Maintaining Systems-of-Systems Fit-for-Purpose

A method and process that identifies prospective exploitation of a composed System-of-Systems' (SoS) Material, Energy and Information **(MEI)** Sources, Sinks and Bearers **(SSB)** in order to equip it to maintain it Fit for Purpose **(FFP)** after experiencing *unpredictable changes* in operation, internal and/or external factors.

Loughborough University

Contents

- The Problem
- FFP Introduction
- Systems-of-Systems, Material, Energy and Information: Sources, Sinks & Bearers
- FFP Method
- FFP Process
- MEI SSB Characterisation Illustration
- Summary

The Problem I'm Addressing

- **Gen. Sir Rupert Smith stated "On every occasion …**
  - I, and those with me, have had to change our method and re-organize in order to succeed.
  - Until this was done we could not use our force effectively ...
  - I consider this as normal - a necessary part of every operation."

- **Robustness and resilience can be designed-in to a system, but**
  - *any benefit they provide against **unknown-unknown** factors is largely due to luck: the major LoD contributor to FFP maintenance in this circumstance is often the engaging personnel …*

  … the aim is to help them!

Loughborough University

INCOSE SoS Working Group Survey SoS Pain Point

- ***What are effective approaches to integrating constituent systems into a high-functioning SoS?***

- *Legacy systems which "… are not configured or managed to allow insertion into the overall System-of-Systems. This creates interoperability concerns between the older and newer systems."*

- *"In the cases where systems are owned/operated by different organisations …. The systems may transfer data and information reliably between systems (if you're lucky) but different processes, cultures, working practices between different participating organisations can lead to problems"*

Loughborough University

INCOSE SoS Working Group Survey SoS Pain Point

- *How can SoSE provide methods and tools for addressing the complexities (e.g. analysis, modelling, prediction and architecture) of SoS interdependencies and emergent behaviours?*

- *"Systems often have interdependencies that are either unknown or unacknowledged. This is exacerbated by interdependencies between systems in development, a system in development and fielded systems, and fielded systems; further, this is compounded by multiple combinations of these."*

Loughborough University

FFP Research Aims

- *FFP research outcomes should be exploitable: not "Shelf-ware"*

- *Outcomes should be incremental: "Quick Wins" en-route*

- *Exploitation should not be a burden on users: A "minimal extra effort" on staff*

- *The FFP research uses an iterative, developmental approach*

- *The end result can be integrated and harmonised with the Thales Product Lifecycle Management system*

FFP Introduction

Changes in the SoS situation, e.g. operational environment, requirement or "LoDs +", often render the SoS not FFP due to a combination of the two reasons below:

- *The SoS capability was degraded and could no longer bring about the desired outcome it was designed to do*

- *The SoS needed to provide different functionality to that it was designed to do in order to achieve the desired outcome.*

Fit-For-Purpose

- This research asserts that SoS' do not maintain FFP because
  - *they cannot implement the correct, timely and complete interchange of MEI between the SoS constituents and externally necessary to achieve a particular result.*
- The FFP method and process
  - *engineers SoS constituent systems to enhance the likelihood of the composing SoS being maintainable as Fit-For-Purpose having experienced **unforeseeable** changes in operation, internal and/or external factors.*

FFP Method:
Outline Description

"Creating the method"

Loughborough University

Preface: SoS, SSBs and MEI

A System-of-Systems (SoS) is a set of collaboratively integrated systems that have operational and managerial independence *(after Maier, 1998)*.
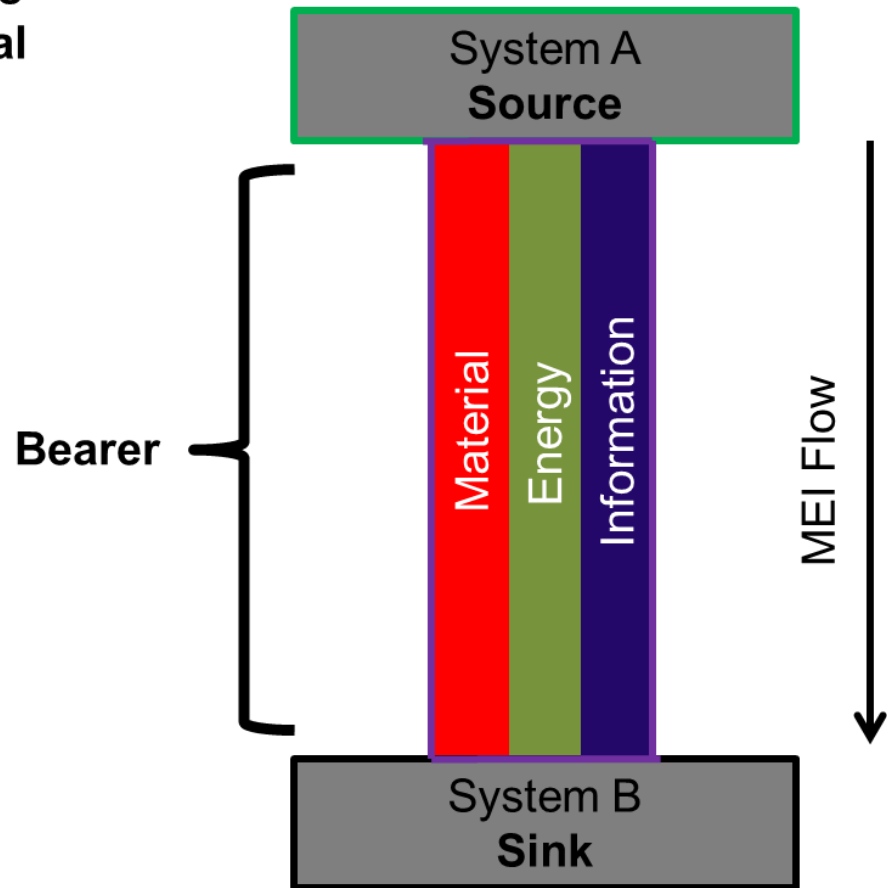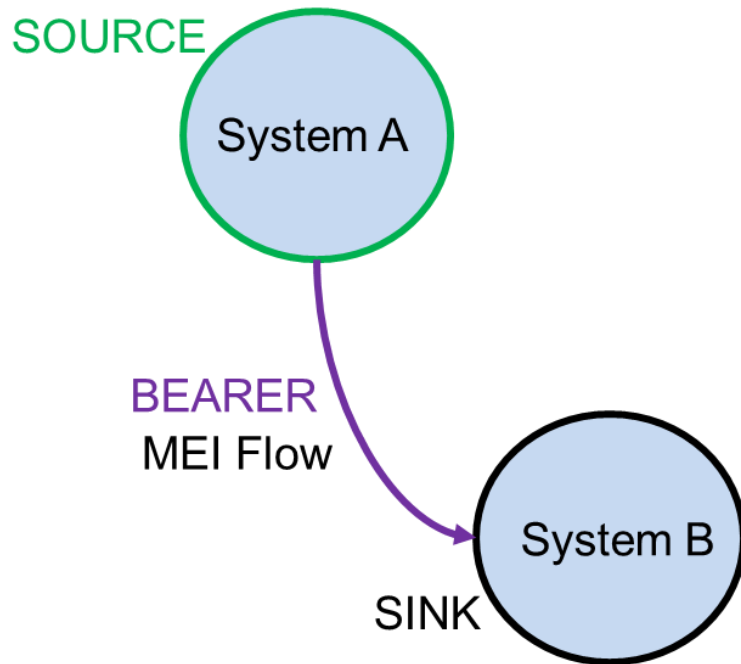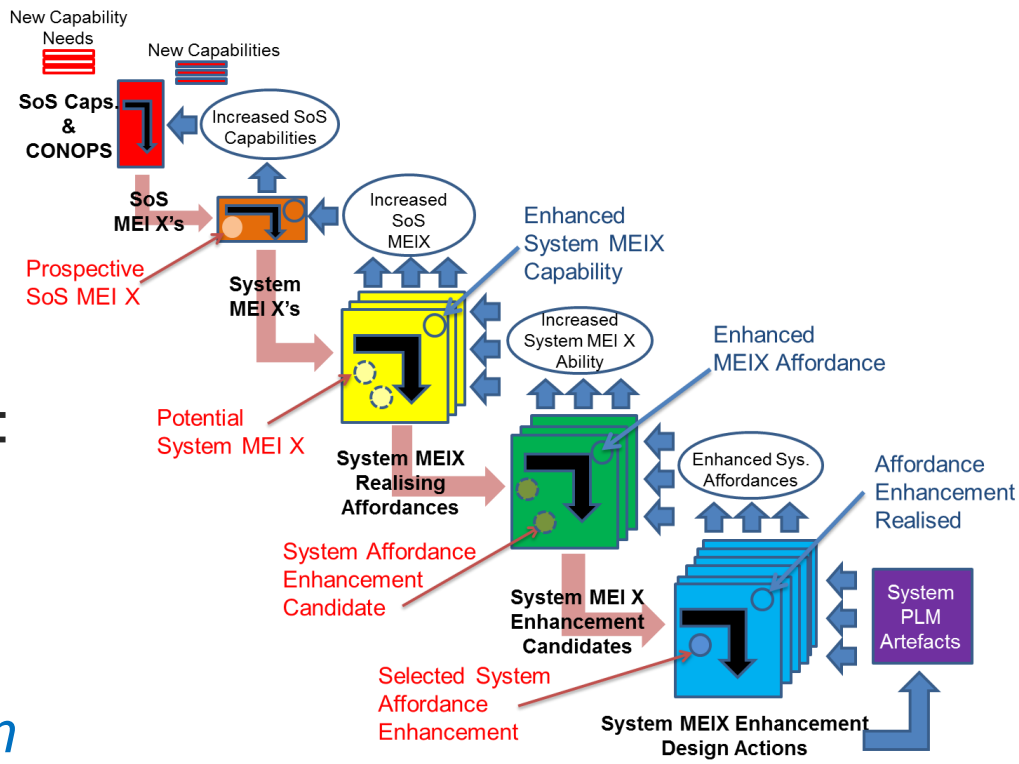
FFP Method Outline Description

The FFP method is envisaged in the form of a transform cascade

.

The transforms relate "Whats" to "Hows"

.

The "Hows" become the "Whats" of the next level down: (what's needed to enable the How)

.

The FFP method relates SoS capabilities down to subsystem functionality in terms of MEI SSBs

FFP Method: Implementation

Designing the Process
to
Realise the Method

Transform Realisation 1

- Each transform is realised as a model of the Material, Energy and Information (MEI) Sources, Sinks and Bearers (SSBs) in a form commensurate with the capability component / Line-of-Development (LoD) and particular case being examined.

-

- Ideally the intended ("Designed-For") MEI SSB parts of the transformation meta-models would be abstracted from existing engineering design & development information to maintain fidelity with the real products and services.

FFP Process

Loughborough University
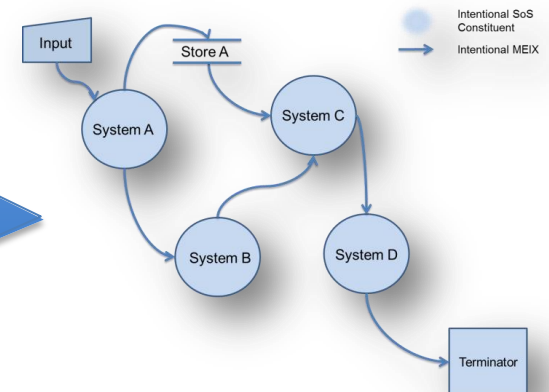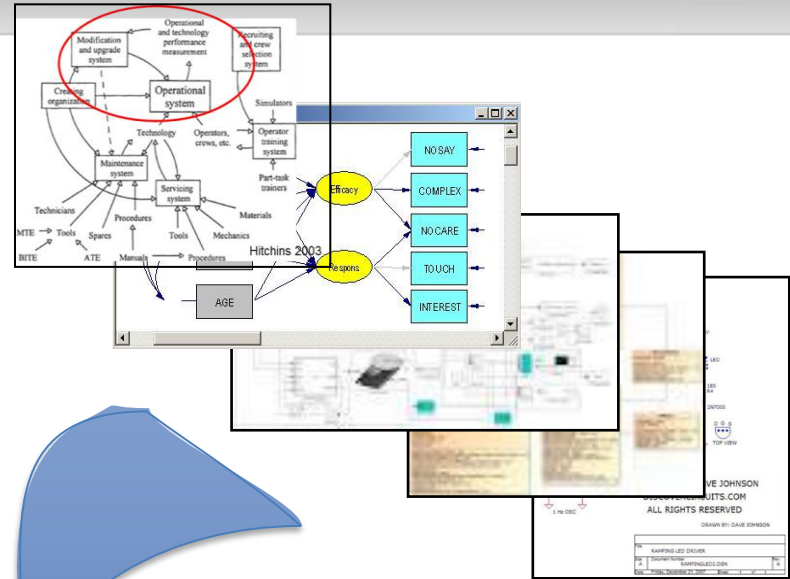
Transform Realisation 2

- Examples of the **source** documents for the abstracted model might include:
  - System CONOPS
  - System and Software Requirements and Design Specifications
  - Master and subsystem Interface Schedules

- However, to get the complete picture we need to discover and characterise the affecting SSBs that are *inherent* and *independent* of the "designed-for" SSBs drawn from the source information.

FFP Process

Loughborough University
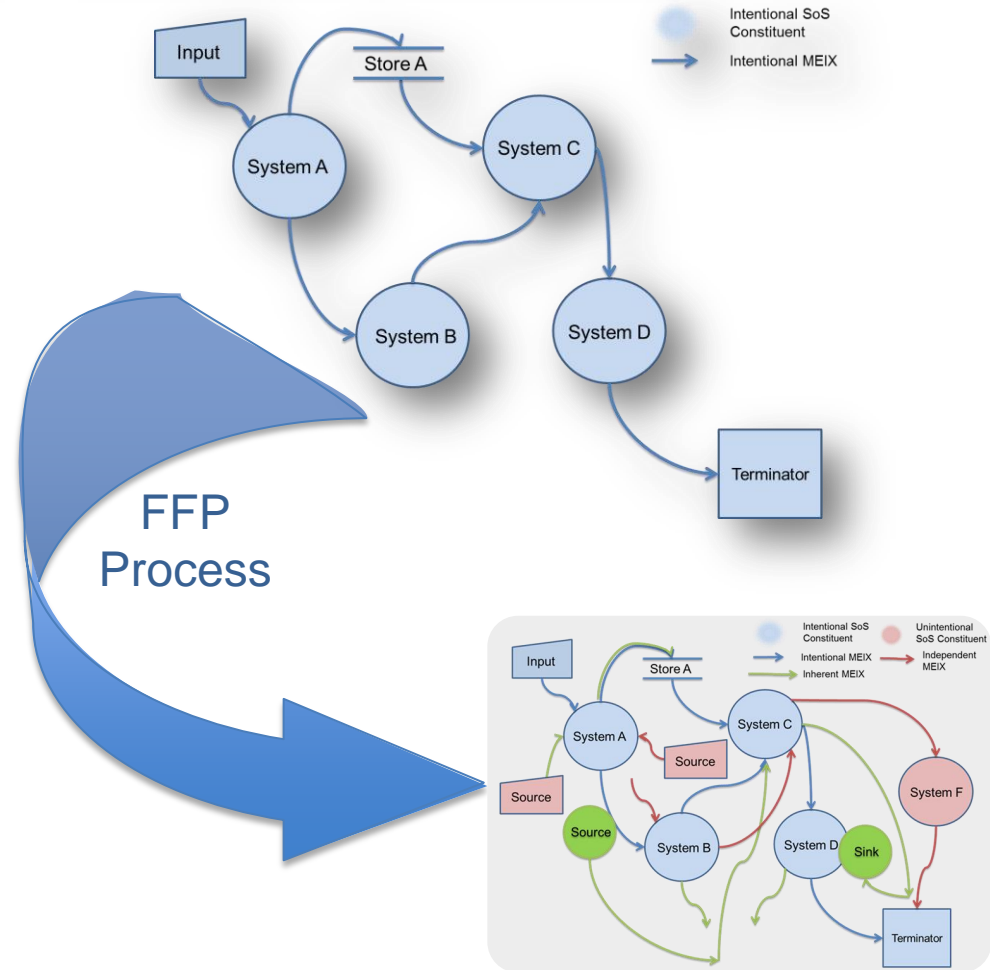
Example: Intentional, Inherent & Independent Connections

- For example, a Steel Wire Armoured (SWA) DC power cable _Intentionally_ connecting two components will also _Inherently_ conduct AC, connect them thermally, magnetically and also mechanically, any of which *might be exploitable… or cause problems!*

- In addition there may be _Independent_ connections to and from sources and sinks outside the system of interest: E.g. vibrations from remote machinery via a common structure.

Loughborough University
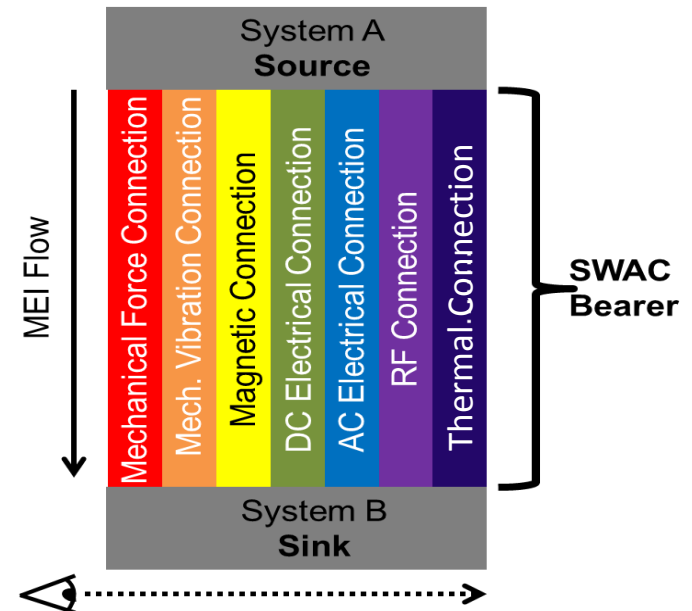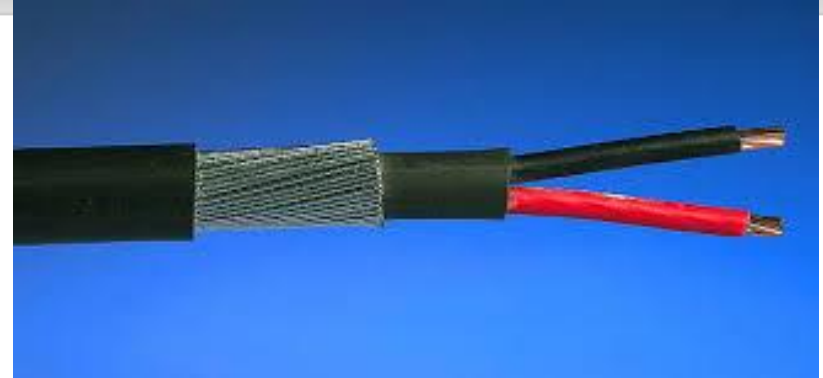
Abstracted Transform Meta-Models

- The abstracted meta-model will bring together the Sources, Sinks and Bearers (SSBs) of Material, Energy and Information (MEI) that the FFP process has identified as:
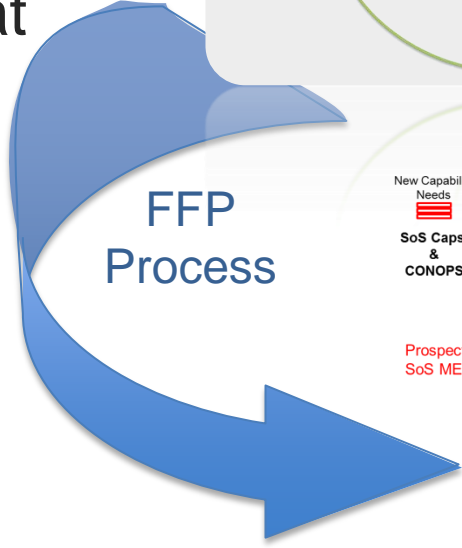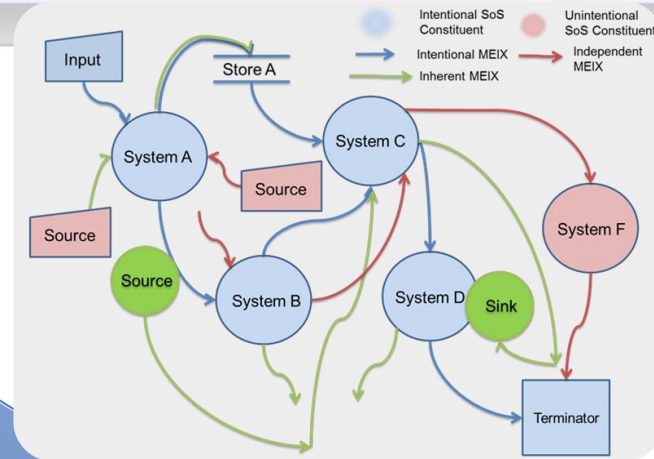
  - *Intended* ("Designed-For"), drawn from the disparate source documents

  - *Inherent* with the Intended SSBs

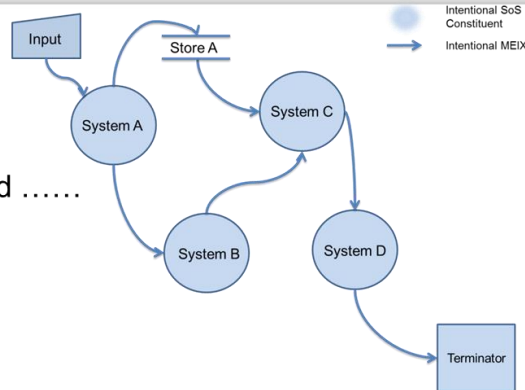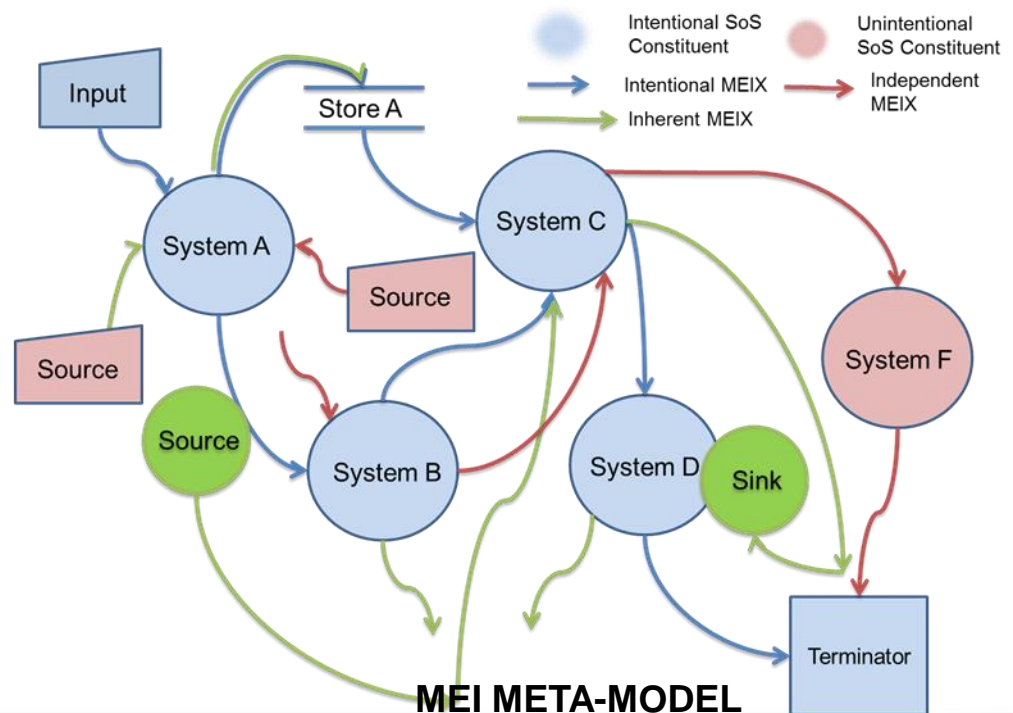 - *Independent* of the intended SSBs

FFP Process

Loughborough University
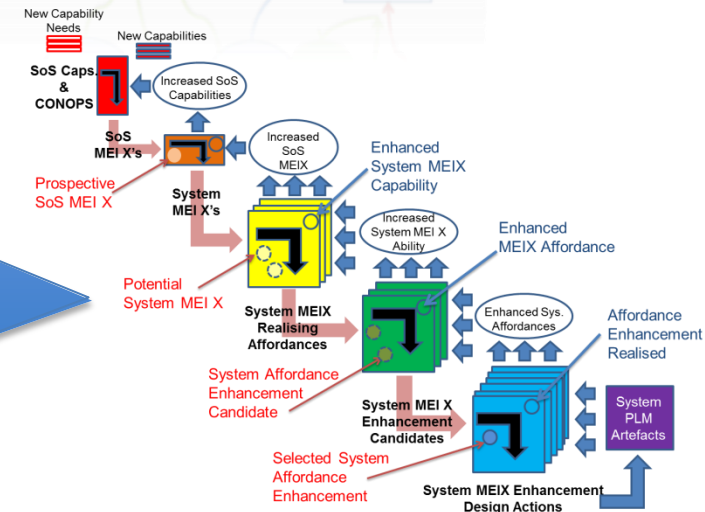
What was "Designed-For"…
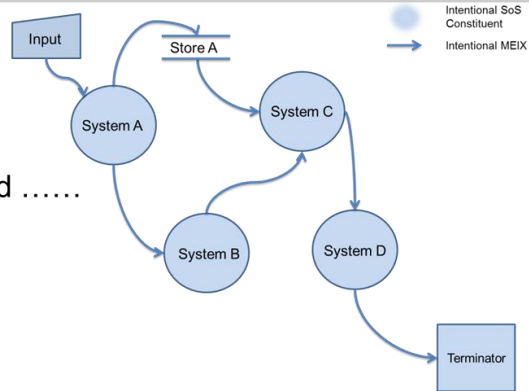
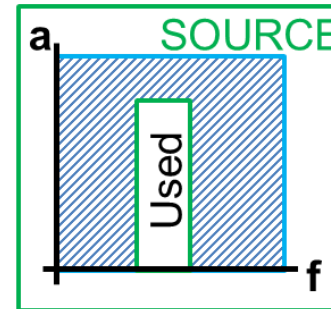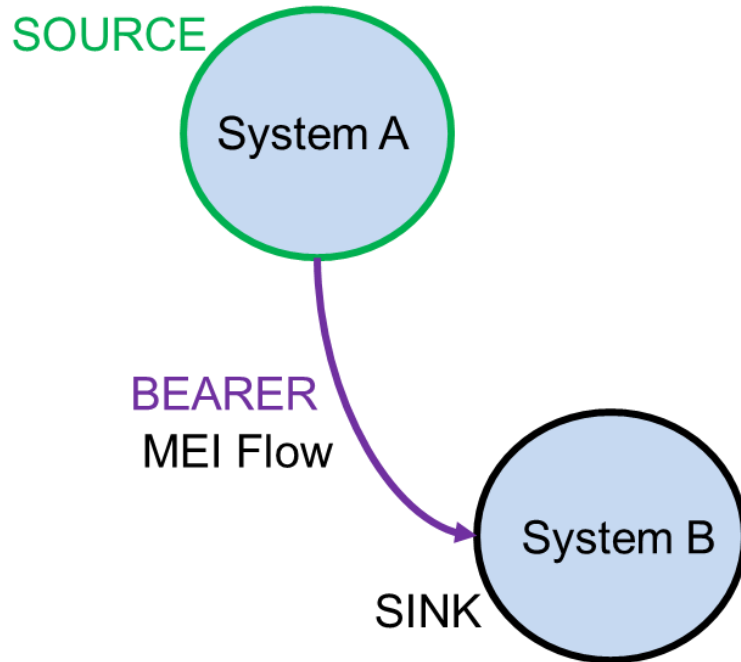What we thought we had ……

What we thought we had ……

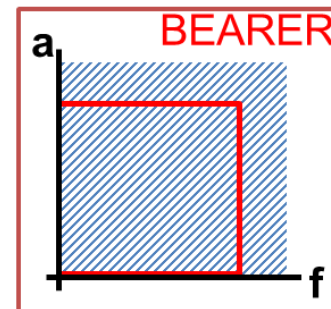What we actually have ……

MEI META-MODEL

MEI Source, Sink and Bearer Characterisation Illustration

To explore
opportunities for MEI exchange enhancement
and
risks of unintentional exchange

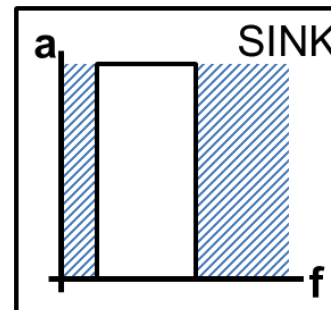Loughborough University

Source / Sink / Bearer Headroom

Exchange Headroom … Potential for exploitation …?
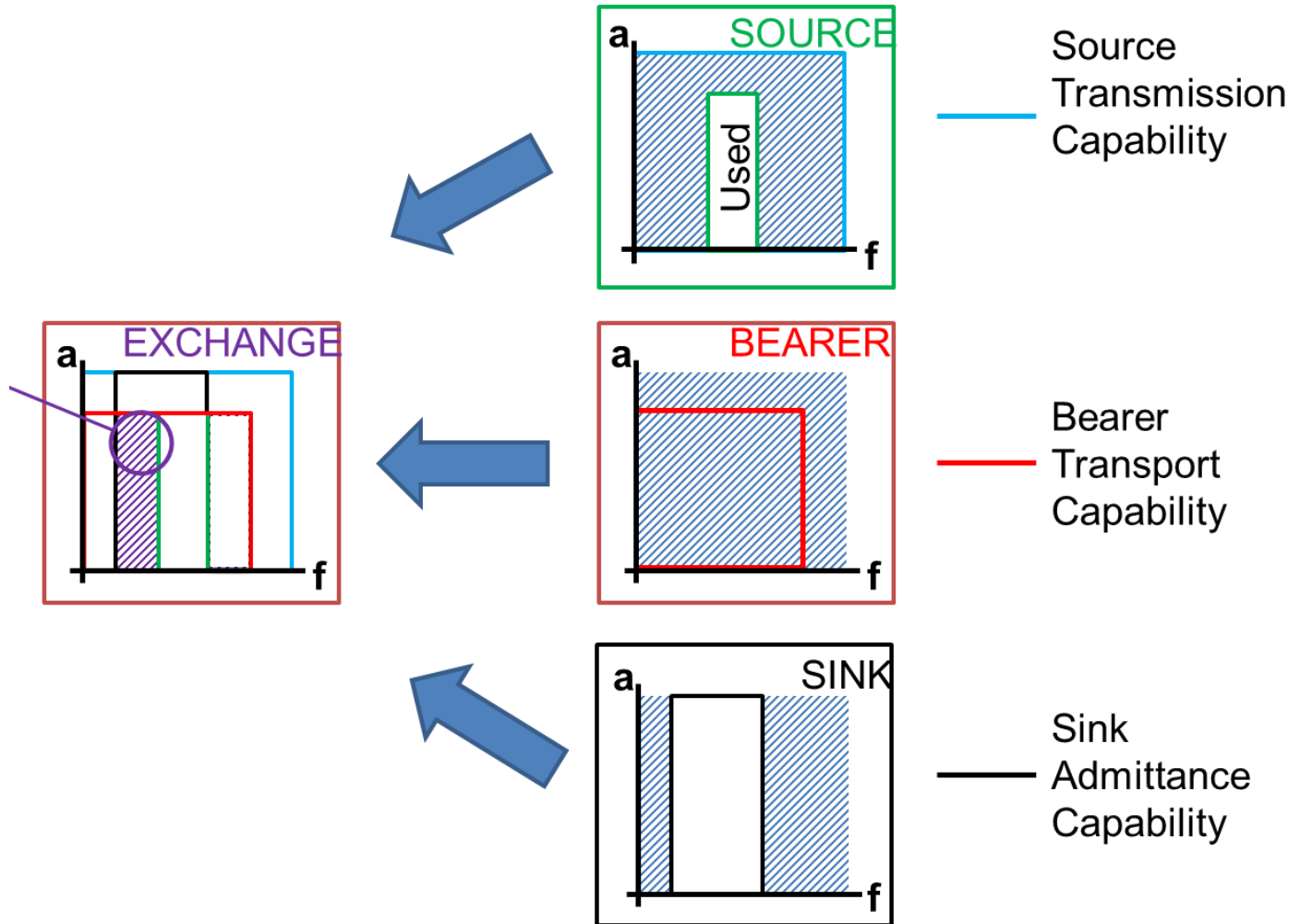
Exchange Headroom … A.K.A. Unintended Exchange Susceptibility?
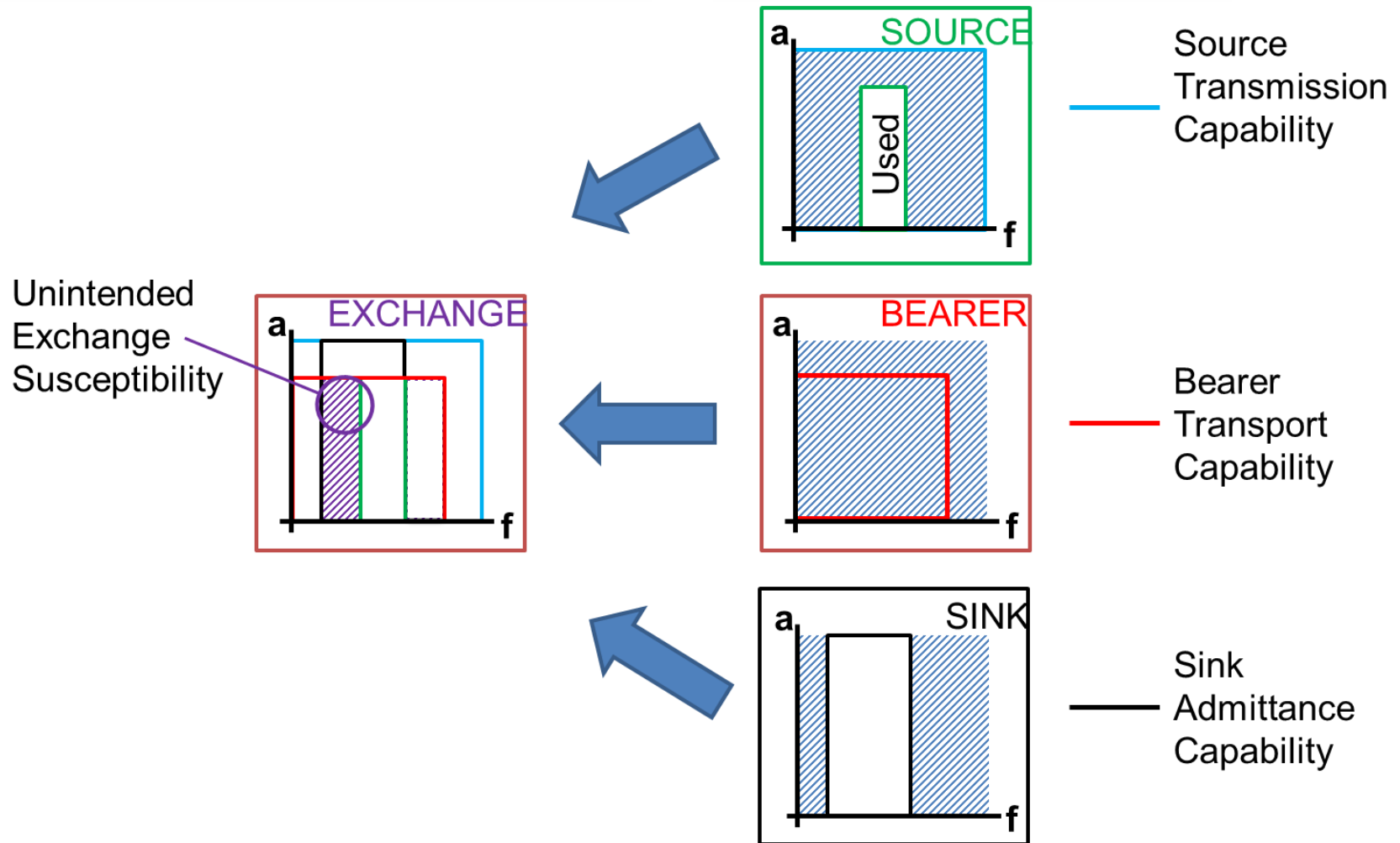
Illustrative Example

Carrier Group Operations

Loughborough University

Example: Aircraft Carrier-to-Aircraft Information Enhancement

- A Light Projector mounted on the carrier deck uses an array of lamps to indicate ship movement and approach angle to a landing aircraft's pilot.

- A scheduled replacement of the obsolete incandescent lamps utilises LEDs which _inherently_ have a much wider bandwidth. Hence the potential for carrier to aircraft interaction (Information) is greatly increased.

- A modification incorporated to allow modulation of the light beams _enables_ information transfer between the carrier and aircraft to be enhanced.

Loughborough University

Example: Unforeseen External Change threatens loss of the SoS FFP

- A SoS (a carrier group of ships) provides a military capability.

Example: Unforeseen External Change threatens loss of the SoS FFP

- A SoS (a carrier group of ships) provides a military capability.
- An unforeseen change in the political situation means that military tasks achieved by manned aircraft become indefensible.

Loughborough University

Example: Unforeseen External Change *but FFP maintained*

- A SoS (a carrier group of ships) provides a military capability.

- An *unforeseen* change in the political situation means that military tasks achieved by manned aircraft become indefensible.

- The enhanced carrier to aircraft interaction via the light projector is exploited to provide a command link to an unmanned aircraft (UAV) enabling maintained fulfilment of military tasks.

FFP Summary and Way Forward

FFP: Summary

- *FFP process guides thought to identify MEI sources, sinks, bearers and interactions that may not otherwise be included in SoS /System modelling and lead to unexpected emergent phenomena only revealed "**late in the day**": A more complete insight.*

- *FFP process may highlight groups of constituents forming unintended networks*

- *FFP process shows unused capacity for MEI exchange that may be exploited to extend and/or enhance the supra-system capabilities, or may be susceptibilities for undesirable exchanges*

- *These enhancements could be activated to fulfil MEI exchange shortfalls enabling a composing System-of-System to be **maintained** as Fit For Purpose to address new unforeseeable tasks and/or changes, both internal and external.*

- *FFP: Not a panacea for all ills: and certainly not a substitute for wisdom & expertise!*

Loughborough University

FFP Way Forward

- *Carry out a whole-process FFP case study on a mature industrial project, evaluate the outcome and commensurately mature FFP method and process.*

- *Apply the matured method and process to a project in the early in its lifecycle, and evaluate outcomes*

- *Port FFP to the capture and visualisation tools in use by industrial collaborator or at least make integrate-able with lifecycle management system.*

Maintaining Systems-of-Systems Fit-for-Purpose

A method and process that identifies prospective exploitation of a composed System-of-Systems' (SoS) **Material, Energy and Information (MEI)** Sources, Sinks and Bearers **(SSB)** in order to equip it to maintain it **Fit for Purpose (FFP)** after experiencing *unpredictable changes* in operation, internal and/or external factors.

Thank you for your time!

s.w.hinsley2@lboro.ac.uk

Loughborough University