROCESS DEFINITION	4
2.1	CUSTOMER REQUIREMENT	4
2.2	V-MODEL	4
2.3	SIMILAR	6
2.4	NEEDS ANALYSIS	7
2.5	PUGH MATRIX	8
2.6	QUALITY FUNCTION DEPLOYMENT	9
2.7	FAILURE MODE EFFECT ANALYSIS	9
2.8	IDENTIFYING CONSTRAINTS AND ROUTE CAUSE ANALYSIS	10
3	REQUIREMENTS	11
3.1	CUSTOMER REQUIREMENTS	11
3.2	FUNCTIONAL REQUIREMENTS	11
3.3	PERFORMANCE REQUIREMENTS	11
3.4	DESIGN REQUIREMENTS	12
3.5	DERIVED AND ALLOCATED REQUIREMENTS	12
4	DISCUSSION	12
5	CONCLUSION	12
6	REFERENCES	13

1 INTRODUCTION

1.1 SCOPE

Requirement for an Explosive trial within a test cell or chamber has been sought. This document covered the systemic approach to taking a requirement from the customer and using suitable systems engineering practice and methodology to demonstrate the holistic role that systems engineering plays within the lifecycle of tests and trials within the explosives industry. The generalised example is given context in 1.2 and its definition given in 2.1. A critical evaluation was undertaken of the methodology that was implemented.

1.2 CONTEXT

Trials within the explosive industry have had a standardised nature for the majority of test procedures however, there is a notable amount of trials undertaken that are bespoke in nature; this documents content does not cover the extent of fully executing a trial. As further defined in 1.4; in addition to the bespoke nature of trials there may also be security constraints that do not allow for significant detail to be divulged. Regarding the details of the explosive device; experience is of a sensitive nature and so the device will not be assessed only mentioned in passing.

1.3 METHODOLOGY

Systems engineering's routes lay within defence (MIL STD 499a 1974) and have been adopted by industry over time. The methodologies that have been developed since its introduction are wide and varied with advancements from industry defined standards (IEEEp1220 1994, EIA standard IS 632 1994) and defence advancements which remain undefined.[1, 2, 3]

A series of systems engineering applications were explored within 2 in order to meet the requirement of this brief:

Systems engineering tool	Application description	Reference in document
V-model	trial requirement to preparedness to initiate an experiment	2.2
SIMILAR model	Trial fielding	2.3
Needs analysis	Definition	2.4
Pugh matrix	mitigation assessment	2.5
Quality Function deployment	Application of a trial to the business unit Technology Centre	2.6
FMEA	Inert device assembly (alignment aid)	2.7
Identifying constraints and route cause analysis	Alignment aid orientation problem highlighted in 2.7	2.8

1.4 LIMITATIONS

Implementing a trial or test within the explosives industry requires a significant and diverse schedule of work from a menagerie of technical disciplines, companies, agencies and government departments this document is to demonstrate likely processes involved within a generic non specified trial in the explosives industry. There are many licensing and legal requirements that must be met within the delivery of a trial. These limitations can be placed upon facilities, individuals undertaking the work, suitably qualified and experienced personnel, technical authorities and company directors. Though some reference may be made to these processes they were not defined in their totality so further information should be sought to the delivery of a trial within national territories from the appropriate documentation. These may be in the form of Mil Std, DEFSTAN or joint service publications (JSP's). [4, 5.]

2 PROCESS DEFINITION

2.1 CUSTOMER REQUIREMENT

Customer requirement focussed on the experimental requirement and so assumption is made for; safety, facility and legal requirements that are predefined by company protocol and procedure.

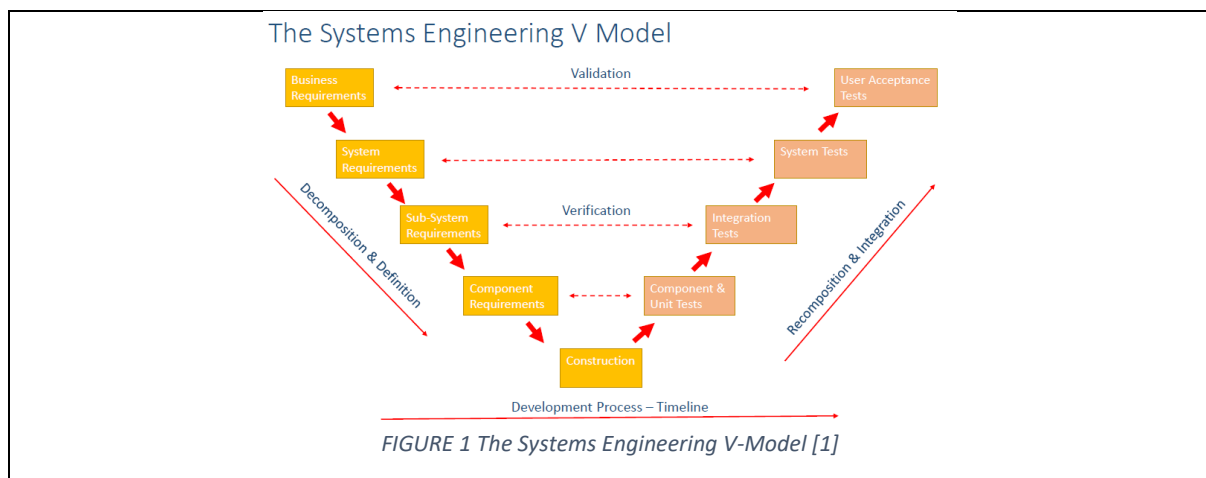
Delivery of an explosive trial pertaining:

- Initiation and full consumption of the device
- Primary diagnostic capture at specific undefined points (High power X-ray; 2 Axis)
- Secondary Diagnostic capture at specific undefined time window (High framerate still image capture; single view of interest)
- Tertiary diagnostic capture from ionisation pins to confirm detonation
- Quaternary diagnostic – device components of interest recovery
- Safe manufacture and assembly of the device
- Safe and effective fielding of the trial
- Reliable and adequate collection of data that is comparable to legacy trials

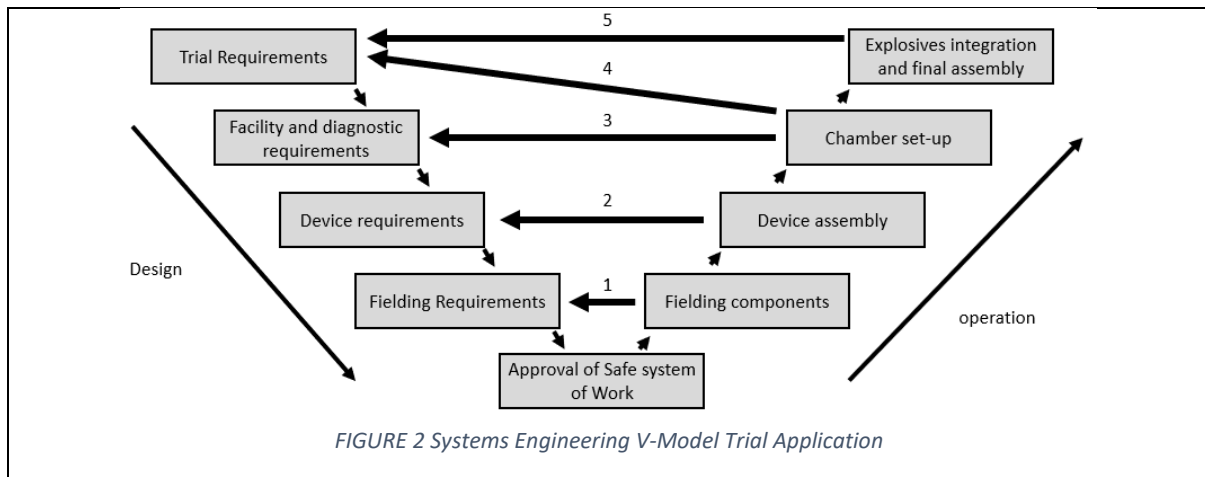
Delivering the trial can be undertaken with several different methodologies; below is some example applications of different methodology within the trials remit.

2.2 V-MODEL

The engineering v model enables a simplistic visualisation of the concept of systems engineering process practice. The segregation and derivation of requirements from the business requirement enable a modular delegation of requirement to specialist teams meaning, in an operations type context; each team will receive their requirement to deliver; culminating in the autonomous delivery of the business requirement.



The V-model below demonstrates the delivery from requirement to preparedness to fire of an explosives trial in terms of fielding capability.



The process though not exact in its delivery; denotes the process in which fielding activities may be delivered. During process there is cross cutting stakeholder activities.

Majority stakeholders are TCO and Trial Lead Scientist they are present through the entirety of the v.

Other stakeholders include but are not limited to: project personnel, project manager, trial engineer, trial sponsor, design authority, technical authorities, fielding authority, facility management et.al.

Stage	Example of works
Design	• Trial requirements: at this stage the main customer requirements are defined and broken into subsections • Facility and diagnostic requirements: facility and diagnostic operation delivery that supports the experiment in its containment safety and diagnostic capture • Device requirements: design of the device to function as expected including the incorporation of diagnostic requirements to enable endorsement of function • Fielding Requirements: facility integration and application of all diagnostics in the operation of the device to enable safe operation of the experiment and successful diagnostic capture • Approval of Safe system of work: the all-encompassing document that defines the full operational sequence that the experiment will take place from entering the chamber through firing to disposal of waste. This document requires substantial stakeholder involvement
Operations	• Fielding components: the design manufacture and delivery of all items required to field the trial • Device assembly: the design manufacture and assembly of the device stored awaiting integration to the chamber set up • Chamber set-up: the full assembly of the fielding furniture initiation train and diagnostics into the facility • Integration and final assembly: integration of the explosive assembly into the chamber set up with any additional diagnostic connections and additional mitigation operations prior to initiating the experiment.
Verification and validation activities.	At various points across the v there are verification and validation activities the following table is a list of the type of activity that may be excised at each numerically defined point in figure 2.

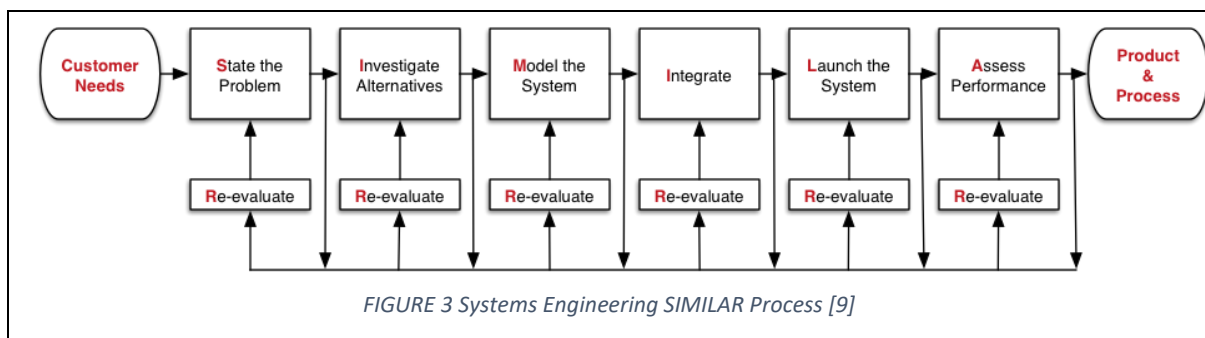
Reference number from Figure 2	Description of function or activity
1	Verification of fielding furniture and components in the form if a process walkthrough; this process involves the dry set up of the trial with minimal hazard to ensure the equipment will be fit for purpose in that trial components will be positioned correctly and be retained up to the point of ignition. (all party stakeholder activity)
2	Verification of device assembly to ensure it is built as designed, this provides all the stake holders confidence in the operation of the device. (stakeholder activity: TCO scientist engineer tech authority)

3	Verification of Diagnostics and facility operation to ensure that the facility will function as intended to contain the experiments effects and to ensure and endorse that the diagnostics of the trial will function as and when intended. (stakeholder activity: TCO scientist engineer tech authority facility management operations management)
4	Validation of the set up prior to introduction of the most significant hazard involves a test of all of the facility diagnostics and fielding equipment. (all party stakeholder activity generally but not required)
5	Validation of the entire set up including the device assessment against all of the requirements involving all stakeholders to enable authority to fire the experiment: to be given by the facility, ensuring confidence and endorsement of all facility device and diagnostic operation.

This model provides an outline of the V models application into delivery of a trial the derivation of requirement from the trial requirements allows all stakeholders in the process to assess and reassess the application of works to deliver trial requirements to fruition. The v model can be applied at most levels of a trials process be it the entirety of the lifecycle or a subsection as expressed in this section. [1, 6, 7, 8.]

2.3 SIMILAR

The ideology of the S.I.M.I.L.A.R. process is an analytical systemic approach to the resolution of a problem that exists either within design or a process. Much like the V model it can be used at a high level or as demonstrated it can be used as a subordinate tool in a relatively small problem. Both the v model and the v model can use contained tools within them as divulged below:



The process itself is an acronym wherein each letter denotes the sub-process or task to be completed to fulfil the systemic process:

Acronym designate	Descriptor	Brief definition
S.	State	Definition of the problem in its entirety, identifying stakeholders, understanding customer needs and type of requirement: a useful tool for this could be needs analysis defined in 2.4 or quality function deployment (QFD)
I.	Investigate	Exploration of additional techniques or processes that are able to combat the problem defined above: tools to complete this action could be a QFD demonstrated in 2.6 or Pugh matrix demonstrated for mitigation selection in 2.5
M.	Model	Taking requirements through to design usually through software implementation function analysis and risk management. FMEA is a suitable tool to use here again demonstrated in 2.7
I.	Integrate	The culmination of all the designs and processes as a conglomerate
L.	Launch	Full operation of the integrated system
A.	Assess	Acquisition and interrogation of data capture from the launch procedure if any anomaly or non-conformance against the requirement is found route-cause analysis is an appropriate tool to combat this demonstrated in 2.8
R.	Re- evaluate	Re-evaluate accordingly

For the given example in 2.1 a SIMILAR approach was applied to demonstrate application of trial fielding however the fielding process is somewhat more iterative in the integration period wherein complications may arise that are due to the bespoke nature of each trial. [1, 10, 11.]

S.	State	Delivery of requirement referenced 2.1 into a test chamber
I.	Investigate	Physics modelling of the explosive element of the trial to confirm consumption Assessment of diagnostic capabilities against requirement for accuracy and reliability without affecting any other diagnostic Device manufacture and assembly techniques to enable safe delivery of the device Fielding furniture assessment to ensure safe and effective delivery of the trial including material assessment fragment close out and jet arresting
M.	Model	Model the trial fielding set up and its conjugate locations within CAD software, and where applicable physics software to confirm operation
I.	Integrate	Inert walkthrough of; device build, fielding component build, fielding set up, confirmation of integration to facilities i.e. mating faces et.al. set up the trial with simulant device in the chamber until suitable conditions have been acquired then integrate explosives and any final assembly components required to meet the trial (reference 2.1 – diagnostic film packs, inert gas to high frame rate camera, removal of simulant equipment)
L.	Launch	Static simulant firings to take place until suitable set up has been achieved, chamber arrangements made then initiation of the explosive with full diagnostic capture
A.	Assess	Assessment of all subordinate process and launch diagnostics until firing then catalogue of data to be reported
R.	Re- evaluate	On completion of the firing the trial performance is assessed to attain any subversive issues and appropriate analysis is undertaken to enable the next firing in the series to be delivered more effectively

2.4 NEEDS ANALYSIS

Made of four basic steps; needs analysis allows an analytical and systemic delivery of a requirements conceptual solution.

Step	functions	Input	Output
Operations analysis	Analyse projected needs	- Operational deficiencies - Existing system - Technology opportunities	- Operational deficiencies - Define operational approach
	Define operational approach	Analyse projected needs	Function translation
Functional analysis	Function translation	- Existing system - similar system - Define operational approach	- Analyse projected needs - Subsystem function allocation
	Subsystem function allocation	- Function translation - Partitioning criteria	- Function translation - Subsystem technology conception - Define feasible concept
Feasibility definition	Subsystem technology conception	- Existing system - Function translation - Define feasible concept - Subsystem function allocation - New concepts	- Function translation - Define feasible concept
	Define feasible concept	- Subsystem function allocation - Subsystem technology conception - Feasibility criteria	Subsystem technology conception
Needs validation	Design effectiveness model	- Define feasible concept - Validate needs feasibility - Previous analytical models	- Validate needs feasibility - Analyse projected needs
	Validate needs feasibility	- Design effectiveness model - Measure of effectiveness	- Concept deficiency - Design effectiveness model - Concept exploration and operational requirements

This application would be unlikely to be applied within a bespoke trial given the nature of their operation however, its applicability to training or, a capability within the diagnostic or facilities remit would be prevalent. Its application to a standardised trial could likely be exercised but is omitted due to its scale relative to the assignment brief constraint's.

The application of a needs analysis is enabled by “drivers”

- Need drivers; Desuetude or alien factors may leave the current system unfit for purpose
- Technology drivers; Technological advances may result in more effective delivery or decrease in overhead

It is common for technological advances to be quantifiable in exceeding the current systems operational capability so must be assessed contextually; operational concept projection. Application of a needs analysis will define if a change is fit for purpose and function within its function and feasibility steps. The validation stage assesses the proposed concept against the initial requirement measures its effectiveness and denotes the projected deficiencies to enable informed decision on the application to concept exploration to meet the operational requirement. [1, 12, 13.]

2.5 PUGH MATRIX

A Pugh matrix is used to attain a weighted function comparison between a multitude of designs for the same function an example to be demonstrated is fragment mitigation against hydrodynamic trial output in the form of ballistic fragmentation and for this example copper slag.

The system is operated by a scoring method in this case the Likert method commonly seen in surveys and its endorsement will be taken from personnel experienced in the field of trial fielding. The semantic differential in this case can be ability to meet the given feature requirement with 0 being not at all and 7 being completely meeting the requirement. [1, 14, 15, 16, 17.]

A sectional design will be described for each option

Design	Description
a	25mm aluminium sheet adjoined to a wooden framework
b	25mm steel sheet adjoined to wooden framework
c	75mm plywood sheeting adjoined to wooden framework
d	Water filled container 100mm thickness held in a wooden frame (filled when in place)
e	12mm chipboard box filled with agricultural water suspension media such as perlite (filled in situ where possible)

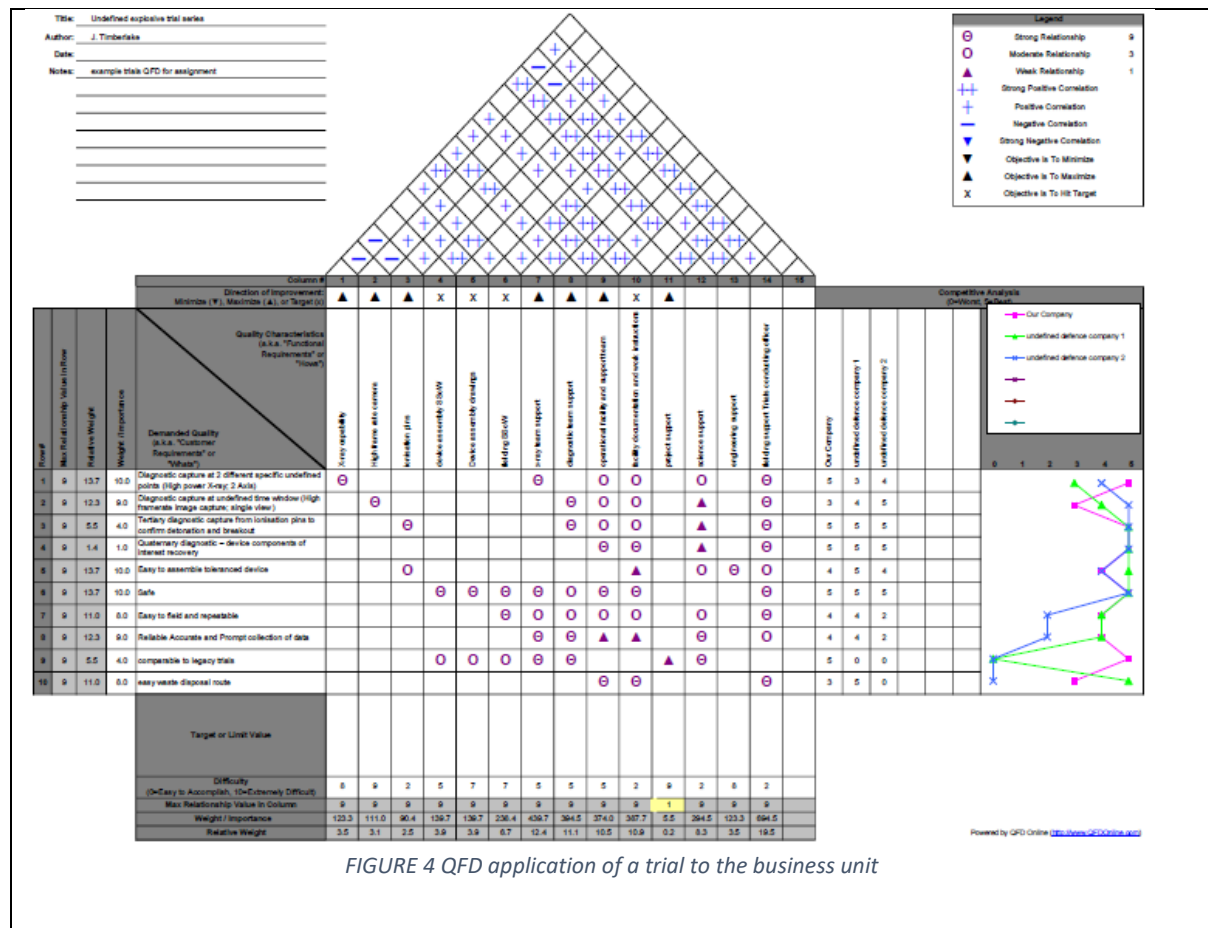
Each requirement defined in the matrix is weighted to further accentuate customer need

Feature requirement	Customer weighting	Design a	Design b	Design c	Design d	Design e
Easy to handle	3	5	3	4	4	6
Lightweight (handling and kinetic weight transfer of fully assembled mitigation [mean value])	3	5	2	6	2	7
Easy to field	3	4	4	5	2	6
Ability to absorb blast	2	2	2	4	4	7
Large fragment capture (ballistic)	2	3	6	3	5	6
Small fragment capture (ballistic)	1	6	7	5	6	6
Hydrodynamic plasma capture	1	4	7	7	6	6
Able to quench blast	2	1	1	1	7	7
ESD compliant	3	1	1	6	2	7
Easy to dispose of through current process	3	1	1	7	4	7
Weighted total		70	65	91	86	151

2.6 QUALITY FUNCTION DEPLOYMENT

Quality function deployment defines the relationship between customer requirement and business function it can be applied to a system, product assembly or process. The completed matrix will weigh the relevance of each quality characteristic to delivery of the requirement. In addition, QFD can be used as a subjective measure of delivery against requirement to suggest benchmarking against competitors.

Below is the application of a trial to the business unit and the QFD defines weighted measure of work distribution across the technology centre facilities and teams in order to achieve the trial requirement. The competitors are undefined defence companies with similar capability.



Interrogation of the matrix reveals higher weightings are attributed to the human element of trials delivery, for delivery of diagnostics to be achieved the relative support systems from specialist teams should be implemented and the systemic integration of all the trial deliverables are enabled by the fielding support usually the trials conducting officer in support of the trial lead. [1, 18, 19.]

The competitor analysis is subjective and with no endorsement to the input values is irrelevant but could not be omitted.

2.7 FAILURE MODE EFFECT ANALYSIS

Failure mode effect analysis (FMEA) is a predictive tool to highlight potential system failures across an application. FMEA predicts the likely cause of failure as well as the effect of that failure on the rest of the system, generally implemented by a group led input; the document can be kept and updated to highlight potential upcoming non-conformance in both process led work, or design work.

A design FMEA is subjected to component, sub assembly, assembly and systems; it enables the design team to highlight inappropriate implementations such as material choice specification or fixing method at a preliminary stage of product development where changes to design are relatively simple and inexpensive to alter and rectify.

Process FMEA's are implemented on processes designed for the delivery of a requirement; be it the manufacturing processes involved in developing the aforementioned design FMEA targets or processes such as delivery of a trial. They enable suitable combative measures to be applied to manufacture and assembly non-conformance or highlight potential safety or time led concerns.

The purpose of a generic FMEA is to engage the authoring team to assess and challenge the specification; to contextualise each sequential execution should be envisaged and evaluated for potential failure.

Below is a simplistic FMEA performed on the alignment interface device used in place of the explosive device during the initial set up phase within the test cell or chamber.

FAILURE MODE AND EFFECTS ANALYSIS																
Item: <u>Simulant device assembly (alignment)</u>			Responsibility: <u>TCO</u>			FMEA number: <u>1</u>										
Model: <u>80087355</u>			Prepared by: <u>J.Timberlake</u>			Page: <u>1</u>										
Core Team: <u>JTC</u>						FMEA Date (Orig): <u>today</u> Rev: <u>draft</u>										
Process Function	Potential Failure Mode	Potential Effect(s) of Failure	S e v e r i t y	P o t e n t i a l C a u s e (s) / M e c h a n i s m (s) o f F a i l u r e	O c c u r r e n c e	Current Process Controls	D e t e c t a b i l i t y	R P N	Recommended Action(s)	Responsibility and Target Completion Date	Action Results					
											Actions Taken	S e v e r i t y	O c c u r r e n c e	R P N		
mating face to adjustable base stand	fit in wrong orientation	misalignment of trial	8	Hard	base plate not directional	6	process led in 250W	8	384	redesign plate to be single directional	DO and design authority 30/02/2021	single directional plate implemented	3	1	3	9
	Does not fit in debossed area	misalignment of trial	8	Hard	tolerance inaccurate	4	Visual inspection and certificate of conformity	6	192	enable adequate G&T design review	DO and design authority 30/02/2021	tolerance adjusted	4	1	3	12
	adheres to mating face of charge stand	stops trial whilst replacement components sought delay to programme	8	Hard	tolerance too tight	4	Visual inspection and certificate of conformity	8	256	enable adequate G&T design review	DO and design authority 30/02/2021	tolerance adjusted	2	1	3	6
	does not fit to adjustable base stand	stops trial whilst replacement components sought delay to programme	8	Hard	bolts not aligned manufacturing defect	3	Visual inspection and certificate of conformity	4	96	appropriate machinery at goods in stage	site and facility goods in 30/02/2021	new goods in inspection process implemented	2	1	3	6
	deformation	stops trial whilst replacement components sought delay to programme	8	Hard	damage as result of inappropriate handling	2	Visual inspection and certificate of conformity	3	48	make item registered so handling can be traced	site and facility goods in 30/02/2022	component accountability implemented on trial items	4	2	3	24
	damage to firing points	stops trial whilst replacement components sought delay to programme	8	Hard	damage as result of inappropriate handling	2	Visual inspection and certificate of conformity	4	64	make item registered so handling can be traced	site and facility goods in 30/02/2023	component accountability implemented on trial items	4	2	3	24
alignment nodes	Does not attach to main assembly	stops trial whilst replacement components sought delay to programme	8	Hard	Incorrect thread design defect	3	Visual inspection and certificate of conformity	4	96	redesign to manufacturing transforms assess assembly integration process	Design authority 30/02/2021	redesign complete rigour added to process	2	1	3	6
	is not removable	stops trial whilst replacement components sought delay to programme	8	Hard	damage as result of inappropriate handling	4	Visual inspection and certificate of conformity	6	192	make item registered so handling can be traced	site and facility goods in 30/02/2023	component accountability implemented on trial items	2	1	3	6

FIGURE 5 FMEA performed on the alignment interface device

FIGURE 5 FMEA performed on the alignment interface device

Interrogation of the analysis shows the mating face orientation is the highest in terms of risk priority number (RPN) prior to implemented measures in that the table indicates it has the relatively speaking highest likelihood of failure with the most severe consequence that will not be easy to detect. The RPN value essentially sets out a priority led order to take preventative measures to enable failure avoidance. Following measures implemented the highest RPN is represented of mishandling at an acceptable level. [1, 20, 21, 22.]

2.8 IDENTIFYING CONSTRAINTS AND ROUTE CAUSE ANALYSIS

Application of route cause analysis and identification are almost identical in their execution the predominant difference remains time of application; a root cause analysis is usually implemented following identification of a non-conformance or execution of an FMEA type activity wherein a more proactive approach would be to attempt to visualise constraints during the requirements capture.

The concept in itself remains the same once a highlighted problem has become apparent it needs to be investigated to ensure its route cause has been sought and any potential propagative issues that have not been found as yet may be combatted collaterally.

The 5 why methodology seems to be the most pragmatic delivery of a route cause analysis in that it is simple and effective.

The primary failure with the highest RPN number in 2.7 demonstrated its effect as a misalignment with the trial set up. Below is a demonstration of the application of the 5 why process to combat this non-conformance.

Why	Demonstration	Possible cause/ MOST LIKELY CAUSE
Why 1?	Inability to align the trial with use of lasers	No visible error in laser, no obvious damage to mounting equipment, ERROR WITH ALIGNMENT DEVICE
Why 2?	Alignment device not functioning as intended	No visible damage, no obvious manufacturing error visibly not mounted correctly
Why 3?	Alignment device not in correct orientation	User error, Design error
Why 4?	User not able to easily ascertain directional requirement due to omnidirectional positioning of the base	Poor design, inappropriate design interrogation and control
Why 5?	Design standards outdated and no Quality personnel available to endorse design assessment protocols specifically mating face constraints and company design guidance	Staffing, budgeting, quality standard implementation

As can be seen from the 5 why assessment route; cause can be taken back further than what is demonstrated above, in terms of a collaterally highlighted problem mentioned above there is an apparent lack of implementation of quality procedure and outdated documentation (again circumventing quality standards and controls). This sort of issue can lead to systemic failure of a multitude of minor problems which culminate in a major issue; usually highlighted with a safety related failure before the appropriate full assessment of quality standards would have otherwise been implemented, usually by the appropriate authorities prior to prosecution. [1, 23, 24, 25, 26.]

3 REQUIREMENTS

3.1 CUSTOMER REQUIREMENTS

Often complex ambiguous and skewed in terms of the actual customer wants and needs customer requirements should pertain a measure of expectation for delivery of a system [1, 2, 12.]:

Measure of expectation	Question	Trial Example
Operational location	Where will the system operate?	Range, test cell or bomb chamber
Context	How will success be measured	Completion of a report containing data from the fielded trial with a safe and complete resolution
Performance	What's the minimum to achieve the requirement and what additional requirements would be beneficial	Minimal data required as per 2.1 primary and secondary data acquisition tertiary and quaternary are additional
Effectiveness	How efficient or effective must the system be	Accurate data to be collected within a specified tolerance and time frame
Lifecycle	How long will the system be operational	Commercial system run-time in the order of years operational trial time in the chamber in the order of weeks
environmental	What environments will the system be subject to	External weather requirements in a specified location to enable adequate assessment of suitability of component even if majority of lifecycle is in a store.

3.2 FUNCTIONAL REQUIREMENTS

Functional requirements are the operational component of requirements and lead derivation of functional analysis. These functional tasks, actions or activities must be realised for function to be met. i.e. primary diagnostic capture. [1, 2, 12.]

3.3 PERFORMANCE REQUIREMENTS

Performance requirements contextually set alongside 3.2 could be at a specified time with a minimalistic tolerance set either side allowing a parametric window of operation. Performance requirements are usually stipulated with an attached conditioning be it time related, quantity of functioning ionisation pins or frequency output of Photonic doppler velocimetry. During a multi-

diagnostic trial such as the suggested in 2.1 there is an enveloping sequentially incremented delivery of diagnostics capture and post firing again there is remnant safety requirements to be met to ensure final delivery of the resultant data and return control of the operational facility to the management team. [1, 2, 12.]

3.4 DESIGN REQUIREMENTS

Design requirements are subjugated by standards, guidance and other ideological documentation. For components, sub-assemblies, assemblies and systems these can be in the form of standards or company technical documentation. Often in the case of operational process a work instruction, Standard Order of Procedure, Technical Instruction or Publication will be referenced in the delivery of the requirement. Additional design may require different ideological approaches in terms of environment such as Forestry Sustainability commission sourced wood to ensure an environmentally responsible approach to material sourcing. [1, 2, 12.]

3.5 DERIVED AND ALLOCATED REQUIREMENTS

Derived and allocated requirements are stemmed from the application of a high-level requirement constraining a lower level requirement either through implication in a sense of derivation or specification in terms of allocation. An example of this may be a top-level assembly retaining a weight limit; that will require sub-assemblies to not exceed that constraint. [1, 2, 12.]

4 DISCUSSION

Through application of different systems engineering models and tools it was possible to exercise a demonstration of systems engineering within the trials test and evaluation remit. Each application was suggested to compliment a different process demonstrating the interrelated nature of the systems engineering conceptual ideology. Evaluation of each application was completed in context of different stages of a generic explosive trial rather than a single specified trial; this was based upon a lack of knowledge of standardised repetitive testing for velocity of detonation measurement or tests for figure of insensitiveness to suggest some example. Experience has been sought in the application of complex multi diagnostic trials enabling better application to the bespoke system deliveries.

5 CONCLUSION

Systems thinking and risk mitigation are key in the delivery of a trial requirement each stage of assessment must retain analytical assessment and justification. Systems engineering tools enable an interrelated measured approach to lifecycle requirements not only of a particular component or assembly but the processes which their function is enacted. Application of systems engineering tools can enable efficient effective and safe delivery of OME related trials, tests and evaluation in addition to all remnant lifecycle requirements be it procurement, logistics, operation or disposal.

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