So what is “in service systems engineering”?

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Abstract. This paper has been produced to help the INCOSE UK In-Service Systems working group understand the different perspectives of in service systems engineering. It describes four related perspectives of systems engineering in service systems, specifically:

- Managing the system through life to ensure it remains safe and delivers the required performance by monitoring the material state of the system against its design intent and commissioning update, upkeep and upgrade as necessary.
- Improving the system performance by upgrading and updating the system to meet a new/existing requirement.
- Using the system to deliver operational services by defining the services to be delivered, designing and implementing them and continuously improving them
- Reducing the cost of the system and managing obsolescence by optimising the system’s supply network

The paper concludes that that it is considerable benefit to considering all four perspectives, as:

- They increase the range of options to improve system effectiveness and reduce cost of ownership
- They highlight some of the reasons why in-service systems are so difficult to change
- The show some of the cultural misunderstandings that can occur between the systems engineering and in-service support communities.

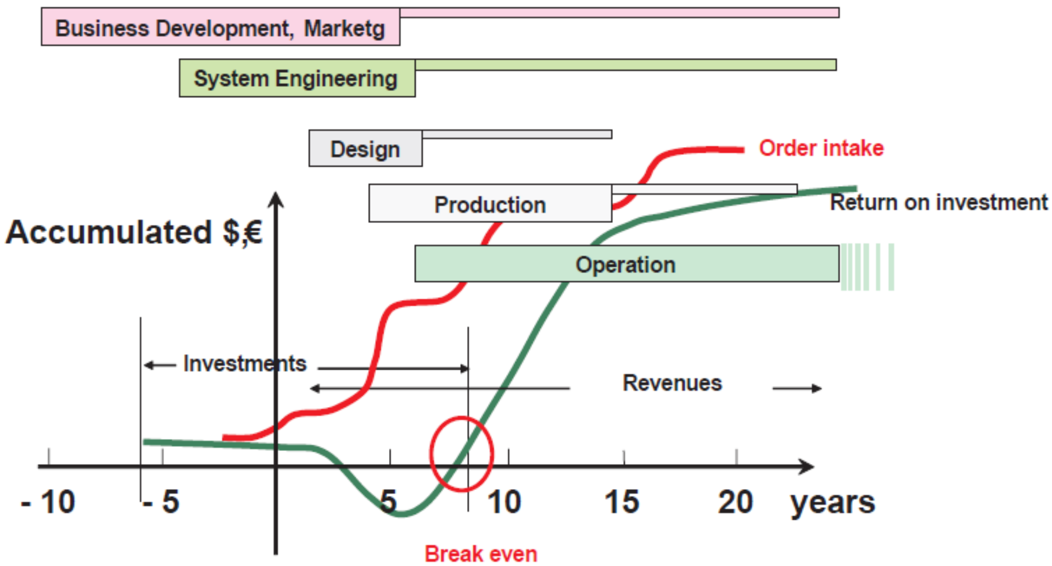
Finally this paper has confirmed the benefits of Checkland’s soft systems in clarifying a complex situation.

Introduction

This paper has been produced as part of the INCOSE UK In Service Systems (ISS) working group. The aim of the group is to

> *“… write [an In Service Systems Engineering (ISSE)] guidance document. The guidance document should be designed to supplement to the SE Handbook, so it should cross refer to the SE Handbook and avoid duplicating content from the SE Handbook.”*

Systems Engineering (SE) has been applied to new equipment procurements of significant capabilities in the defence, aerospace and more recently transport sectors. Whilst not explicitly excluded from application to in-service systems, the assumption amongst large proportions of systems engineers is that by the time the system is in service, systems engineering is over. This is reflected in standards such as ISO 15288 and the INCOSE SE handbook [Haskins].



Generic business lifecycle from INCOSE handbook 3.1

There is some logic to this assertion. SE is most effectively applied in the early phases of a project where there are few constraints and changes are cheap to make. High quality systems engineering applied very early in the lifecycle will ensure that the right system is acquired, in the right way.

However, applying SE to ISS can be beneficial. Good SE can help manage safety and operational risks through life, help manage system upgrades and manage the delivery of business services using the system.

Implementing good SE practice on an ISS is, however, problematic for several reasons:

- The management and use of ISS does not fall within the project/programme management paradigm assumed by most systems engineering standards and textbooks. Rather ISS are managed using asset, operations or service management principles.
    - This adds a language problem – with the same concept named differently – and different concepts with the same name.
    - Operations management has a different balance between reaction and planning. A ‘sense and react’ paradigm can often be more effective and efficient than a ‘plan and execute’ one.
- Determining the system of interest can be far harder than in a new procurement.
    - This is partly inherent. In service systems are often part of other systems. For example a radio can be part of a train, a signalling system, a passenger information system and a rail service.
    - This issue is made more complex because of commercial and programmatic interfaces. In some respects the very success of systems engineering at the project level (creating clear defined boundaries) makes delivering an effective (multi-system) capability more difficult.

The current INCOSE UK team looking at developing guidance on Systems Engineering In Service Systems had to deal with these issues head on. The initial discussions identified that some of the group were viewing in service systems engineering in terms of the most familiar part of in service management to traditional systems engineers – the management of an upgrade/update to an existing system. Others, however, saw systems engineering as being useful in the design and management of operational services using the system, the day-to-day management of operational and safety risks and the optimisation of the systems support network.

Rather than try to argue which was the 'correct' definition of in-service systems engineering, the author agreed to lead a short task to articulate the different perspectives of what in-service systems engineering could be. This task would then be able to focus the team on a single definition (or definitions) of what they would focus on, and possibly provide a framework for the final deliverables

Introduction to Checkland's Soft Systems

Soft Systems Methodology (SSM) was developed by Peter Checkland at the University of Lancaster, UK. SSM is aimed at understanding complex social situations before problem definition. The key difference between soft and hard systems is the degree of agreement on the purpose of the system. To design a hard system it is necessary to come up with a clear purpose (or compatible set of purposes). There are often significant disagreements as to the purpose of soft systems.

A soft systems approach helps the systems engineer to express the different stakeholders' weltanschauung[1] of the system either to bring stakeholders into alignment, to identify the need for multiple solutions to different problems or to design a solution that can meet all needs.

These different weltanschauung are often not superficial perspectives that people can move between. They tend to be deeply ingrained, linked into peoples fundamental assumptions and beliefs as to how the world is, or how it should be. Understanding these worldviews is critical if we are to:

- Communicate between groups with different worldviews
- Have a common understanding of the purpose and applicability of key SE techniques to in service systems
- Start to converge on a common understanding body of knowledge of how to apply SE to ISS

Finally the discussion is further confused by the perspective of an individual within the supply chain. For example, to:

- A radio manufacturer, the radio is a system, and a power supply a sub-system;
- An aircraft manufacturer the aircraft is the system and the radio is a sub-system;
- A defence capability planner both the aircraft and the radio are sub-systems within the air-defence system.

[1] Checkland uses the German word Weltanschauung to describe the different perspectives of the system

Each of the individuals uses systems engineering techniques (such as requirements management, architecting or trade studies) at different levels. The worldviews are independent of the level of an individual within the supply chain.

Checkland's approach was selected as it was suitable for describing the different perspectives, had been previously used by author [Kemp] and well understood and respected within the INCOSE UK and international community.

Three elements of Checkland's methodology were used in this analysis:

- The concept of different, complementary, weltanschauung
- The development of root definitions describing the customer, actors, transformation, owner and environment for each weltanschauung
- A simple activity diagram for each root definition

Four perspectives of In Service Systems Engineering

An initial dialogue of what individuals considered in-service systems engineering identified three different weltanschauung. These were worked up into three different root definitions. As the author attempted to develop activity diagrams, it became obvious that one of the weltanschauung needed to be split into two. This led to the following weltanschauung:

- Managing the system's operational and safety risks – balancing changing requirements, environment and the degrading material state of the asset – and commissioning maintenance, renewals and enhancements.
- Changing the system – systems engineering a renewal or enhancement project.
- Using the system to deliver a service – engineering the technical and business services to be delivered using the system
- Optimise the system supply network to optimise support – engineering the supply network to reduce whole life costs and improve performance

These are explored in the following root definitions and activity diagrams.

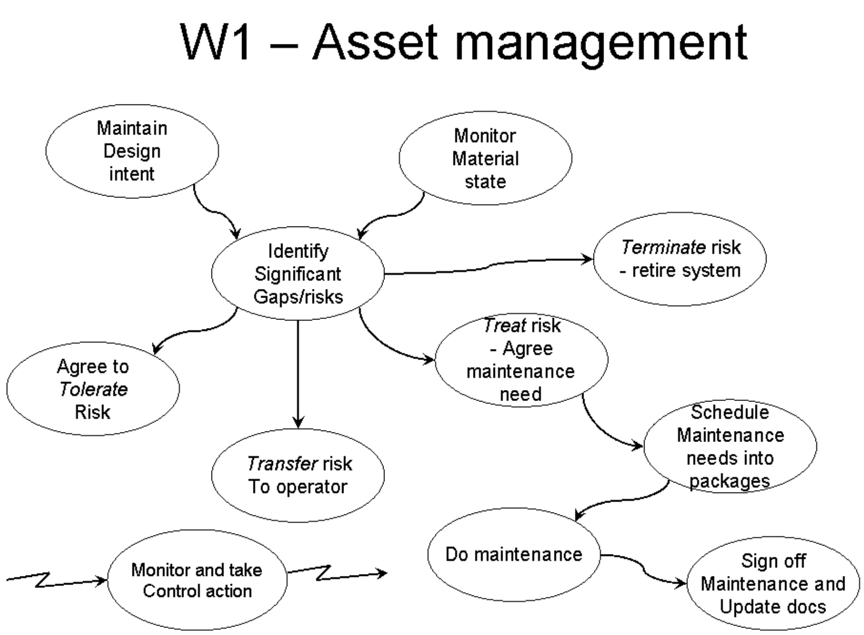
Managing operational and safety risk

Customer	Equipment users and owners
Actors	In-service design authority
Weltanschauung	Managing the system's operational and safety risks
Transformation	The in service design authority monitors the system's material state, its current and future use and decides whether the risk can be tolerated, whether it can be transferred to operators, whether the system needs upgrading or retiring. If the system needs changing the service design authority commissions maintenance, renewal or enhancement work. The system design authority ensures that the work has been completed and documentation updated.
Owner	In service design authority
Environment	Users and their use of the system, enhancement/renewal project delivery, sponsor's business case for upgrade, sponsor's trade-off decision of upgrade vs other option, obsolescence monitoring/tracking, condition/environment monitoring/tracking, initial development of system design/management information (configuration, architecture, performance characteristics, failure modes, planned maintenance schedule, …)

Table 1: Root definition of managing the systems operational and safety risks

This weltanschauung follows an operations management paradigm, with four interrelated sets of activity being undertaken concurrently (based upon ISO 10303 - Product Life Cycle Support activity model):

- The management of the design intent against the material state of the system. The deign/design intent includes all of the traditional SE products (effectiveness, performance, requirements, architecture, …). The material state includes all of the evidence that the system is as designed as well as the evidence that it is not. The design



authority role is primarily about managing this gap – is the system safe to operate, will it deliver the required operational effectiveness, does the system exhibit unintended emergent behaviour?

- The commissioning, oversight and acceptance of maintenance. This is essentially acting as the technical sponsor for upgrade (new capability), update (replacing obsolete sub-systems) and upkeep (returning to safe and capable level) – from initial commissioning through to acceptance that they have been completed as needed. This involves concept exploration, requirements management and may also involve packaging several different upgrade, update and upkeep tasks into a major upgrade programme.
- The management of supplies – making sure that replacement parts (which could be complex engineered products or simple consumable items) are available when needed.
- The management of information. In theory this is a simple task. Coupling modern IT, support data sets (such as PLCS) and support processes will ensure information is captured one and used by everyone who needs it. In practice developing an equipment support information system is a complex, risky and expensive systems engineering task in itself!

Upgrading or updating the system

Customer	Sponsor
Actors	System design authority, upgrade/update project team, sub-system suppliers
Weltanschauung	Upgrading or updating the system
Transformation	The service design authority commissions an enhancement or renewal, defining required system and sub-system performance, costs and timescales (including fit-opportunities). The upgrade project manager oversees delivery a sub-system that that is embodied into the system and commissioned. The service design authority confirms that the system meets the enhanced requirements.
Owner	System design authority
Environment	Initial upgrade/update business case and decision to initiate the project, sub-system design and development, project resourcing/initiation process,

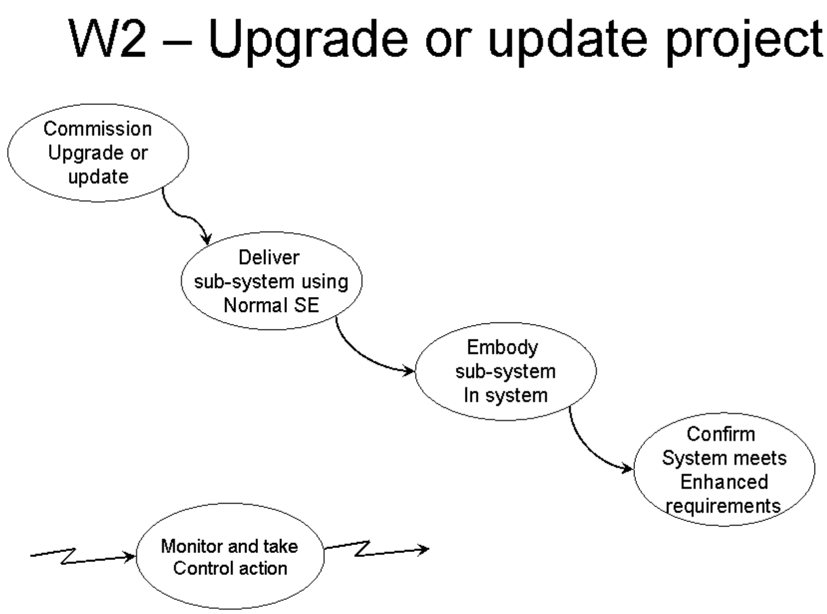
Table 2: Upgrading or updating the system

Sometimes called upgrade, update, enhancement or renewals this weltanschauung is about embodying a change to an existing system. To most traditional systems engineers this is the simplest of the three weltanschauung as it uses the project/programme management paradigm that they are familiar with. It follows the traditional systems engineering lifecycle (from the INCOSE SE handbook 3.1):

- Concept. The bulk of concept trade-off's undertaken in this stage will have already been completed by the time an upgrade/update project has been initiated. Most of the concept work involves clarifying stakeholder's needs (system/sub-system function, performance and effectiveness), proposing viable solutions (assuming system upgrade/update).
- Development. This is nearly a conventional development phase. Three key differences: the need to embody the change in the in service system; the need for a 'make, buy or reuse'

decision; and, the need to undertake regression testing on the functions and performance of the system not being improved to ensure that they are not compromised.

- Production. Again, this is nearly a conventional development phase. Regression testing is required. Also there may be a need to tailor individual 'mod kits' or embodiment plans to cope with variations in system configuration. There is a need to ensure that the embodiment of the change does not disrupt ongoing service delivery.
- Utilisation. No change.
- Support. No change
- Retirement. Almost a conventional retirement phase. The elements removed will obviously need disposed of in an environmentally safe manner.



As the changes need to be embodied in a particular fit opportunity, the programme may be run under a 'fixed time - variable scope' rather than 'fixed scope – variable time' paradigm.

Using the system to deliver a service

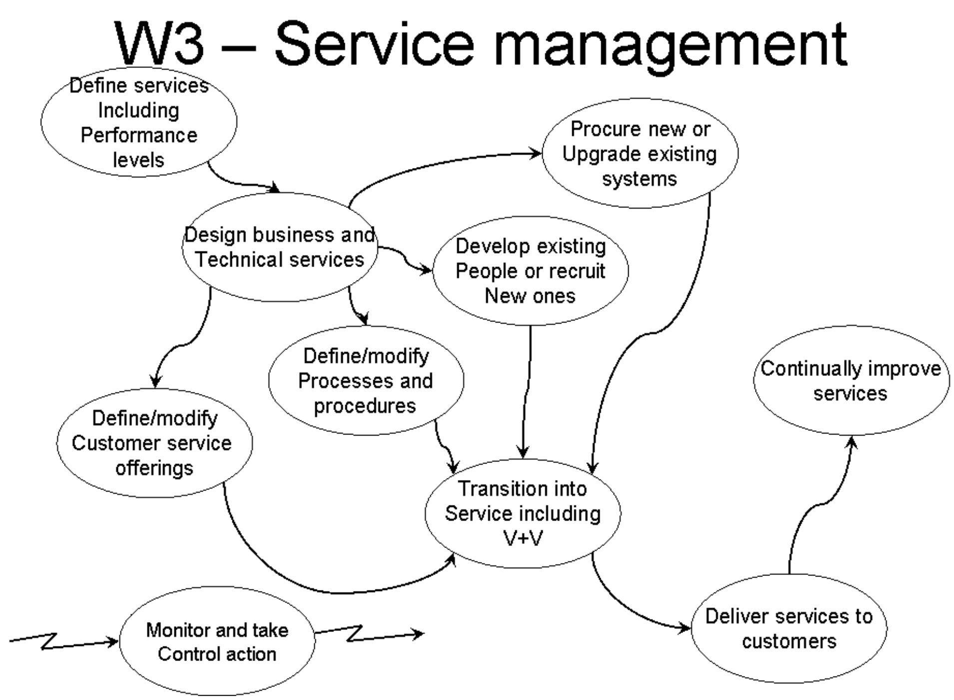
Customer	Service customers
Actors	Management board, service design authority, operations, sub-contractors, in-house engineering
Weltanschauung	Defining, designing and delivering services using the system.
Transformation	Company management board determine the services (and the levels of service) that they want to offer. Service design authority designs the services to meet service performance levels, based upon current, planned or new systems, processes and people. Service design authority sponsors new or upgraded systems, which are delivered by in-house engineering or sub-contractors. Services design authority writes new (or modifies) processes and trains people. Service design authority manages the transition of new systems from system suppliers into live business services, possibly piloting or working up services prior to going live. Operations deliver the services to customers (using a mixture of processes and systems). Operations and the service design authority diagnose service failures to determine which

	system (or interaction of systems) caused the failure and fix. All stakeholders undertake continual service improvement.
Owner	Management board
Environment	Company strategy, new/upgraded system acquisition/SE approach

The third weltanschauung involves using the technical/product system as part of a business or operational system. It comprised five concurrent processes (from ITIL information service management v3):

- Service strategy – determining the services that will be delivered. This includes defining the functions, effectiveness and performance of the services.
- Service design – designing the service to deliver the agreed functions, performance and effectiveness.
- Service transition – introducing new components and services, including the necessary V+V
- Service operation – delivering services to customers (which often have a lifecycle of their own) and recovering from service failures
- Continual service improvement – improving all elements of the service based upon feedback

This weltanschauung is a mixture of the programme and operations management paradigm. It is also operates concurrently over several different lifecycles:



- The strategy lifecycle – where changes to strategy are agreed, new services introduced into service and the impact on the business observed.
- The individual service development lifecycles, where a new/upgraded service is defined, designed, new/upgraded (sub-) systems procured, transition into service.

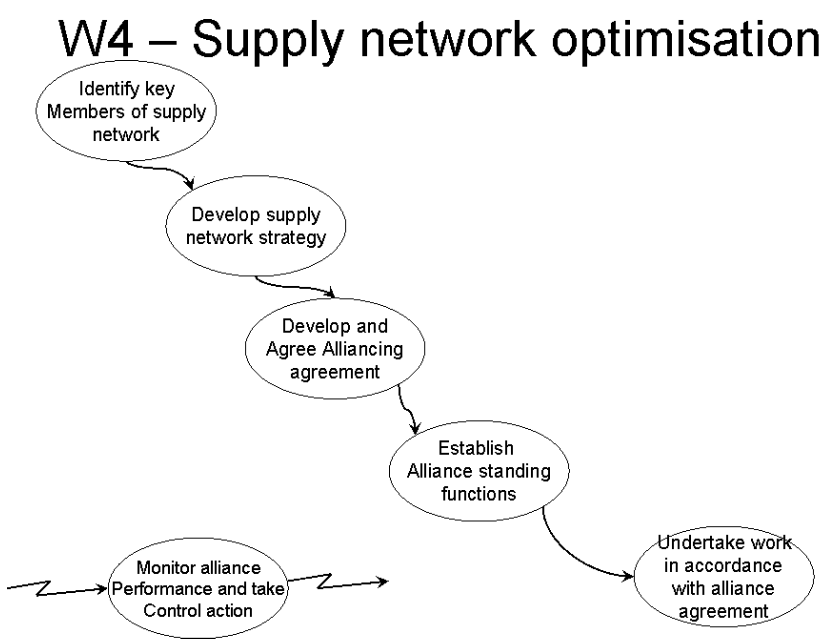
- The individual (sub-) system lifecycles.

All three of the different lifecycles are, of course asynchronous, but interrelated. There are significant challenges associated with: understanding the evolving architecture of operational services, technical services and systems; understanding the context of individual systems; and, regression testing.

Supply network optimisation

Customer	Equipment users and owners
Actors	In-service design authority, maintainers, system sponsor
Weltanschauung	Optimising the supply network to achieve value for money
Transformation	The in service design authority and key members of the supply network and agrees to improve supply network performance. The design authority and key members determine the procurement approach to be taken for key sub-systems (i.e. collaborate or compete). The design authority and key suppliers implement an integrated strategy for asset management, update/upgrade and service delivery. They implement the standing elements of the alliance (programme office, systems engineering function, collaborative working environment, …). Individual elements of work are undertaken in accordance with the alliance strategy.
Owner	In service design authority
Environment	Users and their use of the system, asset management, upgrade/update project delivery, service delivery

The final weltanschauung involves optimising the supply network to deliver a cost effective support infrastructure for the system. As the system design is already fixed, this activity often provides the primary means of reducing the whole life costs of the system, and hence often attracts the most management effort.



At the heart of the weltanschauung is the need to determine the commercial approach to be adopted for the through life management of sub-systems and overall systems integration. Options range from the highly competitive (such as reverse auctions) through to highly collaborative (such as partnering and alliancing).

Where there are systems integration challenges (such as improving or sustaining system performance and effectiveness) at least the systems integration function would benefit from a more collaborative approach.

Implementation is a 'standard' application of the Systems Engineering approach to a Hitchin's level 3 and 4 system.

Application of Systems engineering to each weltanschauung

Each weltanschauung benefits from the application of SE.

The most obvious is the 'upgrading or updating the system' weltanschauung – where the standard SE process can be applied with minimal tailoring. Changing an existing system implies more constraints than would normally be present – however the basic processes, concepts and principles are identical. Applying this weltanschauung is critical for major improvements to performance or reductions in whole life costs.

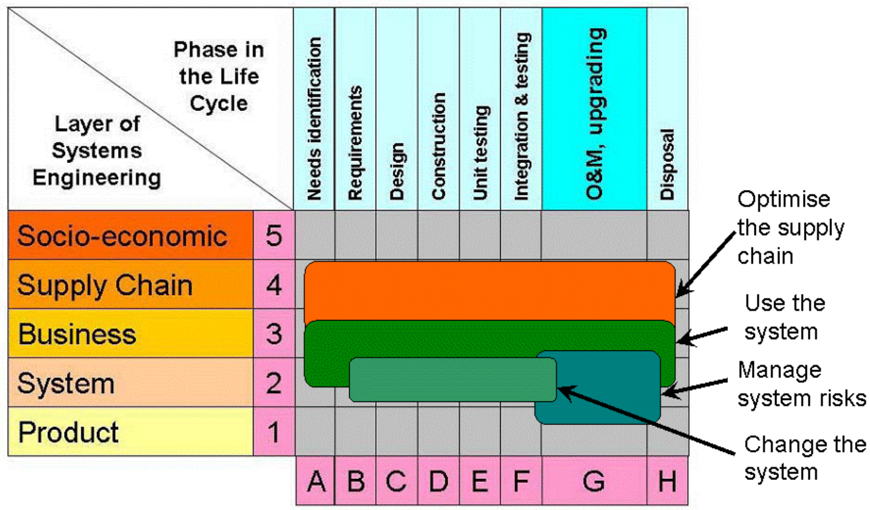
The 'managing the operational and safety risk' weltanschauung requires some tailoring – primarily around the use of SE methods and tools within an operations management framework. However there are at least three areas where SE methods and tools can be used:

- Managing the design / design intent and material state involves a range of familiar products – such as requirements, performance/effectiveness measures, architectures, systems schematics. The SE role is based around maintaining and using these products rather than creating them.
- Running a continuous concept evaluation phase – packaging maintenance packages into coherent programmes of work. Once initiated overseeing upgrade/upkeep programmes through V+V to acceptance.
- Systems engineering the support Information Systems.

Applying this weltanschauung is critical for sustaining the current levels of performance, effectiveness and whole life cost.

The 'using the system to deliver a business service' weltanschauung requires the application of systems engineering to the business services that need delivered. Whilst this exhibits some properties associated with System of Systems or Family of Systems engineering (primarily because of the asynchronous service/system/sub-system lifecycles) – this is just about applying 'plain old systems engineering' to a novel system of interest. Applying this weltanschauung can offer significant increases in effectiveness with minimal increases in whole life costs.

Finally the ‘optimise the supply network’ weltanschauung is an example of a Hitchin’s level 4 system. It follows a standard SE development approach, albeit with a novel system of interest. As the system is already in service, ‘equipment related’ whole life costs are largely fixed. Optimising the supply network offers the greatest prospect for reduced through life costs.



Diagrammatically, the four weltanschauungen are shown plotted against the Hitchins-Kasser-Massie Framework [Kasser] showing the different focus of each weltanschauung. Interestingly, whilst the system is ‘in-service’, three of the four-views actually show significant levels of change associated with their own lifecycles. This is a good illustration of why few people naturally see all of the worldviews.

Approach to the analysis and results of completing it

The analysis was completed part time over a period of five weeks, with the author undertaking the bulk of the work and other working group members reviewing the work in progress and providing useful insights and corrections. Whilst all of the group members were in the UK, the development of the analysis was undertaking without and face-to-face meetings. After an initial three hour meeting where the group agreed that there was disagreement over what the focus of the work was, the group only corresponded by e-mail and telephone.

The analysis was produced as a white paper, produced against an agreed set of requirements and timescales. Due to the part time nature of the group, this meant that the work was essentially resource and timescale limited.

The author spent 1-2 days effort, with the reviewers spending a similar amount in total. This high tempo and productivity was possible because:

- The author was intuitively aware of the different weltanschauung from ten years working in this domain. Despite this the opinions and analysis improved significantly during the analysis.

- The reviewers had similar levels of experience.
- There was a clear time and resource cap – quality and completeness needed to be traded out.

This meant that the original white paper was probably not as concise or clear as it could have been. This was exacerbated by the realisation the need for a further worldview. This became obvious as I tried to develop a combined activity model for W1 and W4. This led to the two worldviews being split.

Overall the paper met all but one of its requirements (failing on the number of pages), however the view of the working group was that it:

- Confirmed that there were multiple perspectives of in-service systems engineering
- Confirmed that the guidance should cover all of them
- Confirmed that the structure of the guidance should follow the worldviews

Ultimately the analysis was successful, as it helped a diverse group of individuals to come to agreement on a multi-faceted problem with minimum confusion and discussion. What was most impressive was that this was completed with so little effort and without face to face meetings. Checkland's Soft Systems once again proved to be an excellent tool to focus the dialogue on the key issues – increasing the 'dialogue to noise' ratio.

Finally, following the success of this approach (and a similar one undertaken by the INCOSE UK architecture working group) the newly formed INCOSE UK Capability working group has undertaking an analysis of 'what is capability engineering' using Checkland's SSM.

Conclusions and recommendations

This paper has described four different perspectives of in service systems engineering – managing the ISS, changing the ISS, using the ISS to deliver business/operational services and optimising the ISS' supply network.

This paper has confirmed that SE techniques can be used in all four perspectives. In particular:

- The asset management perspective is about selecting alternative approaches to maintain or improve system performance. These are core SE functions.
- The upgrade/update perspective is a traditional, if constrained, application of project SE.
- The using the ISS to deliver services perspective is about the design and delivery of services. This is the application of standard SE. As the ISS performance is generally optimised, this activity gives the greatest potential for optimising business/operational effectiveness.
- The optimising the supply network perspective is about designing the right supply network to optimise the ISS. As the ISS cost of ownership is largely fixed, this gives the greatest potential to reduce cost of ownership.

The different perspectives should be used to help select the best way to improve the effectiveness, performance or cost of an in-service system. In particular changes to the way a system is used to deliver a service or improvements in the supply chain may prove more cost effective than expensive update or enhancement projects.

The different perspectives can also be used to help explain the different mindsets between project delivery and in-service management. The different balance between planning and reacting can be a source of significant frustration – both to traditional systems engineers who feel that in-service engineers are failing to plan enough – and the in-service engineers who know that there is no point in planning too much as the situation will change. *Culturally this is possibly the largest barrier to moving from traditional to in-service systems engineering.*

The paper has shown, once again, the value of Checkland's soft systems to understand different perspectives of a situation. It enabled a team that had met face to face for less than four hours to come to agreement on a multi-faceted problem with minimum conflict and discussion. To slightly misuse a military term, it acted as a significant 'dialogue multiplier'.

Whilst the group that undertook the analysis was not an international one, the communication media were the same as used by international groups. Checkland's Soft Systems should be considered a standard tool to help working groups to understand whether differences of opinion are actually masking underlying disagreements as to the purpose of the activity being undertaken.

Acknowledgements

I would like to thank Bruce Elliott, Lloyd Bridgewater and Stuart Leinster-Evans, David Wright and the rest of the UK in-service systems working group for their support, guidance and suggested amendments.

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Biography

Duncan Kemp is a systems engineer and programme manager with over twenty years experience in the defence and transportation sectors. He has worked on a range of programmes including railway systems, communication systems, command and control systems, nuclear submarines, guided weapons and unmanned aerial vehicles.

Duncan has undertaken a range of technical roles including requirements management, programme design, systems architecting (both forward and reverse), risk management, effectiveness and performance management concept generation, interface management, modelling and simulation, solution selection, integration, verification and validation, transition to operation, lifecycle definition and enterprise integration. Duncan is experienced in the use of hard and soft systems engineering methods and techniques.

Previous roles have included

- Deputy director for UK Ministry Of Defence (MOD) acquisition reform. Duncan initiated and managed a range of acquisition improvements including improving the agility of acquisition projects and writing the challenges for change section of the MOD's defence industrial strategy.
- Chief architect for Command, Control, Communications and Computing (C4) for the UK MOD. Duncan established the C4 architecting capability and led the development of the UK's goal architecture for deployed operations in 2012 and beyond.
- Developing the UK's first System of Systems safety case. After identifying that the MOD had introduced a new system that introduced new system of systems hazards that no-one was accountable for managing, Duncan led a study that developed an initial safety case articulating the hazards and proposing mitigations.

Duncan is currently the lead systems engineer for rail in the UK Department for Transport (DfT). He is responsible for improving strategic whole life, whole system, decision making within rail; supporting current and future rail programmes; and, growing the engineering competence in DfT and the rail industry.