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Illuminating the Unknown: Mapping Project Uncertainty in Civil Nuclear Infrastructure

Fiona Saunders, The University of Manchester, UK

Proceedings Editors

Carrie Dossick, University of Washington and Gretchen Macht, Pennsylvania State University



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ILLUMINATING THE UNKNOWN: MAPPING PROJECT UNCERTAINTY IN CIVIL NUCLEAR INFRASTRUCTURE PROJECTS

FIONA C SAUNDERS¹

ABSTRACT

The UK nuclear industry is poised to begin the biggest programme of new capacity generation for thirty years. This renaissance in nuclear new build will take place alongside a slew of existing projects to provide new test facilities, extend the life of the existing fleet of nuclear power stations and safely decommission those reactors and sites that have already been taken off line. The challenges facing these large, long-term and complex engineering projects are legion and non-trivial and they will be delivered against a backdrop of increasing nuclear industry skills shortages. Given the safety-critical nature of large-scale nuclear projects and their importance to UK infrastructure, it is essential that the risks, uncertainties and complexities involved are not underestimated (PMI, 2013) and that every effort is made to deliver them in a safe but timely manner. Based on in-depth interviews with project management practitioners, this study enriches our understanding of the dimensions of project uncertainty in large-scale civil nuclear projects, a vital infrastructure sector for the UK economy and one where, for reasons of safety, failure is not an option.

Its conclusions are three fold: first, the Uncertainty Kaleidoscope, posited in Saunders et al. (2015) is shown to be a valid representation of the dimensions of project uncertainty in civil-nuclear projects. Secondly, the major sources of uncertainty in large scale civil nuclear projects are the environment and organisational context of the project and the project's inherent complexity, followed by organisational and supply chain capability to deliver it and the absence of key project information or understanding. Lastly, the study found that the dimensions of project uncertainty are broadly similar across two different types of civil nuclear project (new build vs. life extension/decommissioning projects), with the exception of environmental uncertainties, where differences in the contextual factors of project uncertainty are more pronounced.

KEYWORDS: uncertainty, nuclear, complex projects, project management

INTRODUCTION

Large scale and complex engineering projects are central to modern society. Without them there would be no reliable infrastructure, iconic buildings or inspiring Olympic Stadia. However, one of the myriad challenges facing these projects is how to adequately identify and manage their risks, uncertainties and complexities in order to minimise the potential for failure (PMI, 2013). In the specific domain of civil nuclear projects, safe and reliable delivery of the project is an imperative and project managers must bear the burden for projects, whose timescales are often long, budgets vast and technical complexity high. Irrespective of whether the aim of the project is to deliver new nuclear power generation capacity, extend the life of the

¹ Senior Lecturer, The University of Manchester, UK, fiona.saunders@manchester.ac.uk

existing fleet of nuclear power stations or safely decommission an already shutdown nuclear reactor the project landscape will be dominated by complicated regulatory requirements and the need to be “in control” at all times.

This study builds on a previous exploratory study (Saunders et al., 2015) into how project management practitioners conceptualise project uncertainties in safety-critical projects, which posited the Uncertainty Kaleidoscope as a framework for understanding the dimensions of project uncertainty. The aim of this second study is to validate the uncertainty kaleidoscope on a larger sample of specifically civil nuclear projects including new build, life extension and decommissioning projects. It is based on semi-structured interviews with 18 project management practitioners involved in 5 current nuclear projects. Content analysis was used to interpret the interview data and indicative interview quotations and polar diagrams utilised to map the different dimensions of project uncertainty and explore whether they vary across different types of civil nuclear projects.

This paper is structured as follows: First the extant literature on project uncertainty is reviewed and framed within the context of complex projects. Secondly, the design of the empirical study is described. Findings are then presented, discussed and implications for practice and future research highlighted.

Theoretical Background

Within the domain of project management there has been extensive coverage of uncertainty (see for instance Loch et al., 2006; Perminova et al., 2008; Cleden, 2009; Hillson, 2002; Atkinson et al., 2006; Saunders et al., 2015). This scholarship identifies the possible sources of uncertainties in projects (Ward and Chapman, 2003; Atkinson et al., 2006; Cleden, 2009; Winch, 2010; Saunders et al., 2015) and articulates various approaches (analytical and behavioural) to dealing with it (c.f. DeMeyer et al., 2002; Chapman and Ward, 2002; Olsson, 2006; Harris and Woolley, 2009). The scholarly discourse around the management of uncertainty in projects is closely related to the management of risk and there has been much discussion as to the difference between risk and uncertainty (c.f. Hillson, 2004; Loosemore et al., 2006; Perminova et al., 2008; Sanderson, 2012).

One useful lens through which to view project uncertainty, particularly when exploring large-scale, highly- technical civil nuclear projects, is that of complexity theory; a growing sense that the environment (both natural and social) is not entirely within our control and that the mathematically based predictive models we use to understand it are limited, if not flawed (Milly et al., 2008). Complex systems emerge from environments comprising many interconnected components, resulting in system behaviour that is emergent; i.e. it cannot be predicted from the behaviour of the individual components (Whitty and Maylor, 2009). Scholars distinguish between descriptive complexity (that which is based on technology, structures and organisations) and perceived complexity (complexity that is subjective and is ascribed by people on the basis of their own experience and understanding of a specific situation) (Crawford, 2013). Projects can be described as complex systems as they are concerned with both technological issues and a raft of organisational issues, many of which may lie outside the control or even influence of the project manager. Added to this, the socially constructed nature of projects, and their reliance on a diverse group of project actors, also introduces perceived complexity into the project dynamics,

where individuals may interpret and act on the same project situation in a very different manner (Thomas and Mengel, 2008). A final related concept also arises from the study of complexity theory: that of deep uncertainty - where decision makers either do not know or cannot agree on input parameters, appropriate models of analysis or even the desirability of particular decision outcomes (Lempert et al., 2003).

In simple terms, uncertainty is a state of unknowing - where the individual lacks full and complete knowledge of a situation. The world of civil nuclear projects is however anything but simple, and in the demanding organisational setting of a project to rid a sensitive natural environment of the evidence of 30 years of nuclear power generation, system complexity and deep uncertainty can have profound consequences on the project. Daily, the individuals tasked with delivering these projects must wrestle with technical dilemmas such as how to minimise the impact of the unexpected when relocating intermediate level radioactive waste from a storage facility which was sealed shut in the 1960's and where nobody knows the actual condition or stability of the stored materials. Or what level of corrosion and structural weakening is permissible in the cores of a nuclear reactor before the power station must be taken off-line. These are the challenges facing project managers in the UK civil nuclear industry; challenges that are replete with both uncertainty and system complexity.

INTRODUCING THE UNCERTAINTY KALEIDOSCOPE

The sources of uncertainty in safety-critical environments such as civil aerospace and civil nuclear have been extensively discussed in Saunders et al. (2015) and include the *complexity* of the project, the *environment* in which it is being delivered, the *capability* of both the project team and the wider supply chain, *temporal* issues such as the timescales and speed of the project, the availability of *information* and *individual* team member perceptions of uncertainty. Each of these six dimensions of project uncertainty can be further broken down into a number of different contextual factors. For example, environmental uncertainty may emerge through external factors such as political, market or competitor activity or may arise as a result of organisational culture, behavioural norms or decision making processes, or due to the organisation's level of tolerance of uncertainty. Information uncertainty is similarly subdivided into an absence of information, lack of knowledge, inadequate understanding of cause and effect relationships, poor estimating ability and lack of clarity of project objectives. Many of the contextual factors are also interrelated: for instance the number and diversity of actors on a project impacts both the inherent complexity of the project and also the potential breadth and alignment of external stakeholder demands that the project may face. Both these factors will shape the overall level of uncertainty on the project. Saunders et al. (2015) synthesised these different dimensions of uncertainty into the "Uncertainty Kaleidoscope" – see Figure 1.

The Uncertainty Kaleidoscope was developed from a systematic review of the literature on project uncertainty and a small number of in-depth interviews (n=8) with project management practitioners in both civil nuclear and civil aerospace industries. Contextual factors in normal text in Figure 1 were reported in the literature and factors in italics only emerged during the interviews. The framework is in the form of a kaleidoscope as a metaphor for understanding project uncertainty. It reflects a key similarity between large-scale projects and the eponymous children's toy; in that a kaleidoscope can generate a multiplicity, perhaps even an infinite number of distinct landscapes of project uncertainty from the same six dimensions – *complexity*, *environment*, *capability*, *time*, *information* and *individual*. New uncertainties may also emerge

as the project progresses. This is equivalent to the kaleidoscope being shaken, which may lead to the emergence of a very different project landscape. For example, the ‘as built’ drawings of a nuclear reactor may be insufficiently accurate to prevent major new uncertainties emerging during the project to decommission the site and return it to a clean state. Such sudden changes in project landscape, often small but on occasion highly consequential, can affect the likelihood of the project objectives being achieved, or may even lead to new project objectives being necessary. Finally, it is important to note that the usefulness of the kaleidoscope does not lie in its predictive power, but as a framework to enable project professionals in safety-critical environments to better anticipate where uncertainty may reside in projects, before it might cause unwelcome surprises to the project team.

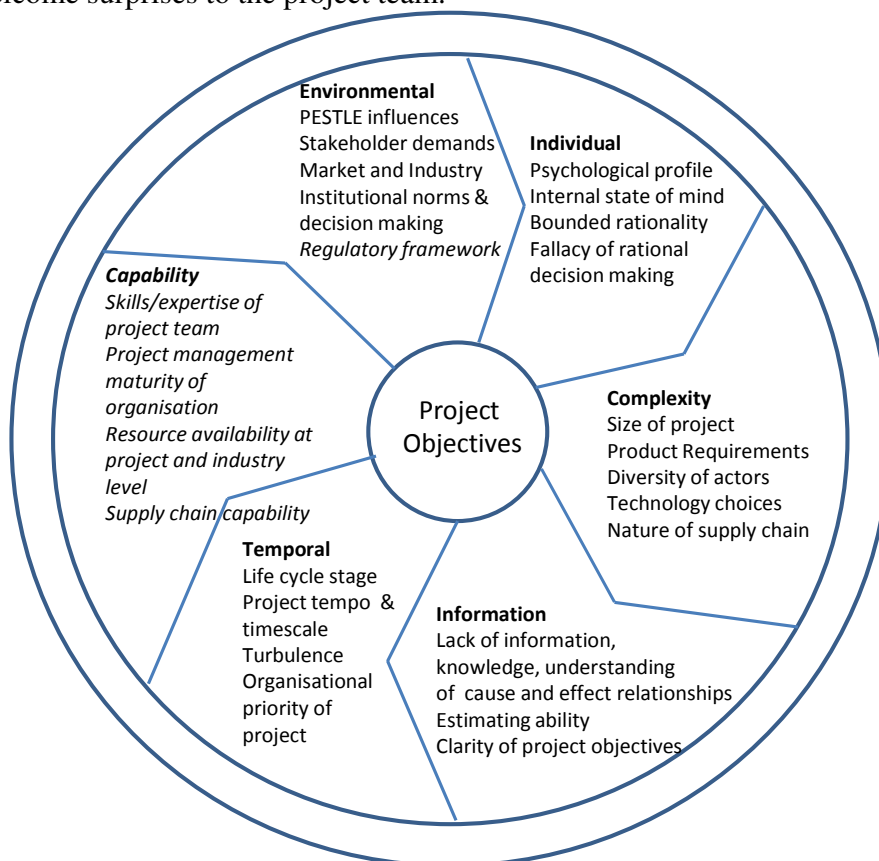


Figure 1: The Uncertainty Kaleidoscope (from Saunders et al., 2015)

One limitation of the Uncertainty Kaleidoscope, as presented in Figure 1 is that it was based on interviews with a small sample of project management practitioners. The purpose of the study reported on here is to refine and validate the kaleidoscope using a much larger sample of respondents involved in large-scale civil nuclear projects.

METHODOLOGY

Given that the aim of this new study is to refine and validate the Uncertainty Kaleidoscope against a larger dataset of civil nuclear projects, the methodology employed is consistent with that described in the earlier exploratory study reported in Saunders et al. (2015). The approach was qualitative, based on semi-structured interviews with 18 project management

practitioners involved in 5 large-scale civil nuclear projects in the UK. The projects were selected to reflect two main types of current projects –“*new build projects*” and “*life extension/decommissioning projects*”. The projects ranged in size from a three year, circa £35Million budget to a 10-12 year, circa £14Billion budget and were each at different stages of the lifecycle. Two projects were new build/new facility projects. Of these one involves the completion and commissioning of a major new nuclear test facility. The other is concerned with the construction of a new nuclear power station. The remaining three projects are life-extension/decommissioning projects; the completion of a new storage facility for intermediate level waste, the development of safety-cases to extend the life of the UK’s existing fleet of nuclear power stations, and decommissioning specific sections of an already off-line nuclear power station. Each project is located within the United Kingdom, but most encompass supply chains that are complex and often international in nature. Each project is also highly regulated, both internally through an independent in-house regulatory division, and externally by the Office for Nuclear Regulation and the Environment Agency.

Individual face-to-face interviews (lasting between 50minutes and 1hour) were undertaken at the project sites between March and September 2014. Between three and four respondents per project were interviewed to minimise individual respondent bias and to allow more valid cross-project comparisons to be undertaken. An anonymized list of the projects and the respondents is provided in Table 1 below.

Project Description	Industry Sector	Project Type	Respondent Roles
Provision of two new civil nuclear test facilities	Civil Nuclear	new build	Senior Project Manager Project Manager Risk Analyst
Planning of new nuclear power station	Civil Nuclear	new build	Programme Manager Programme Manager Programme Manager Programme Manager
Transfer of intermediate level waste to storage facility	Civil Nuclear	life extension/ decommissioning	Project Engineering Manager Project Director Project Controller Commercial Manager
Reactor life-extension project	Civil Nuclear	life extension/ decommissioning	Group Head of Project Technical Lead Sub-project Manager Sub-project Manager
Decommissioning of specific elements of a former nuclear power station	Civil Nuclear	life extension/ decommissioning	Project Manager Commercial Manager Client account director

Table 1: Study projects, their classification and list of respondents

Respondents were asked to discuss the sources of, and influences on, project uncertainty in the specific project on which they were employed. Respondents did not have sight of the uncertainty kaleidoscope either before or during the interviews and so their responses were based on their experiences on that particular project. Transcripts of the interviews were analysed using content analysis, a technique where a set of categories are established – in this case based on the earlier Uncertainty Kaleidoscope (Saunders et al., 2015) - and the number of instances of each

category counted. The *a priori* identification and systematic counting of these specific categories in the interview transcripts then allows inferences to be made from this set of data (Stone et al., 1966). Validity and reliability in content analysis is directly impacted by the level of inter-coder reliability – the consistency of agreement between two or more coders. Consistent with Evans (1996) and Neuendorf (2002) this study used one main coder (the author) with a second coder undertaking a reliability check on the coding counts and categories. During the analysis process a small number of new categories emerged that had not previously been identified during the earlier exploratory study. These were added to the analytical categories, and the Uncertainty Kaleidoscope revised to take account of them. In this sense the study, whilst deductive in its main approach, retained an element of induction that was consistent with the earlier exploratory study. The findings of this study should be transferable to other projects in the civil-nuclear sector, given that the sample is sufficiently large and varied so as to be representative of current UK based civil nuclear projects.

FINDINGS AND DISCUSSION

The findings of this study are presented in two parts. First, content analysis of the 18 respondent interviews is discussed together with its implications for the validity of the Uncertainty Kaleidoscope. Secondly, the major sources of project uncertainty in civil nuclear projects are established and the commonalities and differences between the dimensions of uncertainty across new build and life extension/decommissioning projects explored.

Refinement and validation of the Uncertainty Kaleidoscope

The categories and counts for the content analysis of the 18 interviews are provided in Table 2.

Dimension	Categories (Contextual Factors)	Civil Nuclear Interview Counts
Complexity	Functional requirements of the product	9
	Technology choice	5
	Diversity of actors and stakeholders	5
	Inherent project complexity (including Feedback loops, instability and emergent system properties/ integration issues)	5
	Technical novelty	3
Information	Incomplete and imperfect information	9
	Lack of knowledge or understanding	9
	Incomplete understanding of cause and effect relationships	2
	Inability to estimate accurately	2
Environmental	Environmental turbulence (due to changes in market, political environment or competitor activity)	8
	Competing and conflicting stakeholder demands	7
	Culture (organizational tolerance of uncertainty, Institutional norms and decision making processes, clarity of roles and responsibilities)	7
	Regulatory constraints	3
	Site security	3

	Funding	6
Temporal	Stage of project lifecycle	4
	Project tempo and timescale	3
	Project turbulence (rate of change of project facts, randomness of timing of changes and direction of change, clarity of scope)	8
Individual	Uncertain state of mind in response to triggers in the external environment	3
	Uncertainty exists “in the mind of the person who doubts”	0
	Bounded rationality and Fallacy of rational decision making	0
	Different psychological profiles perceive uncertainty in different ways	0
Capability	Skills and experience of project team members	4
	Project management maturity of organisation	5
	Internal resource availability	5
	Capability (skills, experience and resource availability across industry supply chain)	8
	Client capability	3

Table 2: Categories and counts for content analysis of respondent interviews

All the categories are drawn from the Uncertainty Kaleidoscope (Figure 1), with the exception of integration issues, technical novelty of solution, clarity of roles and responsibilities, project funding, site security, project scope clarity and client capability which were raised by respondents during the interviews and so were added to the list of categories. The emergence of these new contextual factors did not materially impact the Uncertainty Kaleidoscope as they were consistent with the existing six top level dimensions of uncertainty – for example integration issues and technical novelty both contribute to complexity, whilst funding and site security were classified as environmental dimensions of uncertainty. A ‘count’ is defined as the mention of a specific contextual factor of uncertainty by a respondent. Data saturation (Guest et al., 2006) was observed in this study, with no new categories being raised after interview 16.

The results of the content analysis of the 18 respondent interviews enabled the earlier Uncertainty Kaleidoscope to be refined and validated. This refined model is shown in Figure 2 below.



Figure 2: Refined and validated model of the “Uncertainty Kaleidoscope”. Contextual factors in italics arose from the empirical studies; those in normal from the literature.

The refined Uncertainty Kaleidoscope shows the 6 dimensions of project uncertainty (previously these were referred to as perspectives). Each dimension comprises a number of more specific and detailed contextual factors. There are a number of minor differences between the previous and now-validated version of the model. First, the dimensions have been reordered around the kaleidoscope so that they appear in a more logical sequence. Temporal has been renamed Time, and Environmental renamed Environment. The contextual factors affecting Individual and Information uncertainty remain unchanged but additional factors have been added to Capability (client capability), Complexity (technical novelty and integration issues), Time (changes in scope, information and priorities) and Environment (project funding and clarity of roles and responsibilities). As stated previously, the utility of this framework lies not in its predictive power but as a model to help project professionals in complex civil nuclear project environments articulate more confidently where uncertainty might reside in projects. Using the

Uncertainty Kaleidoscope to explicitly frame, discuss and debate uncertainty in the early stages of project gestation may increase project managers’ confidence in addressing the uncertainties with which they are confronted. As a minimum it will enable areas of uncertainty to be identified and explored, rather than being ignored or overlooked. As an added benefit it may also lead to a gradual change in perspective from uncertainty as risky, problematic and something to be feared, to uncertainties as potential opportunities, from which the project may exploit and profit (Olsson, 2007; Schlesinger et al., 2012).

The major sources of project uncertainty in civil nuclear projects

Figure 3 depicts the total number of mentions of each dimension of uncertainty across all 18 interviews.

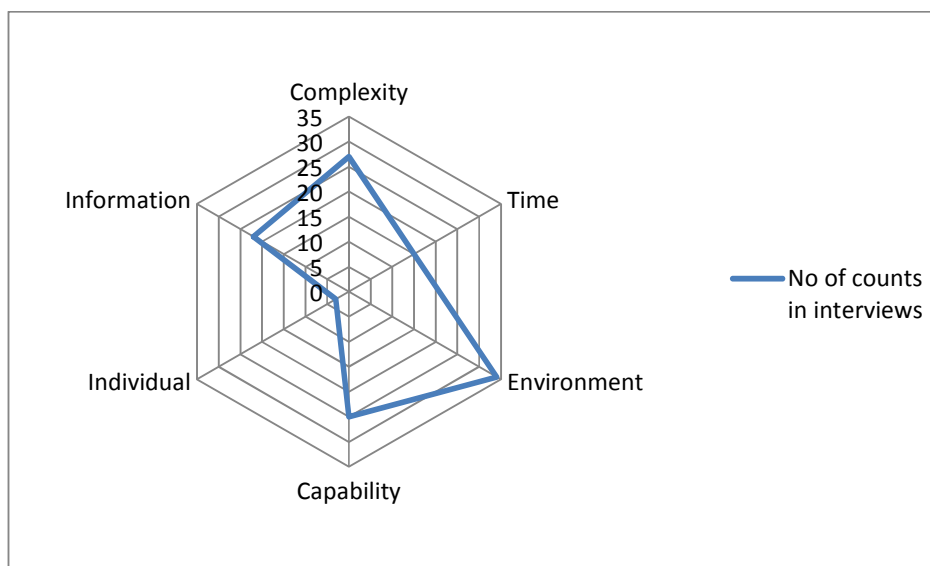


Figure 3: No of mentions (counts) of each dimension of uncertainty across all respondent interviews

The most commonly mentioned dimension of project uncertainty is the project Environment, followed by Complexity, Capability and Information. The impact of Time and Individual Perceptions of uncertainty were mentioned much less frequently by respondents. This ranking of the dimensions of project uncertainty is not entirely surprising given that the studied projects are all complex, large-scale engineering projects which are being delivered by highly skilled teams of professionals to demanding safety and performance standards, under the spotlight of powerful and proactive regulatory authorities. Perhaps project management practitioners, being on the whole pragmatic individuals, downplay project uncertainties associated with time and individual perceptions as they are more within their locus of control, whereas environmental uncertainties, such as the external political landscape and the organizational and contractual structure against which the project must be delivered are less easily influenced. The influence of project complexity on the project uncertainties is also noticeable in Figure 3; with respondents discussing the nature and clarity of the project functional requirements on the new nuclear materials test facility project, technical issues in terms of instability and emergent system properties within the reactor core of in-service nuclear

power stations and integration issues that arise during the construction of a new nuclear power plant. This inherent technical complexity of the project is then further exacerbated by the number and diversity of stakeholders to whom the project must regularly report.

Further insights into the dimensions of project uncertainty across civil nuclear projects are yielded by increasing the granularity of the content analysis to the specific contextual factors of uncertainty.

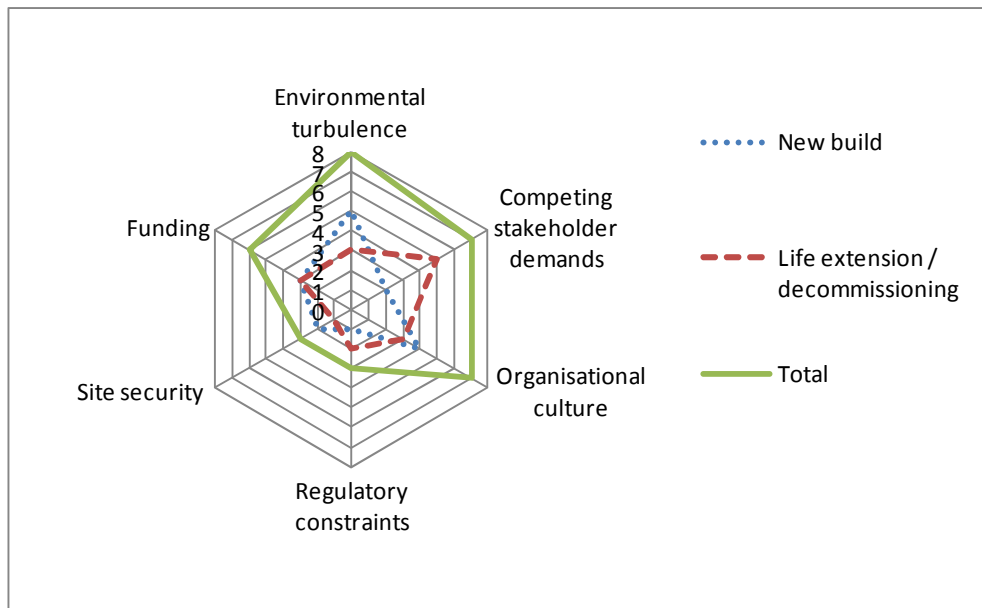


Figure 4: Contextual factors of the environment as a dimension of project uncertainty: Number of mentions across all interviews and broken down by project type

The Environment (Figure 4) was the most often mentioned source of uncertainty in civil nuclear projects. Respondents described multi-organisational project environments, replete with diverse organisational cultures, where the “ways of doing things round here” had often yet to be established in the project. The primary challenge facing project managers was not the novelty of the technical solution, but rather satisfying the myriad internal and external stakeholders, many of whom held a metaphorical axe over the project and its continuing existence. The major difference between new build and life extension / decommissioning projects was that on new build projects the sources of environmental uncertainty were more likely to be political or market driven: witness the recent extensive media coverage over the decision whether or not to proceed with the building of Hinkley Point C power station in Somerset (c.f. WNN, 2014). Here the project final investment decision is highly contingent on UK government support in the form of a long term pricing mechanism (Contracts for Difference), and its approval by the European Union, and on the ability of the project to attract private investors – with both of these uncertainties lying outside the sphere of influence of the project managers that are tasked with delivering the project. In contrast, in life extension/ decommissioning projects a greater source of uncertainty arises due to competing stakeholder demands, with proposed technical solutions having to be signed off by a succession of diverse stakeholder groups.

Environmental uncertainty also emerged from unclear roles and responsibilities within organisations. This was due to the absence of norms or precedents for the project to follow as was the case on the project to construct a new intermediate level waste storage facility, or, on the project to build a new nuclear power station

“There is organisational uncertainty in terms of having clear roles and responsibilities and accountabilities, and the working arrangements between the project and the responsible designer.” Programme Manager (New nuclear build)

On this project there were two competing cultures both present within the same host organisation: the responsible designer’s engineering dominated culture and the delivery focused nascent project delivery organisation, and effective ways of working, project processes and accountability mechanisms between the two were still inchoate and emerging.

Added to this securing project funding was an ever present source of uncertainty in this study, with project managers often unable to recruit staff due to ongoing funding uncertainties. This lack of funding was often used as an excuse for inaction at the planning stages of projects, followed by an inevitable rush to deliver the project once funding sanction was given.

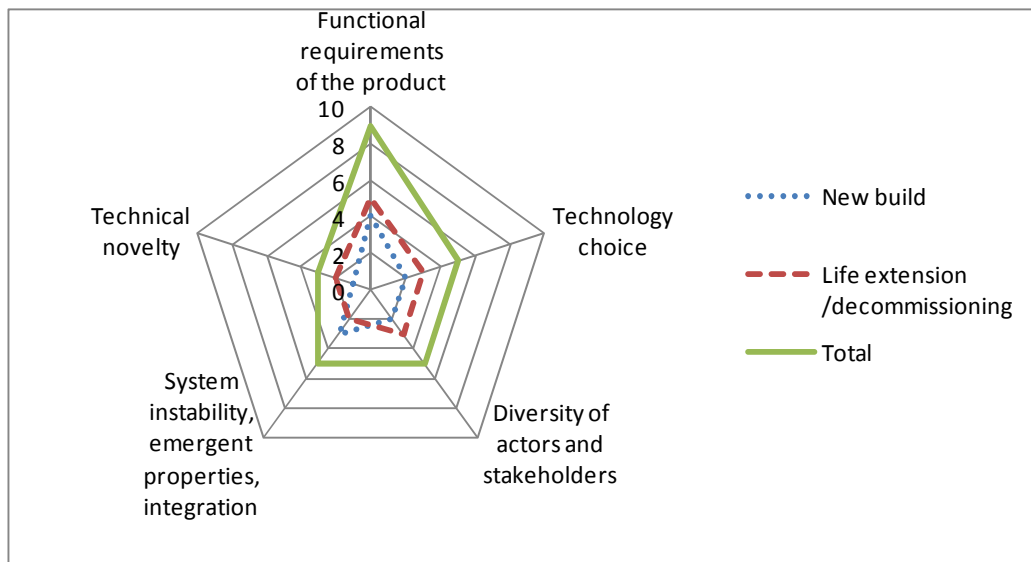


Figure 5: Contextual factors of complexity as a dimension of project uncertainty: Number of mentions across all interviews and broken down by project type

In contrast to Environmental uncertainty, the shape of the polar diagrams for Complexity as a dimension of uncertainty (Figure 5) is broadly similar between new build projects and life extension/decommissioning projects. In both types of project Complexity in the functional requirements of the product (for example: the range of nuclear materials that a new test facility had to be able to characterize), and how well these requirements had been documented was the most oft mentioned contextual factor. The relationship between project complexity and resulting uncertainty was captured eloquently by one respondent chronicling the difficulties inherent in a reactor life extension project,

“we are dealing with a chaotic, volatile and extremely dynamic system and it will be hard to understand what the causes of difference between model and experiment might be.”

Another respondent spoke of the integration challenge facing a new nuclear power station project

“It’s a very congested set of buildings, very close working, lots of difficult access problems and I foresee integration of all the work that needs to be done as a mammoth challenge for us. So I think there is a huge level of uncertainty around that.”

Although high levels of uncertainty do not necessarily imply a dynamically complex project, the all pervasive nature of complexity residing in these civil nuclear projects does confirm that project complexity is a major influence on project uncertainty. Rather less important to respondents in this study were issues of technical novelty, for example, when and how to implement new technologies within the project, with this study reinforcing Kettunun et al. (2007)’s view that the nuclear industry remains a very conservative one.

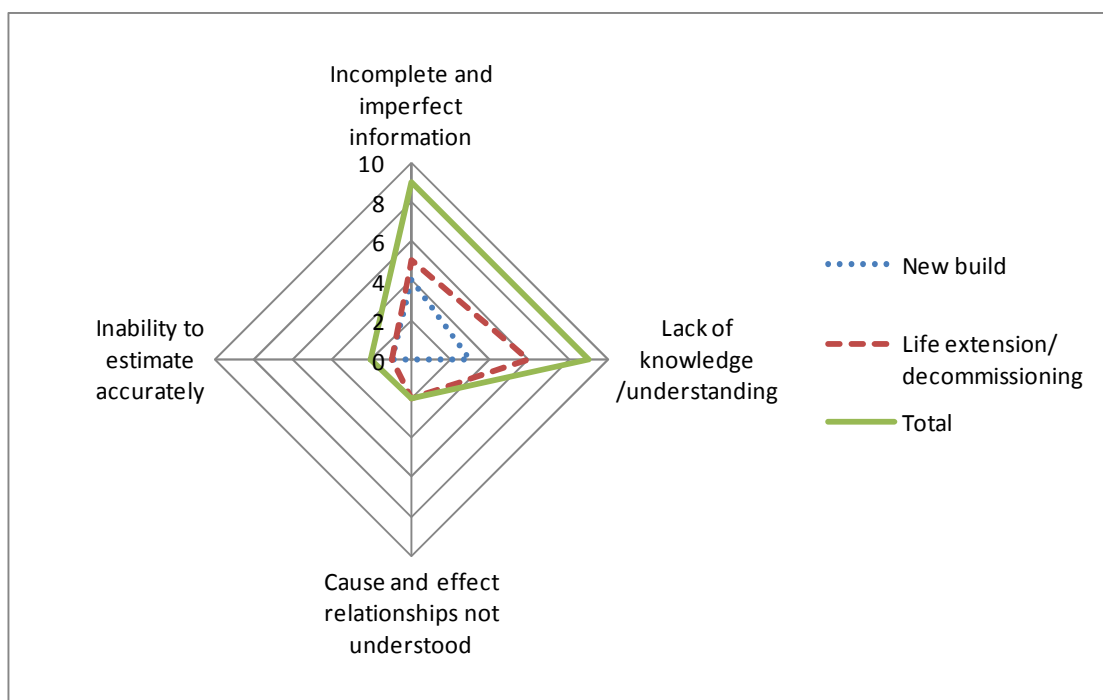


Figure 6: Contextual factors of information as a dimension of project uncertainty: Number of mentions across all interviews and broken down by project type.

Figure 6 depicts the similarity between different types of civil nuclear projects in terms of Information as a dimension of project uncertainty. Most of the Information uncertainty in this study arose from missing or incomplete information or a lack of knowledge of understanding. In these large-scale nuclear projects missing information may result from poor past record keeping over what materials were stored where, a lack of ‘as built’ drawings of old facilities, and or ,on new build projects, failure of the relevant design authority to share critical drawings and design information. To quote the Engineering Project Manager on a project to construct and commissioning an intermediate level waste storage facility

“we have uncertainty around the waste we are going to put in the containers[....]. That’s because the source facilities at [X] from which the waste is being removed have a chequered past and the record keeping and continuity of knowledge hasn’t been maintained.”

In addition, many nuclear subsystems, for example the performance of graphite bricks under seismic load, were perceived as being chaotic and extremely dynamic, making it hard to understand cause and effect relationships and leading to difficulties in fully understanding the significance of particular test results. This in turn impacted and often delayed the preparation of essential safety cases, without which a nuclear power station must be immediately shut down.

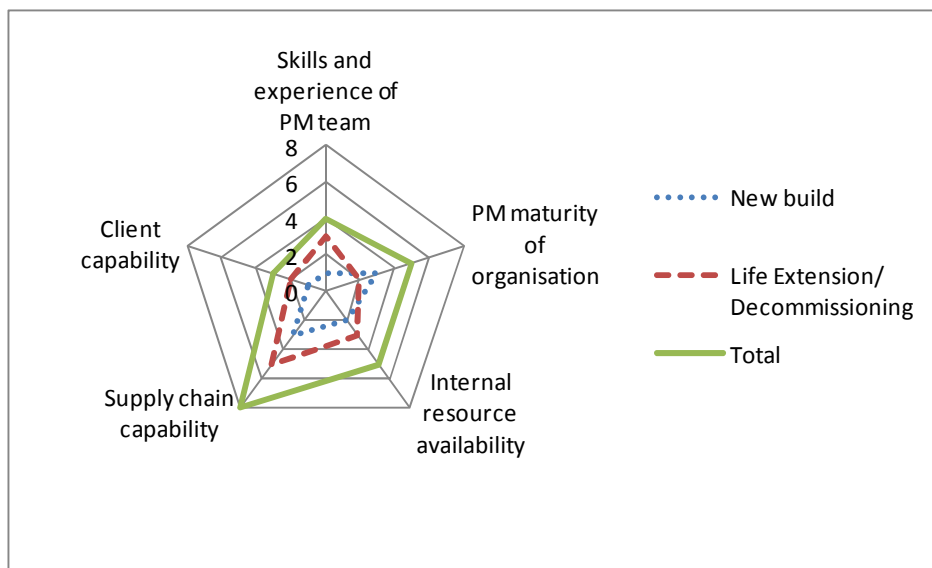


Figure 7: Contextual factors of capability as a dimension of project uncertainty: Number of mentions across all interviews and broken down by project type.

Figure 7 shows the sources of uncertainty around Capability across civil nuclear projects. Here the findings within both new build *and* life extension /decommissioning projects in this study are consistent with earlier work by Saunders et al. (2013), in that the majority of the uncertainty emanates from a lack of supplier capability within a long and often fragmented supply chain. Lack of investment and attention to the nuclear skills base in the UK (Cogent, 2009) has caused the nuclear supply chain to wither, leading to extreme resource challenges for nuclear projects that require nuclear-grade capability from external suppliers. Respondents described a dangerous assumption that was still prevalent within nuclear projects; that there was an unlimited pool of external skilled resources ready and willing to bid for any project work. This assumption was not held for internal resources, with respondents acknowledging that another area of uncertainty across projects was securing internal resources, particularly in specific technical disciplines such as design or safety case authoring. The following two quotations, from a new build and life extension/decommissioning project respectively, provide evidence of these difficulties.

“looking back I would say that we did not have the commissioning experience or understanding in the programme team” (Project Manager, new test facility) and *“absolute*

resource issues are massive – especially nuclear design issues” (Commercial Manager, intermediate level waste storage facility).

These problems were compounded by a sense that project managers often did not control their resources leaving them vulnerable to other project priorities, or even to other projects outbidding them for key staff.

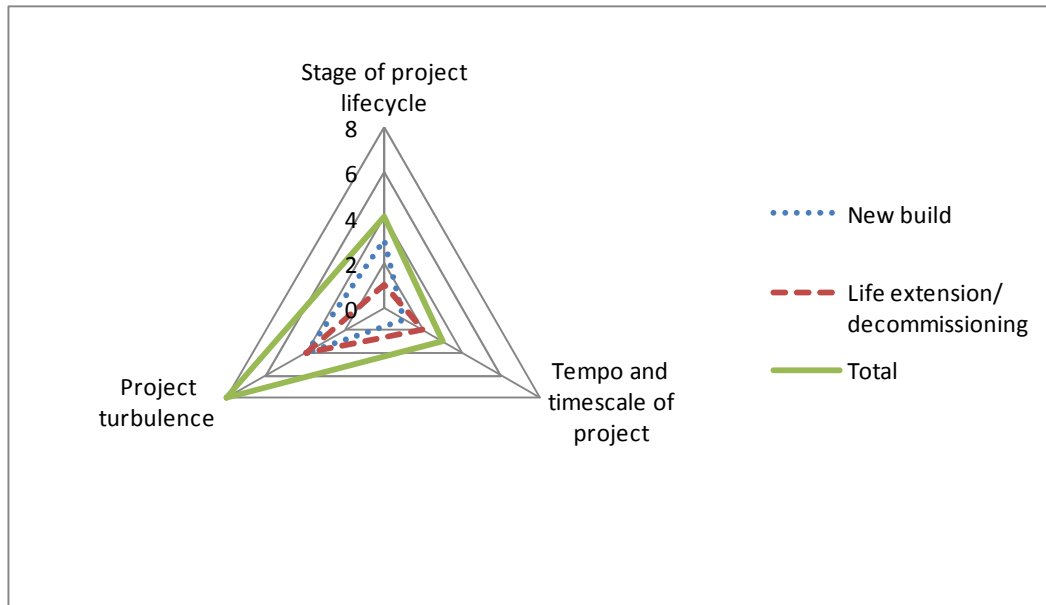


Figure 8: Contextual factors of time as a dimension of project uncertainty: Number of mentions across all interviews and broken down by project type.

The similarity in shape of both polar diagrams in Figure 8 indicates agreement across both types of project as to the role of Time as a dimension of project uncertainty. The greatest contributor to uncertainty in both new build and life extension / decommissioning projects is project turbulence, which manifests itself as changes in project scope, objectives and priority. One of the nuclear decommissioning projects in this study faced repeated changes in project scope, requirements and permitted methods of working which delayed the project and damaged client-contractor relationships. Similarly, on a life extension project the Technical Lead argued that there were uncertainties

“in timing due to the novelty of the work – its research not handle turning. We are doing new things so timescales may be longer or shorter. In terms of costs- this is novel work so we don’t always know what the costs will be.”

Less frequently mentioned contributors to temporal uncertainty were the lifecycle stage of the project and the speed and timescale of the overall project although several respondents acknowledged the generally accepted view (Atkinson et al., 2006; Cleden, 2009) that uncertainties are highest at the inception phase of projects and gradually reduce as the project evolves. Interestingly the notion of project pace - one of the three dimensions of complexity (along with uncertainty and technical scope) identified by Shenhar (2002) - was highlighted in this study as a source of uncertainty, as articulated by the project controller on the intermediate level waste storage facility:

“The big issue here is identifying the real requirement date. Is it a real requirement or is it the earliest possible if everything goes well.” This provides further evidence of the layers of interconnectedness between project complexity and project uncertainty.

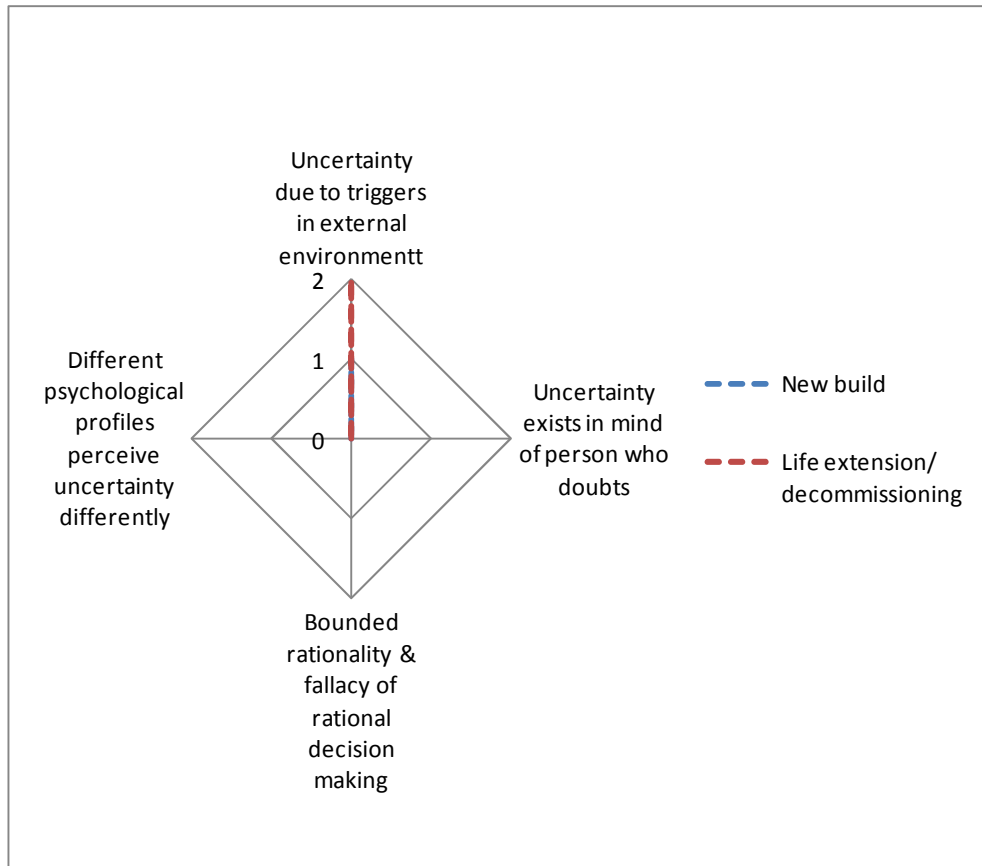


Figure 8: Contextual factors of Individual as a dimension of project uncertainty: Number of mentions across all interviews and broken down by project type.

Once surprising finding in this study was the lack of discussion of individual perceptions of uncertainty (Figure 9); a strong theme in the literature (Kahnemann and Tversky, 1982; Head, 1967; Madsen and Pries-Heje, 2009). There were minimal mentions of sources of uncertainty that were due to internal perceptions. Instead, respondents across both types of projects viewed uncertainty as residing “out there” in the external world, rather than arising due to differences in the way different individuals perceive uncertainty. One possible explanation for this could be the pragmatism of the project management community, and a focus on delivering a challenging project rather than worrying about whether uncertainties exist “out there” or “in the mind”. An alternative, although untested, hypothesis could be that large-scale complex civil nuclear projects tend to attract individuals who are comfortable or have learnt to be comfortable in dealing with high levels of uncertainty.

CONCLUSIONS

This study has addressed the dimensions of uncertainty in large-scale civil nuclear projects. It draws three main conclusions which provide new insights into project uncertainty in safety-critical project environments. First, the Uncertainty Kaleidoscope, posited in Saunders et al. (2015) has been shown to be a valid representation of the dimensions of project uncertainty in civil-nuclear projects. Few new sources of uncertainty emerged during the 18 interviews and those that did were consistent with the existing categorisation of the 6 dimensions of project uncertainty – Complexity, Time, Environment, Capability, Individual and Information.

The second key finding is that the major sources of uncertainty in large scale civil nuclear projects are the environment and organisational context of the project and the project's inherent complexity, followed by organisational and supply chain capability to deliver it and the absence of key project information or understanding. Less significant dimensions of uncertainty are the timescale and tempo of the project and individual project management practitioners' perceptions of, and capacity to deal with project uncertainty.

Lastly, the study found that the dimensions of project uncertainty are broadly similar across two different types of civil nuclear project (new build vs. life extension/decommissioning projects), with the exception of environmental uncertainties, where differences in the contextual factors of project uncertainty are more pronounced.

The implications of this study are profound and important to the delivery of safety critical projects in the civil nuclear sector. Failure to appreciate the uncertainties, complexities and risks is a major cause of poor delivery in contemporary projects. This study enriches our understanding of the dimensions of project uncertainty in large-scale civil-nuclear projects, a vital infrastructure sector for the UK economy and one where, for reasons of safety, failure is not an option. Articulating and validating the sources of, and influences on uncertainty in the form of a highly visual framework proffers a way forward for project management practitioners to identify project uncertainties as early as possible and to stay attuned to their presence throughout the project lifecycle. By identifying areas of uncertainty early on in the project lifecycle, when the scope may be very fluid, costs and timescales little more than unsubstantiated estimates, it may be possible to reorient project managers' perceptions of project uncertainty as unwanted and negative and bound up with risks to project delivery, into a more expansive, optimistic understanding of uncertainty as an opportunity to be exploited with positive approaches for changing how projects are delivered.

Limitations

The ontology underpinning this study is closest to the positivist research paradigm, viewing the dimensions of project uncertainty as in some sense objective, real and external to the respondents, as opposed to being socially constructed by the actors engaged on the project. There are dangers in this positivist approach, as it can tempt researchers to believe that their conclusions are objective and imbued with predictive power. There is a risk that the Uncertainty Kaleidoscope could be construed as "pseudo-scientific", whereas in reality it serves only as a visual representation of the myriad landscapes of project uncertainty that may arise in safety-critical civil nuclear projects. Like many models it is intended to be memorable and to act as a practical framework to enable proactive and productive discussion and debate over where the sources of uncertainty are within a specific project context. Like all models it has limitations and the author acknowledges the weaknesses inherent in using a kaleidoscope as a metaphor for

projects. After all, the usual purpose of a kaleidoscope is to be shaken to make new patterns, in contrast to projects, which in an ideal world would remain stable and not subject to such violent perturbation.

Aside from the philosophical limitations of this study there are a number of practical caveats that must be placed on the data collected and conclusions drawn. First, the access to projects was to some extent opportunistic, although strenuous efforts were made to ensure that a balanced portfolio of case-study projects was selected. Secondly, although the author interviewed several respondents per project to minimise individual respondent bias it was not possible to further triangulate the findings by accessing other sources of data, for example project documentation or participant observation. Extending the study in this manner would make a fruitful line of further enquiry and importantly would enable a deeper exploration of the project actuality (Cicmil et al., 2006) of civil nuclear projects.

Future work

In spite of these limitations this study, which involved 18 project management practitioners across 5 large-scale civil nuclear projects is large enough and sufficiently representative (given the limitations of accessing such sensitive projects) to enable the findings to be transferable to other safety-critical projects, certainly in the UK civil nuclear sector. Further work is now required to test the validity of the Uncertainty Kaleidoscope across other safety-critical sectors, such as civil aerospace and oil and gas. A more comprehensive study, done in collaboration with UK nuclear stakeholders, and covering the population as a whole would also provide further validation of the contextual factors that influence project uncertainty, and ultimately might lead to a more deterministic, and perhaps predictive, framework for identifying where uncertainty may reside in civil nuclear projects. Finally, another productive avenue for future investigation would be to better understand the practices and routines that project management practitioners enact in order to respond to these uncertainties in their day-to-day project life and to link the use of the Uncertainty Kaleidoscope to enhanced systems of project governance in these safety-critical environments.

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