A Structured Framework for Expressing Requirements and Assessing Solutions [1]

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Martin Kaye is an Engineering Executive within Air Systems New Business function of BAE Systems and is based at Warton Aerodrome in NW England. He has over 20 years experience within the Operational Analysis discipline. He is currently the Operational Analysis team leader on the joint Industry and UK MoD and Defence Technology Centre (DTC) for Systems Engineering for Autonomous Systems (SEAS). Most recently Martin led a multi-Business Unit team to study the operational context for autonomous vehicles across all operating domains. The primary purpose of the study was to identify the key characteristics of future autonomous systems and to thereby identify the common critical technologies that are required for their delivery. Previously he was the Engineering Manager for all OA aspects of the UK Future Offensive Air System (FOAS) study contract, and managed the various studies undertaken to support the customer's Initial Gate submission.

INTRODUCTION

This paper presents a framework, called EURECA™, as the basis for analysing activities in the context of new and emerging societal conflicts. EURECA™ was developed as a suitable mechanism to structure and bound requirements analysis, and provide a high-level assessment of possible systems solutions in a military context.

The paper notes how the growing military interest in an Effects Based Approach to Operations (EBAO) is entirely consistent with Civil-Military Co-operation (CIMIC). A significant challenge in both EBAO and CIMIC is how to measure the effectiveness of the operations and actions that are undertaken. It is suggested that Maslow's model of the 'Hierarchy of Human Needs' is a suitable mechanism for identifying and representing Measures of Effectiveness (MOE).

The paper details the overall EURECA™ approach that begins with the characterisation of operations and then by means of relevant user parameters characterises the associated requirements. The requirements are then expressed as a set of Use Cases, or operational instances. The assessment element of the framework uses high-level analysis to:

- Assess the existing capability against the Use Cases to identify capability gaps.
- Assess the capability of possible new solutions against the Use Cases.

The assessment is usually qualitative and made by subject matter experts. Finally the paper shows how links can be made into the more detailed system solution domain and the associated OA modelling hierarchy. This can be extended further into the use of Synthetic Environments for both experimentation, with humans in the loop, and visualisation.

EFFECTS BASED OPERATIONS

The growing military interest in Effects Based Operations (EBO) is to be welcomed as it is an approach that is very applicable to Civil-Military Co-operation (CIMIC). Various organisations have definitions for EBO, a typical one used by the NATO CAFJO (Concept for Allied Future Joint Operations) being "An Effects-Based Approach involves the comprehensive integrated application of all instruments of Alliance's power; both military and non-military, to create campaign effects, which will achieve desired outcomes." The basic approach for EBO is illustrated in Figure 1 below.

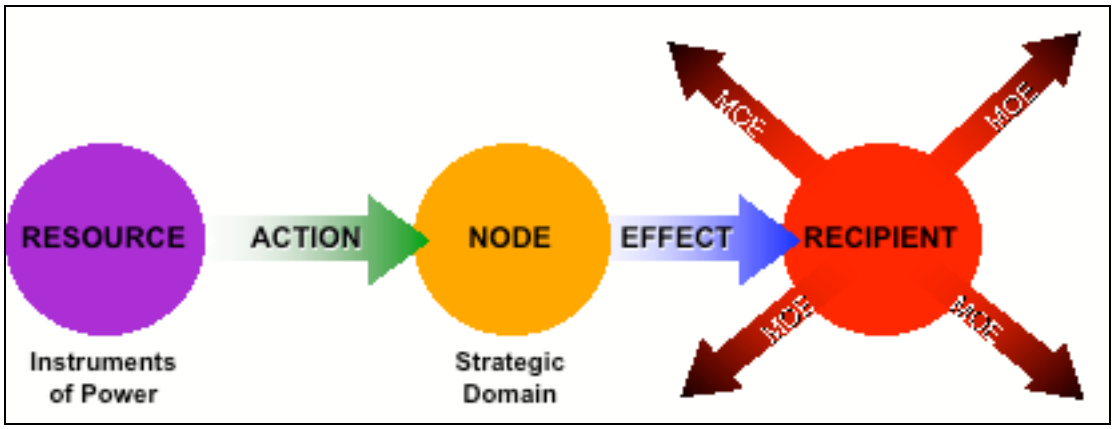

Figure 1: Effects Based Operations.

EBO is concerned with the use of available RESOURCES or Instruments of Power, such as political, diplomatic, economic and military means. More specifically they refer to entities such as brigades, diplomats, food, goods, lawyers, money, politicians, ships, squadrons, etc. These resources are used to perform ACTIONS at a NODE, such as attrite a force, broadcast a statement, build a base, destroy a bridge, distribute aid, impose a sanction, negotiate a treaty, occupy territory, offer a financial incentive, pass a resolution, transport refugees etc. These actions are taken in order to cause EFFECTS that may be physical / functional / systemic such as to deny, destroy, disrupt, restore, fix, establish, negate, neutralize… and/or psychological such as to coerce (deter / compel), demoralize, motivate…

Of interest to both the commanders in charge of the operations and the operational analysts is how the resulting effect on the recipient can be measured. The recipient can be infrastructure or people, both friendly and hostile. It is crucial to be able to measure the effect to determine whether the strategic objectives agreed prior to the start of operations are being achieved. With knowledge of the effectiveness of the operation to date it is possible for the commanders to make informed decisions about the next activities to be undertaken. For example it may be necessary to increase the resources available to achieve the objectives, or it may be possible to reduce the level of effort.

MEASURES OF EFFECTIVENESS

Military measures of effectiveness are well understood by those who are members of the armed forces or work in the relevant areas of the defence industry. The same individuals, however, probably have less understanding of the factors that influence people's needs and motivations. An understanding of these would appear to be necessary if we are to be able to measure the effectiveness of joint civil-military operations, particularly in Operations Other Than War (OOTW).

Many theories have been put forward. Of these the 'Hierarchy of Human Needs' proposed by Abraham Maslow would appear to be appropriate for measuring the effectiveness of operations in OOTW. Maslow theorised that whatever needs a person is currently experiencing are the primary influences on the individual's motivations, priorities, and behaviour. A need creates tension, whether pleasant or unpleasant, and the goal of the resultant behaviour is the reduction of the tension or discomfort. Needs and motives are related. A need is a deficit. A motive is a need or desire coupled with the intention to attain an appropriate goal, i.e. people are motivated to work in order to satisfy needs. Only unsatisfied needs are prime sources of motivation.

An understanding of an individual's behaviours and goals provides insight into the person's unsatisfied needs, and vice versa. Maslow developed a method of categorising basic human needs. He placed them in a hierarchical structure containing five groups of needs (or need systems), from primitive or immature (in terms of the behaviours they foster) to civilised or mature needs. He speculated that individuals fulfil needs in ascending order from most immature to most mature. This progression is analogous to climbing a ladder, when the individual must achieve secure footing on the first rung in order to step up to the next rung. Although each need may not be met completely, it must be at least partially fulfilled to relieve the tension of that need and to free the individual to pursue the next-highest level. Maslow depicted this progression by means of a five-level pyramid or triangle, as shown in Figure 2. The need systems are in ascending order, with the most basic level at the bottom.

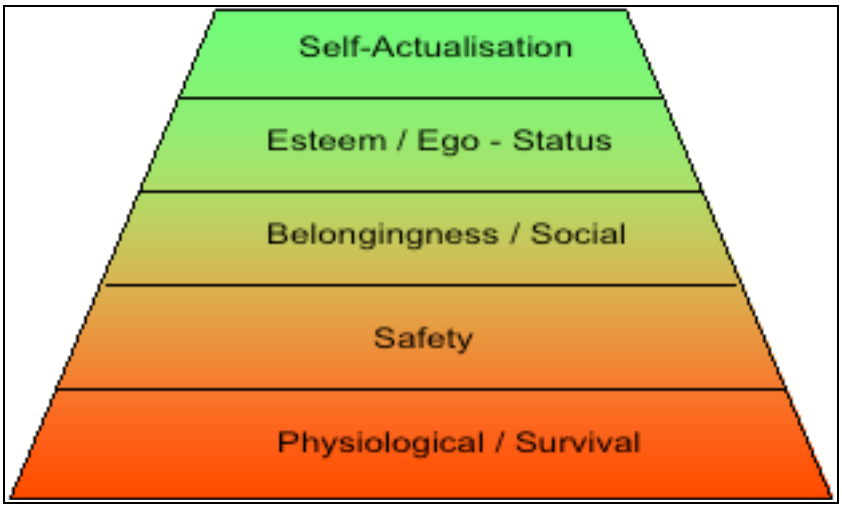

Figure 2: Maslow's Hierarchy of Human Needs.

Maslow also believed that people have an internal need pushing them toward self-actualisation (fulfilment) and personal superiority. However, the prioritisation of needs suggests that one must meet lower-level needs before one can focus on higher-level ones and progress to self -actualisation. The five levels of needs are as follows:

- Basic Survival needs include physiological (bodily) needs such as the requirements for food, water, shelter, clothing, sleep, sex, and so on. The goals range from basic survival to the avoidance of physical discomfort. In our society, they may even include the attainment of a pleasant environment and what we call "creature comforts." If one's survival needs are met, one focuses on comfort. When one is physically comfortable, one thinks about a "better" house or car, a more functional office, etc.

- Safety needs include security, orderliness, protective rules, and avoidance of risk. These needs extend not only to actual physical safety but to safety from emotional injury as well. Many of these needs are met in our society through safe working conditions, adequate salaries, insurance policies, pension plans, safe neighbourhoods, burglar-alarm systems, police protection, medical check-ups, immunisations, and other preventive measures.

- Belongingness/Social needs create tension when safety needs have been met to an adequate degree. These are the first interpersonal needs to be felt after the personal needs (Survival and Safety) have been met. One becomes less preoccupied with taking care of oneself and endeavours to form interpersonal relationships. The desire to be accepted and liked by other people, the need for love, affection, and affiliation (or belonging) centre around one's interactions with others. This also includes the need to feel appreciated by others. Attainment of this goal is facilitated by family ties, friendships, and membership in work and social groups.

- Esteem/Ego-Status needs are an individual's desires to be perceived as worthy by self and others, to gain status within groups, and to excel. This category also includes the needs for special recognition, social and professional rewards, promotions, awards, power, and achievement. One manifestation of this type of need is ambition. Such needs motivate the individual to seek out opportunities to display competence. They usually cannot be met until the individual has satisfied the Belonging need and feels accepted by some group.

- Self-actualising needs, the highest level and the most difficult to satisfy; include the needs for personal development and self-fulfilment. A person who has satisfied the Ego-Status needs may feel the need for creative expression, personal growth, and challenge. One may fulfil this need by challenging oneself to become more creative, to achieve more, and to measure up to one's own criteria for personal success. One is no longer dependent on the good will of others, nor does one attempt to meet their standards. At the Self-Actualisation level, a person is able to strive for his or her own "personal best". Self-actualising behaviours are growth-motivated, not deficiency-motivated; they include risk taking, seeking autonomy, and developing freedom to act. True self-actualisation cannot be achieved without taking

risks and accepting that the individual alone has the freedom and the responsibility to make choices and work toward goals.

It is not expected that any need is ever completely satisfied; rather, Maslow indicates that there must be at least partial fulfilment before an individual can become aware of the tensions created by a higher-order need and have the freedom to pursue its fulfilment.

Regarding CIMIC operations it would appear that actions taken will be focussed on the bottom three levels of Maslow's hierarchy, and in particular the bottom two concerned with Survival and then Safety. Considering these bottom two levels it is possible to identify a considerable number of metrics or measures of effectiveness to quantify the effects of actions being taken. It is crucial that it is possible to monitor the MOEs with the assets that are available, noting that the available assets will vary during the course of operations. For example it may be relatively simple for an electricity utility to determine what percentage of towns in a province have electricity, or for what proportion of the day it is available. Whereas to determine what percentages of dwellings have a roof or running water may actually mean a door to door survey.

EURECA™ FRAMEWORK

EURECA™ stands for the 'Evaluation of User Requirements by Effects-based Capability Analysis'. EURECA™ was developed initially by BAE Systems and then expanded in joint work with UK MoD. The approach was developed as a way to meet the following objectives:

- Capture in a structured and traceable manner, today's snapshot of the Capability Requirements together with the Customers view of their relative importance.

- Support the Customer in forming opinions of the possible solutions to the above requirements and hence understand the likely requirement viability.

- Baseline the relative confidence in the above views and hence provide focus for further analysis,

The approach was to adopt a single framework whereby both military requirements expression and system capability assessment could be simply measured and mapped. This concept enables the capture of requirements, or aspirations, and also the assessment of current system capability to identify the capability gap in an easy to interpret manner. Furthermore it would enable an initial appraisal of prospective solution candidates to ensure they provide capabilities against the gaps identified. The basic approach is shown in Figure 3.

A small number of top level principles governed the development and implementation of the framework, namely:

- The spectrum of capabilities are initially described in functional terms (based upon the OODA cycle) structured by where the effect is required to be applied, not from where it is carried out.

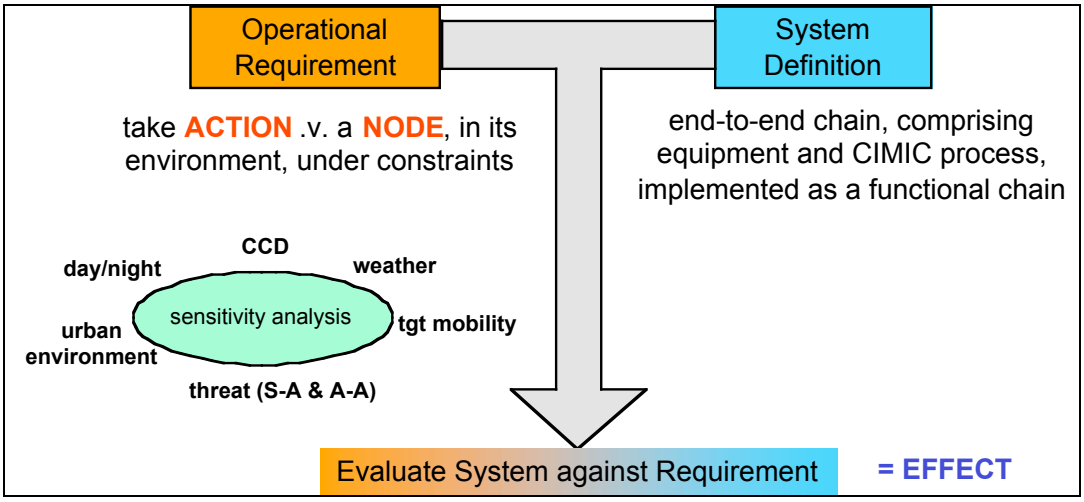

Figure 3: EURECA™ Approach.

- Each high level task, referred to as a Battlespace Task, is characterised by an appropriate set of User Parameters, which are strictly expressed in User terms with no reference to how the requirement may be met.

- The parameter set is kept to the minimum necessary number, considering only the first order factors in each case. The parameters should be mutually independent wherever possible.

- The parameter structures and any requirement captured in them must be wholly Customer owned.

- Use Cases, which are selected combinations of User Parameters, describe the nature and difficulty of the spectrum of operational tasks within the higher level Battlespace Tasks.

- System capability assessment is kept as far as possible to a relatively straightforward compliance mapping of systems (via their functionality / performance) against the defined Use Cases.

EURECA™ uses a structured decomposition to express requirements. The first stage of the decomposition concerns the components that contribute to capability. These are shown in Figure 4. The main components that have been considered to date are those concerned with 'Operate' and in particular those to do with the OODA cycle, namely 'Observe', 'Disseminate' (Orientate), 'Command' (Decide) and 'Effect' (Act).

BATTLESPACE STRUCTURE

The overall set of military operations in the battlespace are structured into a matrix of battlespace tasks as described in Figure 5.

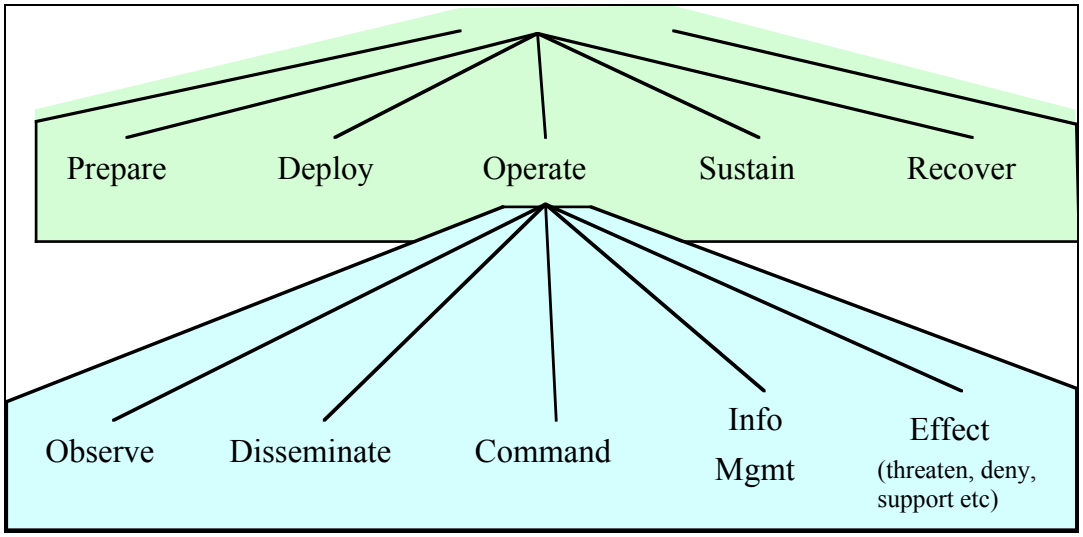

Figure 4: Capability Components.

			Task					
		Characteristic	**C2I2**	**Comms**	**ISR**	**Deny**	**Occupy**	**Support**
Battlespace Area	Ground	Friendly/Home						
		Close/Contested						
		Deep/Hostile						
	Above (Ground)	Friendly/Home						
		Close/Contested						
		Deep/Hostile						
	Below (Ground)	Friendly/Home						
		Close/Contested						
		Deep/Hostile						
	(Water) Surface	Friendly/Home						
		Close/Contested						
		Deep/Hostile						
	Above (Water) Surface	Friendly/Home						
		Close/Contested						
		Deep/Hostile						
	Below Surface	Friendly/Home						
		Close/Contested						
		Deep/Hostile						
	Space	Standard						
		Survivable						

Figure 5: Battlespace Action Structure.

Each battlespace task is a military action, which either takes place in, or is associated with a battlespace domain. A battlespace domain is characterised by a physical region and a zone. The military actions, regions and zones considered are as follows:

- Four battlespace military actions have been considered which are based on the OODA cycle. These are the military functions to: *Observe, Disseminate, Command* and *Effect*.

- Seven battlespace regions have been identified within which military actions may take place. These are the physical environments of:*Ground, Above*

Ground, Below Ground, Surface (Water), Above Surface (Water), Below Surface (Water) and *Space*.

- Three battlespace zones have been assumed which reflect the 'ownership' or dominant control of the battlespace region. These zones are particularly relevant to ground and above ground military actions and are: *Home/Friendly, Close/Contested* and *Deep/Hostile*.

As an example, a battlespace task would the be to: *Observe ground targets in a deep hostile domain*

DECOMPOSITION OF BATTLESPACE TASKS

Each battlespace task represents a top-level military action in a specific battlespace domain. For each battlespace task the first step is to characterise the operations (missions) which could take place. In order to describe an operation, a set of mutually independent key parameters must be identified which adequately capture the relevant operational issues. These parameters are referred to as the User Parameters and describe what the User wants to achieve. They take one of three forms, an objective, a constraint or a dependency.

	OBSERVE TARGET PARAMETERS	Requirement Values			
		EASY	MEDIUM	HARD	GROWTH
General Characteristics	Area Of Interest	Small	Medium	Large	Theatre
	Function	Fixed	Relocatable	Mobile	
	Depth	D_1	D_2	D_3	
Behaviour	Signature Manipulation	None	Canopy	Camouflage	Concealed
	Window Of Opportunity	Continuous	Regular/Hours	Irregular/Hours	Random/Minutes
Environment Characteristics	Weather	Clear	Broken Cloud	Heavy Cloud	Heavy Rainfall/Snow
	Terrain	Flat	Undulating	Mountainous	
	Day/Night	Daylight	Bright Moonlight	Starlight	
	Environment Sensitivity	None	Limited	High	
	Clutter Environment	Distinct	Some	Cluttered	
Object Signature Characteristics	RF Emissions (ELINT)	High Power	Low Power	LPI	None
	RF Emissions (COMINT)	High Power	Low Power	LPI	None
	Thermal Contrast	High	Medium	Poor	None
	Visual Signature	Highly Reflective	Medium	Poor	None
	RCS	Large	Medium	Small	None
	Acoustic	Loud	Medium	Soft	None
Other Indicators	Surrogate Movement	Continuous	Regular/Daily	Irregular/Weekly	None
	Surrogate Communication	Continuous	Regular/Daily	Irregular/Weekly	None
	Surrogate Thermal Signature	Strong	Weak	None	
	Surrogate Visual Signature	Clear	Partial	None	

Figure 6: Observe User Parameters.

Each User Parameter should be qualified by a number of values or possibilities, which further describe the operation in terms of level of increasing difficulty. Up to four levels may be defined reflecting - relatively easy, moderate or difficult, or growth. For example: the area of interest to be covered by an observation may range from a few km^2, through hundreds of km^2, to many thousands of km^2. An example decomposition is shown in Figure 6 for Observe

User Parameters. As part of the process it is necessary to accurately record definitions and assumptions so that the process can be used, and developed further, possibly by different groups of people. Figure 7 shows definitions of the communicate parameters that are used to express the 'disseminate' requirement.

	Communicate Parameter	Definition
Time Criticality Issues	Data Priority	The importance of the observe data to be transmitted expressed in terms of the relative time needed for exploitation by A-G tasking
	Depth Of Operation	Contact battle is Close, 2nd echelon forces etc are in Interdiction Zone, Deep is beyond range of stand-off S&R assets and further divided into depths D1,D2 & D3
	Level Of Decision Making	Low level decisions are tactical and are made at a local level. High level decisions have strategic implications and are made at the centre. Between these sit operational level dicisions which may be delegated (decentalised). Strategic decisions by coalitions may involve leaders at a number of locations anywhere in the world.
	Location Of Decision Making	Tactical decisions may be made at the local level. Operational decisions may be made in theatre. Strategic decisions may be made outside theatre anywhere in the world
Operational Issues	Comms Detection By Enemy	The acceptability of any transmission of observe data being detected by the enemy
	Background Comms Intensity	The level of own comms into which the new message must be inserted
Data Properties	Source Data Quantity	The total amount of raw data obtained by the observe task.
	Data Quality Acceptability	The acceptability to the recipient of less than perfect data
	Interoperability	The suitability of the observe data (raw/final) for use by different organisations.
Environment Characteristics	Weather	Is about signal attenuation due to the amount of water in the atmosphere
	Other Obscurants	Is about signal attenuation due to solid particles in the atmosphere
	Terrain	Gross physical environment characteristics

Figure 7: Disseminate Parameter Definitions.

USE CASES

A Use Case is an operational task description expressed as a combination of User Parameters and is constructed by picking one value for each Parameter. The choice and selection of these operational tasks is entirely open, however, collectively they must reflect the spectrum of possibilities, from relatively easy to relatively hard, likely to be encountered in military operations. In theory, the possible number of Use Cases is very large (product of all parameter levels) and it is therefore important to select a relatively small set of Use Cases important to the Customer.

Each Use Case must also convey something of the operational objective and the approach taken has been to incorporate this in the textual description of the Use Case. For example: looking for evidence of battle damage to a previously attacked building describes one Observe Use Case, whilst looking for evidence of which buildings are being used and which are empty describes another. Two sample Observe Use Cases are shown in Figure 8.

REQUIREMENTS PRIORITY

It is important to capture, for each Use Case, the customer's essential, desirable and aspirational requirements. In order to do so the customer is asked to consider each Use Case under a number of increasingly severe operating conditions and to score his requirement preference. By mapping the Use Cases against an appropriate constraint a two dimensional matrix results for which each cell may be colour coded to reflect priority. This allows Customer Requirements to be visualised in Excel spreadsheets and underlying rationale captured in cell comments, as shown in Figure 9.

	OBSERVE TARGET VARIABLES	Industrial Complex		Leadership Personnel	
		Observe the process flow associated with a widely distributed military industrial complex. Establish the functions of individual sites and individual buildings. Observe which buildings are being used and those which appear to be empty/potential decoys.		Look for evidence of military leadership who move location daily within a city environment. Intercept military comms and then triangulate for location or HUMINT	
General Characteristics	Area Of Interest	Large	(Hard)	Medium	(Medium)
	Function	Fixed	(Easy)	Relocatable	(Medium)
	Depth	D3	(Hard)	D3	(Hard)
Behaviour	Signature Manipulation	None	(Easy)	Concealed	(Growth)
	Window Of Opportunity	Continuous	(Easy)	Regular/Hours	(Medium)
Environment Characteristics	Weather	Clear	Clear	Clear	(Easy)
	Terrain	Mountainous	(Hard)	Undulating	(Medium)
	Day/Night	Daylight	(Easy)	Starlight	(Hard)
	Environment Sensitivity	High	(Hard)	High	(Hard)
	Clutter Environment	Distinct	(Easy)	Some	(Medium)
Object Signature Characteristics	RF Emissions (ELINT)	None	(Growth)	None	(Growth)
	RF Emissions (COMINT)	None	(Growth)	None	(Growth)
	Thermal Contrast	Medium	(Medium)	Medium	(Medium)
	Visual Signature	Highly Reflective	(Easy)	Highly Reflective	(Easy)
	RCS	Large	(Easy)	Large	(Easy)
	Acoustic	None	(Growth)	None	(Growth)
Other Indicators	Surrogate Movement	Regular/Daily	(Medium)	None	(Growth)
	Surrogate Communications	Regular/Daily	(Medium)	Regular/Daily	(Medium)
	Surrogate Thermal Signature	Strong	(Easy)	None	(Growth)
	Surrogate Visual Signature	Clear	(Easy)	None	(Growth)

Figure 8: Observe Use Cases.

		Threat Level			
	Use Case	None (PSO)	Low	Medium	High
1	Industrial Complex	5	5	3	0
2	Leadership Personnel	5	5	5	3
3	etc	5	5	5	3
4		5	5	5	3
5		5	5	5	3
6		3	3	3	0
7		5	5	5	5
8		5	5	3	3
9		5	5	5	5
10		5	3	1	0

Key	
5	Essential
3	Desireable
1	Aspirational
0	Not Relevant

Figure 9: Requirements Priority.

SOLUTION COMPLIANCE MAPPING

The final step in the process is to assess, for each Use Case, whether a current system or postulated future system can or cannot do the task or could possibly be made to do the task subject to further conditions. Again system solutions may be scored against the Use Case versus Operating Condition matrix. Scoring is usually done by subject matter experts (SME) with possible use of some simple models or spreadsheet type tools. Obviously more detailed analytical methods can be used to assess some particular aspects. This is more likely for new and significantly different Use Cases that have not been considered in the past and hence there is little subject matter experience available.

The technique not only enables a solution's compliance against Customer Requirements to be visualised it also enables the comparative capabilities of different solutions to be visualised as shown in Figure 10 which shows the assessed capability of a single solution against the 4 threat levels.

		Threat Level			
Use Case		None (PSO)	Low	Medium	High
1	**Industrial Complex**				
2	**Leadership Personnel**				
3	**etc**				
4					
5					
6					
7					
8					
9					
10					

Figure 10: Solution Compliance Mapping.

Using a common structure to present both the Customer's requirement together with its priority and an appraisal of solution capability enables a ready visual comparison of the two via a simple mapping.

It is important to note that the EURECA™ framework and the processes used to populate the assessments are completely independent. Time and resource constraints will dictate the fidelity of analysis conducted. In summary, the following discrete steps and the process routemap in Figure 11 describe the application of the EURECA™ process:

- Characterise military operations into distinct actions and regions.
- Select the Battlespace Task of interest.
- Characterise the Requirements of the Battlespace Task using User Parameters.
- Formulate the Use Cases (Military Operations) of interest within the Battlespace Task.

- Establish priority of Customer requirements Against the Use Cases.
- Assess the solution (legacy or new) system Capabilities against the Use Cases.
- Compare system capabilities against requirements to establish solution compliance or capability gaps.

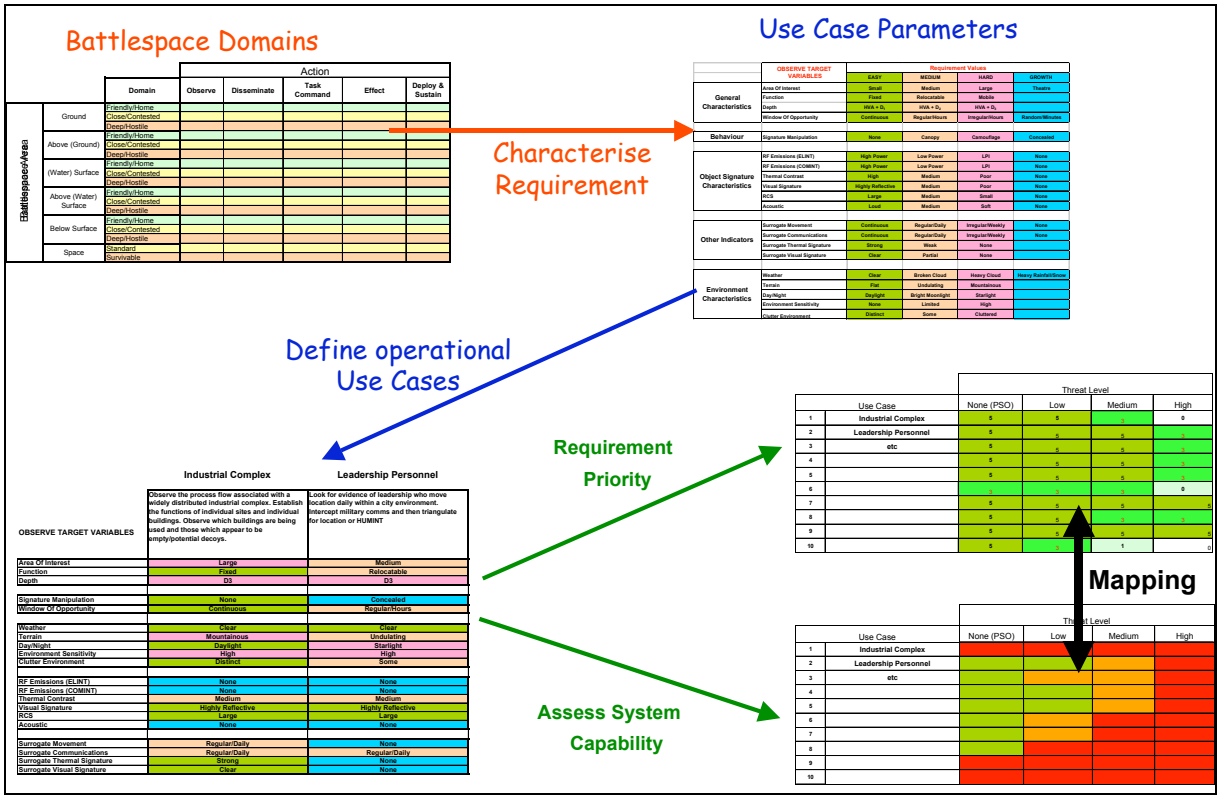

Figure 11: Overall Process Routemap.

LINKS TO SYSTEM SOLUTIONS

The EURECA™ framework provides a link to the system solutions and hence to the overall design process. As the analysis of requirements matures, it is possible to quantify and set target values for the User Parameters. It is then possible to specify system performance parameters. This is done by establishing a relationship between the User and System Parameters, as shown in Figure 12 for some of the parameters relevant to the observe function.

SUMMARY

EURECA™ provides a framework and process for structured analysis of problems, it allows:

- "Top down" decomposition of operational problems to understand issues, identify user capability needs and drive out key system requirements.

- "Bottom up" assessments of solutions to assess achieved capability.

It provides a direct link to an Operational Analysis modelling hierarchy, which in turn allows the use of the following.

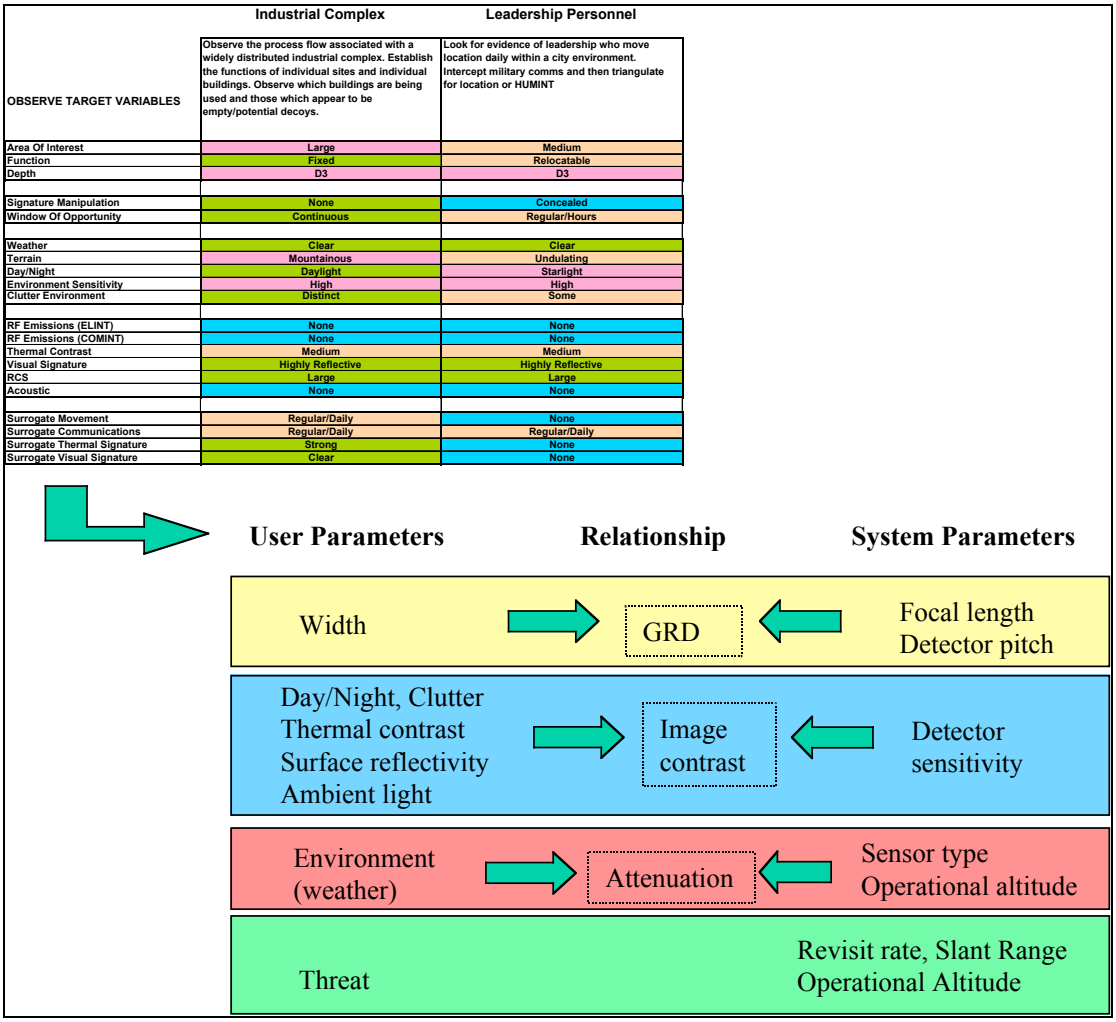

Figure 12: User and System Parameter Mapping.

- Qualitative analysis and quick look models for cost effective exploration of large solution spaces and prioritization of issues for closer investigation.

- Detailed modelling and simulation to provide quantification of requirements, support of trade-off studies, and measurement of delivered capabilities.

Beyond the OA modelling it is possible to run Synthetic Environment (SE) experiments which complement the traditional offline, non real-time OA methods. SE experiments allow:

- Analysis of human-machine interface issues, particularly workload.

- Rapid exploration of concepts of operation / tactics, especially in highly complex and dynamic environments.

- Visualisation and demonstration of capability in a real world context.