INCOSE UK Chapter

Working Group on

Applying Systems Engineering to In-Service Systems

Final Report

The views expressed by the authors in this report do not necessarily represent the views of their employers.

Contents

Executive Summary

It is frequently necessary to change systems that are in service in order to sustain them and systems engineering is just as important in this stage as it is when realising new systems. There is consensus within the United Kingdom (UK) Systems Engineering (SE) community that, while the principles underpinning SE remain the same across the lifecycle:

- some of the issues concerned with sustaining existing systems are more problematic than when realising new systems; and
- the existing SE Body of Knowledge and the competences of SE practitioners tend to be stronger on the issues that are more important when realising new systems than on the issues that are more important when changing existing systems.

This view was expressed at the INCOSE UK Advisory Board and confirmed at a workshop at the INCOSE UK 2007 Autumn Assembly. As a result, the INCOSE UK Board commissioned a working group to advise it on:

- the difficulties encountered, in practice, in applying authoritative guidance on SE, including the INCOSE SE Handbook, to systems that are in service;
- best current practice in adapting SE guidance to overcome these difficulties; and
- additional work that the INCOSE UK Chapter might initiate to assist its members further in overcoming these difficulties.

The working group used the following approach to reach its conclusions and recommendations:

1. Sketch out a number of **In-service SE scenarios** representing a range of issues commonly encountered in performing SE in systems that are in service. The group identified five in-service SE scenarios:
    - Replacement of points at approaches to major railway station;
    - Support of airborne systems;
    - Transfer of responsibility for support;
    - Introduction of Urgent Operation Requirement to an in-service platform; and
    - Incremental development of a military communications system.
2. Create a **map of SE** – a simple table with rows representing classes of SE activities and columns representing stages in the system lifecycle.
3. Survey the map in the context of the scenarios to identify **gaps** – areas where the guidance available in the INCOSE SE Handbook could usefully be strengthened in order to better support SE of in-service systems. Six gaps were identified:
    - **Through-life Validation:** Establishing whether the system (including both the operational system and the support system) and the user needs have drifted apart and some action (a new "V") is required.

- **Domain Knowledge[1]:** Obtaining relevant facts about the environment of the system to be built is the larger part of the problem but the guidance is focussed on Requirements.
- **Architecture Design:** Guidance wanted on modifying architectures: How much should you change / re-evaluate? How to deal with architectures that are implicit in standards?
- **Incremental Acquisition :** Planning out an incremental acquisition process which keeps the service going. Considering backward compatibility and logistics.
- **Integrating project Configuration Management (CM) with system CM:** Delivery project CM information must be integrated into the CM system for the enclosing system.
- **Information Management:** Maintaining accessibility and modification of information through life.

4. Analyse each gap in order to characterise the gap and to identify sources of **good practice** that might be used to close it.

5. Formulate **conclusions and recommendations**.

The group considers that it is desirable to integrate any additional guidance with existing guidance documents (such as the SE Handbook and the SEBOK) rather than packaging them separately.

The group acknowledges that, as a consequence of this, it is necessary that further work should be carried out with international involvement and the involvement of the custodians of existing guidance documents.

The group is confident that, having followed a systematic process to reach these findings, they are sound but it acknowledges that they may not be comprehensive – there may be further areas of potential improvement and further sources of good practice. The group intends to present their work at the 2008 Autumn Assembly and invite feedback. The group would welcome comments from the UK Board and the UK Advisory Board and would wish to work any significant improvements into a reissue of the report

Assuming that its findings receive broad support, the group recommends initiating two parallel further streams of work:

- An international working group should be set up to improve and extend the work carried out by this working group, to achieve a broader consensus on the conclusions and to establish arrangements for integrating additional guidance into existing INCOSE products.
- A UK-led working group to produce a supplement to the INCOSE Handbook providing guidance in the areas identified by the current group. This group should be set up to allow participation by telephone and email. International participation in this group would be invited and welcomed.

[1] We use “Domain Knowledge” to mean “relevant facts about the environment of the system” after Professor Michael Jackson [3].

1 Introduction

1.1 Background and purpose

It is frequently necessary to change systems that are in service in order to sustain them and systems engineering is just as important in this stage as it is when realising new systems. There is consensus within the United Kingdom (UK) Systems Engineering (SE) community that, while the principles underpinning SE remain the same across the lifecycle:

- some of the issues concerned with sustaining existing systems are more problematic than when realising new systems; and
- the existing SE Body of Knowledge and the competences of SE practitioners tend to be stronger on the issues that are more important when realising new systems than on the issues that are more important when changing existing systems.

This view was expressed at the INCOSE UK Advisory Board and confirmed at a workshop at the INCOSE UK 2007 Autumn Assembly. As a result, the INCOSE UK Board commissioned a working group to advise it on:

- the difficulties encountered, in practice, in applying authoritative guidance on SE, including the INCOSE SE Handbook, to systems that are in service;
- best current practice in adapting SE guidance to overcome these difficulties; and
- additional work that the INCOSE UK Chapter might initiate to assist its members further in overcoming these difficulties.

The full terms of reference for this group are attached at Appendix A.

1.2 The working group and the approach used

The members of the working group are listed in Table 1-1. Collectively, the members have significant experience of several sectors including the military, rail and air traffic services sectors. As the working group reached interim conclusions, they tested them against their experience of these sectors in order to try and ensure that they were generally applicable.

Ron Brittain; BAES	Doug Cowper; Cleave Systems Ltd
Bruce Elliott; Arbutus Technical Consulting	Andrew Farncombe; John Boardman Associates
Stewart Leinster-Evans; BAES	Peter Lister; Harmonic Ltd
Ian McNeil; Boeing Defence UK Ltd	Glenn Panter; Thales, aerospace division (UK)

Table 1-1: Working Group Members

The working group used the following approach to reach its conclusions and recommendations:

1. Sketch out a number of **In-service SE scenarios** representing a range of issues commonly encountered in performing SE in systems that are in service (see Section 2 and Appendix C).

2. Create a **map of SE** – a simple table with rows representing classes of SE activities and columns representing stages in the system lifecycle (See Section 3).

3. Survey the map in the context of the scenarios to identify **gaps** – areas where the guidance available in the INCOSE SE Handbook [1] could usefully be strengthened in order to better support SE of in-service systems (See Section 4).

4. Analyse each gap in order to characterise the gap and to identify sources of **good practice** that might be used to close it (See Section 5).

5. Formulate **recommendations** (See Section 6).

The structure of this report follows this process. After this introductory section, there is one section for each of the steps listed which presents the output of that step. Some supporting information is relegated to appendices.

In performing their work, the group was strongly reminded that what systems engineers are able to do when working on a system which is in service is severely constrained by what their colleagues did when performing SE while the system was being designed and built. With this in mind, the group agreed to go slightly beyond their remit and look for additional advice which might be provided on the topic of SE during the realisation of systems which would significantly ease the job of performing SE after the system entered service.

1.3 Referenced documents

1. INCOSE Systems Engineering Handbook, INCOSE-TP-2003-002-03.1, version 3.1, August 2007.

2. ISO/IEC 15288: 2002, Systems engineering -- System life cycle processes

3. Software Requirements and Specifications: A Lexicon of Practice, Principles and Prejudices, Michael Jackson, 1995, ACM Press, ISBN 0201877120.

4. GE/RT8250, "Reporting High Risk Defects http://www.rgsonline.co.uk/docushare/dsweb/Get/Rail-41224/RT8250a.pdf.

2 In-Service SE Scenarios

The group identified five in-service SE scenarios:

- Replacement of points at approaches to major railway station;
- Support of airborne systems;
- Transfer of responsibility for support;
- Introduction of Urgent Operation Requirement to an in-service platform; and
- Incremental development of a military communications system.

These scenarios are described in Appendix C.

3 Map of in-service SE

The map comprises a table with systems lifecycle stages as its columns and SE activities as its rows. The map is given in Table 3-1 as a matrix with the SE activities set out against the lifecycle stages.

Where it is considered that an activity is unlikely to be carried out within a stage, that cell is shown greyed.

It was considered that there was little value in considering the cross-lifecycle activities separately for each stage and that these activities would change in nature rather slowly across the lifecycle so, the related lifestyle stages for these activities have been combined.

Note: preliminary work by the group, aligning the well-known “V” model to the reality of the in-service upgrade process, is described in Appendix D.

	STAGE										
Activity	Concept'	Devt'	Constr'	Int'	Util/Supp	Concept''	Devt''	Constr''	Int''	Ins''	Ret
Stakeholder Req Defn											
Requirements Analysis											
Architectural Design											
Implementation											
Integration											
Verification											
Transition											
Validation											
Operation											
Maintenance											
Disposal											
Project Planning											
Project Assessment											
Project Control											
Decision-Making											
Engineering Environment											
Risk & Opp Mgt											
Configuration Management											
Information Management											
Systems Analysis											

Table 3-1

4 Identification of Gaps

Each cell of our model was considered in the light of the scenarios (Section 2) as to whether the guidance in the Handbook satisfactorily covered this activity in this stage:

- for the operational system?
- for the support system?

6 gaps were identified, which are listed in Table 4-1, below, and marked-up on the copy of the model in Table 4-2.

#	**Name of Gap**	**Characterisation of Gap**
1	Through-life Validation	Establishing whether the system (including both the operational system and the support system) and the user needs have drifted apart and some action (a new "V") is required.
2	Domain Knowledge[2]	Obtaining relevant facts about the environment of the system to be built is the larger part of the problem but the guidance is focussed on Requirements.
3	Architecture Design	Guidance wanted on modifying architectures. How much should you change / re-evaluate? How to deal with architectures which are implicit in standards?
4	Incremental Acquisition	Planning out an incremental acquisition process which keeps the service going: backward compatibility; logistics.
5	Integrating project Configuration Management (CM) with system CM	Delivery project CM information must be integrated into the CM system for the enclosing system.
6	Information Management	Maintaining accessibility and modification of information through life.

Table 4-1

[2] We use "Domain Knowledge" to mean "relevant facts about the environment of the system" after Professor Michael Jackson [3].

	STAGE										
Activity	Concept'	Devt'	Constr'	Int'	Util/Supp	Concept''	Devt''	Constr''	Int''	Ins''	Ret
Stakeholder Req Defn											
Requirements Analysis						**2**					
Architectural Design						**3**	**3**				
Implementation											
Integration										**4**	
Verification											
Transition											
Validation					**1**						
Operation											
Maintenance											
Disposal											
Project Planning										**4**	
Project Assessment											
Project Control											
Decision-Making											
Engineering Environment											
Risk & Opp Mgt											
Configuration Management										**5**	
Information Management					**6**						
Systems Analysis											

Table 4-2

5 Analysis of Gaps

Each of the gaps identified in the previous step was analysed in order to characterise:

- a summary of guidance in SE Handbook 3.1;
- the gap between the guidance on the in-service SE activity and what is needed for in-service SE;
- good practice on in-service SE activity that might be used as a basis for extended guidance.

The resultant findings for the gaps are presented the next six sub-sections.

Systems development SE issues that significantly affect the in-service SE activities associated with these gaps were considered and the following identified:

- the shortfall between the guidance on relevant systems development SE activities and what is needed to prepare for in-service SE;
- good practice on relevant systems development SE activities that might be used as a basis for extended guidance.

The findings for this aspect of our analysis are presented in sub-section 5.7.

5.1 Gap 1: Through-life Validation

The SE Handbook includes the following passage[3]:

> *System validation confirms that the system, as built (or as it will be built), satisfies the stakeholders' stated needs. Validation ensures the requirements and the system implementation provide the right solution to the customer's problem. In other words, "you built the right thing." Validation determines that a system does all the things it should and does not do what it should not do.*

But over the service life of any system we find we must repeatedly ask the question not "did we build the right thing?" but rather "Is the thing we built still right?" because both stakeholder needs and system performance can change. It is from the answer to this question that decisions on initiating system update[4] or upgrade[5] are made.

5.1.1 Summary of guidance in SE Handbook 3.1

Validation is principally considered in Sections 4.9 and 8.9 of the Handbook. These sections are about 2½ pages in length in total and provide guidance on Validation purpose and process. The guidance is usable in terms of consideration of validation activity for a new system to the point of delivery / handover to a customer, but no reference in the SE Handbook was found as to determining whether the system as

---

[3] INCOSE SE Handbook v3.1 Ch 8.9

[4] **Updates** to maintain form, fit and function and/or avoid obsolescence (often referred to as Post Design Services (PDS)).

[5] **Upgrades** to address emerging performance shortfalls

utilised continues to meet the stakeholders' needs or on how decisions to initiate update or upgrade activity are considered.

It is noted that Section 4.10 (The Operational Process) recommends activities to 'Track system performance and account for operational availability' and 'Report malfunctions and recommendations for improvement'. It also notes that:

> *If system performance falls outside acceptable parameters, this may indicate the need for corrective actions, in accordance with the Concept of Support and any associated agreements.*

Also Section 4.11 (The Maintenance Process) recommends an activity to 'Monitor customer satisfaction with system and maintenance support', however, like the other comments in sections 4.10 and 4.11 it is effectively a 1-line comment without substantial additional guidance.

Finally, Section 4.2.4 has, as one of its outputs, the 'Co*ncept of Support' which:*

> *Describes the desired support infrastructure and manpower considerations for maintaining the system after it is deployed. This includes specifying equipment, procedures, facilities and operator training requirements.*

It is in this document that process related to the Good Practice recommended hereafter could be gathered.

5.1.2 Gap between guidance on in-service SE activity and in-service needs

The performance of the system needs to be monitored and awareness of stakeholder needs maintained, so that confidence that the system in use continues to satisfy those needs is also maintained. What is essentially required is a "continuing validation" activity. The need is expressed in Figure 5-1 below in terms of the need to identify the gaps / deltas between current performance and stakeholder need at any point in the system's in-service life.

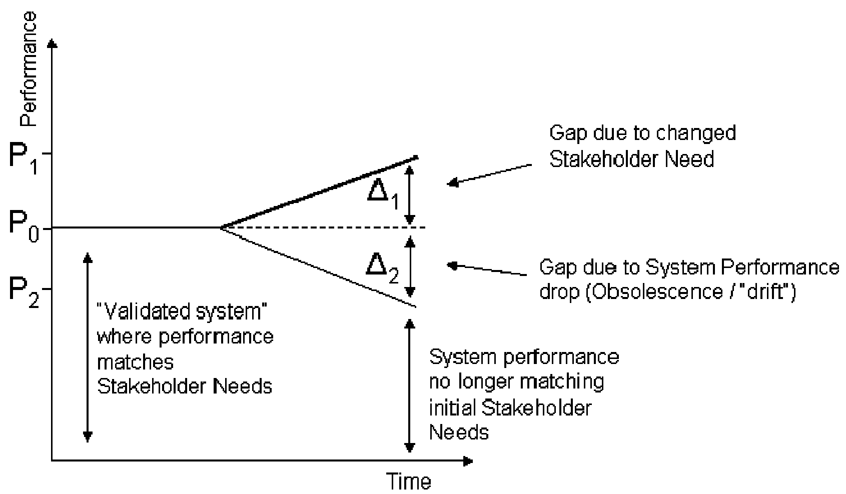

Figure 5-1: System Performance may fail to match stakeholder need over time

Note: Changed stakeholder needs could be due to:

- *a decision to field the system to a new environment;*

- *a change in threat;*
- *changed in legislation or standards, etc.*

Alternatively, stakeholders might wish to do something different with the system, driving the need for new system functions.

The challenge with applying systems engineering on in-service systems is therefore to understand how the concept of "continuing validation" might be / should be applied.

The issue of continuing validation and decisions on upgrading capability is then further complicated in the case where the system when first procured did not initially meet the stakeholders' originally stated needs, but was judged "Good Enough" for the funding and / or technology solution available at the time. This is explained in Figure 5-2 below. The challenge is how to assess whether technology advances and funding can be cost effectively committed on the system under consideration versus committing scant resources elsewhere. Effectively the challenge is to show the improvement in performance against stakeholder needs in a measure that allows comparison against competing programmes.

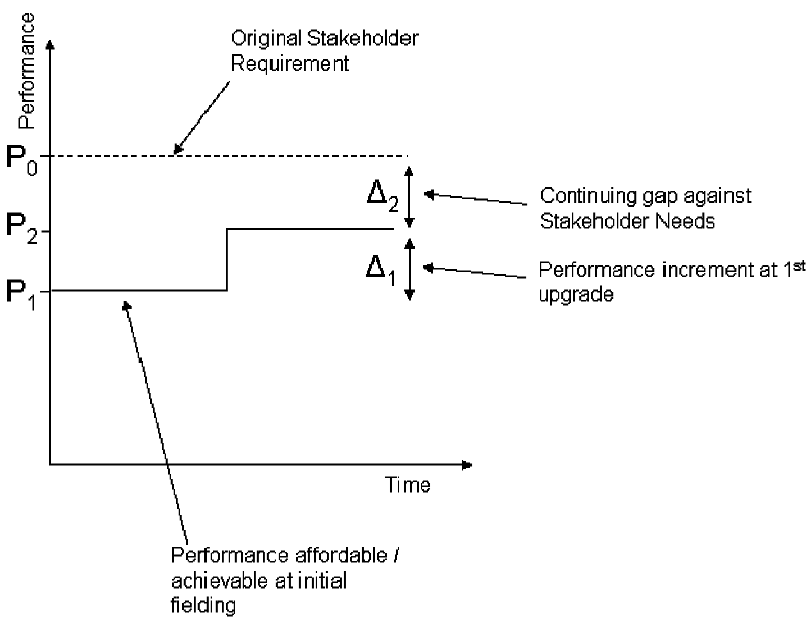

Figure 5-2: Required system performance may be unachievable initially

5.1.3 Good practice on in-service SE activity

Many organisations have processes in place to measure system and subsystem performance against required performance. This might be as simplistic as measuring Kiln temperature, or vehicle speed on a periodic basis and taking corrective action within the system to address any identified "drift" against the specified performance. In the military environment, DefStan 00-40 mandates Data Recording, Analysis and Corrective Action System (DRACAS) processes throughout the design to production stages of a project, but not thereafter. The rail industry has RG Standard GE/RT8250 [4], "Reporting High Risk Defects", although no parallel process for routine fault reporting.

Less common are processes to identify, in a systematic manner, changing stakeholder requirements, ie to continually validate whether the system under consideration meets stakeholder needs. These changes might result from:

- changes to the environment the system inhabits;
- changes to the inputs available to the system;
- changes to the outputs a stakeholder wishes the system to provide; or
- changes to the manner in which a stakeholder wishes to (or actually does) interact with the system.

Many organisations, not least the military, have "lessons identified" processes and an awareness of capability shortfalls, but what is often lacking is a systematic method for exploiting and addressing the lessons or evaluating the nature of the shortfalls and architecting solutions to them.

Good practice integrates these processes with the DRACAS / fault reporting processes throughout the manufacture and in-service stages so that a fault report which starts "I wanted to be able to 'X' but my system didn't do it" can be sentenced "New Stakeholder Need" and subsequently evaluated as such, rather than sentenced "system not at fault, system behaving as designed" and the fault report consigned to the bin. This can be further developed into formal processes such as capability reviews and audits on a periodic and pre-planned basis, which can lead to decisions on whole-system upgrades. It can also be beneficial to develop a more reactive and flexible process to deal with urgent requirements in response to, for example, a decision to deploy the system to a new environment or an urgent safety- or legislation-driven change.

In evaluating new stakeholder needs, good practice further relies on an awareness of both the environment surrounding, and use by the stakeholders, of the system. These might be markedly different from that which was envisaged when the system was designed:

- the stakeholder may not be using certain system functions because they no longer have need for them;
- they may be using certain system functions in conjunction with other systems which were not envisaged when the system was conceived; or
- they may be unaware of certain system functions or capabilities due to inadequate training and education.

When considering SE on In Service Systems, good practice indicates the need for a clear understanding of the relationships between Design Authority and Service (or System) Operating Authority. For the purposes of through-life validation activity described here, the former might be judged to operate in the solution space – it might identify update or upgrade solutions through evaluation of failure reports and/or deliver solutions to identified new requirements. The latter might be responsible for decisions addressing fielding and safe operation of any solution, its support in service, and the determination of whether it is continuing to meet the stakeholders' needs, hence driving new requirements for upgrade for which a solution must be developed. The responsibility, authority and accountability of these organisations (or elements within the same organisation) need to be clearly defined.

Finally, good practice will develop a linkage between the system Measures of Performance, and the related Measures of Effectiveness against Stakeholder Needs, in a language the Stakeholder can understand, in order that informed decisions on committing budgets to upgrades and updates can be made. Good practice in this exploits through-life use of modelling, both architectural and simulation.

5.2 Gap 2: Domain Knowledge

When an In-Service (legacy) system or support system is replaced or modified, one of the issues that can increase the risk on the project is an incomplete understanding of that legacy system, its interfaces and how it is used. This can also be realised as a lack of understanding of the background for certain critical design or maintenance decisions. This "Domain Knowledge" is rarely documented completely and may, originally, have been documented in non-transportable formats or retained in the heads of a number of experts who may or may not still be available.

A further area of Domain Knowledge is embedded within the user community who may be using undocumented features as a necessary part of the operation or maintenance of the system.

Figure 5-2 below, illustrates the hierarchical structure of the different viewpoints from which a legacy system replacement may (need to) be considered. All such viewpoints are valid and a change at one level may impact another. It should be noted that each viewpoint has its own local support system and it may be this that is the source of change rather than the supported system.

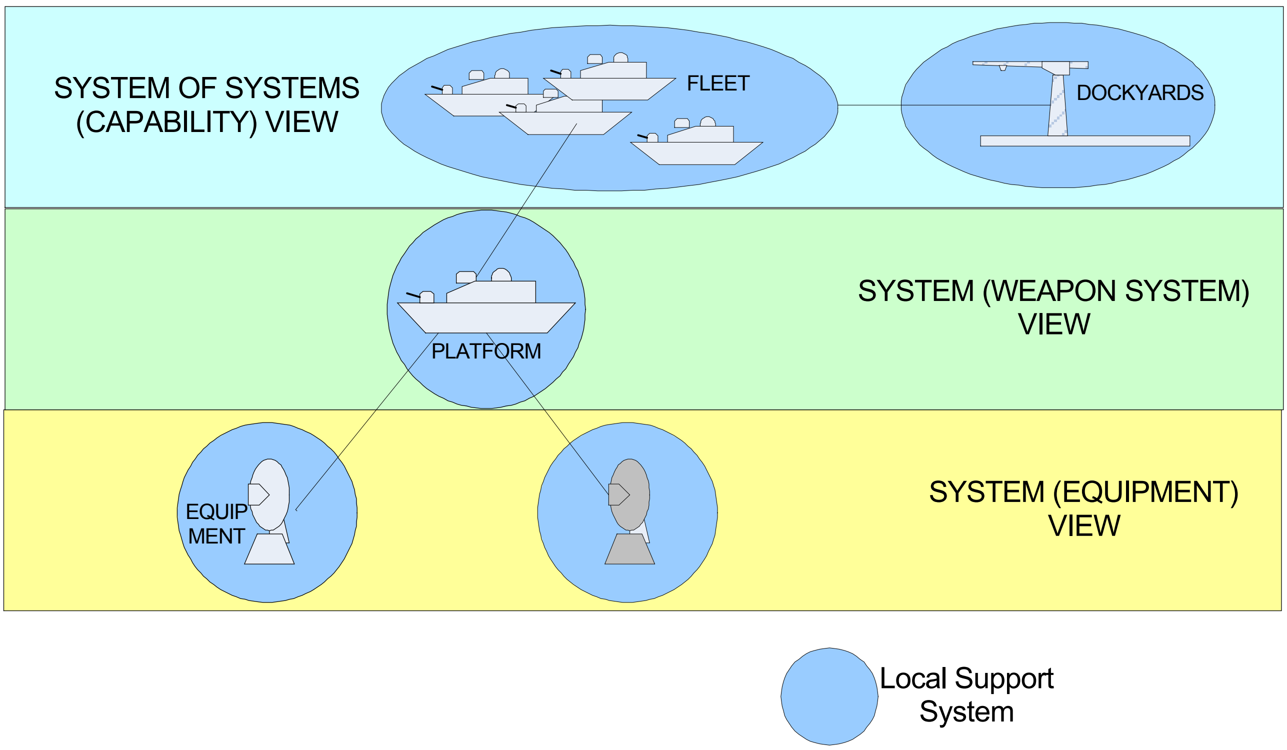

Figure 5-2: Viewpoints

5.2.1 Summary of guidance in SE Handbook 3.1

The issue is mainly relating to knowledge management (closest match in the SE Handbook is Information Management).

The only mention of replacing in-service systems is a single sentence within section 4.10, Operation Process, which states: “When the system replaces an existing system, it may be necessary to manage the acquisition between systems such that persistent stakeholders do not experience a breakdown in services”.

Information Management is covered in sections 5.8 and 8.4 of the Handbook; about 3.5 pages in total that provide guidance on standards for archiving, what is usually considered for archiving and the security considerations implicit in making the archive available to a wide range of people.

5.2.2 Gap between guidance on in-service SE activity and in-service needs

Although the activities and processes concerned with in-service systems are not different to those being developed, the emphasis on some aspects is, as is the reliance on the previous project having carried out the processes properly is paramount. The information archive and the capture of “head knowledge” are not given enough attention.

5.2.3 Good practice on in-service SE activity

No authoritative texts on this topic were located. The group’s understanding of good practice, drawn from the defence and rail sectors is, early in the update project:

- Review information archive to identify gaps;
- Engage with all stakeholders and elicit information to fill the information gaps (stakeholders could include people no longer associated with the in-service system, and should include the Users (including operators and maintainers));
- Identify what aspects are important to the Users;
- Photographs can be a useful method of recording what is actually in place;
- Generate requirements for the replacement system and update the information archive accordingly;
- Assess the remaining information gaps and associated risks;
- Schedule in mitigation actions, e.g.:
    a. update drawings to reflect in-use system;
    b. implement a technology and produceability (obsolescence) survey to ensure that those parts to be retained can be re-manufactured if necessary, or that equivalent technologies are in place,
    c. review the skills & competencies required to update the system and check that they are available;
    d. implement a legislation and regulation survey to check that the system meets current-day regulation/practice and identify what changes need to be made;
- Generate a Knowledge Management Plan to help with the update project and mitigate against future problems.

5.3 Gap 3: Architectural Design

This Section summarises the output of an assessment of the relevance to in-service SE of guidance provided in SE Handbook [1] on the Architectural Design Process.

5.3.1 Summary of Guidance in SE Handbook 3.1

The SE Handbook devotes approximately 2 sides of text, which includes one diagram, on the subject of the Architectural Design Process. The underlying process steps are defined as:

- Define a consistent logical architecture;
- Partition system requirements and allocate them to system elements;
- Evaluate alternative design solutions;
- Identify interfaces and interactions between system elements;
- Define the system integration strategy;
- Document and maintain the Architectural Design;
- Establish and maintain the traceability between requirements and system elements; and
- Define V&V criteria for the system elements.

5.3.2 Gap between Guidance on In-Service SE Activity and In-Service Needs

The guidance provides little help in understanding an existing systems architecture, particularly when it is not explicitly documented, and deciding which elements to retain and which to change.

5.3.3 Good Practice on In-Service SE Activity

The first pre-requisite for in-service SE activity is a maintained architecture with traceability to the current requirements. There is a tendency for in-service systems to be maintained as an “as-built / as-modified” configuration. Unless the architecture and requirements information is maintained in line with this configuration, there will not be a firm baseline on which to further develop the system, and there is a risk of inappropriate changes being introduced.

Assuming that the existing system architecture is well documented (whether through good maintenance of the design artefacts (preferred) or by remedial analysis), it is good practice to revisit the architectural design process to ensure that the proposed improvements are fully integrated into the existing system. There is an understandable desire to minimise the scope of change, but the impact of “appliqué” changes should be thoroughly assessed for adverse impact on the rest of the system. This is particularly important for safety critical applications, where a failure to understand the baseline architecture could result in embedded safety features being overridden.

5.4 Gap 4: Incremental Acquisition

There are arguably three types of Engineering Life Cycles (ELCs):

- Sequential – as realised through a stage identified waterfall or the “V” model;
- Incremental – as realised through Pre-Planned Product Improvement (P3I) or the “W” model; and
- Evolutionary – as through an iterative approach to the “Spiral” model.

Increment: increasing growth in capability or availability; something that is gained or added; an added quantity or character; one of a series of additions; a change in the value of one or more of a set of variables.

Evolutionary: a series of related changes in a certain direction; process of change; organic development; a process of continuous change from a lower, simpler, or worse condition to a higher, more complex, or better state; progressive development.

5.4.1 Summary of Guidance in SE Handbook 3.1

The SE Handbook, although mentioning alternative ELCs, features the "V" model. There is a section (3.4.2) that addresses Incremental and Iterative Development, however this seems to address an extended development process for a system. This does not seem to cover the increasingly common situation where a system is fielded for several years before being upgraded through a planned increment to exploit technology developments, manage component obsolescence or introduce additional functionality to deliver capability. The guidance also states that "IID [iterative and *incremental* development] methods are best applied to smaller, less complex systems or to system elements", and this clearly excludes the more complex and large scale systems that are candidates for incremental or evolutionary development.

5.4.2 Gap between Guidance on In-Service SE Activity and In-Service Needs

An appreciation and understanding of different ELCs is important to tailor generic processes for a particular set of circumstances.

It is also important to create a better understanding of how the "…ilities" (or "design fors") should be addressed within an ELC, recognising the need to include people, processes, products of infrastructure and support services as well as the fielded system. This is important for a "simple" development process, but for incremental acquisition to succeed, the infrastructure and support services must be incremented in parallel to enable the increment to be fielded.

It is useful to note that capability or availability improvements may be achieved solely through an incremental improvement to infrastructure or support services without making any changes to the fielded system, as illustrated below.

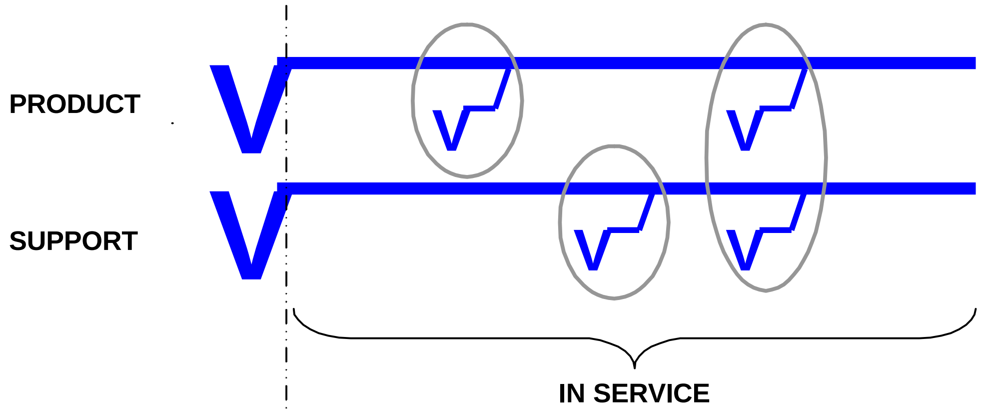

Figure 5-3: Incremental acquisition of product and support capability

5.4.3 Good Practice on In-Service SE Activity

The UK MoD's approach to Through Life Capability Management describes a number of processes and activities that are particularly relevant to planning incremental acquisition. The published material (www.aof.mod.uk) is couched in MoD terminology and lacks (understandably) worked examples, but it does provide guidance on a number of key activities that could be useful in other domains. Aspects covered include:

- Technology Readiness Levels (TRLs) and the approach to use these to plan capability increments to exploit emerging technology
- System Readiness Levels (SRLs) and the approach to use them to manage operational activities
- Through Life Capability Management – planning incremental acquisition and realising through the application of ELC models
- Sustaining Capability and Availability through:
    - Obsolescence management;
    - Handling emergent issues;
    - Product insertions; and
    - Service improvements.
- The use of architecture frameworks to support solution design and enable System of Systems issues to be addressed.
- The consideration of all lines of development that are needed to deliver an operational system (e.g. Training, Logistics, Personnel, Organisation etc.) and not just the equipment

5.5 Gap 5: Integrating Project Configuration Management (CM) with System CM

When an in-service system is changed, the change is normally accomplished by a Project that is a temporary organisation distinct from the Systems Owner (some people would say Asset Owner) and which has enduring responsibility for operating and maintaining the in-service system.

Note. The Project and the System Owner may focus on different systems. To reduce confusion, System with a capital 'S' is used to denote the system that the System Owner is concerned with.

Both the Project and the System Owner should carry out CM but the scopes of the two CM arrangements will be different. The two sets of CM arrangements must be co-ordinated during the execution of the Project and when the Project comes to hand-over to the System Owner.

5.5.1 Summary of guidance in SE Handbook 3.1

CM is treated in Sections 5.7 and 8.3 of the SE Handbook. These sections are about 4 pages in length in total and provide guidance on CM planning, baselines, selecting items to place under configuration control, auditing, and managing change. The guidance would probably be a readable starting point for the CM arrangements of either the System Owner or Project no acknowledgement was found that there might be more than one set of CM arrangements and therefore no guidance on managing the interaction between them.

5.5.2 Gap between guidance on in-service SE activity and in-service needs

It would be useful to provide guidance, written for the Project, on managing the interaction between the Project's and System Owner's CM arrangements. This interaction is considered to fall into two areas:

- issues associated with handover and in particular making sure that handover does not compromise the Systems Owner's CM arrangements; and
- making sure that the effects of changes to the System that occur during the early stages of the Project are taken account of.

5.5.3 Good practice on in-service SE activity

The working group located no authoritative texts on this topic. The understanding of good practice, as given below, is therefore drawn from experience within the team in the military, railway and air traffic domains.

Handover issues

Early in the project, the Project should agree with the System Owner:

- when in the project lifecycle the Project sub-systems will transfer from the ownership of the Project to that of the System Owner;
- how this transfer will be confirmed; and
- the content and format of the information that the System Owner requires in order to register the sub-systems in their CM arrangements.

The Project should design its CM arrangements to ensure that they are capable of generating the required content in the required format. They should be integrated with wide information management arrangements.

If the Project makes a single, atomic handover then there should be no more to do other than to provide the information and confirm its acceptability. There are two issues that may complicate things.

Firstly, it is sometimes the case that final adjustments have to be made to the sub-systems during the commissioning process immediately before handover. There may not be time to update the associated information in the handover package during commissioning. If so then it may be necessary to:

- deliver a baseline of information corresponding to the configuration before commissioning starts;
- record and approved changes made during commissioning; and
- apply these changes to derive a second baseline of information to be delivered after commissioning.

Secondly, it is sometimes the case that the sub-systems are delivered incrementally, with early deliveries being put into service before later deliveries are made. In that case, during the period from first to final delivery, the delivered systems will need to be subject to change control processes for both the Project and the System Owner. To avoid involving the System Owner in localised sub-system changes with no effect on the rest of the System it may be worth identifying a sub-set of Critical Configuration Items within the Project deliveries which have some interaction with the rest of the System and demanding that a Project change requests should be subject to the System Owner's change control if and only if it would affect one or more Critical Configuration Items.

Effects of changes to the System on the Project

When the requirements baseline for the Project is created it should refer to a CM baseline for the System. Critical Configuration Items within the system, that is configuration items that interact with the Project deliverables, should be identified. The Project should register an interest in all Critical Configuration Items and the System Owner should keep the Project informed of any proposed or actual changes that affect the Critical Configuration Items.

Note. As an extreme example of this, the Project may actually become the change authority for Critical Configuration Items. This is common on UK mainline railway signalling projects where the project will go to the National Records Centre and take physical possession of the records for both the signalling being worked on and adjacent signalling. Physical possession of the records is used as a 'token' for change authority meaning that anyone else who wants to change the equipment concerned must now do so via the project. The use of physical records as a 'token' for change authority is unlikely to persist in the railway industry for long and is not suggested for promulgation as good practice but the general approach, supported by some more modern mechanisms is regarded as valid.

Other remarks

Those responsible for asset management must maintain data about the condition of their assets. The group is not certain whether this is best regarded as configuration data but it should certainly be integrated with configuration data.

5.6 Gap 6: Information Management

This issue (Information Management) concerns the examination of available guidance on what processes and facilities are needed to create and maintain (system) information during the life-time of the system.

5.6.1 Summary of guidance in SE Handbook 3.1

The handbook has the following sections relevant to this topic:

- Section 5.7 Configuration Management Process
- Section 5.8 Information Management Process
- Section 8.3 Configuration Management
- Section 8.4 Information Management
- Appendix G.4 Configuration Management

In summary, the guidance states that product configuration information needs to be defined, stored and made available to support product assurance. Section 8 talks about a standards-based (AP233) approach to sharing information between different software products.

5.6.2 Gap between guidance on in-service SE activity and in-service needs

It is considered that in-service SE would benefit from the following additional guidance:

- Be more definitive about what system information needs to be captured and stored during a development stage;
- Be specific about types of system information that is particularly relevant to in-service support and upgrade activities;
- Give some helpful hints/steers on the sort of kit one is likely to need in order to maintain system information. For example, is an industrial strength PDM/PLM tool always needed?
- Point out that although suitable standards and data exchange formats will help future-proof system information, one should not be too reliant on these. As in other areas of technology, one probably just has to accept that from time to time, new kit will have to be bought and information transferred from the old facility to the new one.

5.6.3 Good practice on in-service SE activity

Feedback from in-service people to development people on what information needs to be stored to support in-service work is a very useful and easy-to-do piece of process improvement. Relevant experienced people from INCOSE are probably the best source of good practice in this area.

In extreme situations, one may have no other option other than to create or recover system information retrospectively. This is a difficult undertaking, but knowing what one is trying to recover will certainly help.

5.7 Shortfalls in guidance on systems development SE activities

5.7.1 Focus on support systems

It is not sufficient just to deliver a *product.* To be of value the product must be associated with some sustaining services. This military terminology does not travel to other sectors very well, so this statement is recast to say that the deliverable of a project needs to comprise the *operational system* that performs the desired function and the *support system* (depots, docks, tools, maintenance procedures and so on) that maintains the operational system.

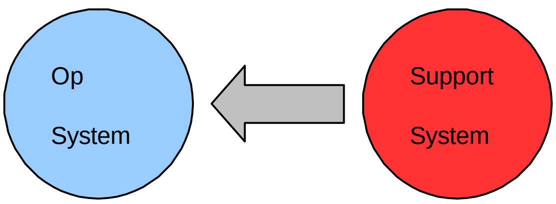

Figure 5-4

While it is generally acknowledged in theory that, when realising a new operational system, SE activities should also be focussed on its support system, in practice, insufficient attention is tends to be given to the support system with serious adverse consequences for SE when the system is in-service.

Additional reminders of this in SE publications, supported by examples and detailed guidance that is specific to support systems would potentially improve this situation.

5.7.2 Establishing systems baselines to support the in-service phase

Obsolescence management (maintaining system form, fit and function) is a relatively well understood process and does not strictly require novel systems engineering activity in the systems development stage. Good practice when design decisions are made is to include technology assessments to evaluate the technologies proposed for the solution system and confirm that none are approaching the end of their utility (that is, the evaluation process seeks to avoid technology dead ends). This leads on to a through-life process where, when a system performance failure is identified, the subsystem that is not achieving its specified (and earlier verified) performance characteristic can be isolated and replaced.

To prepare for through-life assessment of changing Stakeholder needs, it is necessary to set the conditions in the initial system design cycle to facilitate that through-life assessment. For example, it would not be desirable to attempt to reverse-engineer functional decomposition of a complex in-service system to determine the current system functions each time the allocation and decomposition of a new function to meet a new need is considered.

A key element of identifying whether system performance is still meeting changed stakeholder needs, and critically in maintaining the ability to effect change within the system in either event, is therefore the identification and maintenance of system baselines from the initial system design stage through to disposal. Systems Engineers are well used to the identification of "As Required", "As Designed" and "As Verified" requirements baselines in DOORS, and similar architecture baselines in appropriate architectural models. To effectively analyse the system and understand how it can be changed through life to respond to changing stakeholder requirements benefits from the maintenance of "as Built" and "as Used" or "As Maintained" architectural baselines, reflecting the delivered and employed system through-life. Further benefit is accrued from maintaining traceability from these architectures up to the level of measures of effectiveness expressed in "Stakeholder Need" rather than system performance terms.

5.7.3 Establishing standards baselines to support the in-service phase

It is good practice for projects to establish a baseline of the applicable standards used in the development of a system. This baseline may be ‘frozen’ and consequently may not be the same as the baseline of current standards at the time that the system enters into service.

It should be recognised that the need to retain records of the standards used in a system extends into the in-service phase. The group considers that it would be desirable to extend existing guidance to advise project to put in place a mechanism for capturing differences in “as-used” compared to “as-designed” standards.

5.7.4 Structuring architectural designs for the in-service phase

Open architectures, architecture frameworks (e.g. MODAF, DODAF) or those that comply with industry standards (for example those applied to the UK Rail Infrastructure) are easier to upgrade in service because the interfaces are well established. Functional modularity is a classic architectural approach that enables subsystems to be developed on the basis of Interface Control Documents (ICDs) that define the interactions with other subsystems. However, functional modularity does not usually result in a “lean” architecture. Where size, weight and data bandwidth are at a premium (for example space satellites), system architectures tend to be much more closely coupled.

Given that maintenance of a system architecture over a long service life will be a major commitment, it would be good practice to determine at the outset whether the system (or elements of the system) might be excluded from in service upgrade (other than by total replacement). This concept is particularly relevant for System of Systems, where an architecture framework (e.g. MODAF or DODAF) needs to be maintained but the details of the system elements behind the interfaces do not. An example of this is that the commoditisation and technology refresh of computing hardware means that it is not necessary to dwell on the internal components of a computer since they will be completely replaced when the system is upgraded.

Architecture descriptions must be accessible if they are to benefit those trying to understand an in-service architecture. SysML and UML may be precise tools for design, but there is evidence that users are finding difficult to interpret the key architectural features from systems documented in this way. For in service systems, it is important to be able to visualise where the changes are impacting the system, and some mechanism for highlighting the modified areas is required.

6 Conclusions and Recommendations

The following conclusions are reached and recommendations made.

6.1 Conclusions

a) The group has confirmed its initial view that the available guidance on SE in the in-service phase is capable of improvement. The group has found six areas in which significant improvement is possible and has found good practice that may be used as a basis for improved guidance.

b) The group is confident that, having followed a systematic process to reach these findings, they are sound but it acknowledges that they may not be comprehensive – there may be further areas of potential improvement and further sources of good practice.

c) The group considers that it is desirable to integrate any additional guidance with existing guidance documents (such as the SE Handbook and the SEBOK) rather than packaging them separately.

d) The group acknowledges that, as a consequence of this, it is necessary that further work should be carried out with international involvement and the involvement of the custodians of existing guidance documents.

6.2 Recommendations

While the group has been able to bring considerable experience of several sectors to the work, it is considered that this report would benefit from wider review. The group intends to present their work at the 2008 Autumn Assembly and invited feedback. The group would welcome comments from the UK Board and the UK Advisory Board and would wish to work any significant improvements into a reissue of the report

Assuming that its findings receive broad support, the group recommends that the UK Board should work to initiate two parallel streams of work.

- Firstly, it should recommend to INCOSE at a corporate level that an international working group (“Group 1”) should be set up to improve and extend the work carried out by this working group, to achieve a broader consensus on the conclusions and to establish arrangements for integrating additional guidance into existing INCOSE products.

The group acknowledges that, while this is considered to be a necessary step, it will take an extended period during which no benefit is provided to practising systems engineers. The group considers that the UK Chapter is in a position to lead a separate thread of activity that can deliver such benefit.

- Secondly, the INCOSE UK Board should set up a working group (“Group 2”) to produce a supplement to the INCOSE Handbook providing guidance in the areas identified by the current group. Group 2 should be set up to allow participation by telephone and email. The current work should be publicised at an international level, and international participation in this group would be invited and welcomed.

The working group accepts that Group 1 will probably identify new requirements for additional guidance that the output of Group 2 will not meet. However the working group considers that it is very unlikely that Group 1 will withdraw existing requirements so the output of Group 2 should be immediately useful to practising systems engineers as well as providing Group 1 with valuable input to their ongoing work.

A Appendix: Group Terms of Reference

Background

The INCOSE UK Advisory Board (UKAB) has framed a problem that its members encounter in the application of Systems Engineering (SE) to in-service systems (see Appendix B below) and recommends that the UK Chapter Board should set up a Working Group to start addressing this problem. This draft of this document suggests terms of reference for the Group

Purpose and Scope

The Working Group will advise the INCOSE UK Chapter Board on:

- The difficulties encountered in practice in applying authoritative guidance on SE, including the INCOSE SE Handbook, to systems that are in service. The Group should restrict itself to difficulties which are related to the fact that the systems are in the in service stage of the lifecycle.
- Best current practice in adapting SE guidance to overcome these difficulties
- Additional work that the INCOSE UK Chapter might initiate to assist its members further in overcoming these difficulties

In formulating advice, the Group should consider the widest practical range of current practice across market sectors and across business/technical disciplines, drawing on relevant existing INCOSE products, Working Group members' experience and published material.

Membership

The Working Group will consist of representatives from UKAB subscribing organisations, members of the UK Chapter Board or their representatives and other interested parties. The Chair and initial membership will be chosen by the UK Chapter Board. The Working Group may, by consensus, co-opt additional members if this would advance its purpose.

Deliverables

The Working Group will deliver:

- A programme of activities and meeting schedule for the Working Group.
- Minutes of meetings
- A report addressing the points in Purpose and Scope above and including Terms of reference for further work

It is hoped that the Working Group will complete its work within a period of 8 months from its first meeting.

Modus Operandi and Governance

The Working Group will report to the INCOSE UK Chapter Board.

Meetings will be held approximately once every two months, as teleconferences or at a mutually agreed venue, until the report is produced. Deliverables will be circulated to Working Group Members, INCOSE UK Chapter Board Members and UKAB members. Minutes will be approved at the next meeting of the Group.

The Chair will designate a deputy. In the absence of both the Chair and their deputy, the members present will agree a Chair for the duration of the meeting.

B Appendix: Problem Statement: Applying SE to In-Service / Precedented Systems

We are obliged to change systems which are in service in order to sustain them

The drivers for change include:

- Changing mission requirements
- Changing standards and legislation
- Degradation and/or lack of availability of components

The obstacles to accomplishing this change include:

Changing standards and legislation (because although it may be acceptable to use a legacy system which is non-compliant, changes generally have to be compliant)

- Loss of system information
- Loss of skills
- The conflict between the desire to use new technology to postpone obsolescence and the desire to use proven technology
- The problem of fitting the changes into the existing system

Although we do not consider that changing existing systems is different in principle from realising new systems, our experience is that:

- Some of the issues concerned with realising new systems, for instance defining architectures, are less problematic when changing existing systems.
- Some of the issues concerned with changing existing systems (such as fault diagnosis and overcoming the obstacles above) are more problematic than when realising new systems.

We find that the existing SE Body of Knowledge and the competences of SE practitioners tend to be stronger on the issues that are more important when realising new systems and weaker on the issues that are more important when changing existing systems.

C Appendix: In-Service SE Scenarios (Detail)

C.1 Scenario 1: Replacement of points at approaches to major railway station

The work was to replace all the points within a specified area, to current standards, unless otherwise agreed. This very brief specification of the work leaves no significant ambiguities although it does leave some issues (when to deviate from standards) explicitly unresolved.

It seems necessary to draw the system boundary widely enough to encompass the station in order to apply SE sensibly, in which case we are talking about maintenance of a system which is in service.

The job would be straightforward if the track was in open country and there were no deadlines. However, this is not the case. The track is in cuttings or under tunnels for most of the area – almost an underground railway – and work must be completed within 54 hours.

There are a lot of cables threaded in plastic pipes under the tracks, in contravention of current standards. Records are incomplete and it is not possible to establish what all these cables do until the tracks are lifted. A choice must be made between:

- seeking a concession from these standards;
- building a tunnel for the cables;
- building a bridge for the cables;
- placing the cables in hollow sleepers.

Relevant factors include:

- the construction programme (and the curing times of concrete);
- whether there is space to erect a crane;
- the length of the cables;
- the retesting required if a cable is replaced;
- the angle at which the track is fixed (normally tilted a little inwards but gradually returned to vertical on the approach to some points);
- the compatibility between sleepers and the type and angle of track required;
- the position of drains.

This is a true systems problem and, in principle, similar to those faced when building a railway but, in practice, the issues posed by the need to reopen the railway quickly, the poor records of the existing system and the legacy of choices made by previous generations of engineers are such that existing SE guidance requires significant reinterpretation to be useful.

C.2 Scenario 2: Support of airborne systems

Legacy equipments (avionics, communications etc.) fitted to platforms that may be 40 years old needing to be replaced (or significantly modified) because of obsolescence or a requirement to improve to capability. The system concerned can be the complete weapon system (e.g. aircraft and associated subsystems) or limited to an individual subsystem and its interfaces (e.g. a search radar subsystem).

System Engineering challenges:

- Design Expertise on original system may be scarce;
- Design specification and associated requirements documentation may have been “archived” (lost) – best practice has improved enormously over 30 years;
- No definition of what was the delivered performance (as opposed to that that was originally specified);
- Undocumented “features” that are relied upon by the user, maintainer …;
- Poorly documented interfaces;
- Multiple design standards through partly implemented modification programmes;
- Current use of system may differ significantly from the original intention;
- Current design safety standards/practices are likely to be significantly different from those in place at the time of design – how far do you take the lid off the can of worms?; and
- Obsolete design support environments.

C.3 Scenario 3: Transfer of responsibility for support

Taking over established support solutions for (mostly avionics) systems from the MoD, working in partnership with the MoD Integrated Project Teams (IPT), platform suppliers and other avionics suppliers The system concerned is the support system, which comprises two main aspects – the provision of serviceable assets at the right place and time (implicit is the repair, replacement activities across the whole supply chain); and the technical support of the equipments (answering user queries, modifications, safety, obsolescence etc).

System Engineering challenges:

- Understanding, agreeing and documenting the detailed scope;
- Understanding the support environment (current and predicted);
- Understanding current support performance;
- Understanding the future support requirements;
- Timescales and cost limit the detail of the work that can be done at bid stage – deciding where the effort should be concentrated and how the risk for the rest is best covered is critical;
- Aligning different cultures across industry and the MoD to ensure that all are aiming towards the same objectives and speaking the same language.

C.4 Scenario 4: Introduction of Urgent Operation Requirement to an in-service platform

Increasing flexibility is demanded of Military systems as the nature of modern conflict evolves. In part to support such flexibility, the UK MoD undertakes what is known as Urgent Operational Requirements – these are typically characterised as changes to a platform of system that is demanded by operational experience that was not foreseen when the system or platform was originally conceived, in order to achieve a change to the fulfilment of Military Capability needs. Also, they are characterised by short timescale requirements to produce the change, and a short in-service 'life' once the change is embodied – potentially being restricted in in-theatre operations only. Also, that change may not be embodied across a fleet, but could be embodied on selected examples from a given fleet.

In this scenario, UK MoD decides to pursue enhancing the intelligence gathering capability (in theatre) by the integration of a new reconnaissance pod onto the elements of the UK's fixed-wing fleet. The links below provide information on examples of the scenario described in the narrative:

- The official Press Release covering the completion of the integration: http://www.baesystems.com/Newsroom/NewsReleases/autoGen_10741183645.html
- Some more info, from a public news source: http://www.defenseindustrydaily.com/british-harriers-to-get-advanced-targeting-pods-03098/
- Some info on how the product is used by troops on the ground: http://www.airramstein.nato.int/bold_avenger07_press04.htm
- Some background information on the Harrier: http://en.wikipedia.org/wiki/BAE_Harrier_II

System Engineering challenges:

- The technology gap: integrating later-generation systems onto older-generation platforms.
- Availability of design and in-service information that is current and accurate upon which to base a change synopsis.
- Balancing emergent properties (including such things as risk) to provide the required capability.
- Ensuring that the right programmatic controls and monitors are in place such that delivery can be achieved in the right timescales.
- Ensuring compatibility of the systems when the standards and other governing/defining frameworks have changed over time (including legal and regulatory frameworks)

- Understanding, and delivering, potentially 'shrink-wrapped' capability across many the many Lines of Development[6] required to achieve a change to Military Capability.

[6] UK MoD defines Military Capability in terms of the Defence Lines of Development – DLOD's: Training, Equipment, Personnel, Information, Concepts and Doctrine, Organisation, Infrastructure, Logistics, with Interoperability defined as a cross-cutting theme – see http://www.aof.mod.uk/aofcontent/strategic/guide/sg_dlod.htm?zoom_highlight=lines+of+development

C.5 Scenario 5: Incremental development of a military communications system

A military communications system is to be installed across the whole Army as well as selected installations on aircraft and ships that have a need to communicate with Army units. The initial deployment has taken a lot of management because of the necessity to field the system to complete groups of users who need to work together.

Incremental development is necessary to maintain the capability in the face of issues such as equipment obsolescence, increasing user expectations, and the need to add capabilities. The system is installed in vehicles which have to be recovered from operational units and then returned in a controlled manner. The installation programme has to take into account the needs for interoperability within and between units, the deployment(s) that the unit is to be assigned to, and availability of personnel for user training prior to deployment. The circumstances around major deployments mean that finding the opportunity to uplift deployed vehicles drives the uptake of incremental improvements. The sheer number of vehicles equipped (several thousand) and the continual introduction of new vehicle types (all of which must be equipped with the system for compatibility) mean that an incremental change can take years to permeate throughout the entire vehicle holding.

SE Challenges:

- Revisiting up-front requirements exposes misalignment between the system requirements and the as built solution due to the inevitable last minute iterations of the system solution.
- How does one handle incremental changes to the requirement without re-running the whole process? The challenges extend to incremental V&V, incremental safety assessment, incremental training etc. Going back to square one is too costly to contemplate, but how does one ensure that incremental revisions in such areas are sufficient?
- How does one take account of the constraints of having to build an increment into an existing system – what should be kept and what should be changed?
- How does one justify the expenditure in terms of the division between an improved capability and support of existing capability?
- How does one handle issues of interoperability and compatibility between releases, both in terms of equipment and the other lines of development (notably user training, data provision and logistics support)?
- How to roll out upgrades / improvements on a regular basis whilst maintaining an operational capability? This is essentially an operational problem, but may constrain what can be offered in a particular upgrade.
- If there is an overlap of increments it will be necessary to maintain all increments that are fielded until they are phased out. This affects both hardware (e.g. spares holdings) and software (e.g. what version should be installed on a particular configuration; it may not be the most recent).

D Appendix: Rationale for the SE map used

This section contains a description of the rationale for the selection of system lifecycle stages and associated SE activities followed by the map itself.

D.1 Systems lifecycle stages

In the well-known "V" diagram, the progress of a system development (time or maturity) runs from left to right while the left hand descent represents decomposition of the overall system into parts and the ascent represents reintegration.

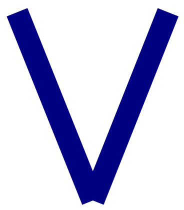

Figure D-1

This is a simplification because there are often multiple interlocking "V"s but nonetheless it serves as a workable map – in principle any systems development activity can be located on it.

The system's lifecycle does not end here and the in-service stage can be drawn as a horizontal line on the right.

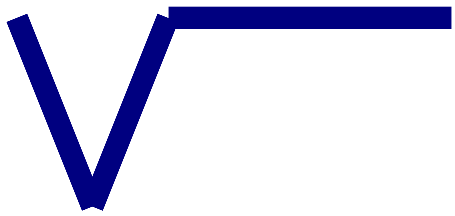

Figure D-2

But any system that is used is changed. Those changes can be regarded as traversing the stages of the "V" lifecycle again. However, things are not exactly the same the second time around. For example, the system will probably remain in service while the change is being designed, leading to some interesting challenges when the change is introduced. So it is worth drawing the change "V" separately. In reality there will probably be many change "V"s, some overlapping. These are implicit in the map.

The end result is therefore as below.

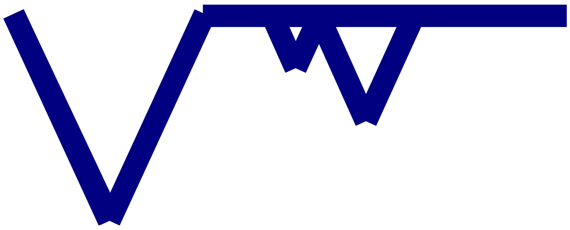

Figure D-3

To provide a framework in which the different needs of the two “V”s and the features specific to the in-service part of the lifecycle can be compared, the “V” lifecycle is extended to make it a “W” lifecycle”. As the intent is to produce constructive criticism of the SE Handbook, the Handbook [1] was used as a starting point. The Handbook discusses a number of different lifecycles but the one that is considered to be most relevant is the lifecycle from ISO/IES 15288 [2], which has 6 stages, and is explained as follows:

Lifecycle Stage	**Purpose**
CONCEPT	Identify stakeholders’ needs; Explore concepts; Propose viable solutions
DEVELOPMENT	Refine system requirement; Create solution description; Build system; Verify and validate system
PRODUCTION	Produce systems; Inspect and test [verify]
UTILIZATION	Operate system to satisfy users’ needs
SUPPORT	Provide sustained system capability
RETIREMENT	Store, archive, or dispose of the system

Table D-1

This is converted to a “W” lifecycle by:

- combining the UTLIZATION and SUPPORT stages (which run in parallel);
- decomposing the PRODUCTION stage into CONSTRUCTION and INTEGRATION (because the in-service issues are different for these two parts);
- showing a second, in-service traversal of the project stages with an additional INSERTION stage to cater for the insertion of the change into the in-service system.

The result is the following lifecycle:

Lifecycle Stage	**Purpose**
CONCEPT'	Identify stakeholders' needs; Explore concepts; Propose viable solutions
DEVELOPMENT'	Refine system requirement; Create solution description; Build system; Verify and validate system
CONSTRUCTION'	Produce sub-systems
INTEGRATION'	Integrate sub-systems; Inspect and test [verify]
UTILIZATION/SUPPORT	Operate system to satisfy users' needs; Provide sustained system capability
CONCEPT"	Identify stakeholders' needs for change; Explore concepts; Propose viable solutions
DEVELOPMENT"	Refine change requirement; Create solution description; Build change; V&V change
CONSTRUCTION"	Produce changed sub-systems
INTEGRATION"	Integrate changed sub-systems
INSERTION"	Integrate change with in-service system; Inspect and test
RETIREMENT	Store, archive, or dispose of the system

Table D-2

D.2 SE activities

The SE Handbook [1] describes SE activities under the following headings as shown:

Technical Processes	Project Processes	SE Support Activities
• Stakeholder Req Defn	• Project Planning	• Acquisition and Supply
• Requirements Analysis	• Project Assessment	• Architectural Design
• Architectural Design	• Project Control	• Configuration Management
• Implementation	• Decision-Making	• Information Management
• Integration	• Risk & Opportunity Mgt	• Investment Management
• Verification	• Configuration Management	• Project Planning
• Transition	• Information Management	• Quality Management
• Validation	• Enterprise & Agreement Procs	• Resource Management
• Operation	• Enterprise Environment Management	• Validation
• Maintenance	• Investment Management	• Verification
• Disposal	• System Life Cycle Processes Management	• Specialty Engineering Activities
	Resource Management	• Design for Acquisition Logistics – ILS
	• Quality Management	• EMC Analysis
	• Acquisition	• Environmental Impact Analysis
	• Supply	• Human Systems Integration
	Enabling SE Activities	• Mass Properties Engineering Analysis
	• Decision Management	• Modeling, Simulation, and Prototyping
	• Requirements Management	• Safety & Health Hazard Analysis
	• Risk and Opportunity Management	• Sustainment Engineering Analysis
		• Training Needs Analysis

Table D-3

For the purpose of this activity, it is considered that the list contains overlap and some activities that are beyond SE. The list was used along with Atkins and BAES publications and group members' experience as input to a brainstorm to derive the following list of SE activities that are considered to be sufficient for the purpose of the working group:

Stage based-activities	**Notes**
	The stage-based activities are primarily associated with a small number of lifecycle stages whereas the cross-lifecycle activities are relevant to all lifecycle stages. Each activity includes not only the tasks that directly deliver value to the SE programme but also the necessary planning and preparation beforehand and maintenance afterwards
Stakeholder Req Definition	
Requirements Analysis	Including documenting Concept of Operations and Doctrines
Architectural Design	
Implementation	
Integration	
Verification	
Transition	
Validation	
Operation	
Maintenance	
Disposal	
Cross-lifecycle activities	
Project Planning	
Project Assessment	
Project Control	Including supply chain management, source management, technical co-ordination and maturity management
Decision-Making	
Engineering Environment	Including tools, equipment and processes
Risk and Opportunity Mgt	Including investment management
Configuration Management	
Information Management	
Systems Analysis	Including Human Factors, Electromagnetic Compatibility, Integrated Logistic Support, Safety and all the "ilities"

Table D-4