Spectrum Management in the acquisition of equipment

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Abstract

Military spectrum management is becoming increasingly challenging as many civil and military users compete for scarce resources. The paper identifies and illustrates the problem by example. It then describes some novel methods in requirements and benefits analysis, to inform equipment acquisition decision-makers on the delivery of spectrally efficient solutions to provide a coherent approach to UK spectrum management. The application of the methods is reported and a proposed solution to raise awareness within the wider community is described.

1 Introduction

1.1 Overview

1.1.1 This paper describes work being conducted as part of the UK MODs Research Programme into the management and use of the Electromagnetic Spectrum. It reports two high-level modelling and analysis studies underway designed to support the spectrum acquisition process and also raise awareness of pertinent spectrum issues. It also references ongoing work supporting the provision of spectrum congestion guidance to projects. The starting point for this work programme is the assertion that spectrum use is expanding and that the battlespace spectrum is already crowded in the heavily used military bands.

1.2 Aim

1.2.1 The aim of the paper is to describe work on analysis methods that are currently being developed to support the UK military equipment acquisition process but may have wider application internationally where the emphasis is now on expeditionary and coalition operations. Sharing this work in a wider community of interest may foster initiatives to discuss the problems internationally in order to reach a solution. The EM environment does not respect borders and without a common effort, military spectrum congestion will remain an impediment to future military operations.

1.3 Scope

1.3.1 This paper covers three studies:

- Requirements analysis
- Benefits analysis
- Spectrum congestion guidance

1.3.2 The methods used for data collection are also covered.

1.4 Background

1.4.1 Historically, the EM spectrum has been viewed as an almost infinite resource and military acquisition programmes have assumed its availability. Burgeoning military programmes with high bandwidth needs have in recent years invalidated this assumption. This is exacerbated by nations selling off bandwidth to commercial users and restraining further in-roads by the military. Civil Spectrum use is expanding near exponentially, creating pressure on the Military to release bandwidth. Perversely, available military spectrum is reducing at the same time as the military spectrum consumers (communications, sensing and Electronic Warfare (EW) systems) are becoming one or two orders of magnitude more demanding in their spectrum needs. Hence, defence capability will continue to rely on ensuring sufficient access to, and efficient use of, the EM spectrum.

1.4.2 Currently EM spectrum management entails co-ordinating friendly forces' use of the spectrum in order to minimise the risk of electronic fratricide or interference in-theatre. EM spectrum management becomes even more complex when operating within a coalition who may not share equipment, doctrine or procedures but, with whom, interoperability is essential. Thus, there is a requirement to be able to scope and, if possible, optimise the EM spectrum demands of potential new systems to maximise spectrum exploitation, whilst preventing interference and reducing vulnerabilities that may arise from hostile disruption to that spectrum.

1.4.3 The EM spectrum demand of a system is largely determined by its system design and, to a lesser extent, by its operational pattern of use. System design may not be finalised until late in a system's procurement cycle and its operational use will undoubtedly evolve during its in-service life. Hence, the MoD requires the ability to model the current/predicted use of the increasingly constrained EM spectrum to preserve and, where feasible, optimise defence capabilities that are dependent upon its use.

1.4.4 The changing nature of warfare, including the introduction of a networked information environment**,** means operations are conducted at a faster pace than before and spectrum requirements are increasingly dynamic in nature and more difficult to predict. Situational awareness is key to decision and information superiority and may only succeed if we develop a multi-dimensional ability to manage spectrum (code, time, space, frequency, and power). Future systems aspire to concepts such as Software Defined Radios and are inherently flexible whilst older systems have little scope for change.

1.4.5 The current method of spectrum management is heavily reliant on slow and relatively inflexible processes, de-conflicting by frequency alone. Whilst this was previously adequate, as newer systems come on-line, users will be presented with an increasingly complex spectrum management problem as they strive to achieve coherence. From a spectrum perspective, this is difficult to achieve if projects continue to assume that spectrum is available for their systems as required.

1.5 Structure of the paper

1.5.1 This paper starts by presenting a brief overview of the problem addressed together with two examples where spectrum congestion issues are likely to become acute in the near future. It then describes two of the analysis methods being developed in the UK to support the MOD equipment acquisition process. A description of the data collection methods used or being developed is also included within this. The results generated when these methods were applied to existing equipment programmes for initial validation purposes are then discussed. The last sections of this paper contain a summary of the conclusions reached so far, the recommendations that have been made and an overview of further work being undertaken.

2 Spectrum congestion – today's problem

2.1 Introduction

2.1.1 Based on some of the key factors that need to be considered for an assessment of spectrum usage, this section of the paper aims to provide two examples within the existing problem space that illustrate, particularly the issue of spectrum congestion, but also other spectrum issues pertinent to today's battlefield.

2.2 Key Factors

2.2.1 In order to understand the problems that we face with spectrum congestion and the measures that can be taken to counter this, we need to understand a variety of factors. These can be split into a number of categories:

- The drivers for Information Exchange Requirement (IER) increase;
- The Technical Factors associated with spectrum use;
- The system (of Systems) level elements contributing to potential solutions;
- The process issues contributing to the problem.

2.2.2 Each of these areas is briefly addressed below.

2.3 Information Exchange Requirement (IER) Increases

2.3.1 There are a multitude of reasons for increasing IERs, some military and some associated with commercial information technology advances.

2.3.2 A prime candidate is the rapid increase in sensor performance coupled with an increase in the number of sensor platforms deployed in the modern battlespace. The increase in resolution and hence military utility, together with the decreasing size, weight and cost of, for instance, Synthetic Aperture Radar (SAR) and Electro-Optic (EO) sensors has resulted in larger IERs to transport this information in the battlespace. Programmes currently in the planning stages envisage deploying sensors in ever more capability areas. Changes in the types of operation that the military are undertaking and the associated rules of engagements in the future are also driving these IER volume requirements, e.g. "man in the loop".

2.3.3 Most government defence organisations worldwide have programmes comparable to UK Network Enabled Capability (NEC) or US Network Centric Warfare (NCW). The ability for military forces to achieve goals for synchronised operations, effects based operations and increased tempo, relies on faster Command and Control and massively improved Situational Awareness. With the development of co-operative capabilities a number of platforms acting together deliver a capability greater than the sum of the parts. It is reasonable, therefore, to suppose that spectrum usage and congestion will increase.

2.3.4 Developments in the commercial IT and IS arena are impacting on the military domain in at least four ways. Firstly Commercial Off The shelf (COTS) technology, particularly software, is not subject to the same constraints as deployable military technology. COTS software, for example, is largely intended for deployment in bandwidth rich, fixed (wired), Local Area Network (LAN) and Wide Area Network (WAN) environments. Secondly the expectations of the military are influenced, if not driven, by the civilian technology they use every day such as cell phones, PDAs and WiFi. Thirdly, the low cost of commercial technology makes it attractive for military use in comparison with technology specifically designed for the battlespace. Finally, the commercial needs for spectrum are encroaching on bandwidth that has traditionally been used for Military and Government purposes.

2.3.5 The above discussion is not exhaustive but is certainly illustrative.

2.4 Technical Factors

2.4.1 For the purpose of analysis, technical considerations associated with spectrum use can be conveniently separated into the RF (the physical layer), the networking and the application layer.

2.4.2 RF considerations associated with spectrum allocation and reuse are the traditional areas of, for instance; modulation scheme, RF power, Frequency, directionality and multiplexing method. These factors contribute to spectrum congestion and are usually considered in any plan for spectrum usage.

2.4.3 Network factors include routing, prioritisation, Quality of Service (QoS) requirements and congestion control. In modern “waveforms” these functions are often linked with the RF implementation. Congestion information in the network layer could be used to control the RF data rate.

2.4.4 At the application layer the key issue is the rate at which data is generated. The technical factors are all to do with appropriate and efficient data generation. Appropriate data and processing can be controlled by the amount data transmission bandwidth available. A specific example is the use of dynamically controlled compression.

2.4.5 These factors illustrate the need for the problem of spectrum use to be viewed holistically. Application and network designers need to consider spectrum constraints if appropriate system design is to be achieved and dialogue between the various communities is essential.

2.5 Systems (of Systems) Level Issues

2.5.1 The term Systems Level in the context of this document is a view of multiple systems using spectrum. At the systems level, various military capabilities (and platforms) come together, each potentially using spectrum in different ways. The key issues at this level are that spectrum use is managed such that military goals can be achieved seamlessly and efficiently; that interoperable security functions allow efficient use of spectrum, and that systems are agile enough that efficient network configurations can be adopted. These points are expanded in the following paragraphs.

2.5.2 Spectrum management across multiple capabilities/platforms and ultimately across the battlespace, is required in the first instance to ensure that RF use is possible with little conflict. It is with this in mind that the current UK Battlespace Spectrum Management System is being designed. In the future spectrum management systems will need to be increasingly dynamic, allowing communications agility to be achieved. Concepts such as Freedom of Spectrum Manoeuvre and Agile Mission Groups will demand this increase in dynamism and other concepts such as Spectrum Situational Awareness will contribute to its achievement. The research work needed to achieve these advances in spectrum management is currently being ramped up. There are unlikely to be any easy answers, the answers will be a synthesis of techniques and technologies.

2.5.3 It is also necessary to formulate policies for waveform adoption, technologies that enable interoperability and roadmaps that allow legacy platforms to participate in the networks. The technologies will include Software Defined Radio, cognitive waveform selection, frequency agile RF broadband antenna technologies and advanced RF filtering techniques. In the UK work is starting on the development of various roadmaps e.g. for Intelligence, Surveillance and Reconnaissance (ISR) and weapon datalinks.

2.5.4 The International defence community also needs to jointly address spectrum issues since the EM environment is a shared asset. It is not only shared between military coalition partners, but uniquely is also utilised by civilians and the Enemy forces.

2.6 Examples of spectrum congestion

2.6.1 This section ends with two examples aimed at illustrating some of the more fundamental problems that exist. The first relates to military use of the 225-400MHz band, the second to Ku band used for Common Data Link (CDL) and Tactical Common Datalink (TCDL). These examples have not been rigorously analysed. It is intended that they provide a brief description of the problem and hence provide some context for the following sections of the report.

Example 1: Congestion in the 225-400MHz Band

2.6.2 This band provides very useful spectrum for military purposes. It has the following features:

- The band is frequencies are potentially wide enough to carry high data rate traffic (>1MB/s).
- The propagation properties are useful for Line Of Sight (LOS) traffic using omni-directional antennas.
- The technology is relatively cheap.
- The wavelengths are short enough that where required directional antennas are manageably sized.
- It can be used for Satellite communication with affordable ground terminals.

2.6.3 With these attractions the band has become increasingly congested. The users include the following (planned programmes are in italics):

- Military Air radio (Havequick II, Saturn etc.) Fixed frequency and Frequency Hopping.
- Battlefield Trunk Radio (Ptarmigan <1MB/s, Cormorant >1MB/s, *Falcon >1MB/s*).
- Higher data rate overlays for Combat Net Radio (US NTDR, *UK HCDR*).
- UHF Satcom Systems (UK Skynet4/*5*, Nato IV, US FltSat, *MUOS*).
- High data rate point to point systems.
- UAV C^2 & Datalinks.
- UHF glide path component of Instrument Landing System.
- *Loitering munitions C^2 and Datalinks.*

2.6.4 Spectrum management is exacerbated by frequency hopping systems (spectrum splatter), high data rate systems using omni-directional antennas and air platforms at high altitude with long and pervasive LOS ranges.

2.6.5 This indicates the need for effective frequency management and careful consideration before new capabilities and platforms are introduced into this band. The example also shows the need for international co-operation to ensure coalition operations can be effective with minimal mutual interference.

Example 2: CDL and TCDL in Ku Band

2.6.6 CDL and TCDL are communication systems used as Air to Ground imagery datalinks. Current CDL/TCDL can provide data rates from ~10MB/s up to 274MB/s with high occupied bandwidth. The system can operate in either Ku allocations or in X band allocations. As currently in service this would allow for approximately 5 channels in X band or 6 channels in Ku band for TCDL and the narrowest mode of CDL. At the highest CDL data rate insufficient contiguous bandwidth exists for even one channel when other users of the band are taken into account. Range factors for omni-directional capability would allow frequency reuse at 300km separation. In practice, highly directional antennas are used on large platforms and for the ground segment. It is generally necessary for small platforms to use omni-directional antennas reducing spectral efficiency. Achievement of LOS in difficult terrain and for range extension may require use of a relay, which may double the channel capacity required. The implication of all this is that providing the number of platforms using the band in close proximity is limited, with good LOS signal paths, the systems may well work well at lower data rates. If however the higher data rates are required, the density of platforms increases, other systems require space in the same frequency band or relay capacity is required to alleviate LOS issues then the band will very quickly become overused.

2.6.7 TCDL and CDL offer excellent capacity for the Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) community, so without other considerations they would be an attractive choice. Consideration needs to be given to the merits of introducing changes to the standards to improve the occupied bandwidth by various means, introducing active power control and allowing lower data rates when these would suffice. In the longer term the use of this technology could benefit from the introduction of some form of network overlay that allows some degree of cognitive or demand assigned spectral usage to be introduced. It also needs to be co-ordinated across the coalition if these capabilities are to be used effectively. It is also worth noting that there is increasing commercial pressure to change the usage of the government X-band allocation the result of which could be the loss of this band.

2.6.8 This example indicates the need to carefully consider the implications of introducing new platforms using pervasive spectrum usage into the battlespace.

2.7 Key points

2.7.1 Both military and civilian spectrum usage is increasing rapidly. If overall military capability aims are to be achieved then all aspects of spectrum usage needs scrutiny. This scrutiny should include in-service capabilities and planned and future programmes.

2.7.2 The above discussion attempts to demonstrate the complexity of the problem and that with correct choices the problem is manageable. The most important issue is how to make these choices in a complex decision space. The solutions are likely to be a complex synthesis of technology, awareness and concepts of use. Even the technology required covers more than just the RF. Rather, it is a complex interplay of RF, Networking, application layers, data processing and sensor technologies.

2.7.3 The subject of this paper is, primarily, to describe the development of analysis tools to allow the spectrum issues to be objectively examined and the range of possible solutions to be assessed. This analysis is essential if the correct decisions are to be achieved in this complex environment.

3 Analysis methods

3.1 Context for the analysis

3.1.1 The process by which UK military equipment is provided is termed Smart Acquisition[1]. The acquisition cycle is sometimes referred to as the CADMID cycle to reflect the successive phases of, Concept; Assessment; Demonstration; Manufacture; In-Service; and Disposal as illustrated in figure 1.

[1] As defined by 'The Acquisition Handbook', published by the MOD, Edition 5-Jan 2004 (www.ams.mod.uk)

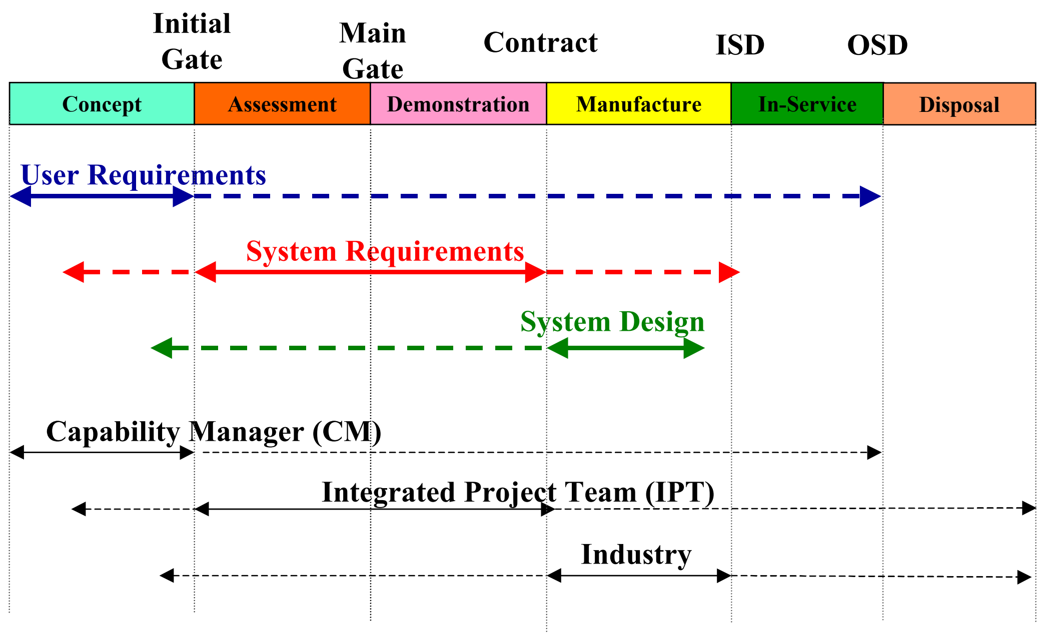

Figure 1 MoD Acquisition Cycle

3.1.2 Specification of the system begins during the Concept Phase with the development of a User Requirement Document (URD) and a Concept of Employment (CONEMP) which identifies how the capability will be used, and critically from a spectrum perspective, the numbers of nodes/stations to be deployed as part of the system as it is the impact that the system will have on the spectrum which is important and not the impact of a single equipment. During the course of the CADMID cycle, the documentation is refined providing increasing granularity and tighter bounds. The Concept is developed and becomes a Concept of Use (CONUSE) which defines an outline System Requirement Document (SRD). Ultimately, the CONUSE is further refined and enhanced into a Concept of Operations (CONOPS) and a full SRD is developed.

3.1.3 The SRD forms the basis of the Statement of Work against which industry is invited to bid for the work. However, it is intended to provide industry with the maximum flexibility to introduce technological innovation late in the lifecycle. This will shorten the time taken to procure systems whilst reducing cost and increasing performance. Hence, the SRD provides broad guidance rather than detailed specification of architectural design. Nevertheless, it must be sufficiently detailed to support system design, and assessment of the potential military contribution of the proposed system in relation to its cost.

3.1.4 The concept of Smart Acquisition is to minimise constraints on system design in the early stages of a project's life cycle and EM spectrum demands are a consequence of design. Hence, in the early stages of the project lifecycle, specific EM spectrum requirements cannot be always inferred from the limited data available, whereas, in the latter stages, design decisions may frustrate attempts to introduce new EM spectrum requirements.

3.1.5 Historically, as the EM spectrum has been regarded as an almost infinite resource, EM spectrum requirements are seen as a consequence of a proposed system's design solution, rather than as constraints applied to it. It is generally assumed that any required spectrum will be made available. To avoid overly constraining industry's solution options, few EM spectrum requirements are included in the SRD. Those that are stipulated tend to be broad rather than specific. Consequently, the only source of information about a new system's planned EM spectrum usage may be from industry. The implication of this is that there is a *threshold point* before which the impact of a proposed system cannot be fully assessed (unless a Commercial Off The Shelf (COTS) solution is being implemented, in which case the threshold may have already been passed).

3.1.6 The threshold point is therefore crucially dependent upon co-operation from industry who may have reservations about early disclosure of commercially sensitive information prior to (and sometimes after) contract award. However, for some complex systems, even if all available information is forthcoming, this might still be insufficient to model performance with an acceptable level of fidelity. Consequently this point, that would normally occur during the Demonstration phase, may be either too late or costly to inform the ultimate design. However, it is possible that the early application of soft analysis methods could lead to the threshold point occurring sooner than if no soft analysis is undertaken.

3.1.7 Use of soft analysis methods early in a project lifecycle could encourage review and revision of the CONEMP[2] (and subsequent CONUSE[3]), URD and SRD from a spectrum perspective. The consequence would be some restriction in design flexibility, but it can be argued that designs not aligned to emerging MOD spectrum policies should not be progressed, and that an appropriate level of design flexibility will remain. The argument is thus that earlier consideration of the issues should lead to more comprehensive coverage of spectrum issues at every stage in the CADMID cycle. This will lead to the critical information threshold being reached sooner, possibly even sufficiently early to allow hard Operational Analysis (OA) to be used to assess contending solutions as shown below, providing industry release details.

3.1.8 Where capability need has not been anticipated an Urgent Operational Requirement (UOR) which either acquires existing COTS solutions quickly or develops a new solution rapidly is raised to provide the capability for the duration of the operation. Guidelines need to be developed to ensure that spectrum issues are also considered as part of the UOR process.

3.1.9 Potential benefits which might arise from early consideration of spectrum issues include:

- Enabling MOD customers to influence industry's eventual design.
- Impact assessment of a new system on the EM spectrum and vice versa to identify affordability.
- Contributing to the hard OA used to inform solution down-selection prior to contract award.
- Wider and better understanding of spectrum issues to facilitate coherent planning of EM spectrum usage across MOD.

3.1.10 The capability managers in MoD responsible for initiation of projects in order to fill gaps in capability will need supporting analysis to support their financial appropriation targets. Logically this suggests that that spectrum should always be explicitly addressed during pre-Concept phases so that the issues are already understood at Concept inception.

3.2 Overview of analysis methods

3.2.1 The current work was initiated to investigate and assess from a high-level analysis perspective, the potential impact which prospective new systems might make upon the battlespace electromagnetic spectrum.

3.2.2 Work undertaken covers the following areas:

- Requirements Analysis.
- Benefits Analysis.
- Spectrum congestion data capture process.

[2] A CONEMP is the applied Concept of Employment for a specific capability within a range of operations/scenarios.
[3] A CONUSE is a developed CONEMP that describes how specific equipment is to be used.

3.2.3 The section on requirements analysis describes a method to assess requirements coverage, judging requirement completeness and eventually allowing gaps to be addressed. The section on benefits analysis discusses a process to quantitatively assess spectrum issues against a number of investment criteria and procurement options. The benefits analysis can address spectrum issues at a variety of stages of the procurement cycle. The section on the spectrum congestion data capture process describes the use of a draft questionnaire intended for use at any stage of the research or procurement cycle. The questions are generic enough that most can be answered at any stage of the procurement cycle and those that cannot be answered should focus the mind for subsequent stages.

3.3 Requirements Analysis

The requirements analysis method

3.3.1 The requirements analysis study within the work programme is associated with the exploration and capture of wider spectrum issues, which are sometimes difficult for acquisition projects to address. The hypothesis under test is that soft analysis and requirements capture techniques can:

- Assist in extracting key spectrum issues.
- Increase the general understanding of spectrum issues (hence improving coverage and timeliness of consideration within the procurement process).
- Articulate spectrum needs more clearly.
- Lead to proposals being restructured in the Concept stage, which are coherent with emerging MOD spectrum policy**.**

3.3.2 The study reported here investigated a soft analysis method that could be applied early in the project lifecycle (possibly even at the pre-Concept phase). An experimental approach was adopted which involved:

i. Development of an Influence diagram, which represents spectrum issues.

ii. Transformation of the Influence diagram (spectrum issues expressed in a variety of styles) into a coherent process model (which could be readily translated into EM spectrum requirements). This is called the Spectrum Capability Requirements (SCR) model.

iii. Extraction of spectrum data from a System Requirements Document (SRD) for a current procurement project as a proof of principle example[4].

iv. Down-selection of those elements of the process model considered suitable for a generic application.

v. Mapping of the extracted data onto the model.

vi. Determination of missing spectrum related requirements, indicating where gaps might exist in the current SRD.

vii. Assessment of the feasibility of applying the method to other project documentation produced earlier in the project life cycle, such as CONEMP, CONUSE, CONOPS[5] and URDs.

3.3.3 Scenario context is more important for soft analysis methods because many scenario characteristics do not form inputs to physical models of the spectrum, which focus on detailed specifics such as the location of every emitter and its physical characteristics. By contrast, the soft analysis process relies

[4] The data resulting from this analysis is only indicative and has not been validated. The purpose of using this example was purely to exercise the method.

[5] A CONOP describes how a range of different capabilities or equipment is used in an operational context.

heavily on the rich context provided from the scenarios to inform the analysis. An example is that the scale of a country's contribution to an operation has an impact on how the deployed forces will operate, which in turn has implications on how a new capability might be integrated.

3.3.4 In order to assess the degree of completeness with which a system's associated documentation addresses spectrum issues it was necessary to develop an assessment benchmark. This was achieved by capturing insights from previous spectrum work, including stakeholder workshop and capability audit output including a Battlespace Spectrum Management (BSM) process model, and the EM Spectrum Benefits Model (described later in this document). Further issues were identified through review of current civil and military UK spectrum policy documentation and by interview with military staff at the UK Defence Spectrum Centre.

3.3.5 The data from these sources was combined into a single influence diagram, which was designed to identify linkages between entities. Although this was considered to be a useful knowledge base there was insufficient coherence in the way issues were expressed to enable its direct use in support of the study.

3.3.6 It was therefore necessary to transform/translate the data into a more coherent representation. This became the EM Spectrum Capability Requirements (SCR) model, currently represented in ®Microsoft Visio and ® Hyperknowledge[6]. The SCR model comprises a collation of data derived from spectrum policy documents and is a development of earlier work to capture the UK BSM process and to derive a benefits model (reported in the next section). The SCR model is process based; it identifies functional concepts from an EM spectrum perspective as processes that the system must undertake in support of an overall aim (e.g., battlespace spectrum dominance). An example of a process is efficient EM spectrum management. Functional requirement statements may then be derived to ensure that a system can satisfy these processes. The hierarchy underpinning the SCR model is illustrated in figure 2.

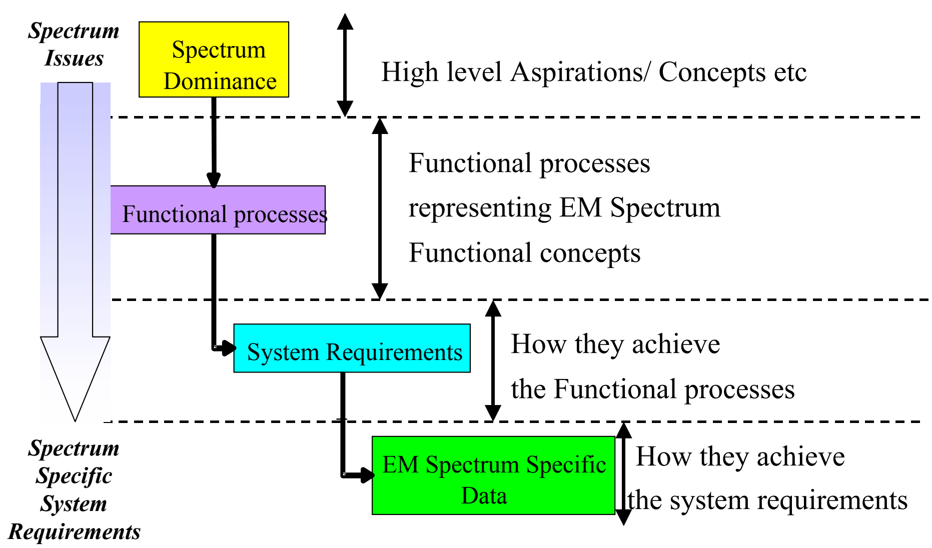

Figure 2 SCR model of the EM Spectrum

3.3.7 The next step was the translation of the influence diagram into discrete entities representing processes, resources and concepts. The transformation process was relatively straightforward and produced an initial SCR model. Although still to be validated, the SCR model was considered fit for the purpose of testing and assessing the feasibility of using soft analysis on spectrum issues.

[6] Refer to www.Hyperknowledge.com for more information

3.3.8 The assessment technique is shown in figure 3. Developing a fuller understanding of spectrum issues and refining the specification for future systems use of the spectrum are both iterative processes. Each successive pass through the process will enhance either the understanding of the systems requirement, the understanding of the wider spectrum issues or both.

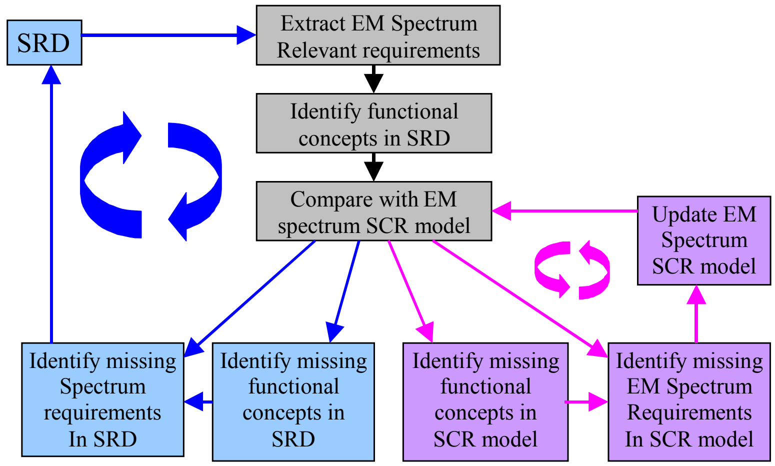

Figure 3 EM spectrum requirement extraction process

3.3.9 It was concluded that, over time, a common view and common practice for treatment of the EM Spectrum could be established, which would support wider knowledge integration and increased EM Spectrum awareness. To be effective this awareness would be needed across all the stakeholders involved in the CADMID process: the Defence Procurement Agency (DPA) for conducting the process of equipment acquisition, the Defence Logistics Organisation (DLO) for in-service support and disposal, research communities and the Directorates of Equipment Capabilities (DsEC) who define the original capability requirement. As the EM Spectrum SCR model develops and evolves, it will increasingly provide a repository of key EM spectrum criteria for subsequent projects. Consequently, over time, the effort and resources needed to undertake the SRD EM spectrum extraction process will reduce by using templates. Given that all System Requirements (SRs) are candidates to be traded out of the SRD it is impossible to guarantee the insertion of additional spectrum SRs into a specific SRD but all those involved in the acquisition process will be better informed on spectrum issues and on the potential consequences of trading out spectrum SRs.

Application of the requirements analysis method

3.3.10 This section describes the application of the requirement analysis process to a UK ISTAR programme which was undertaken to test the analysis method. A large well-defined System Requirement Document (SRD) was selected as the subject. The first step was to examine the SCR model and identify candidate requirements for inclusion in an ISTAR specific extract of the SCR model. Then the potentially spectrally relevant areas of the SRD were extracted and examined in more detail. The explicit spectral requirements already incorporated were noted and through re-expression in a more spectrally coherent manner, further spectrum requirements were inferred. A further tranche of candidate requirements were deduced through examining the complex inter-relationships within the ISTAR specific model. The following table describes the meaning of the shapes and the colour key to the simplified SCR model at figure 4 below which illustrates the results:

COLOUR/SHAPE	MEANING
Purple	Requirements included in the SRD
Yellow	Requirements were inferred from the SRD
Green	Candidate Requirements identified from SCR model
Grey	Relevant to generic ISTAR requirements but not this specific Capability
Unfilled	Not considered relevant to the type of ISTAR Capability within the study
Rectangle	Higher Level Requirement/Mid Level System Benefits
Oval	Specific Requirements

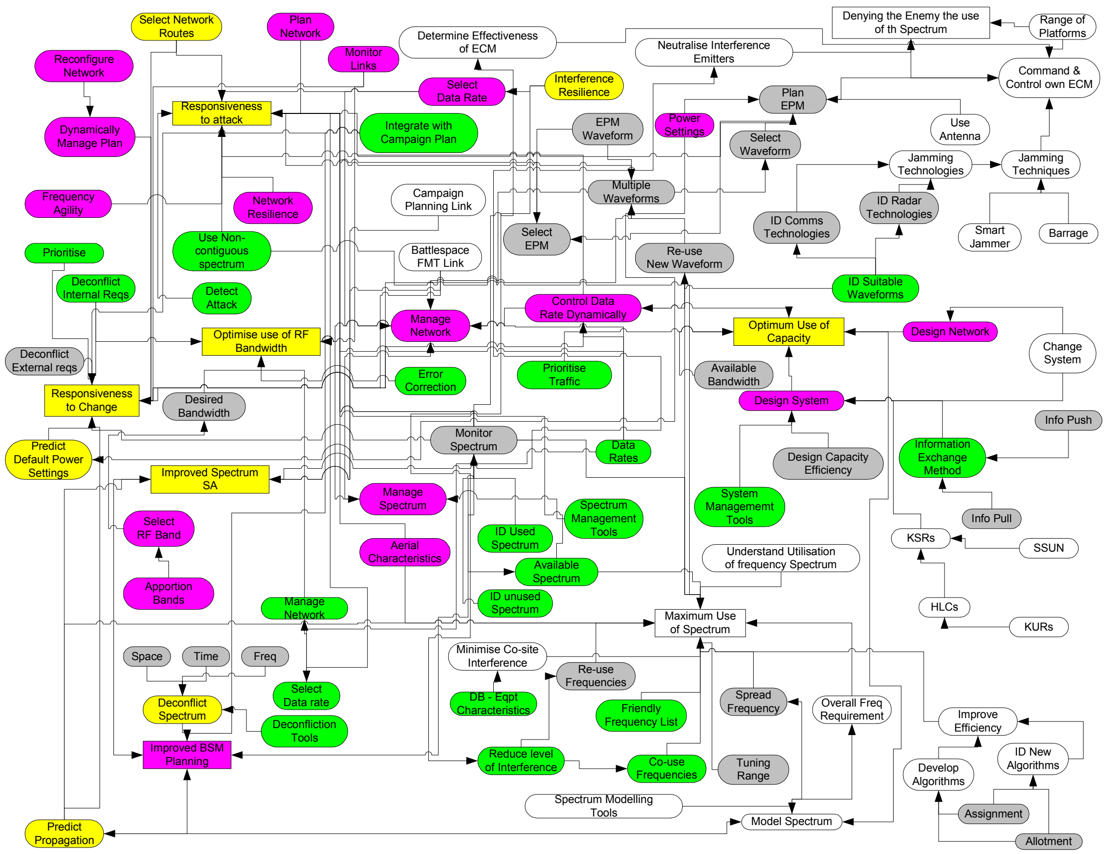

Figure 4 The Spectrum Capability Requirements (SCR) model developed

3.3.11 The results of the analysis were:

- A fuller understanding of military use of the spectrum.
- A better understanding of the spectral needs of ISTAR capabilities.
- Identification of implicit requirements within the SRD which should be stated explicitly (to avoid being overlooked).
- A set of candidate additional requirements which should be considered for inclusion in the draft SRD at its next revision.

3.4 Benefits Analysis

The benefits analysis method

3.4.1 Benefits analysis is a soft analysis method developed to establish the relationships between low level measures of performance and high level measures of effectiveness. The approach is often used to assess the comparative effectiveness of alternative IT/IS system options, where it can be difficult to identify directly how the low-level characteristics of a specific option combine to determine the overall capability of the system. The analysis is most appropriately represented and communicated in the form of a benefits map as shown in figure 5.

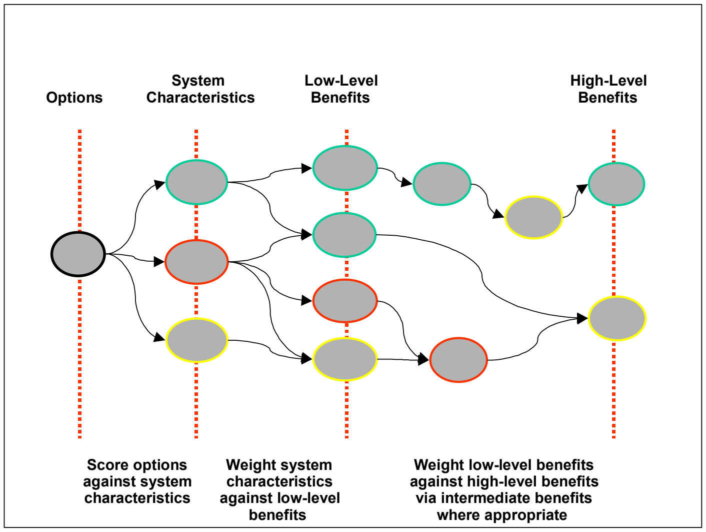

Figure 5 A generic benefits map structure

3.4.2 The map illustrates how a system can be decomposed into a number of critical system characteristics. These characteristics will usually represent the low-level performance of different elements of the system, which will vary according to which specific system option is chosen. In other words, they represent investment variables. Each of these system characteristics will contribute towards the effectiveness of one or more low-level benefits. In turn these will contribute to higher-level benefits[7].

3.4.3 Associated with each node in the map are defined acceptable levels of performance and effectiveness (termed metrics). The capabilities of individual options can be visually introduced into the model, and compared with these metrics (e.g. green-meets the requirement, yellow-just fails to meet requirement, red-fails to meet requirement). Thus the capability of individual system characteristics can be extrapolated across the benefits map into high-level benefits. For intermediate benefits and end benefits, a transfer function can be developed, which determines the concept value in terms of those of its predecessors. Post-scoring sensitivity analysis can be used to identify how sensitive both the scores and the weights at each level are, particularly important in an assessment largely based on judgement. Benefits analysis lends itself well to sensitivity analysis and it is possible to see where small changes in score/weight in key discriminatory areas can 'tip the balance' in a final order of merit.

3.4.4 Benefits analysis is currently being used within this study with the aim of:

- Providing a means of effectively structuring knowledge about pertinent spectrum issues.
- Conducting an option scoring panel which aims to establish the relationships between low level measures of performance for a number of acquisition options that utilise and consume spectrum and high-level measures of military benefit attained through a number of system-level benefits.

3.4.5 Figure 5 illustrates the EM spectrum benefits model structure used during the current study. The formal hierarchical level structure and all-to-all node relationship is a simplification of a true benefits map (as shown in figure 4 above) but is appropriate for the purposes of this study for reasons of ease of understanding, communication and computation. The Figure Of Merit (FOM) represents a means

[7] This structure conforms with the Measures of Merit in the 'NATO Code of Best Practice for C2 Assessment', CCRP 2002 (www.dodccrp.og)

of being able to provide a relative ranking of options by drawing together the scores at the highest level of benefit into a single number.

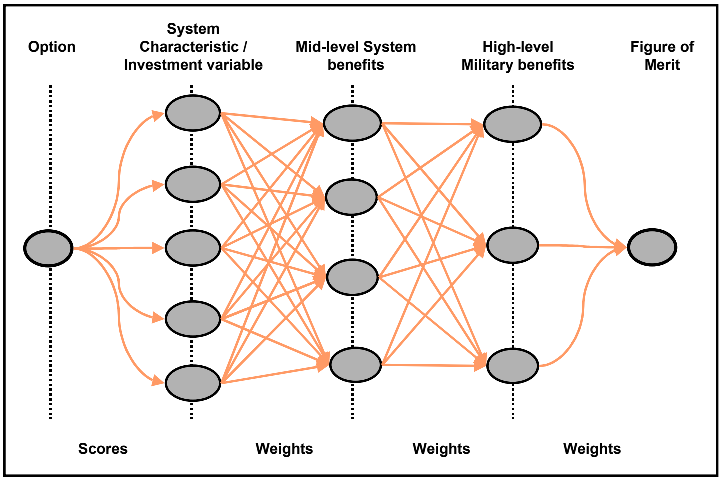

Figure 5 The benefits structure used by the study

3.4.6 The process being followed within the EM spectrum benefits analysis study is as follows:

i. Through a process of knowledge elicitation with stakeholders, the aims and objectives of the analysis have been agreed.

ii. A benefits map appropriate to the aims and objectives of the analysis and structured in the way that figure 5 illustrates, has been developed (see figure 6 below).

iii. A proof of principle assessment has been undertaken with three example procurement options, firstly to exercise the method developed and secondly, to demonstrate and effectively communicate the method to the customer.

iv. Preparation for a more formal assessment is currently underway. In support of this, an option list is being formulated and the benefits map is again being reviewed and refined. The appropriate composition of stakeholders that participate in the assessment is critical and careful consideration is being given to those that have the appropriate expertise to support the particular analysis being supported in order to achieve the desired aims.

v. During the formal assessment:
   - Each procurement option will be scored for performance against each investment variable. The resulting scores at this level of the model will help to discriminate between options in the context of system performance.
   - To take these scores further, a series of weightings will be applied to show the contribution that each investment variable could make to particular system-level benefits. The scores, together with these weightings help to differentiate between options at the system level.
   - In turn, a series of weightings will then be applied to show the contribution that each system benefit could make to particular higher-level military benefits. The scores, together with these weightings help to differentiate between options in terms of military benefit.
   - Finally, a set of weightings will be applied to show the relative contribution of each military benefit to the overall aspiration of attaining efficient spectrum usage in order to derive a single FOM for each option. The FOM will allow assessment of the relative position on the options on an interval scale.

vi. Subsequent to the formal assessment, a sensitivity analysis will be undertaken. This is important in order to identify how sensitive both the model scores and weights are, particularly in an assessment based largely on judgement. As previously identified, this method lends itself well to sensitivity analysis and it is valuable to be able to identify where small changes in score within the model can 'tip the balance' of overall option ranking.

3.4.7 Much of the value of benefits analysis is based on the provision of a structured focus for discussing and understanding the fundamental issues surrounding the acquisition of systems that can contribute in varying degrees to an overall capability in order to provide high-level military benefit.

Application of the benefits analysis method

3.4.8 The benefits model developed during this study is shown in figure 6. This has been derived through a combination of earlier work on the development of a UK perspective on the UK Battlespace Spectrum Management (BSM) process, literature study and a series of stakeholder workshops.

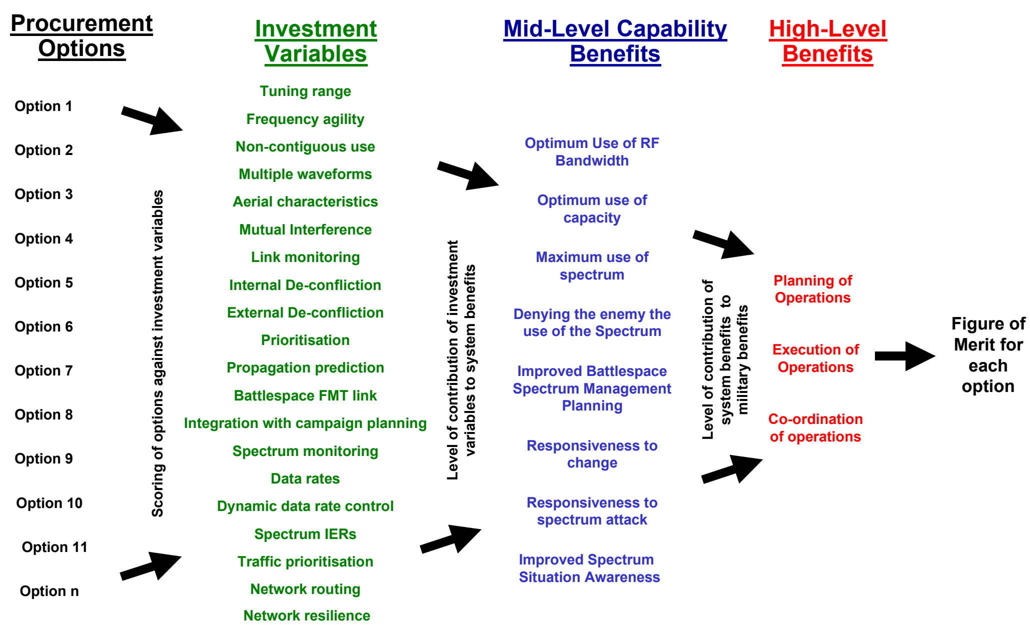

Figure 6 The benefits model developed during the study

3.4.9 The benefits model is now complete and has so far provided a valuable source of structured knowledge. Preparations are underway to conduct a scoring panel in April 05. The benefits model is not yet populated and so has not yet been fully exploited. However, much of value of such a model is the structured knowledge contained within it. This has already been used extensively by equipment specifiers to raise the awareness of spectrum issues within the wider community.

3.4.10 There is potential for further exploitation of the benefits analysis method and particularly, the application of the method within this study in the following areas:

- Awareness of issues within the wider defence community.
- Balance of Investment processes.
- Capability Gap Analysis and Audit Processes.
- Requirements Definition.
- Risk analysis processes.
- Procurement processes.
- Research definition and management processes.

3.5 Development of a congestion data capture process

Background

3.5.1 The Electromagnetic Spectrum is a **finite** resource but the civil communications **requirement** for bandwidth is increasing almost exponentially, driven principally, but not exclusively, by the introduction of new commercial telecommunications services such as Wireless Local Area Networks (WLAN) and Personal Communication Systems (PCS). This increasing rush to consume bandwidth has led to the concept of Spectrum Trading[8] to manage and balance the competing needs of civil users, which potentially exceed the available spectrum. In the short term, funding of the military's use of the spectrum is being maintained. The long-term impact on military communications is yet to be assessed, but pressure is already being generated for the military to make more cost-effective use of the spectrum and release some frequencies for civil use.

3.5.2 Meanwhile, modern military communication systems, also embracing technological advances, are becoming more and more rapacious in their demand for bandwidth, and are deployed in greater numbers than ever before. Additionally, changes in UK doctrine and concepts of operation have led to different ways of working which all have significant additional real or near real time bandwidth needs. Emerging ways of working include:

- Joint and combined operations integrated much more closely than before.
- The introduction of new bandwidth hungry sensors.
- Greater co-ordination of dispersed forces participating in joint fires.
- Larger numbers of decision nodes as command is delegated lower down the chain.
- Distributed Collaborative Planning (DCP).
- Wider dissemination of the intelligence product and potentially of raw data.
- Pulling more information from remote data repositories.

3.5.3 The proximity of many military assets in a relatively small battlespace makes the effects of spectrum congestion more marked. If the spectrum becomes too congested the massive information exchange implied by the network enabled battlespace may be unachievable

3.5.4 To capture the various processes for analysis of the spectrum issues associated with any given programme or capability a questionnaire has been developed. The development of this questionnaire is still in the early stages but is described due to its important role in the acquisition process. The questionnaire is designed to gather background information pertinent to spectrum usage for all procurements that use spectrum and has the added benefit of raising awareness of the subject.

Spectrum congestion questionnaire

3.5.5 The aim of the work developing the questionnaire is to advise on the Spectrum Congestion issues, which should be borne in mind by those aspiring to make use of the electromagnetic spectrum for military purposes. Structured in Q & A form, it also encourages staff to express spectrum issues clearly and offers an opportunity to capture relevant spectrum data about those programmes.

3.5.6 Appendix A presents a modified copy of the spectrum congestion questionnaire which also contains a short summary of the additional information associated with each question. The questionnaire's starting premise is that it should not be assumed that sufficient access to the spectrum will be

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8 Ofcom/RA Joint Consultation on Spectrum Trading (http://www.ofcom.org.uk/consult/condocs/spec_trad/spectrum_trading/)

available to meet the full requirements of new systems, particularly when evolving technology is offering greater capability, often at the expense of increased bandwidth.[9]

3.5.7 The structure of the document is based around the follow list of questions (see Appendix A for further depth):

- What is Spectrum Congestion?
- Why is Spectrum Congestion important?
- Who uses the Spectrum?
- What stage is the capability in its life cycle?
- Who is the capability intended to support?
- What part of the electromagnetic spectrum is the capability intending to use or exploit?
- Who have you consulted on spectrum issues?
- How will the capability use the spectrum?
- How will the capability be deployed?
- Where is this capability intended to operate?
- What is the scale of potential interference effects?
- How will the capability address spectrum congestion issues?
- Overall, How well does the capability use the spectrum?

3.5.8 If the above questions are answered fully they generate a better understanding of how spectrum congestion impacts upon the intended course of action and can help to identify the risk of increasing spectrum congestion. This should, in turn, lead to consideration of a mitigation strategy. Although optimised for military procurement the process is equally applicable to civil needs as spectrum congestion knows no boundaries. In summary, the questionnaire can be used as an aide memoire to encourage the consideration of the impact on the electromagnetic spectrum of any proposed course of action/programme/project or capability.

4 Conclusions

4.1.1 Current and future battlespace systems are placing burgeoning demands on the EM spectrum and the management of this valuable resource will become increasingly complex if future military operations are to be sustained in an international networked information environment.

4.1.2 The nature of military operations in the foreseeable future dictate that spectrum management will be more complex and international.

4.1.3 Discussion during analysis (such as a facilitated judgement panel used, for example in the benefits analysis method) can be used as a vehicle for providing spectrum awareness.

4.1.4 During the system procurement process, benefits analysis is valuable in supporting the decision making process.

4.1.5 Functional requirements for the EM spectrum may be modelled using suitable tools such as ® Microsoft Visio or ® Hyperknowledge. Such an SCR model could increasingly provide a repository

[9] D/EC(CCII)IOCM12/1/2/5 Mod Strategy for Military Use of The Spectrum

of key spectrum criteria and issues for use in subsequent projects and, over time, the effort and resources needed to undertake the extraction process would reduce.

4.1.6 It would be feasible to use an EM Spectrum SCR model, to enable the EM spectrum requirements and impact of each potential new system to be considered, in increasing levels of granularity, at the formal milestones within the procurement acquisition process.

4.1.7 Analysis processes demand data capture processes and these processes increase awareness in their own right. This alone should encourage appropriate consideration of spectrum by the right people.

4.1.8 Soft analysis methods can complement the traditional hard OA used in acquisition decisions.

5 Recommendations

5.1.1 The acquisition process should address the EM spectrum requirements of new systems as early as possible in the procurement cycle.

5.1.2 Based on the current EM spectrum demand, existing physical constraints should be identified and used to inform development of the EM spectrum requirements of potential new systems.

5.1.3 Further refinement of the analysis method to derive the EM spectrum requirements for new systems should be undertaken with an international partner based on a relevant use case.

5.1.4 The data capture questionnaire on congestion issues should be sent to all appropriate stakeholders to prompt an awareness process and to construct a knowledge base of spectrum users.

5.1.5 Visibility of the importance of spectrum and its management needs to be provided spectrum to staff across the defence community from researchers to in-service support staff. Various techniques can be used, varying from frequently asked questions, questionnaires and workshops.

5.1.6 Work should continue to refine the benefits model and the SCR model with a view to introducing their use into the acquisition cycle.

5.1.7 Techniques such as the soft analysis methods described in this paper should be considered by the international bodies responsible for EM spectrum allocation and management.

APPENDIX A Spectrum Congestion Questionnaire

Aide memoire for identification of the impact on the electromagnetic spectrum of programmes, policies or research (Draft 0.A).

Completed for Project Your name here on (dd month yyyy)

This is an *aide memoire* to encourage the consideration of the impact on the electromagnetic spectrum of the proposed course of action/programme/project or capability. Identifying a risk of increasing spectrum congestion should lead to consideration of a mitigation strategy. For an explanation of Spectrum Congestion and its associated issues see the attached notes, which comprise a distillation of a considerable body of authoritative guidance

You may complete this form by using the checkboxes and print it on line, or save it to your own directory and complete it there. Hovering over items in yellow will give context sensitive advice.

DEFINITIONS

Spectrum Congestion ☐ Interference ☐ Harmful Interference ☐
Intrusion ☐ Jamming ☐ Meconing ☐
Electromagnetic Compatibility ☐ Electromagnetic Environmental Effects ☐
Source Document

Summary:

“What is Spectrum Congestion?” Spectrum Congestion occurs when too many users attempt to employ the same part of the spectrum. The principal symptom of spectrum congestion is interference. Interference is the effect of unwanted energy due to one or a combination of emission radiations or inductions upon reception in a radio-communication manifested by performance degradation, misinterpretation or loss of information, which could be extracted in the absence of such unwanted energy. This question covers the following issues: Harmful interference; Electromagnetic Compatibility (EMC).

“Why is Spectrum Congestion important?” Allowing the battlespace to become so congested that own force use cannot be guaranteed makes critical battle-winning information flows vulnerable to unpredictable degradation and disruption. If the information flows are disrupted the co-ordination will become harder and in turn cause a slower operational tempo. If own force tempo becomes slower than that of the enemy then own force operations may become reactive rather than proactive as the initiative will have been lost.

“Who uses the Spectrum?” There are both civil and military users of the spectrum. There is an increasing need for military band spectrum to be released for civil use.

WHAT STAGE IS THIS CAPABILITY AT IN ITS LIFE CYCLE?

The proposed capability is at the following stage:

Concept ☐	Initial Gate ☐	Assessment ☐
Main Gate ☐	Demonstration ☐	Manufacture ☐
IOC ☐	In Service ☐	FOC ☐

<u>Notes</u>

Summary:
"What stage is the capability in its life cycle?" As a capability matures it is possible to define issues more precisely until at Full Operating Capability (FOC) most things should be precisely expressed in terms bounded by measurable characteristics. Consequently, the further through the acquisition process the greater the degree of scrutiny appropriate.

WHO IS THE CAPABILITY INTENDED TO SUPPORT?

The proposed capability is intended to support the following levels:

Joint -	MOD ☐	PJHQ ☐	JFHQ ☐		
Air (All Echelons) -	ACC ☐	Level A☐	Level B ☐	Level C ☐	Airborne☐
Land (Higher Echelon) -	LCC ☐	CORPS☐	DIV ☐	BDE ☐	BN☐
Land (Lower Echelon)	Coy☐	Pn☐	Squad☐		Individual☐
Sea (All Echelons)-	MCC ☐	TFC ☐	TGC ☐	TU ☐	TE(Unit) ☐
Space (impinging on battlespace) -		Communicating☐			Sensing ☐

Users Include You may add explanatory notes here

Notes You may add explanatory notes here

Summary:
"Who is the capability intended to support?" There must be a clear definition of the intended user community so that the scale of any potential deployment can be accurately assessed, as this has a direct impact on the scope of spectrum utilisation by the capability. Enabling services may also need to be included.

WHAT PART OF THE ELECTROMAGNETIC SPECTRUM DOES THE CAPABILITY INTEND TO USE/EXPLOIT?

The section of the spectrum affected :

VLF☐ LF ☐ MF ☐ HF ☐ VHF ☐ UHF ☐ SHF ☐ EHF ☐

UHF Sub Bands

225-400 MHz	☐	400-450 MHz	☐	590-598 MHz	☐
856-933 MHz	☐	960-1215 MHz	☐	1215-1350 MHz	☐
1375-1452 MHz	☐	1559-2450 MHz	☐	2700-3600 MHz	☐

Notes
Source Document

Summary:
"What part of the electromagnetic spectrum is the capability intending to use or exploit?" New capabilities which adhere to spectrum usage policy are less likely to encounter congestion because they will benefit from established UK, NATO and International de-confliction processes, which seek to allow capabilities access to the segments of the spectrum which best support their needs.

WHO HAVE YOU CONSULTED ON SPECTRUM ISSUES?

The following authorities have been consulted and this document is consistent with their advice:

A ☐
B ☐
C ☐
D ☐
E ☐

Notes

Summary:
"Who have you consulted on spectrum issues?" Early involvement of the "spectrum aware" experts mitigates the risk that capability is developed without the spectrum it needs being available. The earlier potential congestion issues are identified the easier they are to resolve.

HOW WILL THE CAPABILITY USE THE SPECTRUM?

The proposed capability involves the following:

Sensing ☐
Communicating ☐
Jamming ☐

Notes

Summary:
"How will the capability use the spectrum?" The three military uses of the spectrum are:

- Sensing – Passive detection/interception of emissions (radiated energy). Active (radiating energy to detect objects by bouncing the energy off the objects).
- Communicating – the exchange of information with other (own force or co-operating) entities.
- Jamming – Transmitting more power on the same frequency as the enemy making reception of the original transmission by the enemy impossible.

HOW WILL THE CAPABILITY BE DEPLOYED?

The proposed capability will be deployed as follows:

	Man	**Vehicle**	**Multi-vehicle**	**Aircraft**	**Ship**	**Fixed**
Combat	☐	☐	☐	☐	☐	☐
Support	☐	☐	☐	☐	☐	☐

Summary:
"How will the capability be deployed?" It is important to identify whether the capability is fixed, man portable, fitted to vehicles, aircraft and ships or deployed in a number of vehicles (which must all be linked for the equipment to work).

WHERE IS THE CAPABILITY INTENDED TO OPERATE?

The proposed capability is planned to be used in:
UK Training Areas ☐ UK Generally ☐ Germany Training Areas ☐
Europe ☐ America ☐ Asia ☐ Africa ☐ Australia ☐
World-wide Ground-Based ☐ World-wide Air-Based ☐ World-wide Sea-Based ☐
World-wide space-based ☐
Notes

Summary:
"Where is this capability intended to operate?" Some capabilities procured to satisfy in-theatre Urgent Operational Requirements (UORs) have subsequently been found to be inoperable in other regions because the frequencies they employ have already been allocated to other users. Capabilities should also be designed to operate in UK and other training areas as well. If the proposed capability does not support this, the sponsor must be fully aware of the consequences and impact of procuring the capability.

Interference Effects

The proposed capability will potentially interfere with:

Scope of effects - UK ☐ Host Nation ☐ Lead Nation ☐ Other Allies ☐ Neutral ☐ Enemy ☐
Civil: Domestic ☐ Commercial ☐ Hospitals ☐ Emergency Services ☐ OGDs ☐
Military Levels affected - Strategic ☐ Operational ☐ Tactical ☐
Military Capability - Communications ☐ Sensors ☐ Weapons ☐ Jammers ☐
Types of Unit – Mobile units ☐ Static capability ☐
Notes

Summary:
"What is the scale of potential interference effects?" The wider the potential geographic usage of a capability the more complex the process of obtaining permission to use the required frequencies. The degree of extant spectrum usage will vary considerably from country to country. There may be strong competition for the available spectrum. Rather than accepting high levels of congestion it may be necessary to plan sub-optimal employment to maximise overall force effectiveness.

HOW WILL THE CAPABILITY MITIGATE SPECTRUM CONGESTION?

The capability will mitigate spectrum congestion through :

Mandatory URD KUR statements ☐
Detailed SRD statements ☐
Adhering to UK and International Legislation ☐
Identifying scale of potential problem through modelling ☐
Employing techniques and technologies identified below ☐

Notes

Spectrum utilisation has been planned to minimise through life frequency allocation costs

☐

This capability will employ the following techniques and technologies
Increased Tuning Range ☐
Efficient Directional Antennas ☐
Use of Non-contiguous Spectrum ☐
Software Designed Radios ☐
Advanced Waveforms ☐
Automatic Link establishment ☐
Free Channel Search ☐
Frequency Hopping ☐
Other ☐

Notes

Summary:

"How will the capability address spectrum congestion issues?" At different stages in the procurement process some methods of addressing congestion issues are more important than others. This section identifies what is appropriate at each stage and the degree of supporting detail required.

OVERALL, HOW WELL DOES THE CAPABILITY USE THE SPECTRUM?

The proposed capability achieves the following scores when assessed against the criteria below:

	Poor	Low	Med	High	V High
Optimising use of RF Bandwidth	☐	☐	☐	☐	☐
Optimising use of Capacity.	☐	☐	☐	☐	☐
Maximising use of the Spectrum	☐	☐	☐	☐	☐
Improving BSM Planning	☐	☐	☐	☐	☐
Respond to change	☐	☐	☐	☐	☐
Responds to Spectrum Attack	☐	☐	☐	☐	☐
Improved Spectrum SA	☐	☐	☐	☐	☐
Denying the Enemy the use of the Spectrum	☐	☐	☐	☐	☐

5.2 Overall Assessment ☐ ☐ ☐ ☐ ☐

Summary:

"Overall, How well does the capability use the spectrum?"

In order to focus on specific ways of improving congestion, quality of service/mid-level system benefits drawn from the earlier analysis work are introduced to facilitate subjective assessment of the overall advantage to be gained by employing the given capability.