ENCORE FEASIBILITY CALL 3

Closing time and date: 12:00 GMT   15th June 2018

1. Summary

ENCORE Network+ is an EPSRC funded project, which aims to explore the opportunities presented by developments in complexity science to improve the resilience and performance of complex engineering systems such as cities, energy and digital systems, space launch and recovery systems and jet engines. Details about the project can be found at www.encorecomplexity.org

2. Scope

ENCORE is calling for a third round of Feasibility Studies within the scope of the Network, as detailed below. This time our emphasis will be on supporting studies which originate from members of Encore's Early Career Network. Joining our Early Career Network is possible at all times (see www.encorecomplexity.org) but you must join the Network to submit a proposal to this call.

ENCORE will award a number of Feasibility Studies to individuals or groups on the basis of the applications received by the closing date of this call.

The scope of the Feasibility Studies should be framed within the thematic areas of the ENCORE Network+ (Appendix A). Further supported by a list of questions from the current Network and Industry (Appendix B). The theme should align with the current EPSRC delivery plan with a strong focus on the 'resilient nation'.

3. Funding available

A total of up to **£20,000 (inclusive of VAT)** is available and we expect to fund between 4 and 8 Feasibility Studies. The projects are expected to start not later than 6th August 2018 and have a maximum duration of 3 months. The applicants are encouraged to explore the possibility of matched funding. Funding will be released on the basis that the applicant submits a full report detailing the outcomes of the study and claims costs against usual research council funding categories.

4. Eligibility

Applications are open to individuals and groups with affiliation to a UK University.

5. How to apply

Applicants are invited to submit a 2 page proposal, and a submission form with their details. Please send completed submission forms and proposals in PDF format by email to encore@sheffield.ac.uk no later than 12:00 GMT on 15th June 2018.

6. Guidance on writing application

Maximum length for the proposal, including references and pictures, is 2 pages, minimum font size 11.The proposal should include:

- A clear statement of the Thematic Area(s) being addressed;
- A problem statement;
- Evidence of how the proposed project fits into the Thematic Area(s) being addressed;
- A statement of the methods to be used and how the skills of the proposer(s) fit to these;
- Clearly defined project outcomes (measurable);
- Details of how the Feasibility Study results will be exploited through further research proposals including: i) a clear statement and justification of funds requested, ii) a clear breakdown of FEC costs.

7. Assessment

The proposals will be reviewed by the Management Team and Steering Committee of the Encore Network+ and will be assessed based on the following criteria:

- Network remit;
- Leadership & ownership of bid by early career academics;
- Realistic objectives within the constraints of funding and time;
- Multidisciplinary and innovative science;
- Industrial support;
- Value in enhancing research activity, with the potential of enhancing further research activities and leveraging additional funding;
- Alternative funding sources

Alternative funding source refers both to the availability of matching funds towards the Feasibility Study itself and to the availability of funding towards the exploitation of the Feasibility Study results (Appendix C).

8. Key dates

Activity	**Date**
Call conditions announced	**3rd May 2018**
Closing date for applications	**15th June 2018**

Funding decision	**9th July 2018**
Latest project start date	**6th August 2018**

9. Contacts

For general enquiries, and for anything concerning this call, please email encore@sheffield.ac.uk

For enquiries about the themes and the scope of the ENCORE Network, please contact:

Professor **Martin Mayfield**
martin.mayfield@sheffield.ac.uk
+44 (0) 114 222 5054

Professor **Liz Varga**
liz.varga@cranfield.ac.uk
+44 (0) 123 475 4802

Professor **Massimiliano Vasile**
massimiliano.vasile@strath.ac.uk
+44 (0) 141 548 2326

Professor **Alan Purvis**
alan.purvis@durham.ac.uk
+44 (0) 191 33 42437

APPENDIX A

ENCORE THEMATIC AREAS

The six Thematic Areas that are being addressed in this Feasibility Study call are outlined below.

1. **Resilience in network and process dynamics:** A key problem for engineers is defining the relationship between how a CES is designed, the behaviour that this design produces in normal use, and how this behaviour alters when the system is subjected to multiple, overlapping shocks and stresses and also in the context of dynamics such as growth and adaptation. Reductionist assumptions on the nature of uncertainty and its propagation through the system can lead to incorrect expectations. An example is that the form of a city may be represented by a static transport network that exhibits a characteristic pattern of mobility, but we lack understanding of how this network interacts with associated energy, ICT and user networks operationally and under conditions of nodal or sub- system failure. This issue is compounded when considering multiple overlapping uncertainties.

2. **Understanding the constraints and design to benefit from these:** High- order CES such as cities or national infrastructure exhibit constraints that are often not considered in the models used to predict their behaviour. Processes such as aggregation and self organisation create temporal and relational constraints. We need to understand how such developmental constraints relate to design and performance in order to benefit, rather than suffer, from such characteristics (Thompson 1917; Kauffman 1993; Goodwin 2001). This is also linked to the CES being constrained to exist in a low- dimensional medium: space- time. Consider a real world energy network is a high- dimensional abstract structure projected onto two spatial dimensions and allowed to evolve in time. A transport network is also high- dimensional in its connectivity, but the structure of this connectivity is constrained by the physical infrastructure that it inhabits (Havlin 2011). Increasingly we are beginning to better understand the role of spatial and temporal constraints in the behaviour and configuration of complex engineering systems. We need systems of systems tools to express these higher dimensional characteristics in order to explore and understand their inherent risks and resilience. In the same way, we are beginning to understand developmental constraints in the growth and morphology of cities (Batty 2009) through exploiting understanding of the behaviour of complex systems (May 1976; Feigenbaum 1980), but we are still mainly focused on the physical properties of cities.

3. **Leveraging natural world examples of complex systems:** Significant opportunities to improve resilience and performance lie in the potential to extend this understanding into the underpinning engineering systems and social structures. Our aim is to extract the design principles that define beneficial attributes and behaviours in naturally

complex systems and use this to inform the design of socio- technical systems. As an example Advanced Energy eco- systems, often referred to as Smart Grid 3.0, will require the properties of self- organisation, self- repair, robustness and adaptation characteristic of naturally complex systems (Carvallo, Cooper 2011).

4. **Managing uncertainty in Complex Engineering Systems:** A challenge for engineers exists in their ability to alter and control the behaviour of existing CES to have predictable performance under uncertainty. Whether this is reconfiguring an energy system to accept a dynamic mix of generation types or updating software in communication networks, the implementation of minor changes can have cascading multi- scale impacts upon systemic behaviour and performance (Newman 2011). Over time multiple changes are a record or description of the emergence in such systems. We need effective tools to deal with uncertainty when the identification of all statistical properties of a system is not possible due to its complexity. The risk associated with the emergence and propagation of uncertainties through complex systems renders the understanding of the degrees of redundancy or resilience of a network false. New techniques are required to understanding the transitional characteristics to develop our ability to predict such failures (Scheffer 2009).

5. **Understanding risks in coupled socio-technical systems:** Research is beginning to link models of CES to models of decision making (Vespignani 2012) to provide a more comprehensive understanding of both the impacts of CES design and management on societies and the potential for societies to be affect of their surrounding infrastructure. For example, water and power networks are key to the resilience of societies, but each is vulnerable to risk and uncertainty on a number of levels. Exploring the mathematical approaches to such coupling of human and engineering systems is a 'blue skies' topic. Applications of particular interest will include understanding uncertainty that should feed through to improved decision making for infrastructure projects.

6. **Understanding the bi-directional impact of human behaviour on CES:** Modelling within CES tends to focus on the ways in which the technical components of systems interact. These systems do not operate in a vacuum as they are developed to serve societal needs. Understanding the ways in which systems impact employee/user behaviour, and the ways in which employee/user behaviour impacts systems is crucial in order to identify dynamic issues that affect CES resilience. Similarly, understanding the impact of systems on individuals, communities and society, as well as the impact of individual, community or societal preferences, responses and expectations, will inform the understanding of the effectiveness of CES. Currently, assumptions about the impact of employee public behaviour on the resilience and effectiveness of CES tends to be built upon anecdote or assumptions. Recent research into emergency response, and critical national infrastructure employee willingness or ability to report to work during

extreme events, demonstrates that these assumptions are often inaccurate (Rogers & Pearce, 2013). Additionally, cyber-security research into employee behaviour demonstrates an innate ability to find workarounds when the system fails to meet the needs of the user (Sasse, 2014). Research opportunities might include the generation of an empirical evidence base related to the impact of CES on human behaviour and the impact of human behaviour on CES in order to improve and adapt our current understanding of the resilience of CES.

In addition to the thematic areas above we would like to **encourage innovative approaches to understanding complex systems.**

Experimental tools allowing the investigation of emergent behaviour, evolutionary approaches to selectively pick resilient solutions and convergent algorithms to pull complex systems back to optimal behaviour when disturbed are all methods within the scope of our mission. It is even conceivable that learning algorithms can adapt to new environmental constraints and increase system performance beyond that designed in at the outset, ie we give the machine the ability to learn new behaviours but allow the freedom for the machine to decide what it learns.

APPENDIX B

QUESTIONS TO CONSIDER:

1. Complexity represents a subtle mix of order and chaos. Complex Engineering Systems move between these two extreme states at a rate defined by the extent of feedback the system creates. - Therefore for CES to be resilient, the speed, quality and quantity of feedback should be a key driver? Can this be demonstrated through modelling?

2. To what extent does or doesn't nature favour centralised network structures and what light can this shed on the design of resilient Complex Engineering Systems?

3. What are the cross domain behaviour traits? - Can the behaviour of financial or biological systems be seen in the infrastructure systems across temporal scales? Can we learn (by experimenting, trialling, simulating, etc.) to do better in engineering systems by using successful behaviours from non-engineering systems?

4. We are poor at evaluating Infrastructure Systems for their performance under extreme shocks and stresses. A possible parallel is banking. Stress testing of the banking system has leapt forward following the financial crisis of 2008. The financial systems are now tested under much more extreme scenarios. Techniques such as extreme value analysis allow researchers to explore uncertainty in financial system models. Is this transferable research?

5. How can we better understand cascading and simultaneous multiple failures across infrastructure systems?

6. Can we identify what might be the unanticipated effects of increasing the complexity of systems?

7. Can we identify design characteristics of complex engineering systems that are resilient to high impact low frequency events? Models would allow us to experiment with extreme scenarios and alternative characteristics.

8. How can we better understand the implications of cyber-physical systems? Are new techniques needed to verify the assumptions of cyber-physical systems?

9. In a highly distributed and highly interconnected network of nodes that cannot be relied upon to cooperate, for example, in the infrastructure supply chain, are there practicable strategies for a) bounding the impact of anomalous external behaviour on local nodes; b) bounding the "amplitude" of emergent behaviours – e.g. in response to

shocks? And do these controls stifle innovation at the node or does the network respond adversely when the node innovates?

10. Can we represent complex networks as learning systems so that actions taken in the network are cognisant of feedback on to the decisions themselves to create an evolutionary approach to infrastructure design? How would decision making rules change if decision makers were aware of the effects of their decisions?

11. How do we design infrastructure systems to accept periods of prolonged extreme loading and how do we identify how system weaknesses vary as loading patterns vary?

12. There is a lack of multidisciplinary and complex systems parameters by which to characterise resilience. This complicates the evaluation of resilience and the ability to make investment decisions to improve resilience. This drives a need to quantitatively describe the resilience of a system, structure or network to enable objective decisions on alternative approaches to the norm that is to increase robustness to disruptive events. How do we do this?

13. Increasingly rapid fluctuations in demand may result from pressure on different parts of infrastructure systems, such as transportation systems, for the movement of people and goods, therefore demand smoothing/infrastructure load shifting etc. are important. How do we design responsive, integrated systems to achieve this and what issues does this raise?

APPENDIX C

When a Feasibility Study (FS) proposal is awarded funds, the totality of these are taken from the amount budgeted for the FSs. This funding already includes the portion given by both EPSRC and the University of Sheffield or any other co-funder/partner in the ENCORE proposal, ie Full Economic Cost Figures.

<u>Example 1:</u> Dr A. King, from the University of Camelot, is awarded 10,000 GBP to carry out a FS on “the resilience of sword release mechanisms subject to multiple unsuccessful pulls”. The study is supposed to take 6 months to complete. ENCORE will pay the sum of 10,000 GBP to the University of Camelot on receiving the FS at the end of the 6 months. No other money will be released through this channel to complement the 10,000 GBP. However, if the University of Camelot wants to contribute towards the costs of the FS, it can. The same applies to any third party (Merlin Swords Industries Ltd. for example) wanting to contribute. Dr A. King can hence use the 10,000 GBP awarded through ENCORE plus any addition they obtained.

<u>Example 2:</u> Dr Green wants to investigate the readiness of the UK Motorway system to the introduction of self-driving cars. However gathering data, workforce and equipment for analyzing the whole motorway network is expensive and requires some preliminary investigation to demonstrate the value of the study to research council's, industrial partners and stakeholders. Dr Green is then an ideal candidate to submit a feasibility study where they can request money to acquire a small quantity of data from the Highway Agency and/or to hire someone to assist them in the analyzing the data. Dr Green should write their Feasibility Study proposal by clearly stating the expected results from the study, their intent of extending the analysis to the whole network after the feasibility study, and the pathway that takes from the
first to the second.

References

Batty M. (2005) Cities and complexity: understanding cities with cellular automata, agent- based models, and fractals. MIT Press, Cambridge.

Carvallo, A., & Copper, J. The Advanced Smart Grid. Artech House.

Feigenbaum M.J. (1980) The metric universal properties of period doubling bifurcations andthe spectrum for a route to turbulence. Ann New York Acad Sci 357:330–336.

Goodwin, B. (2001). How the Leopard Changed Its Spots: The Evolution of Complexity. Princeton University Press

Havlin, S. et al (2011). Dimension of spatially embedded networks. Nature Physics Nature 7,481–484.

Kauffman, S.A. (1993). The Origins of order. Oxford University Press.

May R.M. (1976) Simple mathematical models with very complicated dynamics. Nature 261:459–467.

Newman, M.E.J. (2011), Communities, modules and large-scale structure in networks. Nature Physics 8, 25-31.

Rogers, M.B., & Pearce, J. M. (2013) Risk communication, risk perception and behaviour as foundations of effective national security practices. In B. Akhgar, & S. Yates (Eds.), Strategic intelligence management (pp. 66-74). Oxford: Elsevier Butterworth-Heinemann.

Sasse, M.A. (2014). “Technology should be smarter than this!”: A vision for overcoming the Great Authentication Fatigue. In W. Jonker, & M. Petkovic (Eds.), Secure Data Management: 10th VLDB Workshop, SDM 2013, Trento, Italy, August 30th, 2013, Proceedings (pp 33-36). Switzerland: Springer International Publishing.

Scheffer, M. et al (2009), Early-warning signals for critical transitions. Nature 461, 53-59.

Thompson, D. (1917). On Growth and Form. Cambridge University Press.

Vespignani, A. (2012) Modelling dynamical processes in complex socio- technical systems, Nature Physics 8, 32-39.