**CSWG and Royal Academy of Engineering (UK) Engineering-X Case Studies WS**

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**INTRODUCTION**

The Workshop will consider a few of the Royal Academy of Engineering (UK) Engineering X case studies and seeks to determine to what extent the heuristics identified would of help to prevent unwanted emergence in the systems that failed.

Two types of techniques are to be considered for handling these complex systems. 1: The application of a Complexity Assessment Tool that could help identify the primary sources of complexity before the task commenced, encouraging a focus on the complex aspects. 2: A range of heuristics or short memorable suggestions that if recalled would have prevented unwanted emergence. These are described below.

**Complexity Assessment Tool (CAT)**

Handling a complex system with its inherent uncertainty, as if it were a predictable complicated system is one of the fundamental reasons for project failure. However, one of the identified heuristics that resonated with the team is “Complex systems are not wholly complex”. This is important as handling a complicated system as a complex system is insufficient. Consequently, to effectively handle complex problems, tools are needed to identify, characterize and localize the complexity.

Complexity Assessment Tools (CATs) exist to help users find the source and types of complexity in a system. Difficulty Assessments Tools (DATs) help us to determine where we need to focus our effort or skill. The latter identifies Complex and Complicated elements as both make tasks difficult. DATs are useful for assessing Complex Systems as you can see balance between complex and complicated elements which is insightful. Consequently, the terms CATs and DATs become somewhat interchangeable.

There are many CATs and DATs proposed in literature. However, they tend to mix the system elements and the complexity elements causing confusion. This workshop will test a Complexity Assessment Tool which separates the system and complexity elements so that a thorough examination can be conducted using the created 2D heat map.

**Heuristics**

The following heuristics will be tested against a simplified version of a few of the Engineering X case studies developed by the UK’s Royal Academy of Engineering. The heuristics come from multiple sources based on or qualified by experience. Consequently, some repetition and duplication of insights are present.

They are split into three groups based on their development approach so far:

Group 1 Top down heuristics: The group of 7 Heuristics a-g were developed by considering founding principles of complexity and their implications for how to reduce or handle complexity.

Group 2: Initial bottom up heuristics; This group of 18 (1-18) heuristics were processed or inspired from searching the INCOSE Fellows heuristics database of 600+ heuristics using “complex” and “complexity” as search terms

Group 3: Additional bottom up heuristics: This group of 16 (19-34) heuristics were processed or inspired by searching INCOSE Fellows heuristics database of 600+ heuristics using 32 search terms that were closely related to complex and complexity search terms.

**COMPLEXITY ASSESSMENT TOOLS**

A simple approach for a DAT is to list the system elements on one axis, and the elements of difficulty (complexity and complicated) on the other axis. Which system and complexity elements used can be determined by the organisation based on their local system taxonomy.

System Elements selected by the INCOSE Complex Systems Working Group for this trial are:

* + Organisation
  + Information
  + Process
  + Subject Matter of interest (sometimes tech, legal etc.)
  + Wider environment

Benefits are added to the system element axis as they are essential to capture the difficulty or complexity of the benefits to be realise which is not captured elsewhere.

Complexity elements that can be considered are unfamiliarity, novelness, dynamicity and unpredictability. Complicatedness can often be captured by the amount of intricacy in the system. Adding these to the complexity elements axis enables us to distinguish between these two types of difficulty. In addition, constraints can make an otherwise simple task impossible. They amplify the difficulty or complexity, hence it is considered prudent to also add this on the complexity elements axis.

Consequently, the elements selected for the complexity axis for this trial are:

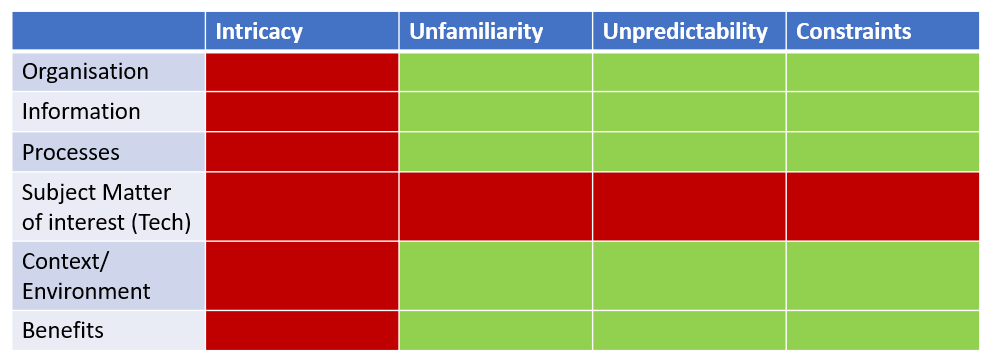
* + Intricacy
  + Unfamiliarity
  + Unpredictability
  + Constraints

This leads to the following grid. Scoring the grid can indicate where your primary difficulties (Heat) are, the level of complexity and if the challenges align to difficulty or system element axis. Each cell in this grid can be scored red (high concern) or green (so major concern).

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|  | **Intricacy** | **Unfamiliarity** | **Unpredictability** | **Constraints** |
| Organisation |  |  |  |  |
| Information |  |  |  |  |
| Processes |  |  |  |  |
| Subject Matter of interest (Tech) |  |  |  |  |
| Context/ Environment |  |  |  |  |
| Benefits |  |  |  |  |

Ideally this grid is scored by a diverse community of suitable familiar and expert individuals with sufficient time allocated for the magnitude of the problem to be addressed. However, you can also use this to quickly check your default assumptions of where the difficulty in the task is. By considering all of these elements, aspects of difficulty that might be overlooked can be identified. It this latter approach we seek to test during this workshop.

To give you a feel on how this might work, there are two examples below. The first on the left is a classic CAT Heatmap grid for an Entrepreneurial task. Typically, when there is a lot of unfamiliarity and unpredictability creating complexity, you need entrepreneurial approaches like Lean Start Up. The second grid on the right is an example of a classic traditional technical challenge. There is a lot of intricacy and relationships to solve, but primarily it is the technology that is the main focus of research and experimentation.

**IDENTIFIED HEURISTICS**

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|  | **Title** |
| A | Establish a Common Compelling community Vision that aligns distributed stakeholders |
| B | Have a learning organisation that accumulates and uses new insight |
| C | Have proactive feedback mechanism to sense change in the system or environment early |
| D | Have a living system that is able to adapt to new knowledge or insight |
| E | Have generous leaders that protect and enable the expertise to lead decision making, rather than seniority |
| F | Have an Equality mind-set, treating others views & visions as equal to your own |
| G | Develop robust relationships between the organisational elements |

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|  | **Title** |
| 1 | Iterate to evolve complexity |
| 2 | Multiple perspectives identifies complexity |
| 3 | Complex systems are not wholly complex |
| 4 | Do not assume complicated pegs fit in complex holes |
| 5 | For every complex problem there is an answer that is clear, simple and wrong! |
| 6 | Grab a complexity survival kit before embarking on complex problems |
| 7 | Establish stability between iterations |
| 8 | Recognise the importance of culture alignment for complex systems |
| 9 | Think big, evolve from small |
| 10 | Complexity needs learning and adaptive organisations. |
| 11 | Prioritise multiple perspectives to enable agility over efficiency |
| 12 | Purposefully Keep options open to evolve |
| 13 | Complex Systems: As simple as possible, but no simpler! |
| 14 | Reuse with extreme care |
| 15 | Focus on holistic usefulness |
| 16 | Complex problems call for strategic thinking |
| 17 | Holistic system health avoids complex system failures |
| 18 | Manage emergence holistically |
| 19 | Successful communication requires an understanding of the listeners’ mental models |
| 20 | Complex system failures enable accelerated learning |
| 21 | It is better to be roughly right than precisely wrong |
| 22 | The unrecognized assumptions are the most dangerous |
| 23 | Good solutions emerge through creative environments. |
| 24 | Manage adverse consequences with proactive feedback structures of mechanisms |
| 25 | Every attempted fix of a complex problem, changes the problem |
| 26 | Identify a compelling community vision to address complex problems |
| 27 | In introducing complex solutions, “how” trumps “what” |
| 28 | It is easier to ignore complexity – and fail |
| 29 | Maintain a compelling community Vision through respectful collaboration |
| 30 | Evolving is the complex system’s superpower. |
| 31 | Minimizing harmful element interactions supports resilient complex systems |
| 32 | Complex systems should allow and enable human flexibility |
| 33 | Bear-hug complex problem unknowns |
| 34 | For complex systems being useful is more important than being right |

Descriptions of each of these heuristics are available in the next section. Group 3 descriptions are not fully matured or approved, and hence are only indicative.

**HEURISTIC DESCRIPTIONS**

**Top down Heuristics Descriptions**

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| **A** | **Compelling community Vision:** Establish a Common Compelling Community Vision that aligns distributed stakeholders |
| **Elaboration** | A team or group that share a common compelling community vision will work more effectively in complex situations. First because, they will come in positively to help work toward the vision each day. Second, because when the unexpected or emergent events occur they will naturally take actions that lead to the desired outcome. Further, as for military or sports teams, the actions taken by others in the team, even those not in contact, becomes a bit more predictable as they should act in the interest of the team’s mission or purpose. |
| **Rationale** | This heuristic is discussed by Daniel Pink in the book Drive. It is discussed under many different names by a plethora of authors.  There are three approaches for creating compelling visions:   1. Sell a community vision to a team, community, or organization. 2. Identify what visions motivate team members, community, or organization team/community/enterprise vision from the team/community/enterprise 3. The team/community/enterprise is established and selected based on their enthusiasm for a predefined and set vision.   Option 1 is least likely to lead to success as it may miss the community aspect. |
| **When to use** | Always |
| **Cautions** | Leaders can believe they have identified the compelling community vision (option 1) as those around them are often motivated to provide positive support. This can lead to a disconnect or resistance to the work, or even sabotage. The best way to avoid this is to allow the community to identify the vision or be heavily involved in a psychological safe space. See robust relationships, equality mindset and generous leaders heuristics below. |
| **Why do I care** | It will help harness the team energy leading to massive increases in productivity and it means when things go wrong the impact of problems is significantly reduced. This is considered the most powerful top-down heuristic. |

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| **B** | **Continuous Learning;** Have a learning organisation that accumulates and uses new insight |
| **Elaboration** | Actively and continuously seek learning opportunities. Knowledge can be acquired through experimentation, training, reading and experience. Identifying the most suitable learning techniques is key. Diversity in learning is key to provide broad coverage around potential changes, but this places greater emphasis on ensuring the knowledge is suitably shared for everyone’s benefit. |
| **Rationale** | Learning and knowledge organizations are now commonly encouraged as established by Senge in his book The Fifth Discipline. It involves the self-mastery of the individual, taking responsibility to challenge the issues you see, to support the community needs. This self-mastery is driven by recognizing when you are part of the problems you face and seeking to change. There are two self-mastery learning options: depth or breadth. Depth learning is suitable for organizations that predominantly handle unfamiliarity complexity, whereas breadth learning is suitable for organizations that predominantly handle unpredictability complexity. |
| **When to use** | You need to create a learning culture so that capturing and sharing of diverse insight through insight sessions is part of the organisational processes. |
| **Cautions** | Do not recruit a team from a single pool of talent and academic backgrounds and send them to the same courses. You will reduce the diversity of their knowledge and hence miss opportunities for rapid progress. |
| **Why do I care** | Learning in and around the edges of your System of Interest prepares you for unexpected change and to have the skills ready to adapt to the new context of challenges rapidly. |

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| **C** | **Proactive feedback:** Have proactive feedback mechanism to sense change in the system or environment early |
| **Elaboration** | Proactively set up mechanisms to frequently Observe and Orient, then Decide & Act (OODA) in continuous feedback loops. |
| **Rationale** | In order to thrive in a complex world, feedback loops are essential and are already commonly identified and used. The Observe, Orient, Decide & Act (OODA) loop has many forms, including: Shewhart cycle, DODAR, reflect, probe, sense, respond, and build-measure-learn feedback loop. This heuristic is captured in the Cynefin framework by using “sense” as the first action in the complex space. |
| **When to use** | Always in complex challenges |
| **Cautions** | The presence of feedback will change the system. Consider the impact of the feedback on the system. Do not just measure feedback on what you expect to go wrong, measure feedback across the system to ensure it is all working as expected. |
| **Why do I care** | It enables rapid learning so that (when combined with dynamic environments and/or living systems) the system can respond to environmental changes and remain relevant and valuable to the community it serves. It enables problems to be spotted before system collapse ensues. |

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| **D** | **Living Systems:** Have a living system that is able to adapt to new knowledge or insight |
| **Elaboration** | Develop autonomous, continuously adapting, and responding systems that are able to respond at a suitable pace to environmental changes. This means these systems are able to adjust to the complex environment in which they reside, and when cpmbined with proactive observation even flourish. |
| **Rationale** | Continuously Adapting and Responding systems or living systems are discussed in the literature in various guises, including Lean Start Up, and Complex Adaptive systems. These living systems are more adaptable when the team and approach are as small and straightforward as possible, until the certainty of the way forward has increased, minimizing investment costs and risks.  Living systems need a sensing capability (principle C); a source of resources to implement change; a decision-making capability; and a purpose or vision as captured in principle A. A simple model of the system and the environment to support constant iteration is critical. |
| **When to use** | Always in complex challenges |
| **Cautions** | Ensure the system has a common compelling vision such that its adaptations are in the interest of the community it seeks to serve, and hence the system avoids becoming self-serving independent of any benefits (the negative image of a bureaucracy reflects a system which serves itself more than any larger community). |
| **Why do I care** | Without living systems projects/programmes can become never ending as new requirements are always identified, that prevent completion. If projects focus on establishing a living system this issue is avoided.  Living systems required much less intervention (e.g. follow on projects) than systems that cannot adapt to environmental changes. |

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| **E** | **Generous Leadership:** Have generous leaders that protect and enable the expertise to lead decision making, rather than seniority. |
| **Elaboration** | Create an environment to protect and nurture teams’ autonomy to ensure they are effective living systems. |
| **Rationale** | In a complex world it is nearly always impossible for leaders to collect all the relevant information in the time available to make a decision. Instead they need to let go of command and control and lead by creating psychologically safe spaces, and protecting the environment for the team of suitable experts to meet the objectives**,** by making its collective decisions**.** Thiscreates dramatic performance improvements.  So leaders, instead of seeking to force the design of the system that they have in mind, need to create the right environment (vision, heuristics, boundaries) that enables suitable solutions to emerge at the right time. This requires leadership courage and generosity, and it involves following others. It is close to servant leadership but recognizes that the accountability and authority is still owned by the leader.  This enables the best decisions to be made, recognizing that there are few right decisions in a complex space that last for long, as something changes or has been missed. |
| **When to use** | When establishing a team and considering your role as leader. |
| **Cautions** | This does not mean the leader can walk away. A leader is part of the team and responsible for setting the boundaries the team operate within and protecting the team from others who will seek to dysfunctionally command and control the team. |
| **Why do I care** | Creating the right environments for experts to flourish and trusting the collective skill of the team is more likely to yield successful results, maintain team morale and build resilient teams and leaders. |

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| **F** | **Equality Mindset:** Have an Equality mind-set, treating others’ views & visions as equal to your own |
| **Elaboration** | Recognising others’ visions, needs, and ideas are important, as your visions, needs, and ideas are important. Accepting you will fail, as others will fail. Associated with the Outward Mindset by Arbinger. |
| **Rationale** | Paradigm or mindset change is the most powerful leverage point to change systems. Moving from a complicated to a complex world requires a mindset change, from a leader expecting to be right at the start and focused on their own performance to a leader expecting to learn on the journey and focus on others’ performance, as equals. By focusing on building communities with robust relationships (see below) that create and solve problems, the community’s performance becomes greater than the sum of the parts.  In addition, when applied, this principle creates a safe psychological space for those who are less inclined to come forward and those less experienced to share their insight, creating the right environment to capture the benefits of a diverse workforce to identify new insights. |
| **When to use** | Now! Equality mindset is a paradigm shift that prepares leader to operate in complex challenges. |
| **Cautions** | This is not saying others’ needs are more important than yours. But providing you with the mindset to consider others’ needs as you address yours, so you can be mindful of ways to help the collective outcome. Collaboration rather than competition. |
| **Why do I care** | It creates the psychological safety to accept failure and success in others and self positively, so that you can build collaboratively towards common outcomes. |

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| **G** | **Robust relationships:** Develop robust relationships between the organisational elements. |
| **Elaboration** | Spend time building robust relationships to form (organisational) teams that know each other and can work together to respond to change effectively. Understanding the strengths and challenges each team /organisation has enables the teams and organisational wholes to become greater than the parts. Robust relationships also create the psychological environment where you can talk honestly and openly about the challenges and hence effectively address them as a team. |
| **Rationale** | The value of teamwork in complex environments such as sports, warfare, and gaming is well recognized. Teamwork is just as applicable in organizations because it is not the strength of any individual’s IQ, but the team’s collective intelligence that drives success in a complex environment. Consequently, success is driven by the quality of interactions or relationships, more than it is on the quality of the individuals. This change from a focus on individuals to teams and partnerships affects almost everything in an organization, from team learning goals to team incentives and rewards.  Techniques for creating strong relationships include living, training, and working closely together – as is often the case for military and sports teams, highlighting the enormous value of team-building events. However, a powerful alternative is storytelling. Storytelling aids understanding and helps us to see each other as people rather than objects and hence develops relationships. |
| **When to use** | Regularly spend time developing robust relationships. Especially when working in partnerships or teams where components are competing rather than collaborating and when working in teams or partnerships that do not have a good knowledge of each other. |
| **Cautions** | Do not think of team building as a waste of money. It is an investment in resolving the next unexpected or unwanted event more rapidly and at lower cost. |
| **Why do I care** | It enables teams and partnerships to address problems more cost effectively and rapidly. It creates the right environment to allow different voices to be heard and hence identify the most suitable approaches. |

**Initial Bottom Up Heuristics Descriptions**

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| **1** | **Iterate to evolve complex systems** |
| **Elaboration** | Apply iterative approaches to developing or evolving a complex system.  These approaches include Agile, Spiral, Lean Start-Up etc., to incrementally deliver and evolve a complex system. |
| **Rationale** | You cannot develop a complex system right the first time, because we discover so much new information, and stakeholders often have to co-create new knowledge to be successful. Sense and iterate frequently, adjusting at a pace that is at a higher frequency than the change. Being within the decision loop enables you to influence the environment. If you are in a high change environment you need to sequence the work to minimise overall risk ASAP. A slower pace of change than the external decision loop implies firefighting. Choosing the right pace of change is critical for complex systems. Complex systems should be engaged in a manner that they support change, via identifying suitable leverage points. |
| **When to use** | When considering any complex system. |
| **Cautions** | Change needs to be planned and well thought through to minimise unintended consequences. If you do not fully understand the system or the environment you must act cautiously to ensure you do not cause more harm than good. Use feedback to ensure the impact of change is as expected. Don't change for the sake of change. Unnecessary change can be a major source of added complexity. |
| **Why do I care** | You cannot develop a complex system right the first time. |

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| **2** | **Multiple perspectives identifies complexity** |
| **Elaboration** | Observe a system from multiple perspectives to determine complex characteristics. Different perspectives include levels of abstraction, stakeholder perspectives, familiarity levels, and a range of boundary choices etc. If you cannot access expertise or training to determine or identify that the system is complicated, treat it as complex. |
| **Rationale** | Since single perspective on a system virtually guarantees that you will not see all relevant information. you do not fully understand the system or the environment you must act cautiously to ensure you do not cause more harm than good. |
| **When to use** | Continuously as part of reflective practise. |
| **Cautions** | Familiarity with problem space and the solution space both need to be considered. |
| **Why do I care** | Identifying aspects of complexity in systems prevents failure. |

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| **3** | **Complex systems are not wholly complex** |
| **Elaboration** | It is counterproductive to merely label a system as complex or not complex. Always identify and assess where the types of complexity are within the system. |
| **Rationale** | Seek to understand and capture the type, location, characteristics and scale of complexity exhibited in the SOI and the WSOI throughout the lifecycle and respond accordingly. Consider treating complex elements of system differently to complicated or simply system elements |
| **When to use** | When determining what part of a system is complex and therefore requires special attention. Using a Complexity Assessment Tool or by reviewing the Characteristics of the task The System Of Interest represents the aspects that you can act on and manage or lead. The Wider System Of Interest may only be influenced at best. |
| **Cautions** | Do not use only one approach for dealing with all types of complexity. Complexity is multi-dimensional and varied. |
| **Why do I care** | Even if a system is simple, the environment in which it is intended to be used, and/or stakeholder interactions may well be complex. There is no “one size fits all” way to address complexity; instead, it is imperative to identify specific characteristics and types of complexity, and address each individually. |

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| **4** | **Do not assume complicated pegs fit in complex holes** |
| **Elaboration** | Do not assume successful techniques for complicated systems will be helpful with a complex system. Do not assume that a Systems Engineering technique that has worked well in the past, even in past complex challenges, will be successful for this complex challenge. |
| **Rationale** | Complicated systems assume stable systems that work well with static structural or semantic modelling. Complex systems are fundamentally different and suggest the need “to change everything” - mindset as well as techniques. Complicated systems are well understood using partitioning and reductive techniques, while complex systems are not. |
| **When to use** | When choosing an approach for a complex problem, be careful in applying past successful approaches. Apply experimental, incremental and/or iterative approaches to test suitability. |
| **Cautions** | Do not hesitate to use applicable proven approaches for complicated portions of a complex system. |
| **Why do I care** | Techniques useful for complicated systems typically use partitioning and reductionism; these techniques often obscure the very inter-relationships which make a system or environment complex. |

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| **5** | **For every complex problem, there is an answer that is clear, simple, and wrong** |
| **Elaboration** | As we learn, do not be overly attracted to potentially simple problems or solutions without due diligence. Avoid jumping to solutions that have not been carefully analysed, especially in terms of unintended consequences. These are like Fixes that fail and Shifting the Burden system archetypes. |
| **Rationale** | Popular communication often uses “sound bites” which make it seem obvious that a simple solution will work. The quick fix may have unintended consequences that may not be immediately apparent. Do not assume an answer is right, while the problem is not well understood. A complex system is required to solve a complex problem. |
| **When to use** | When you are currently failing in applying a simple approach, a sound bite approach seems attractive but still needs to be checked. However, it is the job of systems engineering to fully understand the situation, and why an overly simplistic solution will not work. In complex problems, remove as many unnecessary dependencies as you can, but no necessary ones. |
| **Cautions** | Do not assume simple solutions are not possible. Elegant solutions are optimal when they can be realised, so we need to check if it is overly simple or elegant. |
| **Why do I care** | Popular communication often uses “sound bites” which make it seem obvious that a simple solution will work. However, it is the job of systems engineering to fully understand the situation, and why an overly simplistic solution will not work. |

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| **6** | **Complexity understanding should precede action** |
| **Elaboration** | It is important to understand, recognize and characterize complexity as a first step before you engineer or deal with complex systems. This is likely to require effort through learning and/or suitable experience. |
| **Rationale** | Understanding and recognizing complexity in the environment and system to be developed will enable the creation of more suitable solutions. |
| **When to use** | Anytime complexity or a breakdown between cause and effect, is likely in the system or the environment. This is often sensed when you feel uncomfortable with current methods for handling the task. |
| **Cautions** | Consulting an expert can be helpful to distinguish between complex or complicated. Sometimes experimentation is required to understand the complexity in the system or the environment. Expertise required: Requires knowledge of Systems Thinking and supporting techniques. |
| **Why do I care** | Not understanding complexity means you may treat a complex task as a complicated task. Misclassifying or treating a complex system as complicated is a major source of project failure. |

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| **7** | **Iterate and/or aggregate with stable system steps** |
| **Elaboration** | Engineers can aggregate and iterate more rapidly with stable intermediate forms (increments) of the design, within an overall architecture, to develop a complex system. The architecture accommodates the system's complexity in the context of its environment. It provides constraints and requirements for the design. Intermediate forms of the system design facilitate learning to better understand the interdependencies for the next increment or iteration. |
| **Rationale** | Engineers iterate and learn from each iteration before progressing to the next stage or increment. Baselines established an increasing level of learning, confidence and willingness to proceed. Expertise required: To implement this task successfully the SE architect skill is required. |
| **When to use** | When designing a large complex system with uncertainty and high risk. This also applies to the implementation system (the system that makes the system). This also applies to organisational evolution. |
| **Cautions** | The amount of documentation or modelling required for intermediate forms should scale to the size of the team to ensure a common understanding. The time allocated to baseline the intermediate forms of the design needs to be sufficiently short to allow for all iterations or increments required to complete the design. When evolving a complex system which is in use, intermediate versions need to be considered carefully. |
| **Why do I care** | Complex systems contain many unknown unknowns, intermediate steps help you to identify and understand them. Failure to iterate with stable system steps can lead to whole system failure, a big bang approach is highly unlikely to work with complex systems. |

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| **8** | **Culture mismatch kills complex systems** |
| **Elaboration** | Organisational culture and structure must adapt and adjust to deal with complex systems or environments. Organizational preparedness is necessary to handle complex systems. See Principle 3 in the INCOSE Systems Engineering Principles. |
| **Rationale** | Organisational culture will hinder the development of complex systems if the organisation cannot accommodate the uncertainty and reduction of control required to produce complex systems. |
| **When to use** | Culture and organizational change take time (years). You can use it for a team to create separate cultures if required using Bi-model or multi-modal approaches. Organizational preparedness includes for example: culture change, training in systems thinking and other complexity techniques, changing reward structures, breaking organisational silos, awareness of complexity principles and heuristics, and servant leadership. |
| **Cautions** | An organization needs complicated and complex (innovative) parts with their different cultures for success (Bi model or multi-model working, Principle 13). There are many different views on the definition of culture that need to be considered. |
| **Why do I care** | Organisations successful in implement complicated systems is highly unlikely to be good at creating complex systems, without culture change. |

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| **9** | **Think big, evolve from small** |
| **Elaboration** | Think big, assess all, but start small and continuously evolve when handling complexity. Invest in conceptualisation and exploration with small prototyping exercises before embarking on larger investments. Start development in small increments, test your assumptions and wait until sufficient uncertainty has been removed to make the time investment fruitful. Applies to both the operational and intervention systems. |
| **Rationale** | Big compelling visions help align behaviors, but big steps cause avoidable risk. Building on the lessons learnt from the prototyping exercises in a safe to fail environment makes it possible to test key assumptions and eliminate uncertainties. Small evolutionary steps enable beneficial emergent outcomes that adapt where possible to changes in the external environment. |
| **When to use** | For all unprecedented systems and for all potentially complex systems, especially when being developed with tight time constraints. The more unknowns in a complex system, the more opportunity thinking big starting small will offer. Using this heuristic at the start of a new initiative is helpful. |
| **Cautions** | Starting small will lead to concerns on progress, so reassurance will be required. Be careful to ensure that approach scales in time. Be careful not to get stuck in apparent safety of small. Using this heuristic mid-initiative can be disruptive, which will often be a good thing! |
| **Why do I care** | Dealing with complexity requires both a big picture view and attention to details at lower levels and getting the foundation right. Using smaller steps to test assumptions with rapid feedback will reduce risk. |

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| **10** | **Complexity necessitates continuous organisational learning and adaptation** |
| **Elaboration** | Understanding your organisation as a complex adaptive system is critical to incorporating improved systems engineering: implement change by observing, orienting, deciding, and then acting in a continuous loop. All social systems are complex adaptive systems. If leaders do not see their organisation as a complex adaptive system, that learns, then it is hard to recognize the benefits of systems engineering . |
| **Rationale** | Systems Engineering is an essential element of any complex adaptive organisation (system). |
| **When to use** | When helping an organisation deal more effectively with complexity. |
| **Cautions** | While learning and adapting the organisation needs to maintain focus, continuity and momentum in the system development and evolution project. Do not stop the learning process when you finish an activity or make a decision, organisational learning needs to be continuous in anticipation of future challenges. |
| **Why do I care** | Any organisation that seeks to be successful in handling complexity needs to include within it a systems engineering capability. Systems Engineering benefits will not be fully realised unless organisations see themselves as complex adaptive systems. |

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| **11** | **Deprioritize optimization, prioritize multiple perspectives.** |
| **Elaboration** | Optimization of any single function constrains accommodating all the different perspectives. Understanding the many and varied perspectives of a complex system is essential to inform balanced system-wide optimisation. As examples, different stakeholders, levels of abstraction, systems behaviors, and systems structures provide different perspectives.  No complex system can be optimized to all parties concerned, nor all functions optimized while maintaining the flexibility to adapt. Try to achieve an acceptable “optimal” balance across all the different perspectives, including current and future needs. |
| **Rationale** | Accommodating multiple perspectives is more important than optimisation in dealing with complex systems. Optimizing a system for overall benefit across the multi-perspectives of complex systems means that we need to accept that specific benefits will be sub-optimised. |
| **When to use** | When developing success criteria for a complex system. Helping others to realise that balancing all perspectives saves money in the complex domain, as efficiency saves money in simple and complicated domains. |
| **Cautions** | Pursuing optimization and efficiency in a complex world may lead to failure if all the perspectives are not considered. Incorporating all perspectives is expected to save money, but may increase costs in the short-term. |
| **Why do I care** | Pursuing optimization without understanding all perspectives will lead at worst to system failure and at best to lots of rework. |

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| **12** | **Keep options open to evolve** |
| **Elaboration** | During the development and evolution of complex systems, create options and keep them open for as long as possible. Resist the temptation to close options prematurely because any improvements in certainty and cost are likely to be illusionary. Useful tools include Systems Thinking, and iterative methods such as Lean Start-Up, SaFE etc. |
| **Rationale** | Conventional wisdom says that keeping options open causes cost increases and delays development. But when change is inevitable, it is cheaper to have a system that is sufficiently flexible, than one that is brittle to change. |
| **When to use** | In complex situations, especially when the environment is unpredictable. |
| **Cautions** | Sometimes it is cheaper to throw away an unsuitable iteration and start again (fail fast) than maintain system options. This heuristic is specifically not suitable for complicated systems. |
| **Why do I care** | Ideal timings for making many architectural and design decisions in complex systems is typically a lot later than making similar decisions for complicated systems. |

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| **13** | **Complex Systems: As simple as possible, but no simpler!** |
| **Elaboration** | Complex systems should be made as simple as possible to deliver all needed system outputs, but not simpler (reflection of a phrase attributed to Albert Einstein). System complexity ideally should match the ideal complexity for fulfilling all system outputs, but often it is somewhat greater. If it is less, it is often because sufficient perspectives have not been taken into account.  Design system elements so that they are as independent (modular) as possible; low external complexity (low coupling) and high internal cohesion. E.g. Service Orientated Architecture. |
| **Rationale** | In each operational context and decision timeframe, the minimum system complexity required to fulfil all the system outputs is the optimal system complexity. |
| **When to use** | In architecting and designing complex systems. |
| **Cautions** | A more complex system solution than the optimum can fulfil the system requirements, but not as elegantly, while an overly simple system will fail. |
| **Why do I care** | Customers and stakeholders want simple, even elegant solutions. For complex challenges it is tempting to over simplify the design, by ignoring or scoping out aspects of the complexity. This approach will often lead to system failure. |

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| **14** | **Reuse with extreme care** |
| **Elaboration** | An element good enough in a previous system needs careful analysis before being applied to another complex system. The previous system element (including Commercial Off The Shelf and Military Off The Shelf) is unlikely to be good enough in coping with new or different complexity. |
| **Rationale** | We need to ensure we abide by fit form and function when we are considering system elements in a new context. A little change, even in the fine details of the system, can cause disproportionate effects in the overall system. Existing system elements embody design decisions that are not always explicitly described, making it difficult for engineers to understand their potential effects on a new system. |
| **When to use** | When considering re-use of a system element. |
| **Cautions** | Small scale modifications can result in radical changes, either in the magnitude of an individual change or the cumulative effects of many changes. |
| **Why do I care** | Reuse of parts and subsystems which can work well in other systems can be disastrous in complex systems if done without full insight. |

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| **15** | **Focus on holistic utility** |
| **Elaboration** | For complex problems, focus on holistic utility, not optimization of any single objective. Removing flexibility to reduce costs is inefficient in complex domains. |
| **Rationale** | Optimisation can be counterproductive with complex system development as objective functions are difficult to define. Solution flexibility is required to adjust and adapt when uncertainty in the system, environment, or both causes a new issue to be resolved. Insufficient agility and flexibility are a major source of failure in complex systems. |
| **When to use** | During the whole lifecycle. Though special attention during the scoping phases is required. |
| **Cautions** | Holistic is the opposite to reductionists approaches. Efficiency should include agility and flexibility across the whole, not optimizing for a single use. |
| **Why do I care** | If organisations handling complexity continue to focus on reducing flexibility to achieve efficiency rather than adaptability they will fail. |

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| **16** | **Complex problems call for strategic thinking** |
| **Elaboration** | Strategically assess the areas of complexity to select handling approaches thoughtfully.  Different areas of complexity may require different strategies.  Acquire a broad overview and look for synergies to bound the complexity areas.  Do not assume one successful approach to handling complexity will handle other complexity types effectively. |
| **Rationale** | Decide what is worth doing strategically by exploring the unknown and uncertain as profitably as you can. “If I had only one hour to save the world, I would spend fifty-five minutes defining the problem, and only five minutes finding the solution” (Quote attributed to Albert Einstein). |
| **When to use** | When complexity is encountered. Especially at the start of an activity and at phase or transition boundaries during the system lifecycle (i.e. key decisions points). |
| **Cautions** | High re-work costs are likely to be incurred if this heuristic is not applied. Be careful not to get lost in the details. |
| **Why do I care** | Lack of complexity appreciate can lead to missed risks and opportunities. |

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| **17** | **Holistic system health avoids complex system failures** |
| **Elaboration** | Proactively and holistically manage the unexpected emergent health issues within a complex system to mitigate failure. The resilience and health of the system will be high if the complexity has been sufficiently addressed. Chances for recovery from a single failure or flaw, even with complex consequences, are fairly good if system health is managed holistically. The likely recovery from two or more independent failures will also increase with holistic system health management. . |
| **Rationale** | Holistically manage the health of a complex system to mitigate failure. Traditional health management consists of designing out failures so they cannot occur. Complex system designs require proactive monitoring and elegant response to prevent symptoms escalating into failure. |
| **When to use** | For safety critical or expensive systems when resilience is particularly important. |
| **Cautions** | Do not measure too much, unnecessary measurement can overuse system resources diminishing the system benefit. Ensure you understand the system state before changing the system. Take care that the response to unhealthy signs does not exacerbate the underlying health problem by causing an overreaction with unintended consequences. |
| **Why do I care** | Given the inevitable emergence of unexpected behavior in a complex system, it is necessary to design for health monitoring to enable recovery to a state which supports continuing operation. |

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| **18** | **Manage emergence holistically** |
| **Elaboration** | Proactively and holistically manage unexpected emergence within complex systems to mitigate failure and realise opportunity. Complex systems can lead to emergent opportunities as well as threats. Spotting opportunities and threats require proactive observation and sampling of the system to monitor the design boundaries to help them to be identified. Complex sociotechnical systems are confounded by social complexity which much be accounted in the management of emergence properties, both social and technical. |
| **Rationale** | Unexpected emergence is difficult to predict and can affect the system performance from many perspectives and at many scales. Managing emergence holistically allows for the consideration of all levels of impact. Social systems are inherently complex, compounding any systems complexity, with opportunities and threats frequently occurring. The inability to detect emergent events can lead to missed opportunities and threats. Partial or singular perspective management of emergence can lead to a failure to understand the system operation and a failure of system performance. |
| **When to use** | In complex system should have emergence managed holistically. Sociotechnical systems that confound the system technical complexity are more challenging, requiring more care in design and understanding. |
| **Cautions** | Take care that the response to emergence does not exacerbate the problem by causing an overreaction or unintended consequences. Especially important to identify the facts, independent of confounding factors (such as biases, social structures, power structures, politics, competence or autonomous system actions), to enable well informed conversations. |
| **Why do I care** | There is a high risk that opportunities will be missed and that failure may well be a disruptive surprise rather than managed. |

**Additional Bottom Up Heuristics Descriptions (DRAFT)**

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| **19** | **Successful communication requires an understanding of the listeners’ mental models** |
| **Elaboration** | Unless you share the same understanding of what words means or the implications of those words in the context they are being used then communication fails. |
| **Rationale** | The misclassification of complex and complicated tasks is a key cause of project failure. To be successful in a complex space which is often dealing with new concepts we need to ensure that all stakeholders share the same mental models and word definitions. |
| **When to use** | When communicating others unfamiliar with your approach, context, or culture. When using words or mental models not traditionally used in the way being applied. |
| **Cautions** | None |
| **Why do I care** | If you are not communicating effectively it increases the likelihood of a catastrophic system failure. |

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| **20** | **Complex system failures enable accelerated learning** |
| **Elaboration** | Failure is more inevitable with complex systems. However, failure is also a useful way to probe the complex system on the points directly relevant to the task at hand. Consequently, probing the system and failing (by experimentation) is a key learning mechanism and is an effective way to acquire the required learning rapidly. |
| **Rationale** | If you can not understand the system then probing and experimentation is key |
| **When to use** | When seeking to understand a system that can not be understood effectively in the time allowed or cost effectively by studying it. |
| **Cautions** | Use fail safe experiments, remembering every action changes the system. |
| **Why do I care** | Embracing failure as a key learning mechanism provides the psychological safety to try new novel ideas and understand the system more rapidly. |

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| **21** | **It is better to be roughly right than precisely wrong** |
| **Elaboration** | In a complex world being right for anything beyond a short period is highly unlikely due to the amount of change and information to comprehend. Hence spending time seeking accurate answers to be precise in your decision making, is less beneficial than being roughly right and learning through proactive observation, learning and adaptation is much more effective. |
| **Rationale** | In complicated system where the system can be understood and change justifies the effort in being right for longer, precision is beneficial. A complex system turns this mindset on its head, because it is difficult if not impossible to acquire all the right information and even if you did at a pint in time, change in the context may make that effort void. Consequently, it is better to be roughly right and adapt with the changes and learn through experimentation. |
| **When to use** | Helping teams to make the mindset shift to the complex or digital age. |
| **Cautions** | This does not mean you apply no effort in making the right choice. System Engineers still to navigate all the available information in the time available to maximize the probability of placing the roughly right solution in the region of the right answer. |
| **Why do I care** | It enables progress to be made more rapidly, and echoes a mantra of many customers “Give me an 50%/80% solution today rather than a 100% solution later”. Suggesting they unconsciously see the foolishness of applying complicated techniques to complex challenges, |

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| **22** | **The unrecognized assumptions are the most dangerous** |
| **Elaboration** | An assumption that is uncaptured, if wrong is more likely to cause system wide failure before detection. |
| **Rationale** | This heuristic applies to complicated systems too, but is particularly relevant in complex systems. When there is so much information to consider, many more assumptions are required. It is important that the critical assumptions, ideally all assumptions, are captured, as when they are proven wrong through proactive monitoring you can rethink the system design to respond to the change. If you assume you have designed based on the right assumptions, failure is likely. Accept that you have not caught all of the assumptions you need to proactively sense system performance even in parts of the system you consider “Safe”. |
| **When to use** | When documenting the system design and determining your proactive sensing of the system to watch for unexpected failure modes. |
| **Cautions** | Do not get caught in the rightness trap of spending too much time trying to document all the assumptions to prove you are right. Just spend sufficient time considering the assumptions without jeopardizing delivery. |
| **Why do I care** | An unrecognized assumption is harder to spot and can cause systemic failure. |

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| **23** | **Good solutions emerge through creative environments.** |
| **Elaboration** | Create an inclusive, diverse environment to make sure all voices are included and respected in conversations to identify the best solution. |
| **Rationale** | The best solutions are identified when the best and suitably diverse group of people accessible to you that understand the problem, or can understand the problem sufficiently, are given an environment where they communicate without fear or embarrassment or punishment. Where every voice is respected no matter the grade, age, background or charisma. |
| **When to use** | Creating teams who have to solve complex problems. Creating a workshop to solve a particular complex problem. |
| **Cautions** | Ensure top managers are briefed as to why this environment is needed. This environment will need to protected, and only once proven safe from outside interference is it truly effective. |
| **Why do I care** | Creative environments will identify solutions that solve the most complex problems or overcome threats and competition most effectively (and cost-effectively). |

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| **24** | **Manage adverse consequences with proactive feedback structures or mechanisms** |
| **Elaboration** | Create feedback mechanism across your system to spot failure before the system fails. |
| **Rationale** | Adverse consequences or emergence is to be expected in complex problems. Proactively creating continuous feedback mechanisms will enable you to react before problems lead to systemic failure. |
| **When to use** | In designing systems |
| **Cautions** | Place feedback points in even in areas expected to be safe. |
| **Why do I care** | If you do not spot flaws in the system early your system will fail. |

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| **25** | **Every attempted fix of a complex problem, changes the problem** |
| **Elaboration** | Implementing a fix or even probing the system is highly likely to change the system. |
| **Rationale** | Complex problems are generally not completely understood, and often reflect the history of the system. Every attempted fix changes that history and hence will often change the problem. It is best to assume that this is always true. This aligns to the Lean Start Up principles of fail-safe experiments. Think about interventions and the impact they might have on the system before probing it. |
| **When to use** | When experimenting |
| **Cautions** | Do not let this prevent experimentation. Just do so thoughtfully. |
| **Why do I care** | To ensure the process of designing a solution does not worsen the problem or move its resolution beyond your reach. |

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| **26** | **Identify a compelling community vision to address complex problems** |
| **Elaboration** | Create a common compelling vision to align stakeholders and hence remove unnecessary complexity from the system |
| **Rationale** | When teams are aligned to a common compelling vision, then the work and any changes during that work will adapt to a common north star. Consequently, having a sharing a common aiming point means that all work is more productive, and when things go wrong the response is more aligned. |
| **When to use** | At the start of activity |
| **Cautions** | Review and sense, change, noting it is what motivates the community not the boss that really has power. |
| **Why do I care** | Team working collaboratively and change more likely to be seen as an opportunity to move further towards goal. |

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| **27** | **In introducing complex solutions, “how” trumps “what”** |
| **Elaboration** | For complex problems how you respond is more important than what you change. |
| **Rationale** | Often Systems Engineers will focus on what the change needs to be. But how you implement that change, the build logic and business change, is more important in complex systems as each aspect will cause its own emergence within the system, and possibly in the environment, as you progress. The “what” envisaged at the start maybe need to change by the end of the implementation process due to external or emergent system factors. Consequently, getting the “how” right is more important. Quite often the first element is paradigm, culture or mindset change. |
| **When to use** | When considering build logic and business change, ensure sufficient resources are allocated and the right culture is considered first. |
| **Cautions** | You still need to fully understand what you are aiming towards |
| **Why do I care** | To ensure that the business change and build logic is considered sufficiently to enable success and avoid shortcuts which can cause project failure. |

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| **28** | **It is easier to ignore complexity – and fail** |
| **Elaboration** | When it comes to complex problems, often the easy way is to pretend it is complicated and hope for the best -- sticking your head in the sand. However, this of course leads to frequent failure. |
| **Rationale** | Often complex problems are treated as complicated problems. This leads to significant amounts of failure, as project scope, time, cost and quality are changed to make it feel like success. This is possible as failure is often celebrated by both parties (supplier and customer) as often both parties have a vested interest in the project looking it like a success. |
| **When to use** | When considering a new mandate or challenge |
| **Cautions** | Not every problem is complex, thought it often feels like that at the start. Get the right team together and using a Complexity Assessment Tool to determine what parts, if any, are complex and segment the task accordingly. |
| **Why do I care** | To ensure that true progress is made within organisations, rather than just effort that is likely to result in eventual failure. |

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| **29** | **Maintain a compelling community Vision through respectful collaboration** |
| **Elaboration** | Communities visions need to go beyond the bounds of the immediate team. By successful collaboration with all stakeholders, you can identify the vision that aligns the work and this can be used to support productive teamwork and accelerated progress towards end goals. |
| **Rationale** | Common compelling visions can be used as a North Star to ensure partners and individuals within those organisations are working towards the same end point. This aids effective collaboration without seeking to control every aspect of the work. |
| **When to use** | When partnering with others, and when there are many stakeholders including ones not on the development team |
| **Cautions** | You still need good communication |
| **Why do I care** | It helps partner organisations to work together effectively, and significantly decrease the likelihood that stakeholders with divergent aims will disrupt the project. |

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| **30** | **Evolving is the complex system’s superpower.** |
| **Elaboration** | The changing nature of complex systems is also its superpower. Although designing and building a system to be readily evolvable adds complexity, it makes the system much more likely to be useful for a longer lifespan. |
| **Rationale** | Each change seen is an opportunity that can lead to ever improving services and capabilities. Being able to change to accommodate environmental changes means the system stays relevant and beneficial. The law of requisite variety means a complex system is required to address a complex system problem. |
| **When to use** | When designing systems to cope with complexity, build in adaptability (Living systems, proactive observation and continuous learning) |
| **Cautions** | The ability to evolve needs to be designed in, not assumed. |
| **Why do I care** | It means a problem can be solved once, rather than the symptoms caused by the use of the system and changing circumstances creating the need to discard the system and build a new one. |

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| **31** | **Minimizing harmful element interactions supports resilient complex systems** |
| **Elaboration** | When creating systems, study the relationships between elements and where necessary put in thresholds to prevent one element being able to harm another element, preventing cascading failures. |
| **Rationale** | Complex systems will have unexpected interactions between elements of the system. To make these systems resilient placing thresholds and limits on behaviour of interfaces is required to prevent harmful interactions. |
| **When to use** | When designing systems to cope with complexity. |
| **Cautions** | Be careful not to prevent future flexibility and adaptability in the system. The intention is only to reduce harm. |
| **Why do I care** | This heuristic prevents cascading failures and limits system failures near any components that fail. |

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| **32** | **Complex systems should allow and enable human flexibility** |
| **Elaboration** | Complex systems benefit from the adaptability and processing capability of humans. System design should allow and harness human flexibility. |
| **Rationale** | Humans are often the main source of complexity. However, they are also uniquely capable of handling complexity. This is a reflection of the Law of Request Variety. Ensure that your systems are able to utilize the complex handling skills of human elements. |
| **When to use** | When designing systems to cope with complexity. |
| **Cautions** | You may need to put thresholds in place to prevent humans doing harm to other system elements |
| **Why do I care** | Humans operating a system often have the creativity and insight needed to use the system to effectively deal with situations and inputs never foreseen by the original designers of the system. |

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| **33** | **Bear-hug complex problem unknowns** |
| **Elaboration** | Complex problems need to be fully embraced, accepted, and handled effectively to successfully handle the unknowns. |
| **Rationale** | Expecting, planning and preparing for the unknowns (failures and successes) enables us to provide system resilience and identify opportunities for improvement and progress. |
| **When to use** | When developing and operating a complex systems. |
| **Cautions** | Have a “b” and a “c” plan. Do not assume that your initial assessment of areas of complexity in the system was fully informed. |
| **Why do I care** | Seeking to identify and understand unknowns vastly increases the likelihood of successful development and operation of a complex system. |

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| **34** | **For complex systems, being useful is more important than being right** |
| **Elaboration** | For complex problems, having a solution which is totally right is improbable for any significant length of time. Consequently, it is more valuable to focus on usefulness by identifying the best answers in the time available. |
| **Rationale** | The benefits of spending time on being precisely right is substantially less in a complex system (due to frequent change), and much harder to achieve than it is in a complicated system. Consequently, it is more valuable to focus on usefulness by identifying the best answers in the time available and learn through action. This applies to developing heuristics too! |
| **When to use** | Always, but especially when time is constrained |
| **Cautions** | This does not justify making no effort in coming to the best decision. However, the effort needs to be scaled to the time available to act before the decision is too late to support cost-effective system development. |
| **Why do I care** | This enables progress to be made. This progress should be protected by proactive observation of the system to spot errors before they become major failures. |