An Initiative to Strengthen Guidance on the Systems Engineering of Systems which are Already in Service: First Progress Report

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Abstract. A number of INCOSE members believe 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 is not as strong in these areas as it could be.

A working group within the UK Chapter of INCOSE has been working for two years to strengthen SE guidance to serve better the large number of systems engineers who are working on systems that have entered service. An international working group has been formed to take the work further. It is timely to provide a report on the work to date so that the emerging conclusions can be scrutinised, challenged and improved upon and this paper provides just such a report.

Motivation

While working to improve the SE practices of a large UK rail company, one of the authors was involved with a project to replace some of the switches[1] at a major UK railway station. The specification for the work comprised a plan of the station with an area marked on it and a requirement to replace all the switches within the specified area, to current standards, unless otherwise agreed.

Such a job would be straightforward if the track was in open country and there were no deadlines. However, this was not the case. The track was in cuttings or under tunnels for most of the route and work had to be completed within 54 hours.

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

- seeking a concession from these standards;
- building a tunnel for the cables;
- building a bridge for the cables; and

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[1] Switches are known in the UK as 'points'

- placing the cables in hollow sleepers.

Factors relevant to this choice included:

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

The problem is a true systems problem in that the difficulties are concerned with interactions between parts of the system rather than with the parts themselves. The problem is a challenging one, even though its general nature is routine.

Projects such as these did not at the time routinely employ SE practices. The author's attempt to apply traditional SE practices to assist the project was frustratingly unproductive. The experience was rather like trying to use a Metric socket set on a car with Imperial bolts: the tool is clearly designed for this sort of problem but it does not quite fit.

Some of the reasons for this frustration were as follows:

- Sharpening requirements ought to help any project and the requirements for this one – a paragraph of text, a plan of the station and a blue line – did seem unsophisticated. However, this very brief specification left no significant ambiguities, although it did leave some issues (when to deviate from standards) explicitly unresolved. The real uncertainty did not concern where the project wanted to get to; it was about where it was starting from. Michael Jackson (1995), uses the phrase "domain knowledge" to mean the facts about the environment that one must take into account when specifying a system to meet is requirements. In Jackson's language the requirements difficulties are mostly to do with the domain knowledge rather than the requirements themselves.[2]
- SE handbooks and standards move on from establishing requirements to creating a system architecture. But we are not creating an architecture here – we have one already, at least at a general level. Our challenge is to find out exactly what it is – most of the architectural decisions were taken long before the phrases "systems engineering" or "systems architecture" had been invented – and then to adapt and apply it.
- The business of making the transition from the old system to the new one is a first-class part of the problem. Solutions that are otherwise completely viable must be rejected if they cannot be built in time. Moreover this is, in railway terms, a rather simple transition. When simultaneously replacing the trains and signalling on a Metro line, the transition may last several years and its complexity is a major part of the SE problem.

[2] Jackson's distinction is useful but the phrase turned out to be a source of endless confusion and does not figure in current products of the work

For in-service systems, design is a 4-dimensional problem – the migration path is as important as the final system.

It is not that existing guidance is valueless in each of these issues – far from it – but it needs to be augmented before it can be applied to best effect.

Initially the author used this example in discussion with colleagues in the INCOSE UK chapter whole were working in other sectors as examples of SE issues specific to the rail sector. He was rapidly disabused of this misunderstanding. Every time he put forward an issue, the response would be a precise analogue on the sustainment of a frigate, aircraft or communications system.

These conversations led members of the INCOSE UK chapter to the conclusion that there was an issue worth tackling but that the issue concerned sustaining systems that are in service and the chapter started to get to grips with this issue.

Phase 1

Getting underway. A workshop at the INCOSE UK 2007 Autumn Assembly, with participants from many different sectors, explored the issue and a consensus quickly arose 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 is not as strong in these areas as it could be.

As a result, the INCOSE UK chapter 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 might be initiate to assist its members further in overcoming these difficulties.

A 10-strong working group with experience in defence, aerospace, air traffic control and rail was formed, worked through its remit and presented its report (INCOSE UK Chapter Working Group on Applying Systems Engineering to In-Service Systems, 2008)[3] at the Chapter's 2008 Autumn Assembly.

A summary of the process followed is now presented, followed by the conclusions reached and recommendations made.

The process. The group was keen to follow a systematic, rational approach in order to reach objective and defensible conclusions. The following approach was used:

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;

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[3] The report may be downloaded from http://www.incoseonline.org.uk/Documents/Groups/InServiceSystems/is_tr_001_final_report_final_1_0.pdf

- 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 grid 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.
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 approach is illustrated in figure 1.

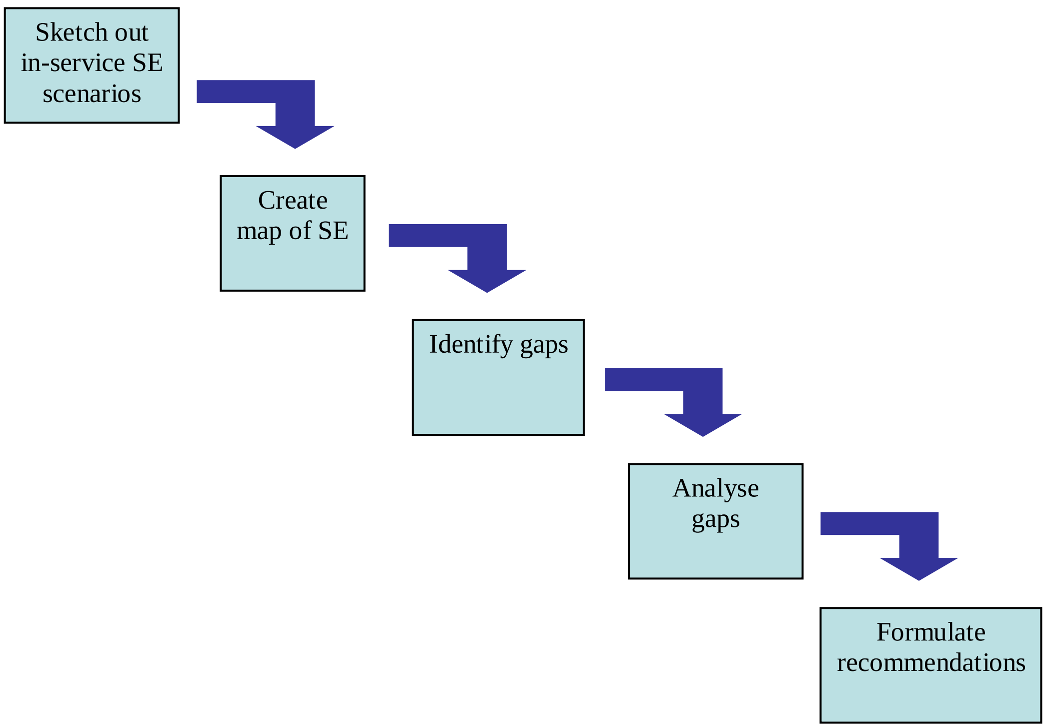

Figure 1. The process used in the first phase of the work.

The map of SE. The heart of the process was the map of SE, a grid of lifecycle stages against activities. The first element of this **model** is a sequence of lifecycle stages that properly took account of the nature of sustaining in-service systems.

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.

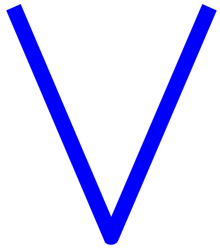

Figure 2. The ‘V’ lifecycle

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This is clearly insufficient for the current purpose as it does not include the in in-service stage, which can be drawn as a horizontal line on the right, to give the following “V+” lifecycle

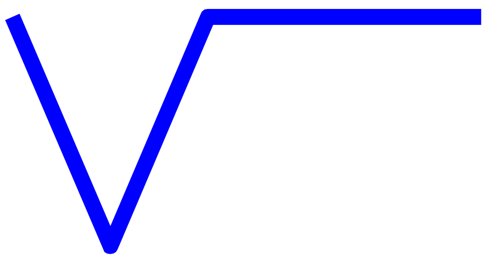

Figure 3. The ‘V+’ lifecycle

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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.

The end result is therefore the lifecycle below, which we refer to as the “W” lifecycle. It is, admittedly, a rather untidy “W” but then, in the group’s experience, sustaining systems is a rather untidy business.

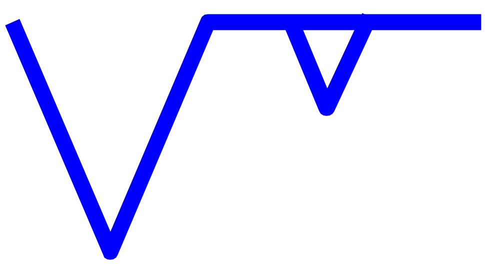

Figure 4. The ‘’W’ lifecycle

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The map requires a sequence of lifecycle stages. As the intent is to supplement the INCOSE SE Handbook, the Handbook (INCOSE, 2008) 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/IEC 15288 (ISO/IEC, 2002), which has 6 stages, as set out in Table 1.

Table 1: The 15288 Lifecycle Stages

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

This was converted to a set of stages for the "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); and
- 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 of this conversion is shown in Table 2.

Table 2: The “W” Lifecycle Stages

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

To come up with the other dimension of the group, the group used the list of activities from the SE handbook together with their own experience and their organisations’ publications as input to a brainstorm to derive the list of SE activities in table 3.

Table 3: Activities

Stage based-activities	**Notes**
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"

The resulting table was rather large (11 by 20) but it was quickly realised than not all cells were in fact meaningful and, in many cases, adjacent cells could be combined and this was used to create a map which the group felt was fit for its purpose – supporting a thorough consideration of SE practices in order to identify gaps.

The conclusions. Analysis of this map led to identification of six gaps, that is, six areas where it was considered that it was possible to strengthen existing SE guidance to support the in-service phase better:

A. **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.

B. **Domain Knowledge:** 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.

C. **Architectural Design:** Guidance wanted on modifying architectures: How much should you change / re-evaluate? How to deal with architectures that are implicit in standards?

D. **Incremental Acquisition:** Planning out an incremental process for acquiring or implementing the change that keeps the service going. Considering backward compatibility and logistics.

E. **Integrating project Configuration Management (CM) with system CM:** Delivery project CM information must be integrated into the CM system for the enclosing system.

F. **Information Management:** Maintaining accessibility and modification of information through life.

The recommendations. While identifying these gaps is a necessary first step, of its own the list is of little help to our customer: the hard-pressed systems engineer trying to apply their discipline to an in-service system. To be of service to them, we need to provide some practical guidance.

But there is already a large body of SE guidance documents and it is growing by the day. The group was aware that an objective set for issue 3.1 of the SE Handbook was to reduce the page count. Clearly, serving the need identified would tend to increase the volume of SE guidance. The group could see that there was a conflict between two objectives:

- to maintain in-service SE as part of mainstream SE and avoid it becoming a separate "ghetto"; and
- to maintain a body of SE guidance of a usable and manageable size.

The group could not see immediately how best to resolve this conflict but, recognizing that it existed, recommended initiating two parallel further threads for the next phase of work:

- Phase 2: Thread 1: A UK-led working group to develop supplementary guidance to cover the gaps identified.
- Phase 2: Thread 2: An international working group to improve and extend the work carried out by the UK working group, to achieve a broader consensus on the conclusions and to establish arrangements for integrating additional guidance into existing INCOSE products.

These recommendations were considered by INCOSE Technical Operations and the Board of the INCOSE UK Chapter and were accepted. The first thread is complete and the second is underway. The following sections describe progress to date and forecast.

Phase 2: Thread 1 – Developing Guidance

The UK Group was reconvened with a new and enlarged membership and started work.

After two meetings, it became clear that members were looking at the problem from different viewpoints. Four viewpoints were identified:

- Managing the System: Maintaining or improving system performance;
- Changing the System: updating or upgrading the system in response to changing needs and circumstances;
- Delivering the Service: Using the system to deliver a provide a service that advances the business objectives of the organisation;
- Optimising the Supply Chain: designing the right supply network to deliver effective support to the system in question at an affordable cost.

Each of these viewpoints is associated with a different system boundary. The 'Managing the System' viewpoint is associated with the system of interest directly while the other three extend this system to include, respectively:

- the project system set up to change the system of interest;
- operational staff and procedures; and
- support arrangements and supply chain.

Figure 5 illustrates the relationship between these four systems.

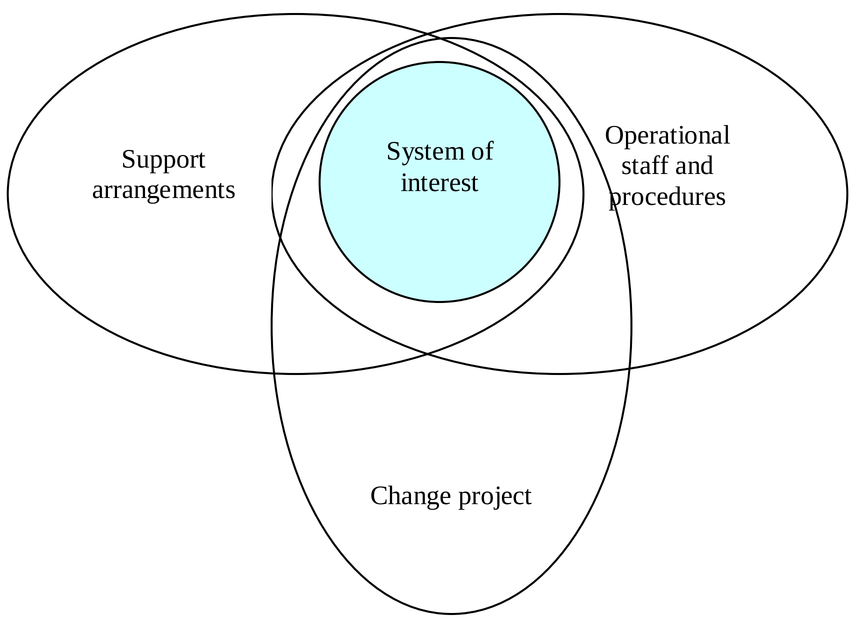

Figure 5. Four systems

The group found this extremely helpful in reconciling input from different people, checking for thoroughness and structuring guidance so that different users can find what they need.

The group also found it helpful to combine two pairs of gaps from the Phase 1 activities and create four new areas for consideration, each related directly to one or more headings from the SE handbook:

- Requirements, Validation and Verification;
- Architectural Design;
- Implementation and Transition; and
- Information and Configuration Management.

The group published its final report (INCOSE UK Chapter Working Group on Applying Systems Engineering to In-Service Systems, 2010) in April 2010. This report includes supplementary guidance in the four areas listed above, organised in each case according to the four viewpoints listed before that. Important themes that arise in that guidance are as follows:

- Requirements, Validation and Verification
  - If you are managing the system, delivering a service or optimising the supply chain, you need to watch for and react to drift between what is needed from the system and what it delivers. This drift may arise from changes to what is needed from the system, from changes its performance or from changes to the economic, political or geographic environments.
  - If you are changing the system, having a clear definition of where you want to go may not be enough; you may need to spend significant effort establishing where you are starting from.
- Architectural Design
  - If you are modifying the architecture of an existing system then, in additional to the traditional, 'forward' architecting – that is, creating the new architecture – you may also need to engage in 'reverse' architecting – that is, understanding what the current architecture really is. This may not be written down or, if it is, the paper world and the real world may not match.
  - Over time, the architecture of a system may become less and less suitable for the system. Deciding when to change the architecture and when to work within it is key to success.
  - Supply chain models have traditionally been addressed, in the main, by disciplines other than SE. However systems architectural techniques are useful in documenting and optimising the supply chain.
- Implementation and Transition
  - If you have to introduce change to a system while keeping it in service then this introduces a whole new dimension to the design and planning problem which requires attention from all four viewpoints if excessive interruptions to service are to be avoided.
- Information and Configuration Management
  - Sustaining real systems too often requires dealing with incomplete and unreliable information. One needs strategies to cope.

- It is not enough for the project and the system owner to follow good practice in configuration management, they also need to co-ordinate their activities in this area if problems at handover are to be avoided.
- Do not neglect the information held in people's heads. With an in-service system, there is usually a goldmine of useful information held by the users, operators and maintenance personnel.

It may be noted that several of the points above are about dealing with the consequences of incomplete or inadequate SE at earlier stages of the system's lifecycle. This may be due to the lack of formal SE when the system was built or lack of emphasis on continuing activities once in-service. Of course, the group supports efforts to make this a less frequent occurrence but, while it remains all too frequent, the group considers that systems engineers should be armed to deal with the problem.

The group supported the view that, while the principles underpinning SE remain the same across the lifecycle, some supplementary guidance is required in order to apply these principles in the in-service phase, noting in particular that many aspects of in-service SE have to be performed continually, outside the rhythm of a project, which is bounded in time.

The group concluded that a well-managed extension of SE into the in-service stage is needed to protect the significant investment made in a system and hopes that the guidance that it has collated will help systems engineers to achieve this.

Phase 2: Thread 2 – Integrating Guidance

The international In-Service Systems Working Group was chartered and held its kick-off meeting on 21st October 2009. At the time of writing, it had 17 members from 4 countries. The group is engaged in three activities:

- considering the guidance produced by the INCOSE UK working group in order to extend and improve it;
- considering the current channels by which INCOSE publishes advice on good SE practice in order to make recommendations on how additional guidance on performing SE on in-service systems should be integrated into these publications; and
- making recommendations on how best to bring the guidance to the attention of practicing systems engineers who can benefit from it.

While the international group is taking the output of the UK group as a starting point it will be doing more than just working out how to fit this into existing structures – new perspectives and new ideas will inevitably drive improvements.

The group understands that co-operation with other INCOSE projects and working groups is essential to bringing its work to a successful conclusion. It already has open channels of communication with the BKCASE project and the Transportation, Knowledge Management and Requirements working groups.

The group is aiming to complete its work and deliver a final report by January 2011.

Acknowledgements

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BIOGRAPHY

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