WSTC 0174 Novel Explosive Filling Project: A Systems Approach

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BAE SYSTEMS

Novel Fills Approach
Project Aim

To use Systems Engineering in the development of a range of Polymer Bonded Explosive formulations that are unmixable in a planetary mixer and require the unique mixing action associated with a Resonant Acoustic Mixing.

The goal for the PBneXt Material is to provide a high performance blast/frag filling.

- The new material will encompass new material properties and processing capabilities as part of its inception and deployment.
- Given the multi aspect complexity of the task an investigative approach is needed not only to what is required from the new energetic material, but what additional emergent factors will need to be addressed is order to develop and implement PBneXt.

Novel Fills Approach
Systems Engineering – what is it?

- Systems Engineering (SE) can simply be defined as "understanding complexity" within the context of the modern world.
- Modern SE encompasses two disciplines:

Traditional "Hard" Mathematical Systems Engineering which assumes that we know much about what is required for the system across multiple perspectives and has a clear vision of what will be required.

Newer Investigative "Soft" Systems Engineering which encompass a journey of exploration in order to learn the problems associated with the current energetic materials, processing, testing and application to products.

Therefore, it is important to understand where we are before deciding where we are going....

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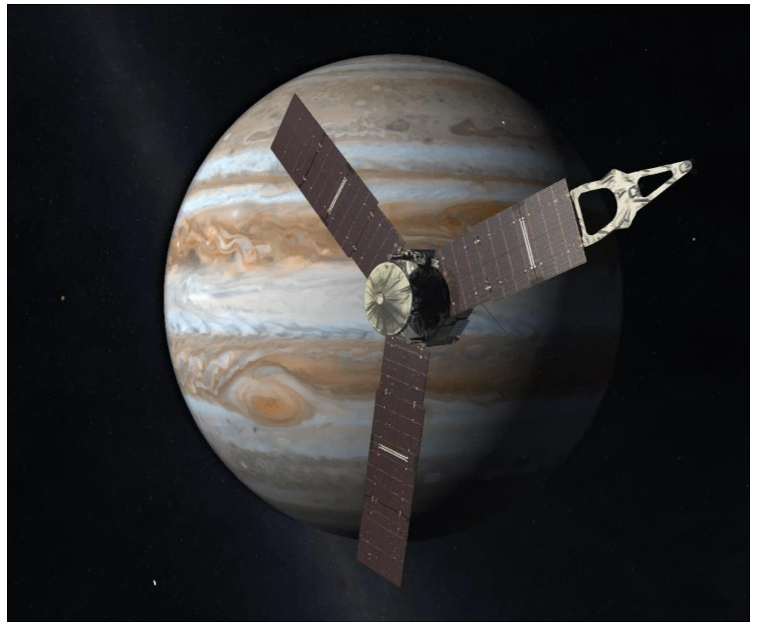
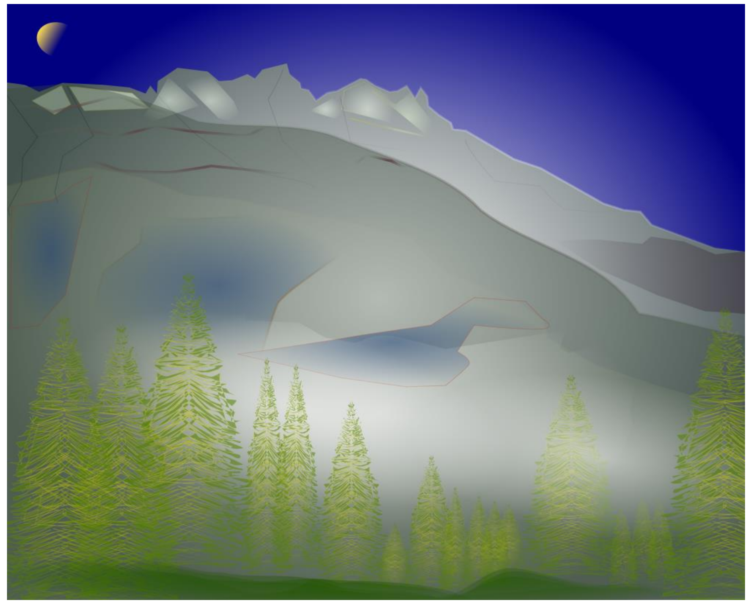
BAE SYSTEMS PROPRIETARY

Types of Problem – PBneXt
A New Explosive Material

Types of Problem	Don't Know How	Know How
Know What	**Quest** Stakeholders are very sure of *what* is to be done but unsure of *how* to achieve it	**Painting by Numbers** Stakeholders are very sure of *what* to do and *how* it is to be done
Don't Know What	**Foggy** Stakeholders are unsure of *what* and unsure of *how* to achieve it	**Movie** Stakeholders are very sure of *how* the change should be made but not *what* should be done

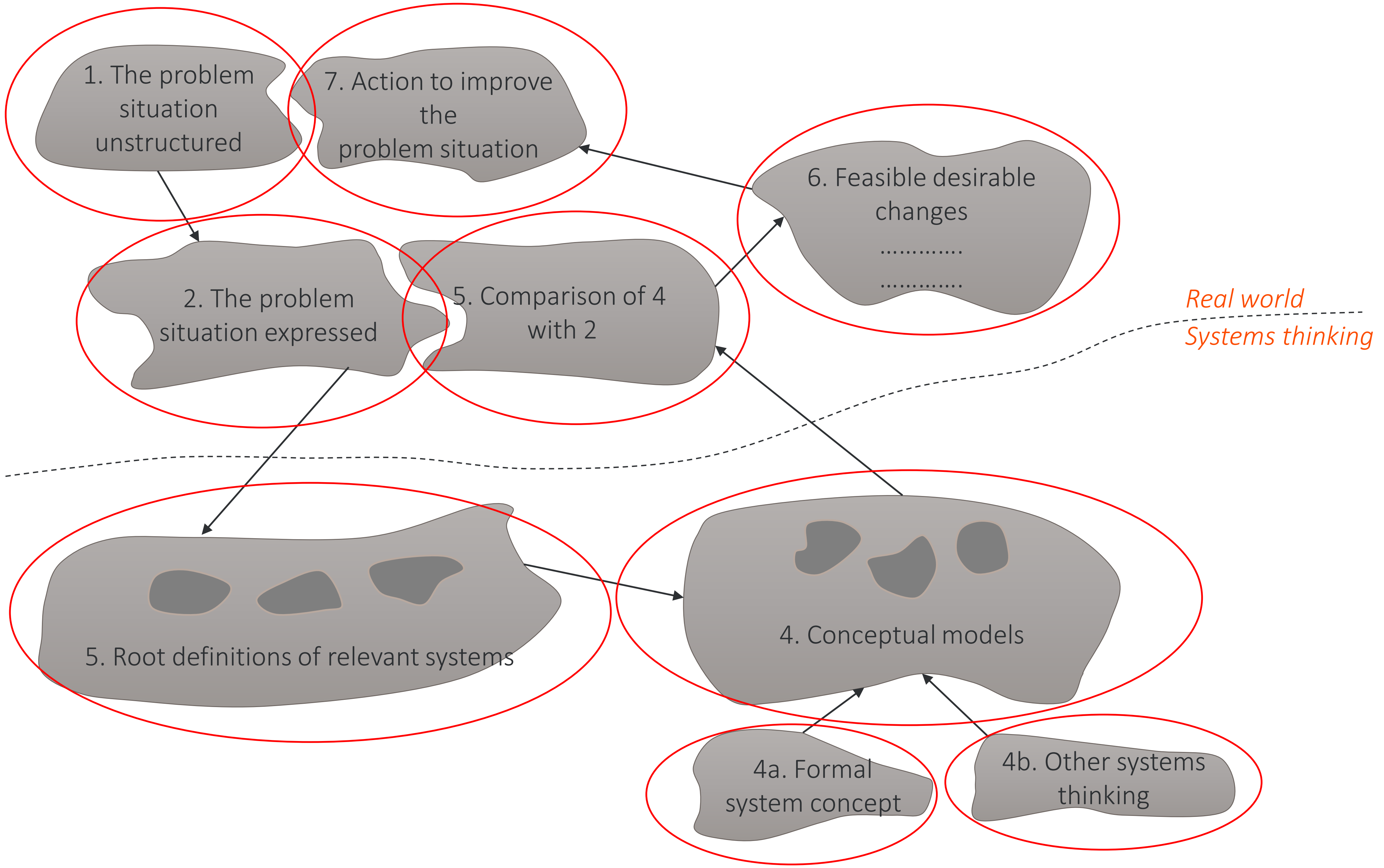




(adapted from Eddie Obeng, 1995)

Systems Engineering for PBneXt
The Analysis Method

Soft Systems Methodology (SSM)



(Adapted from Checkland, Systems Thinking Systems Practice 1999)

PBneXt – Approach
The Problem Situation Unstructured

- We start by considering all the things that are wrong/problematic/challenging about the current warhead explosive materials from the perspective of the Explosive Material Formulation.
- We need to consider manufacturing and processing later, but for now lets just focus on the explosive materials.
- We will then assemble complimentary terms in a picture and remove duplication of terms.

PBneXt
Material Problem Unstructured

PBNeXt Materials - Unstructured

SYSTEM REQUIREMENTS

- Clarity on specification tolerances for WH in order to meet customer requirements (Critical Features).
- Export or End User issues with components.
- Qualification costs and risk aversion.

SUPPLY CHAIN (Purchasing and Goods Inwards)

- Limited options.
- Cost of materials/feedstocks.
- Reliant upon supplier CoA/CoC.
- Shelf life of feedstocks.
- Reliant on old/outdated specifications/standards (e.g. DefStan.)
- Lack of availability of high performance or customised fillers.
- Suitability of generic grades for in house processes.
- Relationship between us and suppliers.
- Supply of feedstock (continuity of supply) e.g. nano Al, water & IPDI.

TECHNOLOGY GAPS

- Technical availability of higher performance energetic fillers.
- Simple analytical techniques.
- Availability of suitable (reliable and repeatable) tests to characterise materials

FEEDSTOCK DEFINITION

- *Current specs don't capture critical features.*
- *Binder feedstock specification.*

PROCESSING

- Throughput hindered by curing time
- Unable to monitor quality during process.
- Long mixing times
- Difficult casting mechanism (Qz for example)
- Short pot life.
- *Large quantities of waste material from standard processing.*
- Inhomogeneous mix.
- Processing properties vary with time (gets worse with increasing viscosity).
- *Handling hazardous materials.*
- A high number of ingredients in the formulation

MECHANICAL PROPERTIES

- Ageing effects upon mechanical properties
- Variable mechanical strength.
- High plasticizer content dilutes binder efficacy wrt mechanical properties

VULNERABILITIES

- Fill Quality – Voids
- Sensitive to friction/impact threats when containing high explosive content.
- Sensitive to void ignition under high setback/impact stress.
- Inherent IM properties of energetic feedstocks made by traditional processing methods (crystal voids/cracks/imperfections???)

ENVIRONMENTAL

- Environmental concerns and demil.
- Substances hazardous to health and environment (AP/IPDI).
- Energy demands of curing process
- Reject material cannot be re-worked and must be burned.

CHEMICAL PROPERTIES

- Leaching of plasticizer.
- Lack of understanding between cure temps and time.
- Integrity of bond between binder and filler.
- Density limitations on current energetic fillers.
- Separation of binder and solids (binder rich surfaces).
- Knowledge of how varying qty components affects bulk material properties.
- Relatively high thermal coefficient of expansion (relative to casing) – can cause defects.

PBneXt Approach
The Problem Situation Structured

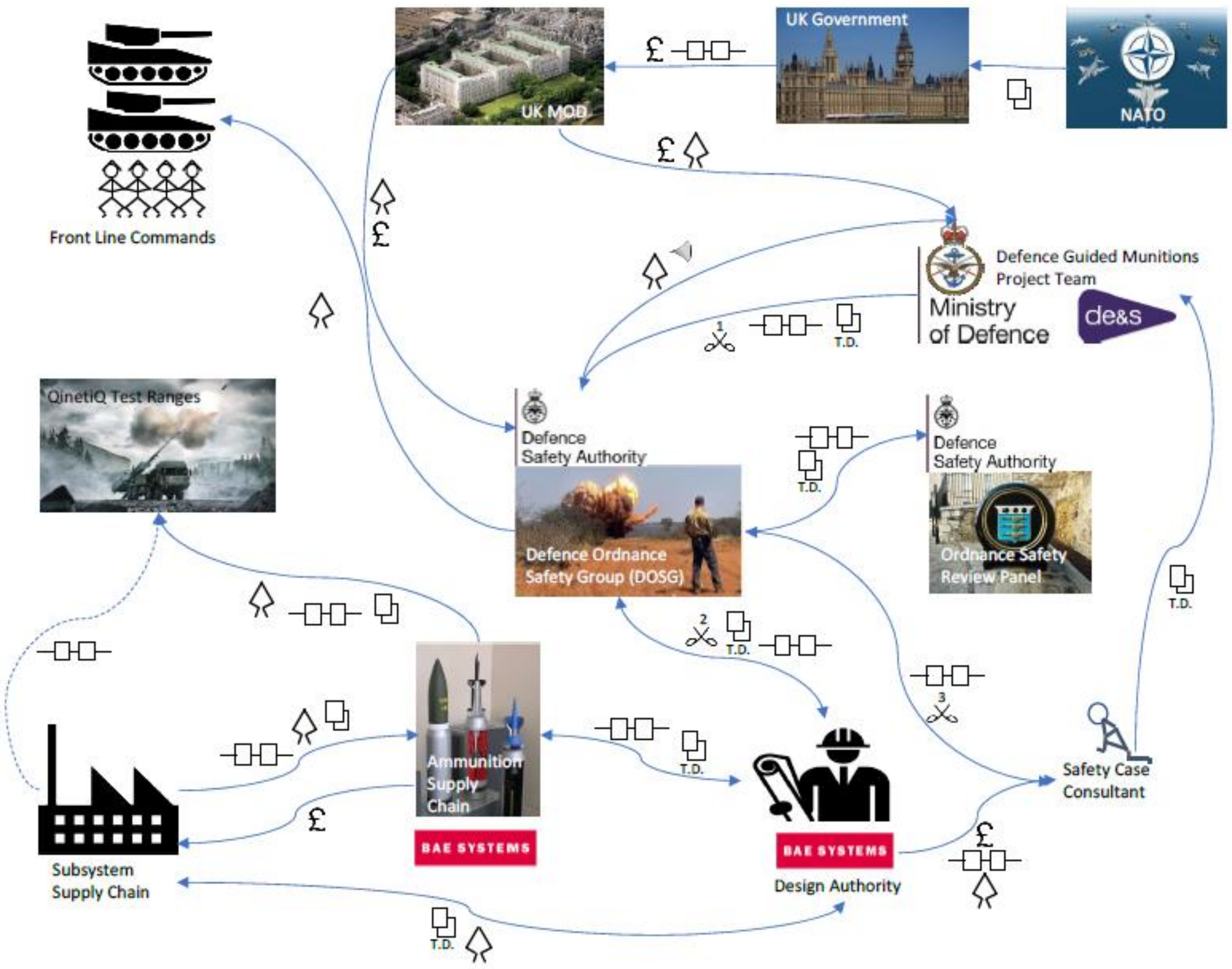
- We have highlighted the factors we consider to be challenging about current energetic materials.
- We now group similar issues to together into themes.
- Once we have a number of grouped themes, we consider if there are relationships between them?
- And the types of relationship……

2. The Problem Situation Structured

Rich Picture Key

- T.D. — Technical Data / Information
- Information
- Support
- £ — Financial Support
- Conflict
- Directional Link
- Bidirectional Link
- Intermittent Link
- View
- Process
- ? — Uncertainty

2. The Problem Situation Structured – An example of a Rich Picture



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PBneXt
Material Problem Structured

PBNeXt Materials - Structured

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The Root Definition

- So having established some notion of the problems associated with Explosive Fillings and what challenges we face with current energetic materials and their processing, we now need to consider conceptual notions of how we may improve the situation.
- HOWEVER, we first need to bound the modelling such that we don't drift outside of an agreed boundary.
- The Root Definition simply defines a system to do What <P> by means of How <Q> in order to achieve Why <R>.

P= A range of a la carte of Enhanced Blast Polymer Bonded Explosive formulations

Q= Enhanced Formulation and Processing

R= Enhanced Blast Performance

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The Richer Root Definition

Customers = UK MoD

Actors = Land UK Energetics Team, Heavy Bomb and Payloads Team

Transformation = Develop a new Explosive Formulation and Processing Capability

Worldview = Land UK remaining the leading strategic supplier to defence contactors in order to enhance market share and profitability

Owner = Land UK SLT, UK MoD, MBDA

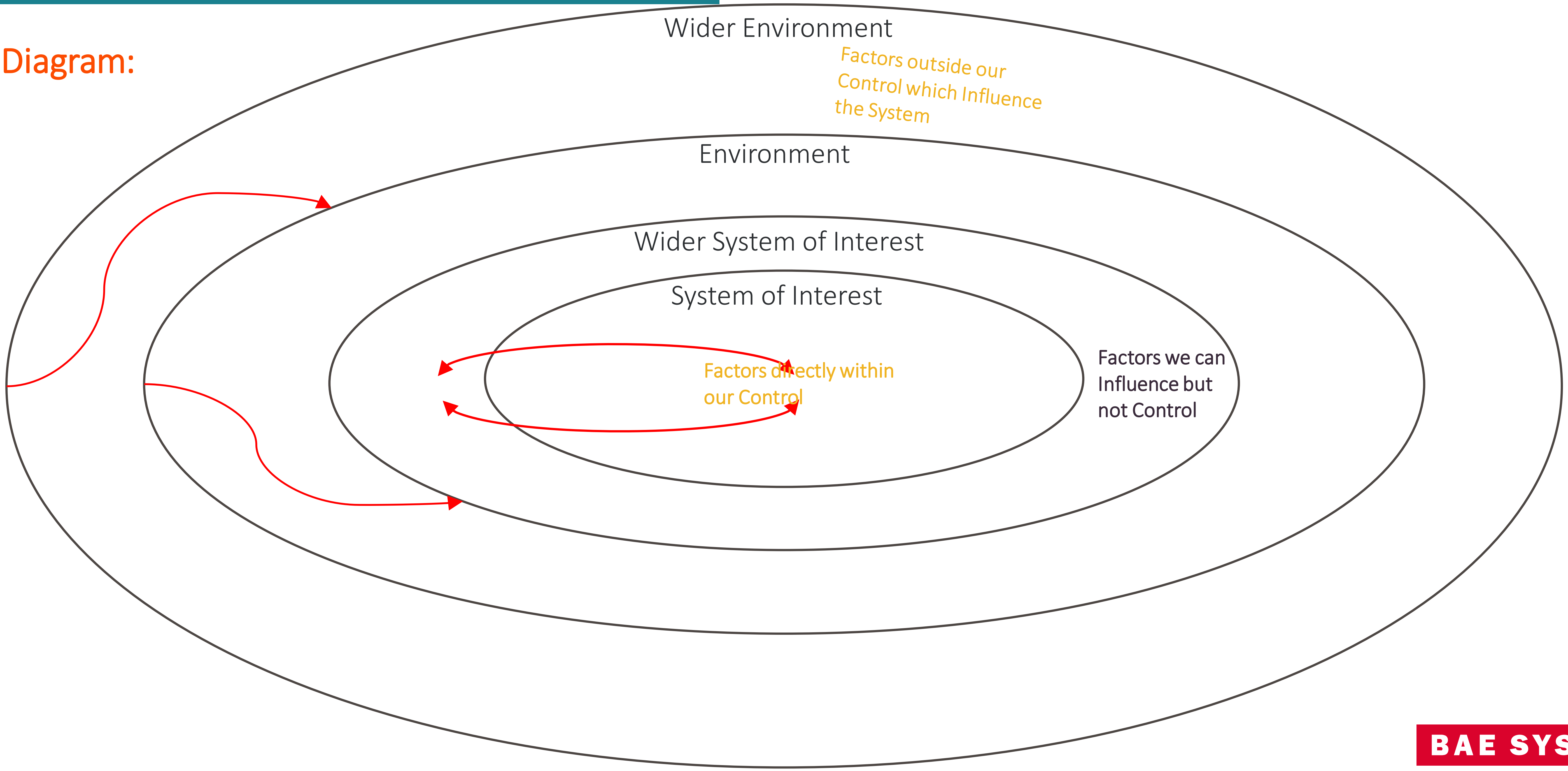
Env Constraints = Glascoed Processing, Revised Training and Skills, Suitable Resources and SQEP, R&D and Testing Capabilities, HSE Regulations, Funding

We now expand this into a Richer Root Definition by means of the acronym **CATWOE**.

Customers	The victims of beneficiaries of T
Actors	Those who would do T
Transformation	The conversion of input to output
Weltanschauung	the world view which makes the Transformation meaningful
Owners	those that could stop T
Environmental Constraints	elements outside of a system which are taken as a given

Conceptual Modelling

System Context Diagram:



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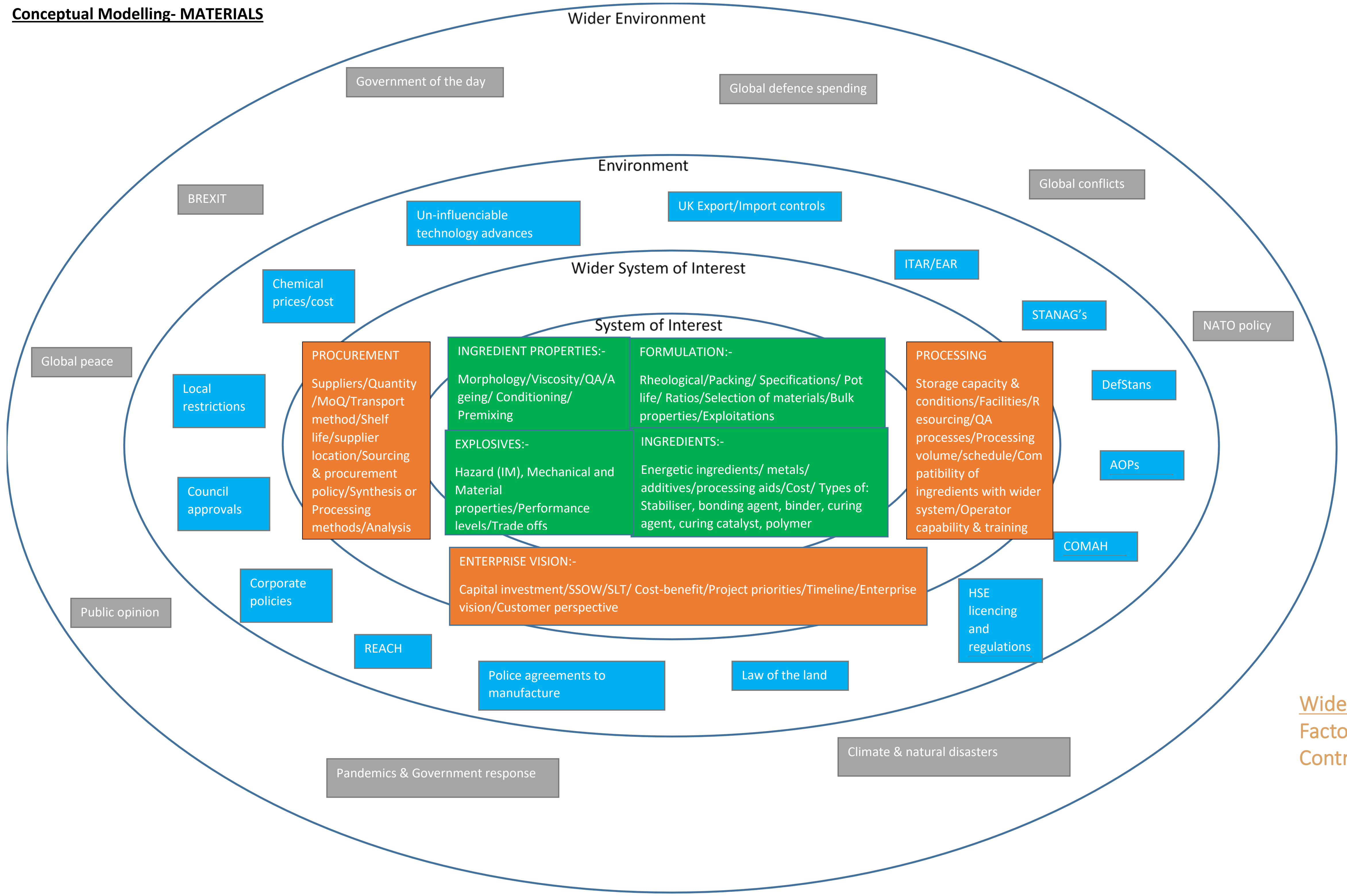
Conceptual Modelling

- System Context Diagram
- System of Interest (SoI) – the system in focus, i.e. PBneXt
- Wider System of Interest (WSoI) – interacting systems or elements which we can influence but not have direct control over (Ammunition Design?)
- Environment – that which effects the SoI but we cannot control
- Wider Environment – Which affects Environment.
- Then we take what is within our SoI (and WSoI) and conceptualise what we might do….

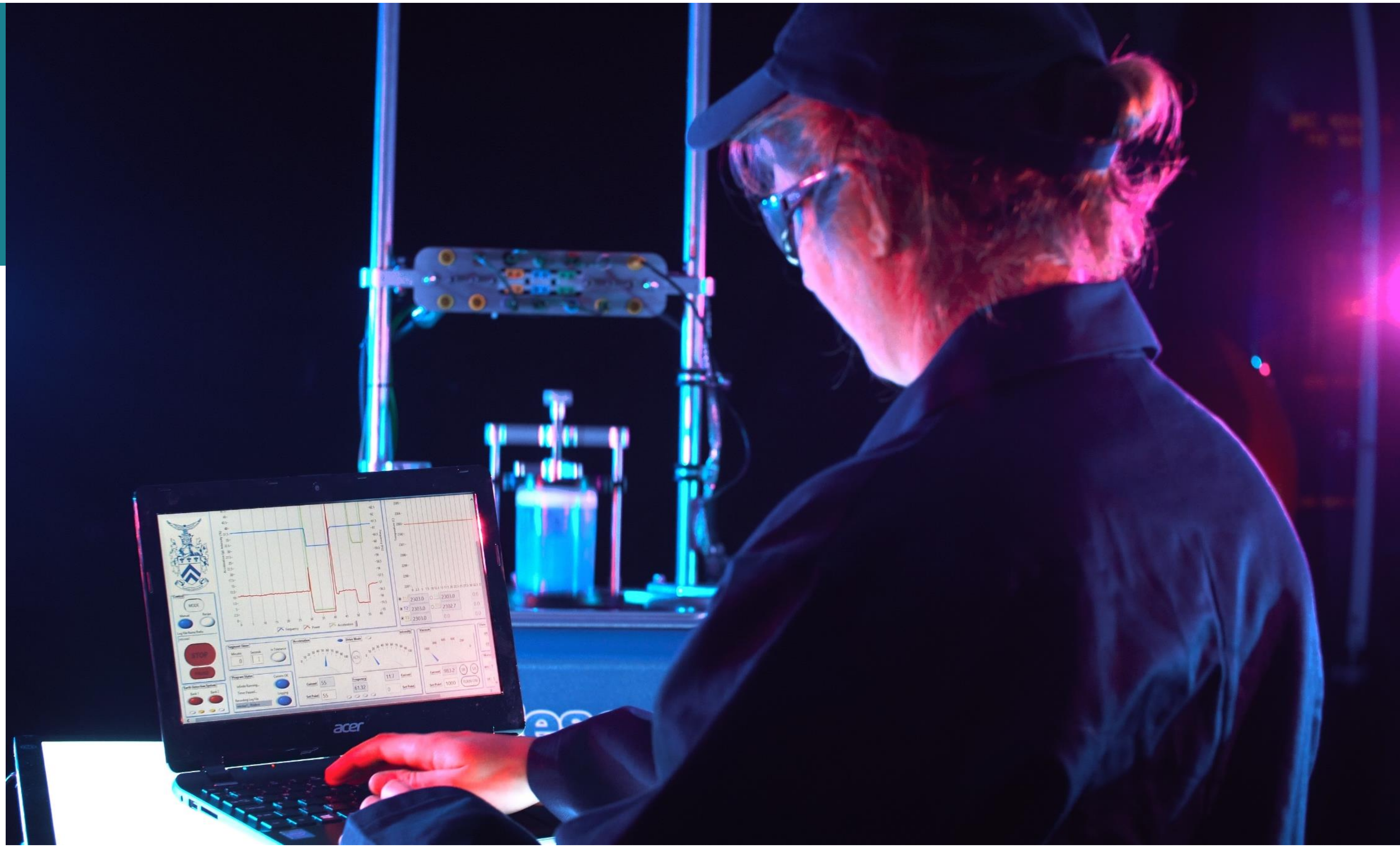
PBneXt Conceptual Modelling Material



System of Interest
Factors directly within our Control

Wider System of Interest
Factors we can Influence but not Control

Conceptual Modelling

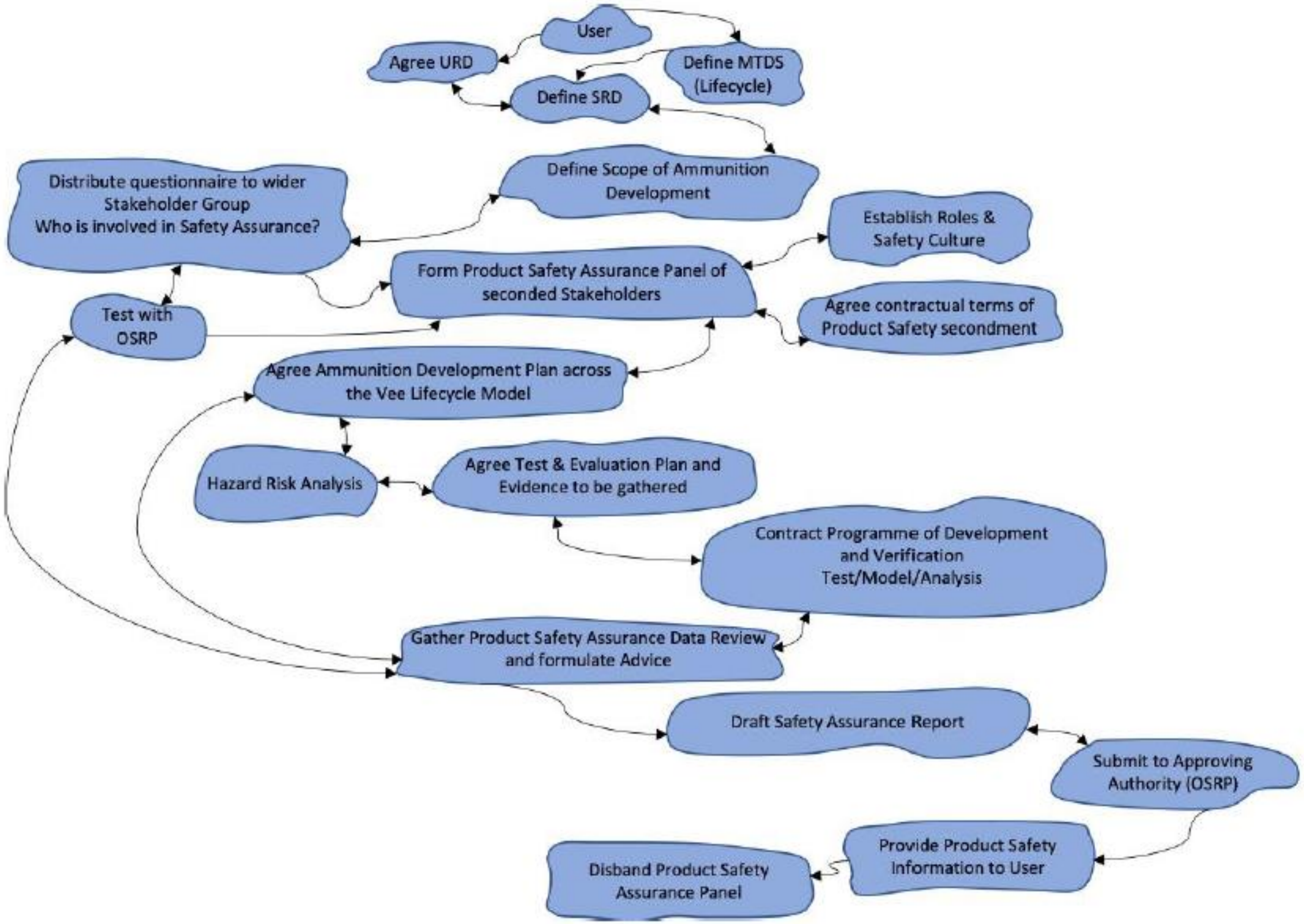


Things to remember about modelling:

- Modelling is an abstraction of reality.
- It is never universally right, but also never universally wrong.
- The benefit is to make us consider what needs to be done…… but perhaps more importantly to promote thought.

Therefore lets consider what is in the System of Interest and capture what we think we need to do.

Conceptual Modelling Example



PBneXt – Approach - Materials

PBNeXt Materials – Systems Concept

SYSTEM REQUIREMENTS

- Form System Requirements
- Better definition of critical features
- Better link between material/filling specifications and critical features

SUPPLY CHAIN

- Assess material supply chain
- Identify different curing components
- Expand supply chain
- Use cheaper ingredients
- Identify soreign capability of supply

TECHNOLOGY GAPS

- Research recyclable formulations
- Synthesize new energetic molecules
- Research alternative energetic binders
- Research multi-purpose materials
- Research suitable fuel sources
- Investigate characterisation techniques not currently in use

FEEDSTOCK DEFINITION

- Tailored crystal/particle quality ingredients
- Optimise material selection to reduce processing time
- Use more stable/robust ingredients
- Assess the need for specific components, e.g. plasticers
- Understand the storage/conditioning requirements for the feedstock

PROCESSING

- Material selection to match new mixing processing
- Processing method independent of pot life and cure time
- Optimise the crystal packing
- Understand and investigate curing reaction
- Understand the effect of catalyst use in the process (quantity/when added)
- Simplify casting processes
- Understand tolerance or acceptability of manufacturing defects
- Improved in line monitoring

PERFORMANCE

- Optimise fuel/oxidiser ratio for application
- Understand effect of top and bottom raw material specs on product performance
- Use different energetic fillers
- Use different grades of materials or blends of grades
- Enhance blast performance

MECHANICAL PROPERTIES

- Understand full range of properties required by system (e.g. mechanical property range)
- Improve mechanical properties
- Stabilise mechanical properties
- Increase mechanical strength of explosive

VULNERABILITIES

- Suitable storage conditions for raw materials
- Understand links between mechanical properties and failure modes
- Use reduced sensitivity ingredients

ENVIRONMENTAL

- Reduce waste
- Use low environmental impact ingredients
- Reduce energy demands of manufacturing processes
- Use non-toxic ingredients
- Assess material for environmental impact.

CHEMICAL PROPERTIES

- Understand ageing mechanisms
- Identify alternative binder polymers
- Understand what the limits are on the explosive material spec so as bulk properties are still acceptable

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Compare the concept diagrams to the problem

At this phase we need to fully check the system concepts against the problem to ensure we have addressed the problems highlighted in phases 1 and 2 of SSM.

- Models are an abstract of reality, a snapshot of what might be.
- Models are never right, nor are they wrong.
- So its important that we get everything down that we may need, and then compare it to the problem space.
- Have we covered everything off (for now)?

Feasible and Desirable Changes

- OK so we have a notion of what we want to achieve but…
- We need to balance this again the realities of the business within which we operate.
- In this instance we reduce number of changes in line with what the business can practically implement within 12 months.

We may wish to characterise, design and manufacture Volvonium, the world most indestructible Swedish steel. However the reality is that we may not have the budget, enterprise backing nor SQEP to do so, therefore its important to consider what is feasible.

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Feasible and Desirable Changes Material

Green = What is achievable within 12 months
Red = What remains in the scope of PBneXt

PBNeXt Materials – Systems Concept

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Action to improve the problem situation

- We should have a number of ideas of what we want to change, why they are important and an appreciation that they are within the scope of what is achievable.
- We can start by listing these and then turn them into functional system requirements.
- Functional requirements are best structured in Verb Noun sequence which describes the manner to enact a change.
- i.e. stabilise energetic, provide braisance, control temperature.
- Let assemble the functional requirements for PBneXt Material.

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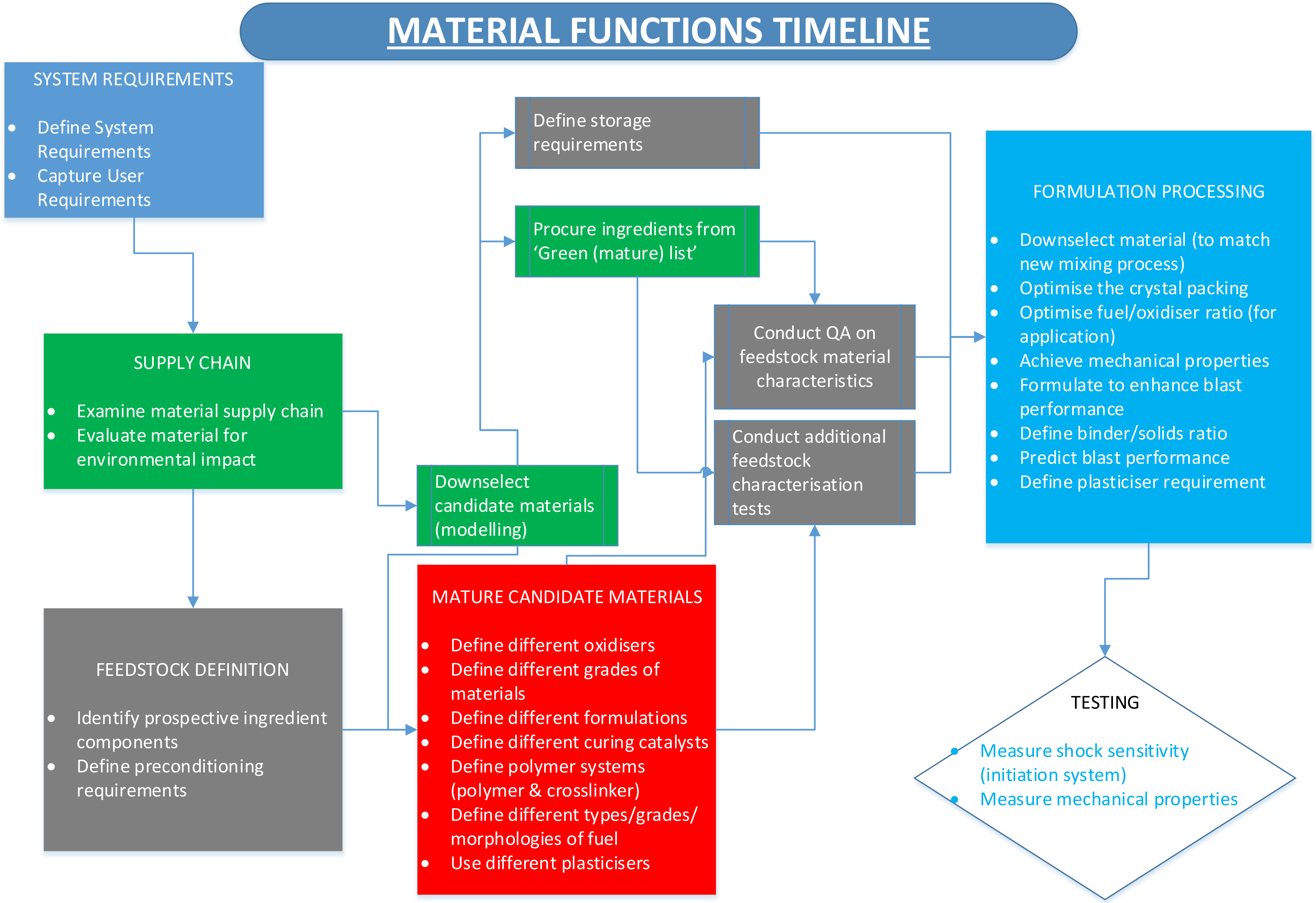
PBneXt
Refined Approach

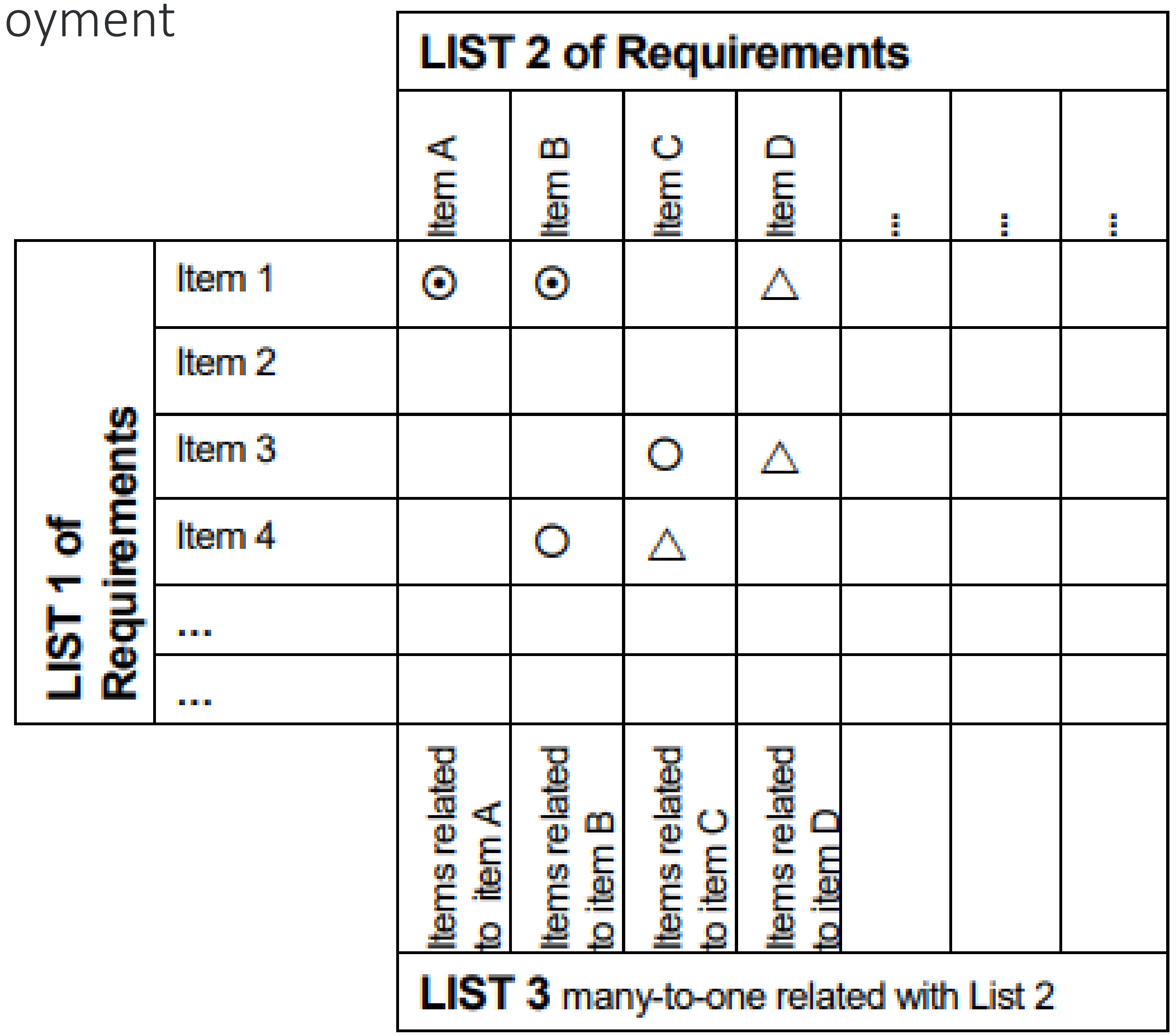


Where do we go next?

- Having completed the Seven Steps of SSM we are now in a position of taking action to improve the problem space.
- The final activities of SSM involved us considering the functional requirements for the energetic material.
- We now need to evaluate the relative importance of these at each level of abstraction (or layer).
- This should lend itself to Quality Function Deployment (QFD).

Where do we go next?

Quality Function Deployment



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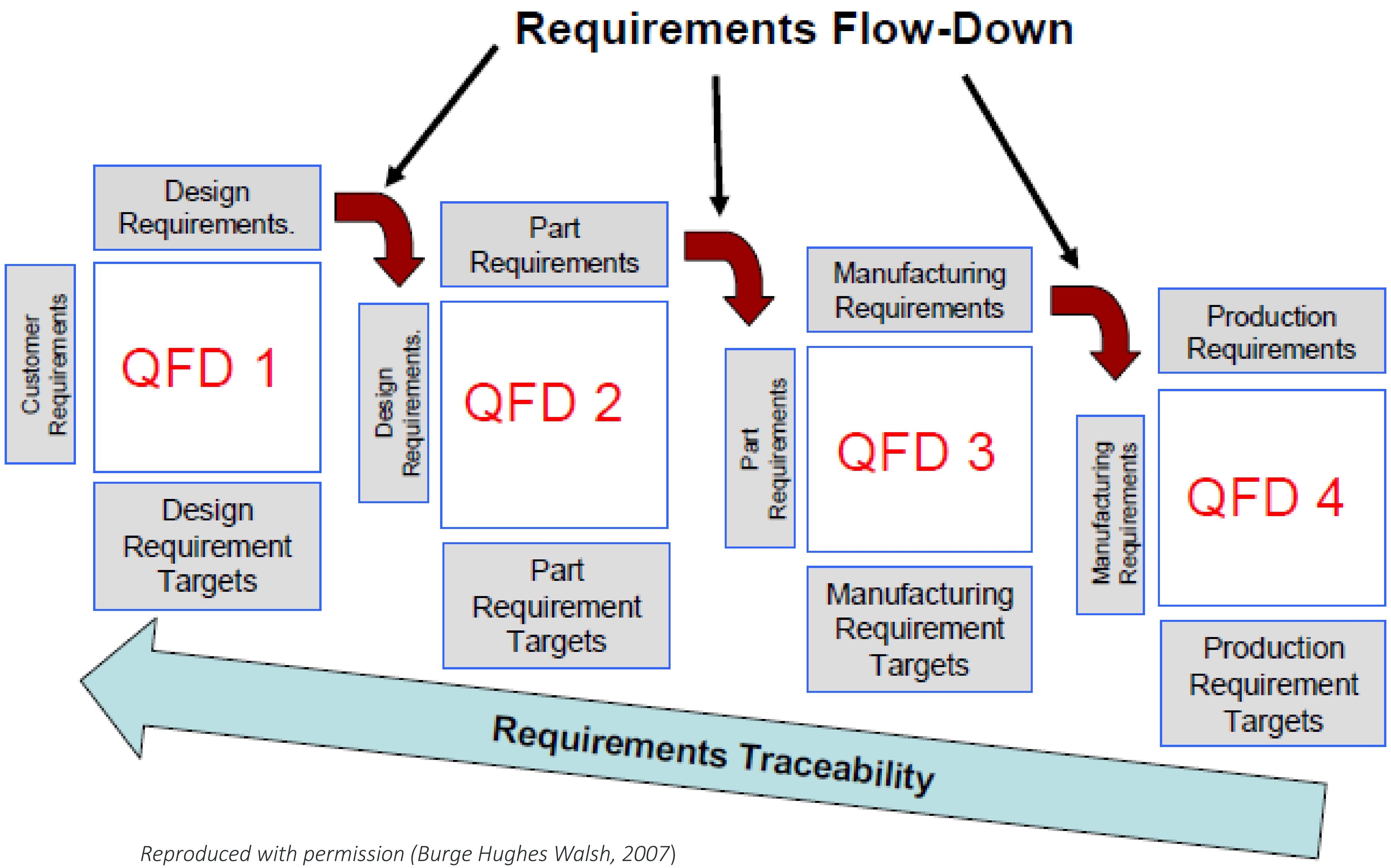
QFD Flowdown – The levels of decomposition.



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User Requirements:

Generally the User will supply a list of User Requirements, these are normally vague, hard to quantify and usually encompass considerations for Ammunition such as:

- Safe
- Reliable
- Accurate
- Lethal
- Development Cost
- Manufacturing Cost
- Long Life
- Legally Compliant
- Maintainable

PBneXt – QFD 1
System Requirements

The User would normally provide these as part of a System Requirements Document (SRD). However we haven't got that luxury yet.

At this point in time we need to try to think what the customer may want the Ammunition to do (Verb/Noun again).

For example:

- Provide Blast Overpressure
- Control Ignition
- Seal from Environmental Effects

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PBneXt – Approach

MATERIAL FUNCTIONS

SYSTEM REQUIREMENTS

- Define System Requirements
- Capture User Requirements

SUPPLY CHAIN

- Examine material supply chain
- Evaluate material for environmental impact
- Downselect candidate materials (modelling)
- Procure ingredients from ‘Green (mature) list’

FORMULATION PROCESSING

- Downselect material (to match new mixing process)
- Optimise the crystal packing
- Optimise fuel/oxidiser ratio (for application)
- Achieve mechanical properties
- Measure mechanical properties
- Formulate to enhance blast performance
- Define binder/solids ratio
- Predict blast performance
- Define plasticiser requirement
- Measure shock sensitivity (FCASW initiation system)

FEEDSTOCK DEFINITION

- Identify prospective ingredient components
- Define preconditioning requirements
- Define storage requirements
- Conduct QA on feedstock material characteristics
- Conduct additional feedstock characterisation tests

MATURE CANDIDATE MATERIALS

- Define different oxidisers
- Define different grades of materials
- Define different formulations
- Define different curing catalysts
- Define polymer systems (polymer & crosslinker)
- Define different types/grades/ morphologies of fuel
- Use different plasticisers

Stuff for later

- Design for tooling available
- Store ingredients appropriately
- Precondition ingredients appropriately

BAE SYSTEMS

PBneXt
User Requirements:

- Safe
- Reliable
- Accurate
- Lethal
- Throughlife Cost
- Purchase Cost
- Long Life
- Legally Compliant
- Modular
- Secure Supply Chain
- Tuneable Output
- Stealth
- Manufacturing Flexiblity
- Environmentally Sound
- All Weather

- Safe handling in theatre
- Safe handling in storage
- Safe handling in transport
- Cope with temp
- Cope with vibration
- Cope with drop
- Cope with humidity
- Chemical Compatibility
- Survive launch
- Interface with system

PBneXt
System Requirements:

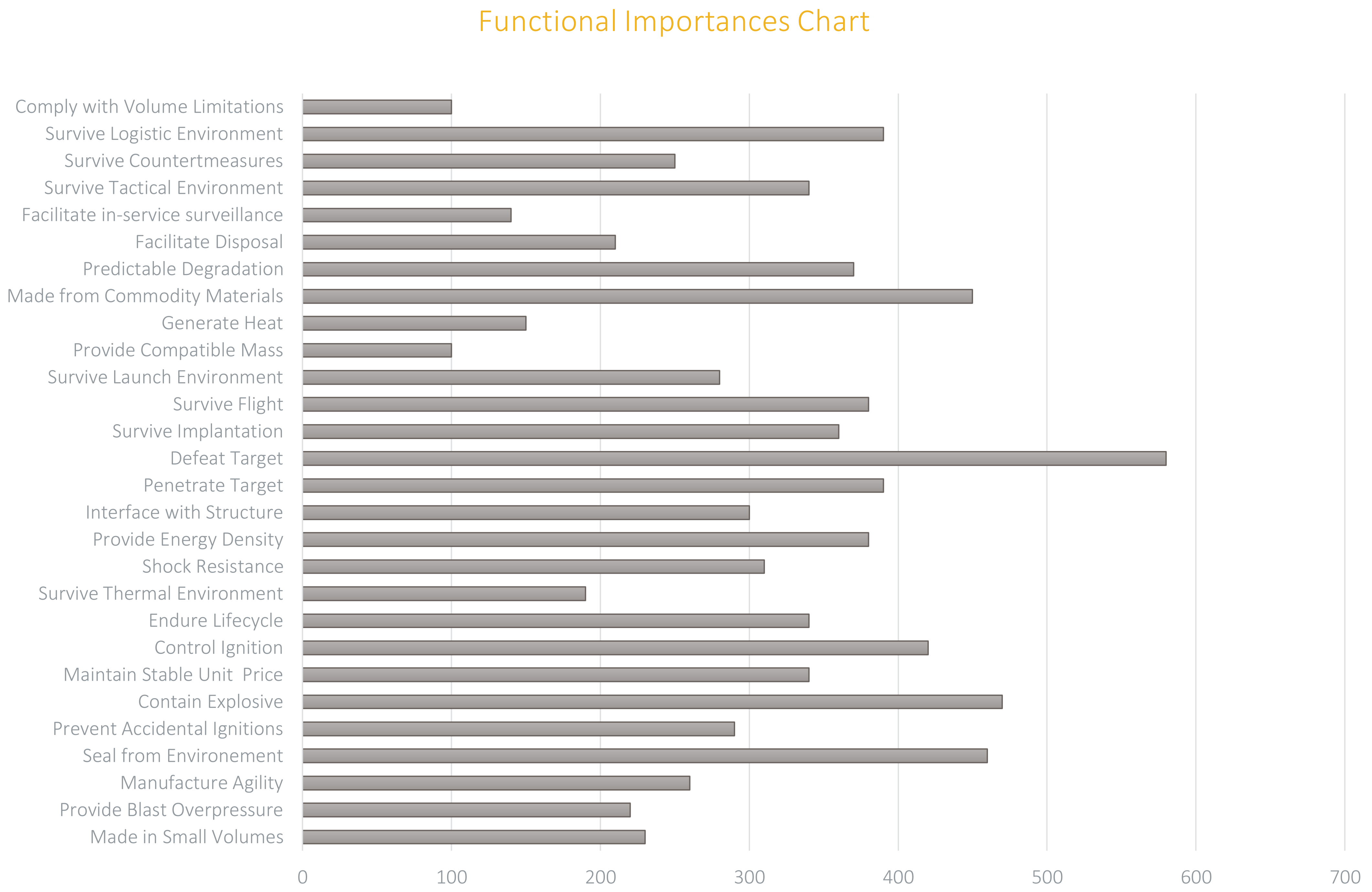
- Made in Small Volumes
- Provide Blast Overpressure
- Manufacture Agility
- Seal from Environment
- Prevent Accidental Ignitions
- Contain Explosive
- Maintain Stable Unit Price
- Control Ignition
- Endure Lifecycle
- Survive Thermal Environment
- Shock Resistance
- Provide Energy Density
- Interface with Structure
- Penetrate Target
- Defeat Target
- Survive Implantation
- Survive Flight
- Survive Launch Environment
- Provide Compatible Mass
- Generate Heat
- Made from Commodity Materials
- Predictable Degradation
- Facilitate Disposal
- Facilitate in-service surveillance
- Survive Tactical Environment
- Survive Countertmeasures
- Survive Logistic Environment
- Comply with Volume Limitations

QFD 1 Matrix: Ammunition Level

ACTIVITY SUMMARY

Warhead Functionality	Importance	Made in Small Volumes	Provide Blast Overpressure	Manufacture Agility	Seal from Environement	Prevent Accidental Ignitions	Contain Explosive	Maintain Stable Unit Price	Control Ignition	Endure Lifecycle	Survive Thermal Environment	Shock Resistance	Provide Energy Density	Interface with Structure	Penetrate Target	Defeat Target	Survive Implantation	Survive Flight	Survive Launch Environment	Provide Compatible Mass	Generate Heat	Made from Commodity Materials	Predictable Degradation	Facilitate Disposal	Facilitate in-service surveillance	Survive Tactical Environment	Survive Countermeasures	Survive Logistic Environment	Comply with Volume Limitations
Key User Requirements																													
Safe	10	1	3	1	9	9	9	3	9	3	9	9	9	9		1	3	9	9	1	3	1	9	3	1	9	1	9	1
Reliable	10		1	1	9	1	1		9	3	3	9		1	9	9	9	9	9	1	1		9			3	9	9	
Accurate	10														9	9	9	3	3	1							3	3	1
Lethal	10		9		3	1	9		9	1	1	3	9	9	9	9	9	3	3	3	9	3	3			9	3	1	3
Throughlife Cost	10	1			3	3	1	9	1	9	1		1							1		9	3	3	3	1		3	
Purchase Cost	10	9		3		3	1	9	1	3	1		1							1		9	3	1					
Long Life	10	1			9	1	1	1		9	3	9	3	3				9	3			3	9		9	9		9	
Legally Compliant	10					9	9	1	1				3					1			1	1		3				1	
Modular	10			3	1		3		3	1				3	3	3	3			1				1	1	1		1	1
Secure Supply Chain	10	1		9				9		1			1									9							
Tuneable Output	10		9				9		9				9	3	9	9	3			1	1								1
Stealth	10															9		3								1	9		
Manufacturing Flexiblity	10	9		9		1	1	1					1	1								9		1					3
Environmentally Sound	10	1			3		3	1		1			1									1	1	9					
All Weather	10				9	1				3	1	1		1		9		1	1							1		3	
		230	220	260	460	290	470	340	420	340	190	310	380	300	390	580	360	380	280	100	150	450	370	210	140	340	250	390	100
Target																													
Benchmark																													

QFD 1 Graph: Ammunition Level



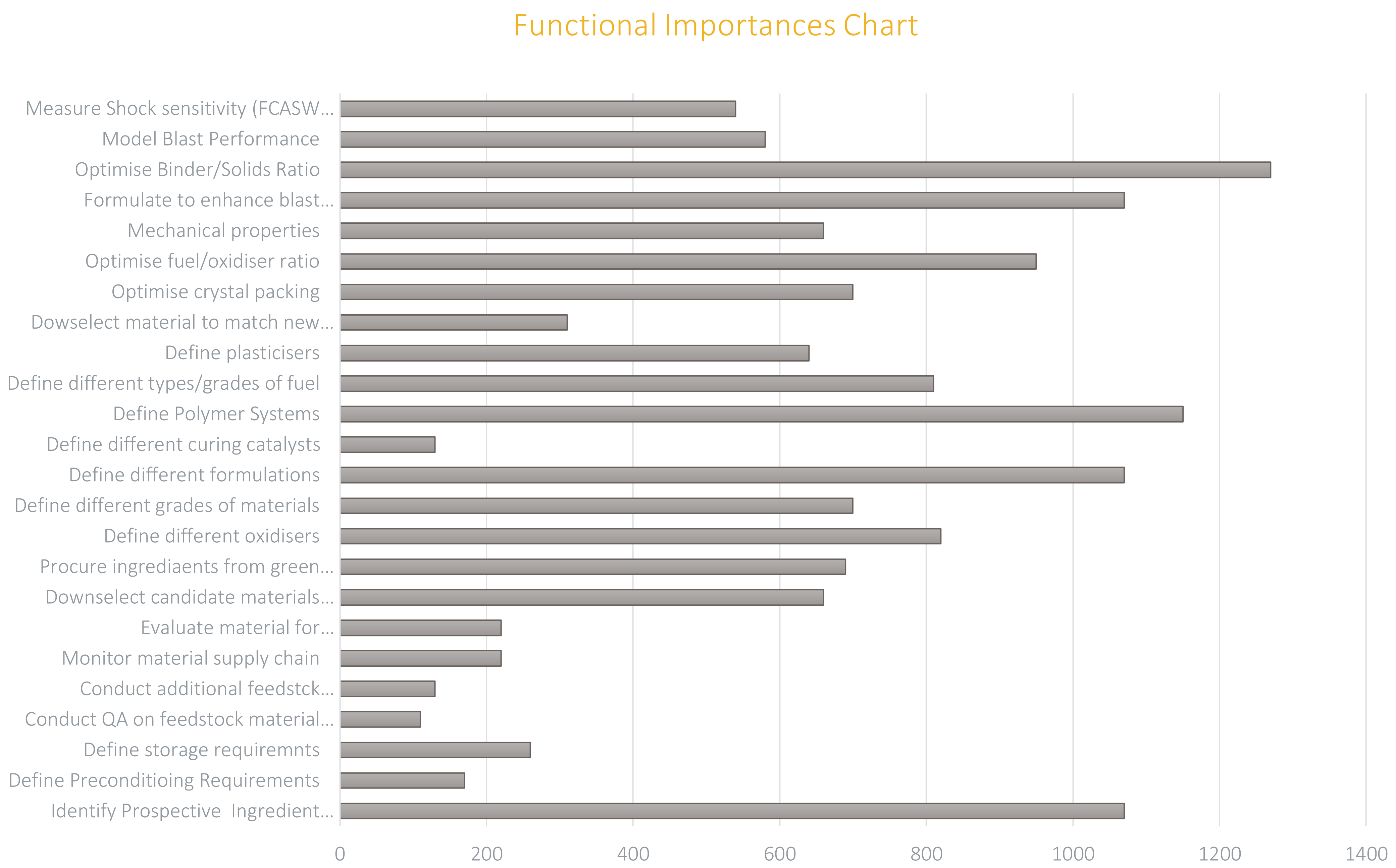
QFD 2 Matrix:

ACTIVITY SUMMARY

Design feature	Importance	Identify Prospective Ingredient components	Define Preconditioing Requirements	Define storage requiremnts	Conduct QA on feedstock material characteristics	Conduct additional feedstck characterisation tests	Monitor material supply chain	Evaluate material for environmental impact	Downselect candidate materials (modelling)	Procure ingrediaents from green mature list	Define different oxidisers	Define different grades of materials	Define different formulations	Define different curing catalysts	Define Polymer Systems	Define different types/grades of fuel	Define plasticisers	Dowselect material to match new mixing process	Optimise crystal packing	Optimise fuel/oxidiser ratio	Mechanical properties	Formulate to enhance blast performance	Optimise Binder/Solids Ratio	Model Blast Performance	Measure Shock sensitivity (FCASW Initiation system)
Functionality																									
Made in Small Volumes	10	1		1			1			9			3				1	1		3		3	3		
Provide Blast Overpressure	10	9				1			9		9	9	9			9			9	9		9	9	9	
Manufacture Agility	10	3	3	3	1	1	3	3		9	1	1	3	3	3	1	1	9	1	3	1	3	3		
Seal from Environment	10		1	1											9		3								
Prevent Accidental Ignitions	10	3	1	1					3		1	1	3		9				1	3	1	3	3	3	
Contain Explosive	10	9							9	9	9	9	9	3	9	9	3		9	9	1	9	9	9	3
Maintain Stable Unit Price	10	3	1				9	1		9			1		1		1	3		1		1	1		
Control Initiation	10	9			1	1			3		1	1	9			1			1	9		9	9	3	9
Endure Lifecycle	10	3	3	9				3					3	3	9		9			1	9	3	3		
Survive Thermal Environment	10	3	3	3							1	1	3		9	1	9		1	1	3	3	3		
Shock Resistance	10	9				1			3		1	1	3		9	1	9		1	3	9	3	3	3	9
Provide Energy Density	10	9							9	3	9	9	9		9	9		9	9	9		9	9	9	
Interface with Structure	10	1								1											3				9
Penetrate Target	10	1																							
Defeat Target	10	9							9	9	9	9	9			9		3	9	9		9	9	9	9
Survive Warhead Implantation	10	3							3		3	3	3	1	9	3	3	3	3	1	9	3	9	3	9
Survive Flight	10	1		1	1	1					1	1	1		3	1	3		1	1	3	1	3		
Survive Launch Environment	10	3		1	1	1					1	1	3		3	1	3		1	1	3	3	3		
Provide Compatible Mass	10	1								1	3	3	3			3			3	3		3	3		
Generate Heat	10	9							9	3	9	9	9			9			9	9		9	9	9	
Made from Commodity Materials	10	9			1	1	9	3	9	9	9	9	9	3	3	9	1	1	9	9		9	9	1	
Predictable Degradation	10	1	3	3	3	3		3		3	3	1	3		9	3			1	1	3	3	3		
Facilitate Disposal	10	1						9		1	9	1	3		3	9			1	1	3	3	3		
Facilitate in-service surveillance	10	1		1	3	3				3	3	1	3			3			1	3		3	3		
Survive Tactical Environment	10	3	1	1									3		9		9	1		3	9	3	9		3
Survive Countermeasures	10																								
Survive Logistic Environment	10	3	1	1									3		9		9	1		3	9	3	9		3
		1070	170	260	110	130	220	220	660	690	820	700	1070	130	1150	810	640	310	700	950	660	1070	1270	580	540

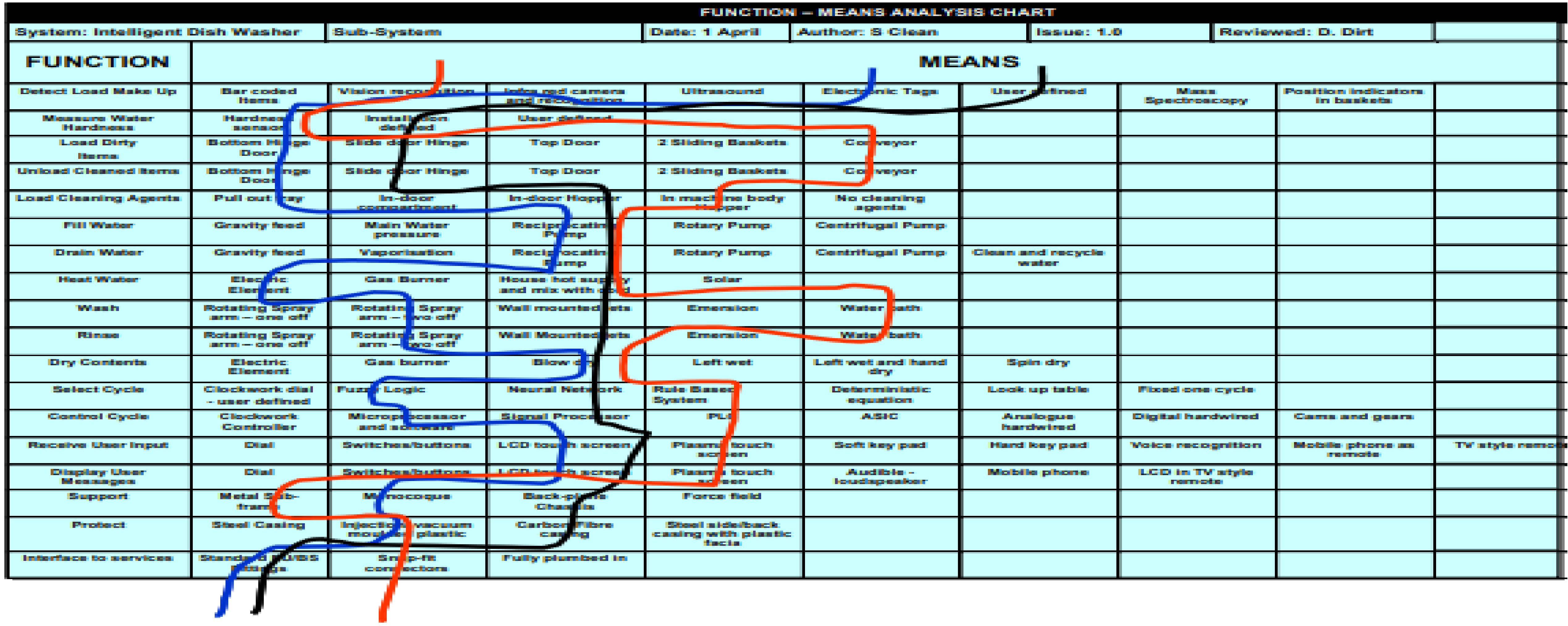
BAE SYSTEMS

QFD 2 Graph:


Functional Importances Chart
Measure Shock sensitivity (FCASW...
Model Blast Performance
Optimise Binder/Solids Ratio
Formulate to enhance blast...
Mechanical properties
Optimise fuel/oxidiser ratio
Optimise crystal packing
Dowselect material to match new...
Define plasticisers
Define different types/grades of fuel
Define Polymer Systems
Define different curing catalysts
Define different formulations
Define different grades of materials
Define different oxidisers
Procure ingrediaents from green...
Downselect candidate materials...
Evaluate material for...
Monitor material supply chain
Conduct additional feedstck...
Conduct QA on feedstock material...
Define storage requiremnts
Define Preconditioing Requirements
Identify Prospective Ingredient...
0
200
400
600
800
1000
1200
1400

What after QFD?

- We will have ranked the criticality of the functional requirements.
- Do we now consider the various means how we may achieve it?
- Function Means Analysis



FUNCTION – MEANS ANALYSIS CHART									
System: Intelligent Dish Washer	Sub-System		Date: 1 April	Author: S Clean		Issue: 1.0	Reviewed: D. Dirt		
FUNCTION	**MEANS**								
Detect Load Make Up	Bar coded Items	Vision recognition	Infra red camera and recognition	Ultrasound	Electronic Tags	User defined	Mass Spectroscopy	Position indicators in baskets	
Measure Water Hardness	Hardness sensor	Installation defined	User defined						
Load Dirty Items	Bottom Hinge Door	Slide door Hinge	Top Door	2 Sliding Baskets	Conveyor				
Unload Cleaned Items	Bottom Hinge Door	Slide door Hinge	Top Door	2 Sliding Baskets	Conveyor				
Load Cleaning Agents	Pull out tray	In-door compartment	In-door Hopper	In machine body Hopper	No cleaning agents				
Fill Water	Gravity feed	Main Water pressure	Reciprocating Pump	Rotary Pump	Centrifugal Pump				
Drain Water	Gravity feed	Vaporisation	Reciprocating Pump	Rotary Pump	Centrifugal Pump	Clean and recycle water			
Heat Water	Electric Element	Gas Burner	House hot supply and mix with cold	Solar					
Wash	Rotating Spray arm – one off	Rotating Spray arm – two off	Wall mounted jets	Emersion	Water bath				
Rinse	Rotating Spray arm – one off	Rotating Spray arm – two off	Wall Mounted jets	Emersion	Water bath				
Dry Contents	Electric Element	Gas burner	Blow dry	Left wet	Left wet and hand dry	Spin dry			
Select Cycle	Clockwork dial - user defined	Fuzzy Logic	Neural Network	Rule Based System	Deterministic equation	Look up table	Fixed one cycle		
Control Cycle	Clockwork Controller	Microprocessor and software	Signal Processor	PLC	ASIC	Analogue hardwired	Digital hardwired	Cams and gears	
Receive User Input	Dial	Switches/buttons	LCD touch screen	Plasma touch screen	Soft key pad	Hard key pad	Voice recognition	Mobile phone as remote	TV style remo
Display User Messages	Dial	Switches/buttons	LCD touch screen	Plasma touch screen	Audible - loudspeaker	Mobile phone	LCD in TV style remote		
Support	Metal Sub-frame	Monocoque	Back-plate Chassis	Force field					
Protect	Steel Casing	Injection/vacuum moulded plastic	Carbon Fibre casing	Steel side/back casing with plastic facia					
Interface to services	Standard EU/BS fittings	Snap-fit connectors	Fully plumbed in						

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Function Means

- Four concepts are shown with one as a baseline.
- The means of achieving each function is highlighted for each concept.

Function															
Mix Acoustically	RAM Batch	RAM CAM	RAM MIX IN CASE	PAINT SHAKER	ETF SHAKER	RAM 5	RAM 55	LAB RAM 2	OMNI RAM						
Understand Viscosity Limits of Process	Rheological modifiers	In-line viscosity measurements	SQEP knowledge	Literature review	Viscometer	Rheometer	Mix trials	Design of experiments	Understand filling technique (limits of tooling/method)	Pot life / curing trials	Review internal studies	bespoke rheometer (scaled up 'capillary')	Shore A hardness		
Design Mix Regime for Ease of Scale	Rheology	SQEP knowledge	Industry knowledge	DoE	In-line monitoring	One pot mixing	Blocked isocyanate (time would be no issue)	Minimise process steps	Recipe mode mixing	Optimal shop layout (flow)	"One-clip" fixture	utomated recording/monitor of key parameters (alarm system)			
Optimise Mixing Parameters	DoE	SQEP knowledge	Industry knowledge	Mix vessel design	Transparent vessel	-line assessment of mix completeness (FTNIR?)	In-line X-ray / CT-scanning	time	temperature	vacuum	acceleration	incorporation	degas		
Load Ingredients into Mix Vessel	SQEP knowledge	Industry knowledge	Auto loading hoppers	Multi feed with pre-mix for single loading	Individual dispensation in sequence	Manual Loading	Automatic dispenser Loading from feed stock supply held separately	Auto dosers	Robots	prepolymers (polymer/isocyanate combo)	Premixes	Heated dosers	Udder type systems for multiple weighing (MIC)	Coke/ice-cream dispenser type system (formulation menu)	weigh in by hand
Fill Uniformly (No Voids)	SQEP knowledge	Industry knowledge	Speed of fill	Viscosity of mix	Angle of fill	Fill tools	Fill under vibration	Pass vehicles over shaker plate to vibrate	Fill under vacuum	Check quality and form through NDA techniques - Ultrasound?	MIC with good degassing	Vacuum casting	Vibration / agitation	Degas during mix regime	ave a formulation that can withstand munitions usage with voids
Define Production Processing Requiremnts	Determine effects of dwell times	SQEP knowledge	Industry knowledge	Engage with Ops	SOPs	PCPs	Mix Cards	Automated recipes	Customer requirements (throughput)	From trial outcomes	total mass	define nett explosive quantity	daily throughput	fast changeover (SMED)	
Design Filling Tooling Needed	SQEP knowledge	Industry knowledge	Finish on the tooling for flow	Geometrics for flow control	Question - What complexity of fill is expected - monolithic chrge with external or integrated initiation inputs	Customer requirements	From trial outcomes (dependent on formulation)	MIC - single or multiple	Vac cast attachments	External designers	Weir plates	CAM set-up	Design to incorporate sample manufacture	In house design	Procure Falcon designs
Prepare Vehicles Prior to Filling	Enusure correct finish	Treat to ensure adherance to case wall	Condition vehicles to match mix temp	Identify subsidiary hardware and furniture	If warhead casing/component involved need for thorough understanding of form and energetic	Adjacent lining facility	Cleanliness check	Labelling / stencilling (bar codes?)	Pre-weigh	temperature condition	Liner / Mix In Case Trials	Optimise Liner Properties			
Standardise curing process	IPDI in excess to account for NCO content variation	Establish best curing agent for process	Premix HTPB and cure catalyst	Shore A and gel time experiments to determine optimat cure time and temp	DoE	SQEP knowledge	Industry knowledge	Curing trials (inc. material analysis - mechanicals)	Calculate curing time	Dedicated curing facility	PCPs / SOPs	Operator training	Standardise across different formulations	Optimise curing components (e.g. NCO/OH ratio)	Identify cure verification tests
Conduct Gel Time Testing	reate database of results for reference	Rheology	GD Labs	External testing	Group 1 testing	Inert vs Energetic formulation comparison	use gel time tester	Viscocity	Use spectrocopic methods	conduct offline	conduct online	N/A			

What after Function Means?

- We have ranked the criticality of the functional requirements.
- We have assessed the means by which candidate solutions may achieve these and created system concepts. Do we now score these and determine the most desirable?

		Pugh Concept Selection Matrix	Wieght	Design Concepts: Electric 4-slot	Electric Conveyor	Gas Grill		
Selection Criteria	Good Toast Quality	Even Toasting	2	S	S	-		
		Good Taste	3	S	S	S		
		Repeatable	3	S	+	-		
		Quick	3	S	S	S		
	Capacity	Large Range of Bread Products	2	S	S	+		
		Multiple Slices/Units	4	S	+	+		
	Long Life	Reliable	1	S	-	S		
		Durable	3	S	S	S		
		Low Maintenance	3	S	-	S		
	Physical Attributes	Affordable	2	S	-	+		
		Attractive	5	S	-	-		
		Safe	3	S	-	- -		
		Good Size	4	S	-	-		
	Easy to Use	Easy to use Controls	5	S	S	+		
		Easy to Load	4	S	+	+		
		East to RemoveToast	4	S	+	-		
		Automated	4	S	S	- -		
		TOTAL +		0	4	4		
		TOTAL -		0	6	9		
		TOTAL SCORE		0	-2	-5		
		WEIGHTED TOTAL +		0	15	17		
		WEIGHTED TOTAL -		0	17	32		
		WEIGHTED SCORE		0	-2	-15		

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Pugh Matrix

- The PUGH Matrix scores the three candidate options numerically.
- Trade-Off of requirements and scores can be made at this stage to introduce hybrid concepts.

		Relative Importance	Relative Importance Weighted			
WHATs – Customer Requirements	How much:- From QFD 1					
Identify Prospective Ingredient components			5	0	3	3
Define Preconditioing Requirements			5	1	1	1
Define storage requirements			5	1	1	3
Conduct QA on feedstock material characteristics			5	1	3	3
Conduct additional feedstock characterisation tests			5	3	3	3
Monitor material supply chain			5	1	3	3
Evaluate material for environmental impact			5	0	1	1
Downselect candidate materials (modelling)			5	0	9	9
Procure ingredients from green mature list			5	0	0	1
Define different oxidisers			5	1	3	3
Define different grades of materials			5	3	3	3
Define different formulations			5	3	9	9
Define different curing catalysts			5	0	3	3
Define Polymer Systems			5	3	9	9
Define different types/grades of fuel			5	3	9	9
Define plasticisers			5	1	3	3
Dowselect material to match new mixing process			5	1	3	3
Optimise crystal packing			5	1	1	3
Optimise fuel/oxidiser ratio			5	1	3	3
Mechanical properties			5	1	3	3
Formulate to enhance blast performance			5	3	9	9
Optimise Binder/Solids Ratio			5	1	3	3
Model Blast Performance			5	0	9	9
Measure Shock sensitivity (FCASW Initiation system)			5	0	0	9
				0	0	0
				145	470	540
Ranking		100		-145	-470	-540

Questions about the Methodologies and Findings