EPOC 2023 Extended Abstract

A MANAGEMENT CHALLENGE BEYOND SCALE AND COST: IS THERE A CASE FOR COMPLEX SYSTEM PROJECTS?

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Introduction and Background

Public and private clients around the world have been undertaking an ever increasing number and range of projects and programmes to tackle a variety of challenges that are themselves increasing in both size and significance (Morris, 2013; Morris and Hough, 1987; Morris et al., 2012). The distinctive feature of projects as organisational forms is that they are temporary, have both distinct goals to achieve and constraints to work in, and they are created to get things done. Given the importance of projects for the economy, innovation, infrastructure and social outcomes, since the 1990s scholars have focused on different types of project oriented organisational settings, for example distinguishing temporary projects from permanent organisations, and considering the contextual setting in which projects are undertaken, leading to studies on the project-based organisation and project-supported organisation (Lundin et al., 2015) and the project society (Schoper et al., 2018). However, despite the importance of the permanent organisational and institutional settings where projects take place, the temporary organisation that delivers projects has not become less important. For example, to describe projects with the aim to design, develop and deliver technical systems at increasingly large scale, scholarly and practitioner literature has coined a variety of descriptor terms, such as: major project, megaproject, programme or portfolio. While the terms major project and megaproject are typically used in reference to scale and importance of the project for their client, a programme or portfolio of projects refers to several projects bundled together either with a common strategic goal (programme) or under the sponsorship or investment umbrella of a single organisation (portfolio) (Maylor et al., 2006). Moreover, both in the context of the scale and cost and multiplicity of units of work to be managed, the underlying assumption is that each of the categories of project-based undertaking represents a conceptually meaningful distinction from the others and, therefore, warrants a stream of both theoretical conversation and practitioner methods to elaborate on its challenges. For example, there is a burgeoning literature on megaprojects (typically defined in terms of $1Bn+ as their estimated cost to the client) that has elaborated on the challenges of such large-scale (often unprecedented) undertakings, referring to their high cost and ambition to achieve success in terms of cost and schedule efficiency. This work touches upon the high complexity, duration, impact and risks inherent to megaprojects (Flyvbjerg, 2014; Söderlund et al., 2017; Flyvbjerg, 2017) and this has more recently been extended into a conceptual discussion on scale and fragility of megaprojects (Ansar et al., 2017). The central tenet of the discourse on megaprojects and major projects remains the scale of endeavour in terms of relative magnitude of capital investment, often overshadowing other characteristics of the project organisation or its outputs.

The purpose of this paper is to prompt a rethinking of the idea of the distinctiveness of a project-based temporary structure based on the proposition that scale and multiplicity alone do not give much indication of kinds of challenges, practices needed, or indeed complexity inherent to such projects. As a response to this challenge, we propose to focus on what are proposed as two equally important characteristics of projects. These are the relevance of the project's task to create or deliver some form of distinct system, and the degree of relative complexity features of the project. These two parameters are proposed for consideration to allow better understanding of the challenges of the kind of projects that can be observed as seeking to generate societal and economic impact. Such projects, which may well also be major or indeed megaprojects in terms of size and scale, will inherently represent high levels of uncertainty and risk, and involve a high number of stakeholder groups. Whilst the private sector will undertake such large, complex system projects, with obvious examples being in the sectors of IT and communications, aerospace, energy, and pharmaceuticals, it is the public sector that can be seen to take on the biggest and most complex of these projects and programs. These are often planned and delivered for the provision of infrastructure services and can now be found across all regions and continents of the world (with the exception now of Antarctica).

Such infrastructure provision is developed in temporary organisational settings that can often rival the complexity of the tangible outputs that they are generating. There is therefore a case to be made for complexity as a key feature of the large-scale sociotechnical system organisation, as a defining characteristic for the project organisation. Drawing on classic works on sociotechnical systems (Trist, 1981; Von Bertalanffy and Sutherland, 1974), complexity theory (Simon, 1999; Simon, 1991), and the work on Complex Product Systems (CoPS) has demonstrated how new forms of innovation could be created through 'project-based working' that was necessary by different parties working either within or across organisational boundaries (Gann and Salter, 2000; Safdari Ranjbar et al., 2018; Davies et al., 2011; Hobday, 2000; Davies and Hobday, 2005). Similarly, in the past two decades there have been specific applications of complexity view in the field of project management which have generated insights on project organisations (Cicmil et al., 2017; Cooke-Davies et al., 2007; Williams, 1999; Brady and Davies, 2014; Pollack et al., 2013) and enriched the view on large-scale infrastructure based projects (Daniel and Daniel, 2019) as well as the approach to theorising on complexity (Tywoniak et al., 2021).

Noting this extant and significant contribution made by this literature, we also have observed the delivery of increasingly large and ambitious projects In many sectors and geographies. Whether we look at aerospace, space and defence, energy supply, IT systems, healthcare provision, we can find many examples projects that have sought to deliver significant impact. Therefore, combining both theoretical insight with empirical data, this paper seeks to make a further contribution to this field of enquiry through proposing the idea of a *Complex System Project* (CSP).

The argument for the consideration of a Complex System Project is that this term – another label in the nomenclature of project management, is that the use of this term conveys not just the recognition of a form of project, but also the implications for its management, leadership, and governance.

First, it is necessary to justify the time and effort needed to even consider the existence of CSP. This begins with an attempt to theorise a type of project that is often found in the delivery of urban infrastructure, and a CSP will often overlap with other established label terms, such as megaproject, large-scale project, major project, or programme. While many of the organisational and management challenges have been discussed in the frame of megaproject, programme, or large-scale project, we posit that it is the intertwining of complexity and distinct systemic features of these projects are what makes it a conceptually separate category. This identification and recognition is then helpful for understanding and analysing the challenges that often occur in their planning and delivery of such CSPs. Although CSPs may be large in size and cost, they will also have a magnitude of the complexity of both the project deliverable and the sociotechnical system that it entails.

Complex systems and task interdependency

Drawing on the work of classic systems theory we define complexity following Simon (1994) suggesting that *"we can regard a system as complex if it can be analyzed into many components having relatively many relations among them, so that the behavior of each component depends on the behavior of others"* (Simon, 1994: p. 26).

Moreover, we adopt the consideration of a complex system, which can be expected to be "*…homeostatic; to have membranes separating them from their environments, and internal membranes between their parts; to specialize, so that complex functions tend to be performed in few locations; and generally, we would expect them to be nearly decomposable"* (Simon, 1999: p.13).

Using the example of living systems to understand the behaviour of socially constructed systems such as organisations and markets, the notion of near decomposability becomes key. A system is nearly decomposable if *"at any level, the rates of interaction within components are within components at that level are much higher than the rates of interaction between different components"* (Simon, 2002: p.587).

Within the subsystem, the task interdependency is reciprocal, meaning that changes in all the system components will affect change in the other components of the system (Thompson, 1967).

This paper therefore proposes to theorise the CSP as a conceptual category distinct from the notions of megaproject, large-scale project, programme etc and one that warrants consideration as a class of projects. The paper duly regards and builds upon the classic notions of organisation theory and systems complexity theory and combines it with the key theoretical principals of the Management of Projects (Morris, 2013) and the CoPS (Davies et al., 2011) stream of work. The aim of the paper is to expressly accept the need to defend the case for further crowding the project management lexicon with the new term 'Complex System Project'. The paper discusses the need and helpfulness for introducing this conceptual term to understand the challenges practices of managing infrastructure projects that deliver complex systems and can be understood as complex systems themselves.

RESEARCH DESIGN

To understand both the nature and challenges faced on a complex system project we have considered the case of London Crossrail, the megaproject to deliver a new line on the London Underground network. The resultant line – the Elizabeth Line – was intended to make a material contribution to easing the congestion for those travelling east-west in and through London and to increase the overall capacity of the underground transport system in London. The delivery of the Elizabeth line, through the project known as Crossrail, has been characterised by significant system-related issues which caused a major delay and cost overruns that have been in the public eye (The Guardian, 2020).

The rationale for selecting this particular project is because through the initial review of publicly available information and exploratory interviews, it became increasingly clear to the research team that the issues and challenges that were faced by this project were not specifically attributed to the *scale and cost* as features of the programme. Rather, they appear to be due to the bold ambition of the project, which is a proxy for the complexity of the intended project deliverable. Whilst the scale of the endeavour to build the Elizabeth line was and is indeed extremely large, there are other attributes of the project that were also (if not even more) significant. This included the need for the project to deliver an integrated high volume, high frequency train system that was extremely safe and very reliable. The need to deliver this integration and complexity at scale had a significant impact on project performance, its behaviour and leadership.

As part of this research, we established a wider research team spanning participants from the Crossrail organisation and arranged a series of workshops and semi-structured interviews with those in the very highest tier of the senior leadership team of Crossrail Ltd. Given that the result of the Crossrail project was the opening of the Elizabeth line in mid 2022, there were recognised sensitivities at the time of field data gathering that preclude providing details of who has been involved in contributing interview data. What can be said is that those involved in the research have been in relevant positions and within the interview dataset were views that considered the project from its earlier phases through to its final completion. Interviews took place after it became public knowledge that Crossrail would not deliver the Elizabeth line by the expected date and for the expected budget. The research took place during the period when the project was in the stages that followed, where resetting, recovering and finalising the project were in play, leading ultimately to the opening of the Elizabeth line. In the many interactions the research team had with the key informants, comprising both interview and feedback sessions, the highly experienced and senior practitioners referred to the various levels of systems complexity as a key defining characteristic of the project, its challenges, and ultimately successful delivery.

Using this Crossrail case as the central example of a *CSP,* further consideration is then given to other noteworthy projects that share similar characteristics. Using secondary data, a growing population of CSPs is recognised and these span both geographies and sectors. The parameters set for consideration as a CSP include both the nature of the project deliverable and the temporary project organisation that is created to deliver the project.

KEY FINDINGS & IMPLICATIONS

Our ambition for this work is to provide valuable output for the audience interested in theoretical discussion and debate as to validity and utility of the notion of a *Complex System Project,* and to the audience interested in the practical insights and recommendations that those leading, managing, and governing such a CSP can consider.

It is first necessary to define the characteristics and features that allow the identification of a Complex System Project. These are:

- Unique goals with a substantive departure from the *business-as-usual* practices.
- Project deliverable challenges whereby any subset of the project deliverable can cause significant disruption or even failure of the project as a system.

The distinctiveness of CSPs as a category is not due to the scale or cost of the endeavour (as it would be in the case of a megaproject) or in the integration of the different loosely coupled sub-unit projects (as in a programme or portfolio) but the tight coupling of the subsystem components within the project in a way that means that interdependencies are reciprocal and multiple, emphasising the near decomposability feature of the system. While the elements of the project can be seen as nearly decomposable and can be managed independently from each other, they are all on the critical path of the system performance, and function and failure of any one of them can render the system dysfunctional. In this way, the management of a CSP is both the management of its parts and, even more importantly, the management of the whole – which is more than the sum of its parts.

We further suggest that the development of such a CSP is not based on its physical scale but on the assembly of a fully functional kernel of the project, embodying the elements that make the project a functional unit, potentially at a smaller scale or before full and final project completion. This delivery of the core of the essential system is accomplished through an iterative process of partial completions, then testing and trialling to make sure that the system delivers its functionality before embarking on the process of scaling. In this way the development of a CSP resembles an innovation process, where a new product or service is developed as a prototype in a protected niche before being mainstreamed onto the market (Geels, 2011). The scaling happens incrementally at the periphery of the functional system kernel of the project and, while it can contribute to an increase of complexity, the scale is not its core feature.

Our preliminary analysis of London Crossrail, as an example of a CSP, suggests that many challenges that led to delays, cost overruns and benefit shortcomings were a feature of the complexity of systems and outputs that they generate, as well as the organisation that produces them. This contrasts with the simpler consideration of this being a feature dominated by their size, scale, and cost. Importantly for those leading and managing CSPs, the management challenge for such CSPs is a feature of the system, structure, and agency that the organisation of the project is enacting. To tackle CSPs requires an understanding of the nature of the interdependencies of the system components across their technical and organisational boundaries. Where the CSP is to deliver a product/service considerably beyond anything currently achieved, then it is seems sensible to advocate that the CSP adopts the hallmarks of a research and development project to address the those elements of the system kernel that will require novel solutions, up to and including the need for full invention of new technologies or other forms of solution. For example, recent developments in the mRDA technology that was used to produce one of the Covid-19 vaccines (developed by Moderna) is now allowing 'individually tailored' cancer drugs to be developed (Smythe, 2022). Whilst a great scientific breakthrough, developing such individual drug treatments at scale is going to be a substantial and complex challenge.

Similar examples can be found in other sectors. In space research, the success of both the Perseverance Rover on Mars and the deployment of the James Webb Space Telescope are both clear examples of CSPs, as are the defence sector examples of the US Department of Defense Joint Strike Fighter and the UK Navy's Queen Elizabeth Class aircraft carriers. In the energy sector, and specifically in the nuclear industry, the new generation of European Pressurised Reactor (EPR) nuclear energy production stations being constructed and the work in nuclear fusion with the construction of the ITER Tokamak in France and the ongoing research and development work being conducted at the US's National Ignition Facility all illustrate the high levels of ambition and complexity that have and are to be delivered. In many of the above project examples, there will have been the need to provide an intrinsically important element or elements on which the entire project's success will have hinged. The management challenge for those at senior levels in a CSP is to recognise that such a system kernel is present and to ensure that the necessary resources, processes and regimes are used to create this successful system kernel in time for it not to delay the full project success.

These Complex System Projects (CSPs) require the interaction of multiple forms of systems that must work to allow safe and confident operation. Multiple experts with potentially highly varied expertise will be needed to contribute to make the system kernel a success. Given the ambiguity and potential difficulty of achieving this, there will be the need for extremely effective project management, leadership and governance approaches, especially where the system kernel of a CSP is subject to extensive third-party regulatory approval – as was the case with Crossrail.

Having considered the theoretical foundations and potential value of a CSP, we now turn attention to those involved in the creation, development, and delivery of a CSP. Using the data we have collected on the Crossrail project as an example of a Complex System Project, we observed, analysed and refined the following principal considerations for those in senior management and leadership positions and make the following provisional recommendations:

1. **The need to be dynamic.** Whilst all projects have a lifecycle, a CSP is more likely to have a more convoluted and non-linear lifecycle. This can be expected to be extremely challenging to manage by those from project backgrounds not familiar with CSPs. Unlike more straightforward projects, CSPs will have within them sub-projects that are akin to research and development (R&D), and hence the need for overt and dynamic knowledge management, extensive stakeholder engagement, and the need to set up control systems to monitor and measure progress using many differing forms of metric.

2. **The importance of establishing and interacting with the future operator as early as possible.** Where a CSP is going to be handed over to an operator (as is the case of Crossrail, the JSF and QE aircraft carrier), a CSP will need to transition into operations in a carefully considered way. As the CSP is reasonable to consider that a CSP will deliver a highly idiosyncratic outcome, there is the clear need to identify and work closely with the operator of the CSP from the earliest opportunity, and with that operator being given sufficient forms of power and voice within the temporary project organisation. Such deliberate and significant inclusion and involvement reduces the risk of misunderstanding and dislocation of the CSP during its progress. This

involvement also increases the opportunity for smooth integration, preparation and transition of the CSP into operation.

3. **The impact of the risk of cascading failure.** CSPs are, by their nature and design, an interwoven set of elements that are required to work together. This close coupling of elements brings with it the challenge of ensuring that there is unity or harmony amongst the elements, particularly those most central to the safe and confident operation of the deliverable – we term this the system kernel. In safety critical cases – such as nuclear energy production, this is an area of great concern and will lead to the need for solutions to be created to both monitor and, where necessary, trigger shutdown or failsafe. This type of challenge, one that is safe and reliable, is one well known in the most complex of facilities, machines, and software, but the unique and often highly idiosyncratic nature of CSPs means that managing this risk of cascade failure can lead to considerable project management resource deployment and attention.

4. **This cascade failure risk will not have a straightforward and linear progressive path.** There will be critical points of integration and harmonisation during the lifecycle of the CSP that coincide with various sub-elements and sub-systems being both delivered and tested. As the CSP progresses, so the need for integration and harmonisation will become more challenging and have the potential to produce or cause unexpected results and consequences. Managing this level of uncertainty is likely to put considerable stress and tension on the management and leadership of CSPs.

We further propose that the conceptualisation of a CSP, with its principles as outlined, can be useful to not only managers with responsibilities on both client and delivery angle, but also to those who advocate the use of reference class forecasting in helping to provide more nuance for the front-end planning and ex-ante business cases as well as anchoring for post-project evaluation models.

Finally, the arguments for consideration of a complex system project and the need to carefully shape the temporary organisation that will deliver it from the very earliest stages also leads to the needs for different types of leadership, one that embraces uncertainty and interdependence of different parts and a holistic rather than a parochial view of control. This nature of a CSP demands leaders, leadership, and layered governance that has more facets to accommodate the many issues that a CSP presents. This recommendation is in contrast to a leader/leadership/governance selection model based on the parameters of size and sector.

REFERENCES

Ansar A, Flyvbjerg B, Budzier A, et al. (2017) *Big is fragile: An attempt at theorizing scale.* Oxford University Press Oxford.

Brady T and Davies A (2014) Managing structural and dynamic complexity: A tale of two projects. *Project Management Journal* 45(4): 21-38.

Cicmil S, Cooke-Davies T, Crawford L, et al. (2017) Exploring the complexity of projects: Implications of complexity theory for project management practice. Project Management Institute.

Cooke-Davies T, Cicmil S, Crawford L, et al. (2007) We're not in Kansas anymore, Toto: Mapping the strange landscape of complexity theory, and its relationship to project management. *Project Management Journal* 38(2): 50-61.

Daniel E and Daniel PA (2019) Megaprojects as complex adaptive systems: The Hinkley point C case. *International Journal of Project Management* 37(8): 1017-1033.

Davies A, Brady T, Prencipe A, et al. (2011) Innovation in complex products and systems: implications for project-based organizing. *Project-based organizing and strategic management*. Emerald Group Publishing Limited, pp.3-26.

Davies A and Hobday M (2005) *The business of projects: managing innovation in complex products and systems.* Cambridge University Press.

Flyvbjerg B (2014) What you should know about megaprojects and why: An overview. *Project Management Journal* 45(2): 6-19.

Flyvbjerg B (2017) Introduction: The iron law of megaproject management. *Bent Flyvbjerg*. 1-18.

Gann DM and Salter AJ (2000) Innovation in project-based, service-enhanced firms: the construction of complex products and systems. *Research Policy* 29(7-8): 955-972.

Geels FW (2011) The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental innovation and societal transitions* 1(1): 24-40.

Hobday M (2000) The project-based organisation: an ideal form for managing complex products and systems? *Research Policy* 29(7-8): 871-893.

Lundin RA, Arvidsson N, Brady T, et al. (2015) *Managing and working in project society.* Cambridge university press.

Maylor H, Brady T, Cooke-Davies T, et al. (2006) From projectification to programmification. *International Journal of Project Management* 24(8): 663-674.

Morris PW (2013) *Reconstructing project management.* John Wiley & Sons.

Morris PW and Hough GH (1987) The anatomy of major projects: A study of the reality of project management.

Morris PW, Pinto JK and Söderlund J (2012) *The Oxford handbook of project management.* OUP Oxford.

Pollack J, Costello K and Sankaran S (2013) Applying Actor–Network Theory as a sensemaking framework for complex organisational change programs. *International Journal of Project Management* 31(8): 1118-1128.

Safdari Ranjbar M, Park T-Y and Kiamehr M (2018) What happened to complex product systems literature over the last two decades: progresses so far and path ahead. *Technology Analysis & Strategic Management* 30(8): 948-966.

Schoper Y-G, Wald A, Ingason HT, et al. (2018) Projectification in Western economies: A comparative study of Germany, Norway and Iceland. *International Journal of Project Management* 36(1): 71-82.

Simon HA (1991) The architecture of complexity. *Facets of systems science*. Springer, pp.457-476.

Simon HA (1994) Near decomposability and complexity: How a mind resides in a brain. *The mind, the brain, and complex adaptive systems*. Routledge, pp.25-44.

Simon HA (1999) Can there be a science of complex systems? *Unifying Themes in Complex Systems Volume I*. CRC Press, pp.3-14.

Simon HA (2002) Near decomposability and the speed of evolution. *Industrial and Corporate Change* 11(3): 587-599.

Smythe J (2022) Moderna's mRNA cancer vaccine shows promise in early trial. *Financial Times*.

Söderlund J, Sankaran S and Biesenthal C (2017) The past and present of megaprojects. SAGE Publications Sage CA: Los Angeles, CA, 5-16.

The Guardian (2020) Crossrail delayed again until 2022 and another £450m over budget. *The Guardian, 21 August 2020, Accessed on 20 Dec 2022 at https://www.theguardian.com/uk-news/2020/aug/21/crossrail-delayed-again-until-2022-and-another-450m-over-budget-tfl-covid-19*.

Thompson JD (1967) *Organizations in action: Social science bases of administrative theory.* Transaction publishers.

Trist EL (1981) *The evolution of socio-technical systems.* Ontario Quality of Working Life Centre Toronto.

Tywoniak S, Ika L and Bredillet C (2021) A pragmatist approach to complexity theorizing in project studies: Orders and levels. *Project Management Journal* 52(3): 298-313.

Von Bertalanffy L and Sutherland JW (1974) General systems theory: Foundations, developments, applications. *IEEE Transactions on Systems, Man, and Cybernetics*.(6): 592-592.

Williams TM (1999) The need for new paradigms for complex projects. *International Journal of Project Management* 17(5): 269-273.