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A framework for examining the dimensions and characteristics of complexity inherent within rail megaprojects

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Abstract

This paper presents a framework for examining the *dimensions* and *characteristics* of project complexity, with an emphasis on rail megaprojects. UK government departments have recorded that project complexity has increased significantly over the last decade and highlight that the subject has received inadequate attention, with a detrimental effect on project performance. However departments have not examined the *characteristics* of complexity or made a distinction between complexity emanating from the decisions made by the project itself and the complexity emanating from its context, as they warrant different treatment. By way of response, post examination and comparison of existing frameworks, a new framework is proposed based on a literature review. A case study is examined to illustrate how the framework may be applied.

Keywords: Complexity; Complicated; Megaprojects; Model; Rail; Risk; Uncertainty

1. Introduction

We live in an age of megaprojects. The goals, scale, duration, cost and risk exposure of projects in the UK and internationally have grown dramatically over time. These megaprojects typically attract high levels of both public and political interest due to their cost and their impact on the environment, ecology, economy, neighbouring communities and property-owners. However as described in the literature, while an increasing number of large infrastructure developments are being undertaken around the world, the record of performance of these projects is poor (Flyvbjerg et al., 2003a). These ambitious projects have commonly been associated with cost overspend, delays and or shortcomings in scope and quality, (Flyvbjerg et al., 2003b). Analysis of 258 projects found that nine out of ten transportation projects exceeded their budget and for rail projects the average cost escalation was 45% (Flyvbjerg et al., 2004). As a consequence there is a perpetual search for methods aimed at reducing uncertainty, managing risk and improving project performance. One of the avenues of enquiry which has been receiving growing attention is the contribution of complexity to poor project performance. In addition the literature makes frequent reference to the belief that the degree of complexity is increasing (Baccarini, 1996; Braglia and Frosolini, 2014; Flanagan and Jewell, 2005; Gidado, 1996; Hillson and Simon, 2007; Loosemore et al., 2003; Vidal and Marle, 2008; Walker, 2002; Wideman, 1990; Williams, 1999). The UK National Audit Office infers that there is a direct cause-and-effect relationship between projects' lack of comprehension of complexity and poor project performance (NAO, National Audit Office, 2013b). While UK government departments emphasise the significance of complexity there is not a commonly accepted definition. Without a broadly accepted definition accompanied by a consensus on the source, characteristics, implications and evolving nature of complexity, this cause-and-effect relationship is difficult to articulate and subsequently address. Given the goal of understanding and managing complexity to improve project performance, it is proposed that a clear distinction is made between project complexity emanating from aspects under a project's direct control and complexity emanating from a project's context. If a project deliberately and consciously elects to incorporate novel technologies, adopt an

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untried contracting strategy and or significantly subdivide the works thereby increasing the number of interdependencies, by its actions it will have in all probability introduced complexity and a greater management burden. The aim of this paper is to present a project complexity framework (reflecting existing frameworks) as a vehicle to examine the common *characteristics* of complexity with an emphasis on transportation projects. Additionally the aim of the paper is to highlight the imperative that sponsors and project managers need to understand and manage the aspects of complexity as several UK government major projects (which paid inadequate attention to complexity), missed their objectives as a result. The framework is applied to a case study of the High Speed Two railway project to understand the merit of its further development. The contribution this paper makes is the presentation of a complexity framework which goes beyond existing frameworks in that it considers the dynamic nature of projects. It considers for instance the evolving maturity of project management practices, the application of assurance processes and the adaptation of project governance to suit the needs of a project overtime. In addition emphasis is placed on those aspects of complexity under the control of the project and those emanating from its environment. The framework is focussed on rail projects and examines complexity *characteristics* relating to this industry.

2. Literature review

The following paragraphs provide an overview of project complexity prior to proposing a framework of the aspects of complexity to aid the analysis of rail megaprojects: definition of project complexity, complex or complicated, complexity is not a static notion, the perceived importance of complexity in the UK, initiatives to examine and manage the sources of complexity and project complexity stems from uncertainty.

2.1. Definition of project complexity

The Collins English Dictionary (2015) defines complexity as “the state or quality of being intricate or complex” where complex is defined as “made up of various interconnected parts”. While a number of writers have offered a definition of complexity there is no consensus or commonly adopted definition of what it is, (Bosch-Rekveldt et al., 2011; Fitsilis and Damasiotis, 2015, Ochieng et al., 2013, Parwani, 2002; Vidal et al., 2011). It could be anticipated that definitions would be proposed by writers based on the perceived *characteristics* of complexity. Baccarini for example refers to complexity as “consisting of many varied interrelated parts” which can be described in terms of their degree of differentiation and interdependency, (Baccarini, 1996). The APM describe a complex project as one which will typically involve interaction between several organisations and or different units in the same organisation requiring the coordination of the work of several disciplines and involve a wide range of project management methods, tools and techniques (APM, Association for Project Management, 2008). The Major Projects Authority, within their 2013/2014 annual report, describe major projects as complex and ambitious and refer to the challenges of the introduction of new technology, organisational structures and private sector procurement methods (MPA, Major Projects Authority, 2014). The introduction of novel untried approaches introduces uncertainty. If it is accepted that complexity arises not from what is known and under control, but what is uncertain and unpredictable, as proposed by Turner and Cochrane (1993), then a definition of a complex project warranting examination would be “a complex project is one which exhibits a high degree of uncertainty and unpredictability, emanating from both the project itself and its context”. Aspects of project uncertainty emanating from within the project itself include uncertain goals and scope, the adoption of novel technology, together with the choice of organisational structure, project management method and contracting strategy. Until and how they are resolved would impact project performance. Aspects of uncertainty emanating from the context of particular interest include the external stakeholders’ evolving expectations, definitions of project success and the relationships between them. Specifically uncertainty will exist from the behaviour of the stakeholder representatives and how they interact with each other and the project team.

2.2. Complex or complicated

The terms ‘complex’ and ‘complicated’ are labels that are often used interchangeably to describe tasks that are intricate or problematical, as if they were synonymous (Geraldi et al., 2011). However to advance our understanding of complexity it is important to draw a clear distinction between the two ideas, as “complex” is not the same as “complicated” (Maylor et al., 2008; Whitty and Maylor, 2009). A complicated project while large in scale may be largely ‘self-contained’, comprehendible and managed by an organisation so that is highly predictable and runs like clockwork. By way of an example, while the design and installation of the many kilometres of wiring on the Boeing 777 aircraft was complicated, it was describable and ultimately knowable. A complex project however typically has an ever-changing unpredictable political, economic and societal environment with hundreds or even thousands of reciprocal ties. It has stakeholders that can impose radical change and who do not respect and may even oppose existing decisions, schedules, procedures or strategies. An example of a complex project is the Boston central artery / tunnel project (commonly known as the ‘Big Dig’) as the project could not be fully understood simply by analysing its components due to the unpredictable interaction between the project and its environment and between one external stakeholder and another (Chapman, 2014a, 2014b). This distinction is important when seeking to understand the uncertainty associated with complex projects.

2.3. Complexity is not a static notion

The perception of what is considered complex changes with the passing of time. Many activities or projects appear to be complex when they are first undertaken but as experience, knowledge and understanding grows and they are followed by more ambitious projects, they appear less and less complex. Consider for a moment Stonehenge (Green, 1997), St Pauls Cathedral and similar structures (Kozak-Holland and Procter, 2014), Tower Bridge, the Channel Tunnel (Anderson and Roskrow, 1994), the Hubble Space Telescope (Zimmerman, 2008) and the International Space Station (DeLucas, 1996; Jacobs, 1996). Each project has involved greater complexity than its predecessor and perhaps an extreme example - Stonehenge may now be considered simple when compared with a space station which travels at 28,800 km/h and only takes 90 min to make a complete orbit of Earth. As a consequence our understanding of and response to complexity cannot remain static but must be constantly challenged and progressively developed.

2.4. The perceived importance of complexity in the UK

Poor project performance has plagued governments all over the developed World (de Bruijn et al., 2002; Flyvbjerg et al., 2003a). For instance the UK government's Major Projects Authority (MPA) highlighted within its annual report published in 2013 "*for too long only a minority* [*of major projects have been*] *completed on time*, *on budget and to the desired quality*" (MPA, Major Projects Authority, 2013). Management of successful project outcomes has been exacerbated by the evolving nature of projects. This is illustrated by the MPA which stated in the same report: "*the cost*, *ambition*, *complexity and risk of the government*'*s major projects have increased hugely over the past decade*" (MPA, Major Projects Authority, 2013). There is a growing assertion within UK government departments that the management of complexity is a prerequisite for securing successful project outcomes. The National Audit Office (NAO) report 'Over-optimism in government projects' under the heading 'Complexity' states "*our back catalogue shows that*, *in planning projects*, *government does not always take time to understand the complexity and as a result*, *over estimates its ability to deal with the challenges*" (NAO, National Audit Office, 2013b). The MPA conducts gateway and project assessment reviews to determine the deliverability of projects providing a confidence rating for each project using a 'traffic light' approach. There are five confidence ratings, namely green, amber-green, amber, amber-red and red. Within its annual report the MPA identified eight red-rated projects which were diverse in cost, schedule duration and maturity. The red classification is described by the MPA as: "S*uccessful delivery of the project appears to be unachievable. There are major issues on project definition*, *schedule*, *budget*, *quality*/*and or benefits delivery*, *which at this stage do not appear to be manageable or resolvable. The project may need re-scoping and*/*or its overall viability reassessed*" (MPA, Major Projects Authority, 2013). Within a National Audit Office (NAO) report describing the work of the MPA attention was drawn to eight red-rated projects, emphasising each of the project's sensitivity to complexity, stating "*delays occurred because departments initially underestimated the complexity of the project*" (NAO, National Audit Office, 2014b). In addition, within the NAO's report 'Lessons from major infrastructure rail programmes' (NAO, National Audit Office, 2014a) it cites a lack of attention to the *characteristics* of complexity when drawing lessons learned from the Thameslink and Crossrail projects. With specific reference to Thameslink the report states "*Despite the programme*'*s size and complexity*, *the Department* (*for Transport*) *did not devote enough attention to managing the interdependencies between the infrastructure*, *train and franchise early on*" (NAO, National Audit Office, 2014a). However neither the MPA nor the NAO offer a description of a complex project.

2.5. Initiatives to examine and manage the sources of complexity

Against the backdrop of an emerging body of evidence, there are strong indications that traditional, linear project management tools and techniques, while essential, are insufficient to secure successful outcomes for today's most complex projects, (Baccarini, 1996; Williams, 1999). In 2005, Australian, UK and US government bodies (in conjunction with representatives of the defence industry), commenced an initiative aimed at improving the international community's ability to successfully deliver very complex projects. The kernel to this initiative was the establishment in 2007 of an international not-for-profit company to provide global leadership to achieve this goal. That company is called the International Centre for Complex Project Management (ICCPM), (previously known as the College of Complex Project Managers). Since 2005 government support has expanded to include Canada and Singapore. In addition there is a growing number of corporate partners such as BAE Systems, Lockheed Martin, Booz Allen Hamilton and Thales. With support from its corporate partners, ICCPM declares it has developed the world's first Masters in Business (Complex Programme Leadership) through the Queensland University of Technology. The ICCPM's aim is to continue to support the development and delivery of education and training programmes, aimed at improving global capability to deliver complex projects and manage complexity.

The US Federal Highway Administration (FHWA) advise that complex projects require a more robust methodology as opposed to the traditional approach to project management which for a long time "focussed on three elements - cost, schedule, and technical requirements (scope, design, quality, and integrated delivery)". The FHWA has developed a Guidebook for Project Management Strategies for Complex Projects which it explains "provides practical tools and techniques to optimise innovation, minimise schedule and budget risks, and build better projects [and] expands the three-dimensional analysis typically used by departments of transportation to create a model that facilitates project management in five areas: cost, schedule, technical, financial, and context. Methods for assessing complexity factors are also provided to help managers in making rational resource allocations and guide planning and implementation".

The Delivery Environment Complexity Analytic (DECA) tool developed by the National Audit Office (NAO, National Audit Office, 2013c) provides a high level overview of the challenges, complexity and risks to the delivery of a project. It identifies 12 factors drawn from auditing projects which are key in influencing success or failure. Users decide whether the potential impact from each factor is high, medium or low to build an overall picture of the delivery environment and its complexity. The NAO considers the completed DECA provides users with a better understanding of the challenges an organisation faces in realising delivery of a project. It does this by considering areas of challenge, drawing out where the potential risks are, their likely consequences and potential opportunities. Through the review of projects, the NAO has determined that the quality of a project's initiation often dictates the likelihood of its success. Using data from around 5000 projects and organisations the NAO discovered that the roots of failure were to be found at the conception stage. The NAO state they "found striking patterns in the reasons for projects failing, which all related to the importance of understanding the delivery environment and complexity of the project when making a decision whether to proceed". Building on the findings of an assessment of organisations that were successful in "really understanding the challenges of their project" the NAO identified 'patterns' which were subsequently themed into 12 factors, which the NAO used to create the DECA. The DECA assesses 12 factors, each of which are considered to have an impact on the successful delivery of objectives and outcomes.

2.6. Project complexity stems from uncertainty

Ward and Chapman (2003) describe uncertainty in terms of the ambiguity associated with lack of data, lack of detail, lack of clarity related to the behaviour of relevant project players, lack of structure to consider issues and the working and framing of assumptions to consider the issues. The authors consider uncertainty affects five project areas: the variability associated with the estimates of project parameters (such as specification, novelty and activities), the basis of estimates, design and logistics, objectives and priorities and relationships between the project parties. However from an examination of stakeholder management, differing organisational structures, the iterative nature of the development of the design, the problems relating to the timing of the exchange of project information between project 'players', the lack of suitability of linear programmes (and associated software tools) to the planning of complex project activities, it can be questioned whether projects adequately consider their uncertainty profile. This is significant in that Shane et al. (2012) define complex projects as involving an unusual degree of uncertainty and unpredictability (emanating from a dynamic environment) in which many of the critical factors are outside the project team's direct control. Giezen also refers to complexity arising from a dynamic environment, expressed as a 'frequently changing context', which he considers arises from evolving interests, purposes, constraints and ambitions (Giezen, 2012). Brady and Davies (2014) provide examples in their examination of BAA's T5 project and the London 2012 Olympics Construction Programme, stating that each were 'subject to high levels of uncertainty'. Complex projects are also seen to be characterised by unforeseen changes in the project scope arising from the need to satisfy external stakeholder requirements which can threaten the project's ability to achieve the project's objectives. Other authors concur that complex projects are characterised by unpredictability such as Antoniadis et al. (2011) and that project elements "*can change in ways that are not totally predictable and which can then have unpredictable impacts on other elements that are themselves capable of change*" (Cooke-Davies et al., 2011). Aritua et al. (2009) describe complex adaptive systems exhibiting 'non-linearity' whereby small changes in the initial conditions or external environment can have large and unpredictable consequences in the outcomes of the system. This uncertainty is reinforced by Klakegg who states complex projects are subject to unanticipated events that impact on the project after some time delay and this leads to unpredictable outcomes. (Klakegg et al., 2010).

2.7. Appropriateness of planning tools to address uncertainty

The traditional approach commonly adopted for the management of large infrastructure projects is reductionist in nature in that it employs work breakdown methods to subdivide the project activities into manageable sub-parts. The project planning process, more suited to the construction phase, typically treats the interaction between these sub-parts (project components) in a linear manner, whereby the input needs of one activity are met by the output of a preceding or overlapping activity. This process does not take account of the characteristic iterative nature of projects and the design process in particular. In the language of systems dynamics, the process does not take account of feed-back loops (Chapman, 1998).

3. Research methodology

3.1. Research questions

In order to develop a framework based on both theory and professional project actor perceptions, the main research questions to be answered by this paper are:

> "What is an appropriate complexity framework for rail projects?"

> "What are the relevant *dimensions* of complexity relevant to rail projects?"

> "What *characteristics* of project complexity are prevalent and require capturing in a complexity framework to guide both 'front-end' decision making and risk management activities for rail projects?"

3.2. Methodology

The research methodology illustrated in Fig. 1 describes the approach adopted for this paper. The major steps include: (1) a literature review of the background to complexity, (2) examination of existing frameworks, (3) selection of a structure of project complexity *dimensions* against which may be assigned complexity *characteristics*, (4) a literature review of the *characteristics* of complexity (5) synthesis of the

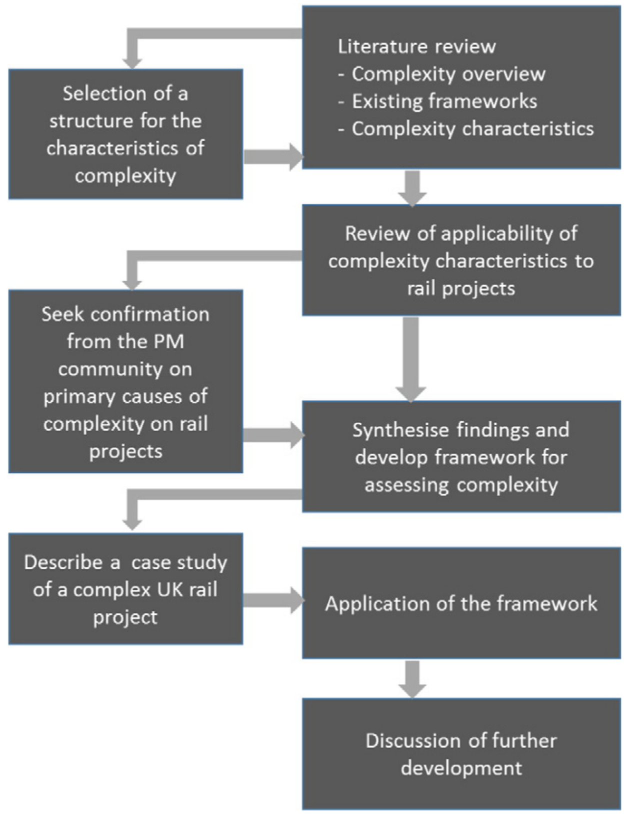

Fig. 1. Outline of research methodology.

literature to develop a framework for assessing complexity, (6) the application of the framework to a case study of a current significant rail project and (7) a discussion of further development.

3.3. Approach to literature review

The literature review entailed a search for relevant literature by the examination of academic science, engineering, and business databases (e.g., LexisNexis, Engineering Village; ScienceDirect, Science Citation Index, ABI/INFORM, ProQuest; PMI Online Library) and general Internet search engines. The review focussed predominantly on papers published during or after 2000 although the papers published by Baccarini (1996) and Williams (1999) for instance were included due to the number of times they have been cited and the frequency with which papers commence by reference to these authors' work. The literature reviewed was predominantly peer-reviewed academic papers, although some grey literature was also examined. In addition papers which did not focus specifically on construction were included in the review for the benefit of a broad perspective. The literature was examined to answer the research questions included above. Guided by the research questions, the review sought to establish aspects of complexity for rail projects and other frameworks established. The search was guided by the stages through which a rail project passes.

3.4. Replication of results

While similar research can be undertaken, the findings are likely to be similar but not identical. Repetition of the research will not produce identical results in the same way that mixing two static chemical substances together (under controlled laboratory conditions) would do. The reason being that the project environment is dynamic and over time the perception of what is complex changes. In addition multiple groups of project professionals, (based on individuals' experiences and their project profession), will have different perceptions of complexity although it would be expected that there would be significant areas of commonality. The intention is to produce a framework that will be suitable for all rail megaprojects. It will not be suitable for other industries such as information technology, aerospace or ship building as they do not involve creating permanent physical assets on the ground.

3.5. Case study

High Speed Two was selected as a case study as: (i) it is currently the largest rail project in Europe, (ii) is the most significant investment in the UK rail network since the Victorian era, (iii) the Department for Transport considers the project to be of significant importance in terms of encouraging sustainable long-term economic growth, reducing carbon emissions and increasing rail passenger capacity, and (iv) it is considered a highly complex project.

4. Composition a framework suitable for rail projects

4.1. Existing project complexity frameworks

A project complexity framework is defined here as a structure which consolidates a series of variables (drawn from the literature and empirical data), which describes the sources of complexity facing project implementation that may potentially impact project performance. The purpose of a complexity framework is to inform management decision making and increase the likelihood of projects meeting their objectives. Six existing frameworks were examined to understand their focus, content and how they might inform a framework for rail projects. The six frameworks are described below, listed in chronological order. Their assessment for suitability is based on the extent to which the variables (*dimensions* and *characteristics* of complexity) address all phases of a generic project life cycle. Each assessment is recorded in a table with the common headings 'Initiation', 'Context', 'Organisation', 'Planning /Task', 'Site' and 'Delivery' to permit comparison. The assessments are not intended to be exhaustive but to highlight the key issues.

Framework 1: Vidal and Marle (2008). Included in their paper "Understanding project complexity: implications on project management".

The framework was developed as a matrix and included organisational and technological characteristics for the headings: project system size, project system variety, interdependencies within the project system and elements of context. 68 elements of project complexity were recorded.

Limitations of the framework: The following observations were made about the framework.

Table 1
Vidal and Marle complexity framework.
'Delivery' refers to design, procurement and build (as frequently they are overlapped)

Initiation	Context	Organisation	Planning / Task	Site	Delivery
No reference to goal alignment, clarity of goals, political influence, uncertainties in scope, requirements or benefits			*No reference to novel or newness of technology or experience with technology (but reference to technological skills)*	*No reference to site characteristics /conditions.*	*No reference to design, the procurement process, contracts or construction*

Framework 2: Wood and Ashton (2010). "Modelling project complexity". The authors' themes of project complexity (and their sub-sections) are described in Fig. 2, below. The primary elements of the table are organisation, planning and management, operational and technological, environmental and uncertainty.

Limitations of the visible framework: The following observations were made about the framework (however it is recognised greater detail was obtained during the empirical study).

Theme	Section within theme
Organisation	Clients brief
	Organisational structure
	The client and project stakeholders
Planning and management	Project coordination
	Programming
	Information
Operational and technological	Technology
	New methods
	Inherent difficulty
	Project size
Environmental	Physical environment
	Project environment
Uncertainty	Location
	Existing structures
	Planning
	Uniformity

Fig. 2. Wood and Ashton complexity themes and 'sub' themes.

Table 2
Wood and Ashton complexity framework
'Delivery' refers to design, procurement and build (as frequently they are overlapped)

Initiation	Context	Organisation	Planning / Task	Site	Delivery
No reference to goal alignment, clarity of goals, political influence, uncertainties in scope, requirements or benefits	*No reference to stakeholder's status, level of influence, public agenda, local laws or regulations*	*No reference to hierarchical levels, information systems, organisational innovation, capabilities or interdependencies – just an overall reference to organisational structure*	*No reference to novel or newness of technology or experience with technology (but reference to technology)*	*No reference to site characteristics/conditions (but reference to 'physical environment)*	*No reference to design, the procurement process, contracts or construction*

Framework 3: Bosch-Rekveldt et al. (2011). The authors describe their framework within their paper: "Grasping project complexity in large engineering projects: The TOE (Technical, Organisational and Environmental) framework".

The framework illustrated in Fig. 3 was developed as a schedule where aspects of complexity are categorised by technical, organisational and environmental 'elements'. On a lower level, the elements were further grouped into 'subcategories'. 50 elements of project complexity are recorded.

Technical	Organisational	Environmental
Goals	Size	Stakeholders
Scope	Resources	Location
Tasks	Project team	Market conditions
Experience	Trust	Risk
Risk	Risk	

Fig. 3. Bosch-Rekveldt technical, organisational and environmental complexity elements.

Limitations of the visible framework:

Table 3
Bosch-Rekveldt et al. complexity framework
'Delivery' refers to design, procurement and build (as frequently they are overlapped)

Initiation	Context	Organisation	Planning / Task	Site	Delivery
No reference to requirements and benefits	*No reference to stakeholder's status, level of influence, public agenda, local laws or regulations*	*No reference to hierarchical levels, information systems, organisational innovation, capabilities or interdependencies.*	*No reference to technology interdependencies or technology skills required*	*No reference to site characteristics/ conditions.*	*No reference to design, the procurement process, construction*

Framework 4: NAO, (National Audit Office) (2013c) **"**The DECA: Understanding challenges in delivering project objectives". The Delivery Environment Complexity Analytic (DECA) tool developed by the National Audit Office (NAO) and referred to above provides a high level overview of the complexity of a project. It is recorded here as a framework although the tool focuses on the conception stage. The tool identifies 12 factors based on identified patterns of events drawn from auditing projects which are described as key influencers of success or failure. The NAO discovered that the roots of failure were to be found at the conception stage. The 12 factors are included below.

Table 4
NAO complexity framework composition.

1	**Strategic importance**. How significant is the client/project to the delivery of the sponsoring body's key strategic objectives and/or legal obligations?
2	**Stakeholders**/Influencers. Who are the stakeholders and how much interest/ influence/support do they have for the planned objectives?
3	**Requirements and benefit** articulation. Are the sponsoring body and delivery team clear about their requirements and what benefits achieving the objectives will bring?
4	Stability of overall **context**. Is there likely to be a change in scope in the future? Is the delivery plan reliable?
5	**Financial impact** and value for money. How significant is the investment in the client/project to the sponsor/delivery body?
6	Execution complexity (including technology). Are the approaches/**technologies** planned for use in achieving objectives new to the delivery body and/or untested?
7	**Interfaces**/Relationships. How many separate bodies/teams are involved in delivery?
8	**Range of disciplines and skills**. Are specialist skills necessary to achieve objectives, and are these available in-house?
9	**Dependencies**. Is anyone else's work dependent on the success of the project/ client, and is it dependent on others?
10	**Extent of change**. Will current working patterns need to change to deliver the expected outcomes and benefits?
11	**Organisational capability**: performance to date. What experience does the delivery body have in delivering similar objectives or work of a similar complexity?
12	**Interconnectedness**. What work has been done to understand the connections between factors affecting the client/project?

Limitations of the visible framework:

Table 5
NAO complexity framework
'Delivery' refers to design, procurement and build (as frequently they are overlapped)

Initiation	Context	Organisation	Planning / Task	Site	Delivery
No reference to goal alignment, clarity of goals, political influence, uncertainties in scope, however reference to requirements and benefits.	*No reference to public agenda, local laws or regulations*	*No reference to hierarchical levels, information systems, organisational innovation or interdependencies, but reference made to organisational capability*	*No reference to technology interdependencies or technology skills required*	*No reference to site characteristics/ conditions.*	*No reference to design, the procurement process, construction*

Framework 5: Dunoviü et al. (2014) "Towards a new model of complexity - the case of large infrastructure projects". The authors' new framework for project complexity is composed of three primary elements namely: **structural complexity**, **uncertainty** and **constraints**. Structural complexity is subdivided into number of elements and the dependencies between them, uncertainty is subdivided into uncertainty of objectives and methods and constrains is subdivided into constraints of the environment, resources and objectives.

Limitations of the framework:

Table 6
Dunoviü et al., complexity framework
'Delivery' refers to design, procurement and build (as frequently they are overlapped)

Initiation	Context	Organisation	Planning / Task	Site	Delivery
No reference to goal alignment, clarity of goals, political influence, uncertainties in scope or financial resources	*The framework refs to 'constraints of the environment' but is not specific in terms of say number of stakeholder's or their interests or level of influence, public agenda, local laws or regulations or political influence*	*No reference to the number of hierarchical levels, departments or information systems, skill requirements, project management methods or organisational innovation* etc.	*No reference to novel or newness of technology or experience with technology (but reference to technological skills)*	*No reference to site characteristics/ conditions.*	*No reference to design, the procurement process , contracts, construction*

Framework 6: HMT (HM Treasury) (2014) Infrastructure UK and the Infrastructure Client Group (2014) "Improving Infrastructure Delivery: Project Initiation Routemap. The Project Initiation Routemap (Routemap) is the result of government and industry working collaboratively with and the University of Leeds, through the Infrastructure Client Group. Built on lessons learned by both the public and private sectors, the Routemap aims to provide a framework to help to identify and address many common and recurring problems, particularly during the early stages of projects. It is intended to enable sponsors and those responsible for project delivery to properly align complexity with the necessary capabilities and other enhancements to ensure a more successful outcome. Pilot applications demonstrated its value as a tool for testing and developing the components and connections required to create a successful delivery environment. The purpose of each Align for Success module is to help: (i) Gain a greater understanding of the complexity-capability results; (ii) Identify and analyse options to better align complexity-capability; (iii) plan for successful achievement of desired outcomes; and (iv) assure enhancement plans during implementation.

Limitations of the framework:

Table 7
Infrastructure UK and the Infrastructure Client Group complexity framework
'Delivery' refers to design, procurement and build (as frequently they are overlapped)

Initiation	Context	Organisation	Planning / Task	Site	Delivery
The Routemap adopts the same complexity assessment factors as the Delivery Environment Complexity Analytic (DECA). Hence the comments are identical to those recorded for framework 4 above.					

4.2. Complexity dimensions and characteristics

4.2.1. Structure for examining and grouping complexity characteristics

From examination of the literature there is no consensus on what the *dimensions* of project complexity are. While a myriad of subjects are raised and recorded they are not focussed solely on construction or rail transportation projects. Given that the ultimate goal is to capture, comprehend and respond to complexity in an orchestrated way for optimum resolution it was considered that rather than simply scheduling the *characteristics* they should recorded against a structure reflecting the sequence in which they would arise, thereby supporting more effective management. A structure considered for examining the *characteristics* of complexity was the generic project life cycle described in the PMIs PMBOK Guide (Project Management Institute, PMI, 2013), namely: initiating, planning, executing, monitor and control and closing. The guide (and its adopted life cycle stages, referred to as Process Groups) is aimed at all projects and not tailored to the construction industry or the rail sector specifically. As a consequence of this lack of suitability (particularly due to the absence of reference to design, site investigative works and the limited description of environmental factors-see Section 2.1.5) it was not considered as a structure for examining and grouping complexity *characteristics*. Transportation projects are unique in that they can stretch over one hundred miles and hence site investigation works take on far more significance than say an Olympic stadium project. Other project life cycles examined included the RIBA Plan of Work 2013 and the Network Rail GRIP stages 1–8, however they did not address all primary aspects of projects (such as finance, context and organisation). Of interest was the study of 18 complex projects undertaken by Gransberg et al. (2013) and their inclusion of 'financial' and 'context' within their five *dimensions* of complexity. Based on the view of interviewed project managers, these two *dimensions* significantly contributed to complexity (and were external to the project). In addition existing complexity frameworks were examined but they did not yield a structure that followed the project life cycle. Based on the previously described frameworks and their respective content, the six common *dimensions* of complexity pertinent to rail construction adopted by this paper to structure the literature review are: finance, context, management, site investigation works, task (which includes scope definition, development of the business case, option analysis, design and procurement), and delivery within which individual complexity *characteristics* can be assigned. During the selection process of the *dimensions*, to check their robustness (degree of comprehensiveness), a simple (included/excluded) comparison was made between (i) the 12 factors within 'The Delivery Environment Complexity Analytic (DECA)' tool [developed by the National Audit Office (NAO)] considered to be contributors (in varying degrees) to the complexity of a project, and (ii) the PMBOK Process Groups covering a generic project life cycle. As will be seen from Fig. 4, while some of the adopted *dimensions* are addressed by the DECA tool and the PMBOK Process Groups map across to the chosen *dimensions*, they are not as comprehensive.

Care was taken in reviewing complexity *characteristics* in that those frequently listed by authors as contributors to complexity may be described as being common to most projects and undistinguishable from simple projects where delivery follows a predictable and controllable path.

4.2.2. Finance complexity characteristics

Morris and Pinto (2007) identify financial systems as a source of complexity. Understanding the financial model, where the funding is originating from, where costs are being expended, and the limitations on design and context flexibility are important to project success. The *characteristics* of finance complexity stems from: limitations on annual spend together with controls on: payment amounts, drawdown on contingency, applications for additional finance, settlement of disputes, termination of contracts and securing private sector funding based on mutually acceptable funding conditions, (not: reports, end-of-year accounts, records, audits and payments to contractors / suppliers / consultants / agents / utilities).

4.2.3. Context complexity characteristics

Chu et al. (2003) underline that 'contextuality' is an essential feature of complexity, considering it as a common denominator of any complex system. Project complexity context-dependence is also underlined by Koivu et al. (Koivu et al., 2004) who emphasise that "the context and practices that apply to one project are not directly transferable to other projects with different institutional and cultural configurations, which have to be taken into account in the processes of project management and leadership". As a

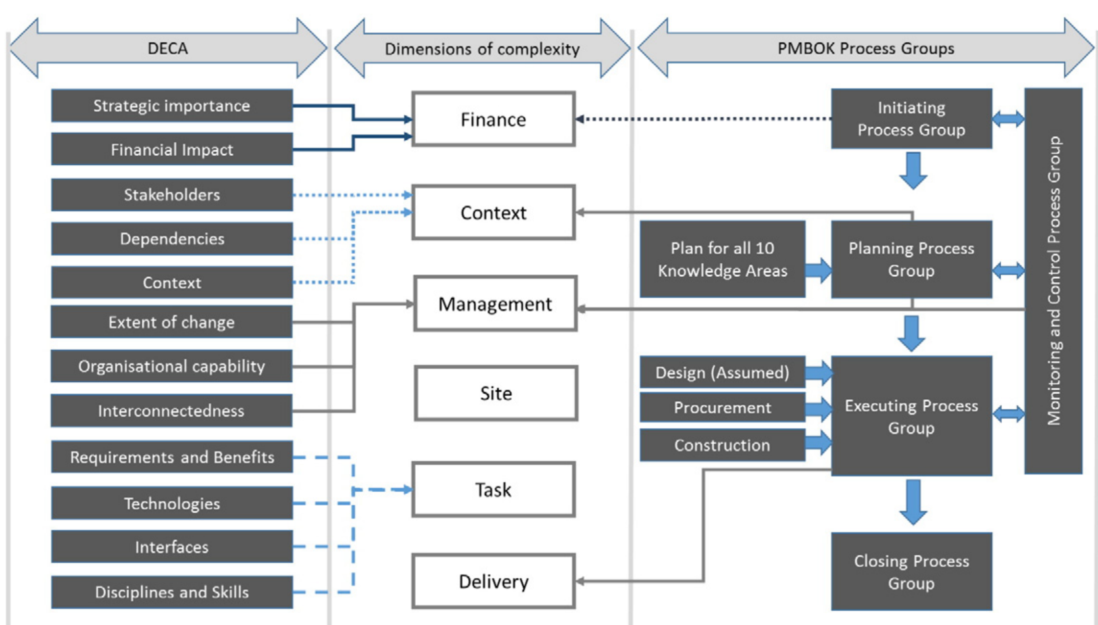

Fig. 4. A diagrammatic representation of the relationship between the *dimensions* of complexity chosen in this paper, the DCA and the PMI PMBOK process groups.

consequence, project complexity cannot be analysed or managed without considering the implications of the context. The aspects of the context under consideration are based on Chapman (2014a, 2014b) who names ten aspects: cultural, political, legal, regulatory, financial, technological, economic, environmental, developmental, and social. These aspects are referred to in the literature as follows: political, technological, economic, environmental and social (Kwak, 2002), legal (Kian Manaesh Rad and Sun, 2014), and financial, regulatory and developmental (National Academy of the Sciences, 2012), and cultural (He et al., 2015).

A key aspect of a megaproject is its external stakeholders. Complexity may stem from (i) the number of stakeholders (Geraldi and Adlbrecht, 2007; Vidal and Marle, 2008; Williams, 1999); (ii) the variety of stakeholders' perspectives (Geraldi and Adlbrecht, 2007; Project Management Institute, PMI, 2013; Vidal and Marle, 2008); (iii) conflicting stakeholder agendas (Sutterfield et al., 2006), (iv) the ever-changing dynamics of stakeholder relationships (Greiman, 2010), and (v) reconciling multi-level project objectives-in terms of DfT/HS2, the DfT it has declared its overarching objectives to be social, economic and environmental (DfT, Department for Transport, 2015), its strategic objectives relating to improving capacity, resilience, reliability and connectivity (DfT, Department for Transport, 2013a); and low-level managerial goals of cost, time and quality.

4.2.4. Management complexity characteristics

The management of a project may introduce numerous aspects of complexity such as: (i) the organisational structure in terms of degree of vertical and horizontal differentiation (Baccarini, 1996), (ii) cultural and language differences between personnel, participating departments and or organisations (Remington et al., 2009); (iii) design of the project governance structure (NAO, National Audit Office, 2009), (iv) maturity of the project management methodology (Albrecht and Spang, 2014); (v) variety of project management methods and tools applied (APM, Association for Project Management, 2008; Vidal and Marle, 2008); (vi) number of gateway reviews (Ellis, 2016), (vii) differentiation among occupational specialisations and the need for integration (Walker, 2015), (viii) the use of virtual teams composed of geographically dispersed project actors (Bell and Kozlowski, 2002), (ix) degree of completeness of definition of the roles and responsibilities of project actors (Cohen and Palmer, 2004); (x) adequacy of leadership (Project Management Institute, PMI, 2014); (xi) appropriateness of project personnel selection (Remington et al., 2009); (xii) unexpected human behaviour resulting from "the interplay of conducts, demeanours, and attitudes of people" (Project Management Institute, PMI, 2014), (xiii) unexpected results from interactions with other projects or programmes (PMI, 2015); (xiv) lack of alignment and agreement between independent governance and review committees which form part of an organisation's decision making process (PMI, 2015); (xv) the iterative nature of the development of the scope and the design due to lack of project definition, initial project uncertainty, the dynamic nature of the context combined with the inappropriate treatment of all activities as linear, ignoring (in systems dynamics language) feed-back loops (Chapman, 1998).

4.2.5. Site characteristics

The location where the project may be sited may introduce complexity from the scale of ground treatment works required, discovery of unexploded munitions, diversity of geotechnical or geophysical conditions, archaeological finds, discovery of protected species, the extent of environmental studies required, discovery of contaminated ground, extent of connections to existing infrastructure, accuracy of utility company records, or poor site investigation (Wood and Ashton, 2007).

4.2.6. Task complexity characteristics

Lu et al. (2015) record task complexity as a primary source of overall complexity. Brockmann and Girmscheid (2007) list task complexity as the first of their five complexity categories. Task complexity may encompass the following *characteristics* of complexity: design, technology and information management.

4.2.6.1. Design. Complexity stems from the number of design disciplines involved in a project whose inputs have to be coordinated and the number of professional services companies operating in the UK leading to team members working with individuals they have not worked with before. As reported in 2007, 23,500 firms employed 225,000 people (BERR, 2007). This position has changed little since the publication of Sir Michael Latham's influential "Constructing the Team" report, an independent review of construction, commissioned jointly by government and the construction industry. Specifically complexity arises from (i) information exchanges arising from the iterative design process (particularly where as new information becomes available, previous proposals and decisions have to be revisited and the design changed to reflect new information), (ii) poor information management, (iii) misunderstandings between the project 'players' leading to abortive design, rework, conflict, adversarial relationships and contractual disputes, (iv) the practise of designers (during early design development) withholding information that might be useful to other design disciplines for preliminary decision making, comparative analysis or design development due to liability concerns or fear that it may inadvertently incorporated in the final design (Smith and Tardif, 2009);

4.2.6.2. Technology. the literature makes repeated reference to technological complexity, such as (i) experience with technology (Project Management Institute, PMI, 2013; He et al., 2015), (ii) adoption of new technology (Geraldi and Adlbrecht, 2007; Tatikonda, 1999; Vidal and Marle, 2008), (iii) innovative, changing, difficult or cutting edge technology (Remington et al., 2009), (iv) techniques that are unknown or untried and for which there are no precedents (Remington and Pollack, 2008), (v) design problems associated with new products (Remington and Pollack, 2008), and (vi) interdependencies between tasks, teams and technology (Baccarini, 1996).

4.2.6.3. Information. Project information is the lifeblood of projects. Hence information management is one of the most important elements of complex projects. The production, flow and control of information is vital to project performance. Complexity stems from (i) the phenomenon of the increasing volume of project information where model and drawing records can exceed one million (Whyte et al., 2016); (ii) aggressive timeframes and the time available to process information forcing project players to make decisions 'before they are ready' (Oehmen et al., 2015); (iii) the need to incorporate changes to the design to reflect unanticipated environmental and planning conditions or unplanned safety and operational requirements, (iv) the volume of information to be supplied for Gateway Reviews and its suitability (HMT, HM Treasury, 2007); (v) deficiencies in the project scope definition (Fageha and Aibinu, 2013); (vi) incomplete and or uncoordinated design information (Ren et al., 2008); (vii) lack of clash analysis; (viii) incomplete tender information (Jackson, 2007), (ix) the requirement for digital technologies for storage, retrieval and automated search of project data, data integrity and sharing information across organisation boundaries (Whyte et al., 2016).

4.2.7. Delivery complexity characteristics

The construction industry is often given the label 'complex' due to its highly fragmented nature when measured against international standards and in comparison with other domestic sectors (House of Commons Business and Enterprise Committee, 2008). When reviewed in 2007, the UK construction industry had more than 270,000 active enterprises. Over 90% of the 186,000 construction companies employed fewer than 10 workers, and almost 72,000 businesses were one-man operations. At the other end of the spectrum fewer than 130 companies had a workforce of 600 or more, although those firms generated around a quarter of the industry's output by value.

Delivery complexity stems from (i) geological condition (Xia and Chan, 2011), (ii), construction method and techniques (Xia and Chan, 2011; Akintoye, 2000), (iii) buildability of project design (Chan, 1998) site constraints, (Akintoye, 2000), (iv) the urgency of the project schedule (Xia and Chan, 2011), (v) quality of design co-ordination (Chan, 1998), (vi) worker availability (Sinha et al., 2006), (vii) worker communication problems arising from different nationalities working together (viii) worker compatibility arising from different nationalities having a different perspective on social behaviour, values and ethics, (ix) the operation of joint ventures (formed due to the scale of projects) (x) the interdependencies between trades which is both sequential (from a planning perspective) and technological (where for instance the work of the security and fire detection sub-contractors is dependent on the installation by the electrical sub-contractor); (xi) a large number of trades working concurrently at the peak of activity given the tradition of fixed duration construction contracts (xii) multiple concurrent work sites, (xiii) site access problems, (Chan, 1998), and (xiv) the neighbouring environment (Xia and Chan, 2011).

4.2.8. Project governance

Project governance can be a major source of project complexity. Organisations governance and review committees established to help manage projects and programmes make recommendations that are not always aligned with those of other committees or those of project or programme teams (PMI, 2015). As a consequence on occasion this leads to complex problems for a project or programme team. This form of complexity the paper describes is not immediately apparent and is a feature of how those engaged in governance define, record, disseminate and convey their goals, strategies and plans to those lower in the hierarchy who have the responsibility of delivering the project.

4.2.9. Project initiation

The project initiation stage is prone to suffer from complexity and the specific areas commonly involved are described by the National Audit Office in their report "The DECA: Understanding challenges in delivering project objectives", (NAO, National Audit Office, 2013c), which was previously described above in "Initiatives to examine and manage the sources of complexity" and "Framework 4".

4.2.10. Assurance processes

Regardless of the merit of assurance processes (NAO, National Audit Office, 2010), their preparation, adoption and particularly their implementation can add to project complexity. As identified by the Australian Government (2015) assurance processes need to be applied judiciously. The project team's review of the assurance findings, their rebuttal or acceptance and the subsequent implementation of the findings may necessitate revisiting documented strategies, procedures and processes or reworking previously completed scope definitions, estimates, risk assessments, contingency provisions, scope changes and or schedules. The assurance process levels included in the proposed framework below are based on HM Treasury's assurance frameworks document "Assurance frameworks" published in December 2012.

4.2.11. Evolving PM maturity

When megaproject organisations are newly formed, typically many of the project actors have not worked together before and hence strategies, policies, processes and systems need to be prepared, aligned and agreed. As a consequence project management practices are not mature 'out of the starting blocks'. As a project moves through the life cycle, the project management practices evolve, are refined and become embedded. However as identified by Albrecht and Spang (2014) project management needs to be mature to deal with complexity arising from the interaction between project participants (project team, client and suppliers). The rate at which maturity develops will add to or detract from the complexity of the project. KPMG (2013) report that from their experience it takes on average 18 months to move up a level in the P3M3 maturity model. The levels of maturity and their associated description included in the proposed framework are drawn from the well-established project management maturity model P3M3 published by Axelos.

4.2.12. Source of complexity (external or internal)

Very few of the authors make mention of those bodies that a project has little influence over and which may be a major source of uncertainty such as external stakeholders, utility providers, approval bodies and the end customer (if different from the customer).

Conversely the writers recorded in Table 8 clearly delineate sources of complexity emanating from both inside and from outside of projects.

Table 8
Extract of the taxonomy of internal and external complexity indicators proposed by Kian Manaesh Rad and Sun (2014)

Level 1	Level 2	Level 3
External	Economy	Changing economy
		Market competition
		Market unpredictability and uncertainty
	Environment	Stability of project environment
		Interaction between technology system and external environment
	Legal and regulations	Local laws and regulations
	Politics	Political influence
	Social	Cultural configuration and variety
		Cultural differences
		Significance on public agenda
Internal	Organisation/team of delivery (Who?)	Capital resources
		Disciplines
		People
		Physical resources
	Process of delivery (How?)	Information
		Tasks
		Time
		Tools and methods
	Project characteristics (What?)	Objectives
		Technical

Adopting a systems dynamics perspective, a project may be viewed as a system which operates within a series of 'concentric' systems where each system impacts the other systems operating within it (i.e. the 'Transport Industry' system influences the 'External Stakeholders', 'Client Organisation' and 'Project' systems). Fig. 5 developed for this paper illustrates these 'concentric' systems where the 'Project' is central and the influence of the other systems diminishes the more remote they are from the centre. Recognition needs to be given to the fact that there will be aspects of complexity under the control of the project and its respective client organisation (typically but not always the sponsor) and aspects of complexity that will emanate from outside of the client organisation (and its projects) over which the project will have no control and which will give rise to uncertainty. Given the goal of understanding and managing complexity to improve project performance, it is proposed emphasis is given to the distinction between project complexity emanating from aspects under a project's direct control and complexity emanating from a project's context, (as illustrated in the taxonomy of complexity indicators proposed by Kian Manaesh Rad and Sun, 2014). If a project deliberately and consciously elects to incorporate novel technologies, adopt an untried contracting strategy and or fragment the works thereby significantly increasing the number of interdependencies, by its actions it will have in all probability introduced complexity and a greater management burden. Management needs to clearly understand the uncertainty and risk exposure its actions expose the project to. Regrettably risk management is often introduced to assess the consequences of management action rather than being involved in shaping and informing opinion to reduce risk exposure (Chapman, 2014a, 2014b). Aspects of complexity emanating from the project's context will be significantly influenced by the external stakeholder's representatives and their expectations and to a lesser degree the transportation industry, national government/economy and the global economy.

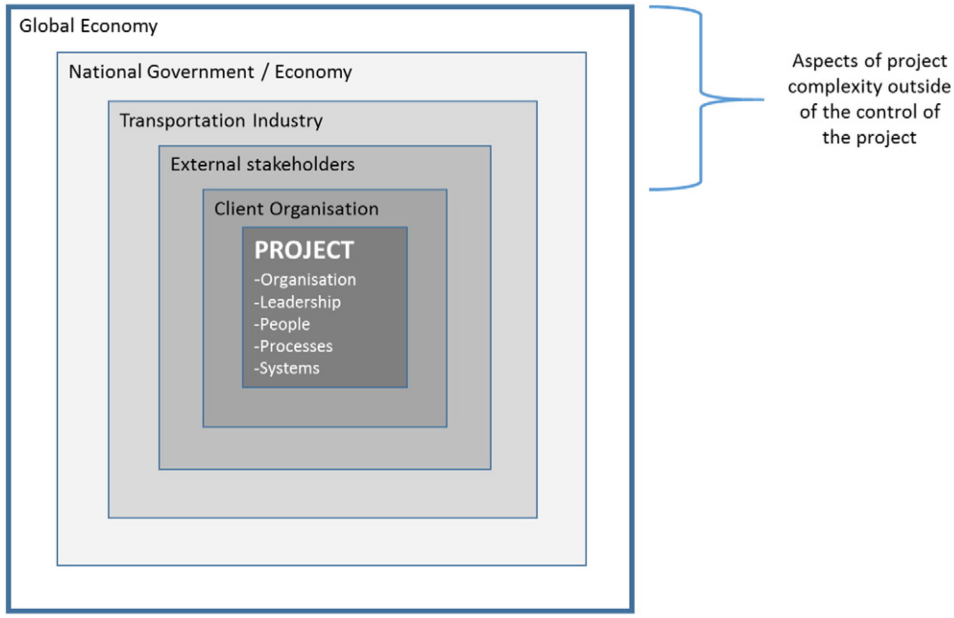

Fig. 5. Project context analysis to illustrate nested systems.

5. Composition of a complexity framework for rail projects

The management of complex rail projects requires a framework of complexity to focus management effort and improve project performance. This framework should be used early in the project life cycle such as during project initiation stage with the aim of supporting decision making. Specifically in terms of (i) accepting complexity or driving simplification where it lies within the control of the project (and does not erode the project objectives and associated benefits) and (ii) managing complexity in the project's environment in terms of for example defining goals, aligning stakeholder objectives, supply chain participation and external approvals. This paper contends there is currently no practical framework of complexity to aid rail megaprojects.

5.1.1. Proposed complexity framework

The proposed framework included in Fig. 6 is composed of five elements, namely project governance, project initiation, complexity *dimensions*, assurance processes and evolving project management maturity. The key component of the framework is the 'complexity dimensions'. The six *dimensions* included in the framework were selected from a review of existing frameworks and confirmed by examination of the literature described in Sections 4.2.2 to 4.2.7 inclusive. The complexity *dimensions* are subdivided into those under the control of the project and those outside of the control of the project. This subdivision reflects the Kian Manaesh Rad and Sun. taxonomy recorded in Table 8. The other four elements of the framework were also drawn from the literature as described in Sections 4.2.8 to 4.2.11 inclusive. It is proposed that these elements will be in a state of flux during the project life cycle and will influence the degree of complexity to which a project is exposed to over time.

5.1.2. Applicability of the framework

The method selected to examine the applicability of the framework was to examine a live rail megaproject. The project selected is currently being implemented and is called High Speed 2. The project's details are described below followed by an examination of the six *dimensions* of complexity drawn from the project complexity framework described in Fig. 6.

6. Case study: High Speed 2

6.1. Background to the project

In January 2012, the UK Department for Transport decided to proceed with High Speed Two (HS2), a programme to develop a new high speed rail network between London, the West Midlands, Manchester and Leeds (Fig. 7). When complete, HS2 will link 8 of Britain's 10 largest cities and serve 1 in 5 of the UK population (Butcher and House of Commons Library, 2015). In total, the scheme is estimated to cost £55.7 billion at 2015 prices including the rolling stock. HS2 is one of the most significant investments in the Great British railway network since the Victorian era, and one of the largest investment programmes ever undertaken in this country (DfT, Department for Transport, 2013a).

The UK government's stated aim is to increase rail transport as the mode of choice for intercity journeys within the UK, while at the same time reshaping the economic geography of Britain by connecting major cities and thereby helping to bridge the north–south divide that has limited growth outside of London and the South East of England.

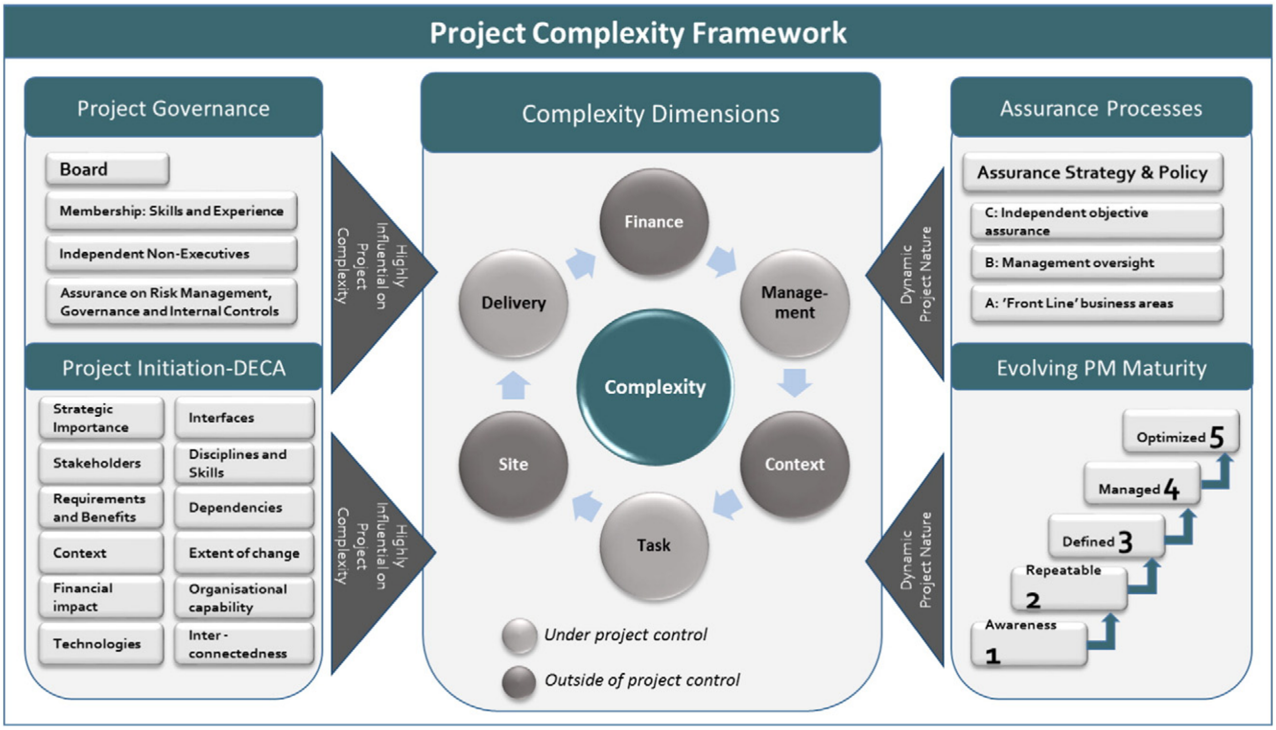

Fig. 6. Framework of the sources of project complexity.

The Department supported its decision with a strategic outline business case.

The Department of Transport's objectives for High Speed 2 are to:

- increase rail capacity to meet growing demand and tackle the projected shortage of capacity on the West Coast Main Line;
- encourage sustainable long-term (including regional) economic growth; and
- help support the government's objectives to reduce carbon emissions, by moving passengers from air and road to rail travel (NAO, National Audit Office, 2013a).

Beyond the dedicated high speed network (between London and Birmingham), trains will connect with and run on the existing major north–south rail routes called the West Coast Main Line (WCML) and the East Coast Main Line (ECML). Provision has been made for extensions to the Phase One network at a later date such as a future link to Heathrow Airport. A previously proposed connection to the existing High Speed One (HS1) in London to allow services to connect to mainline Europe by way of the Channel Tunnel has been removed.

The project will be completed in two phases:

- Construction of Phase One, approximately 230 km (143 miles) long, is expected to take place between 2017 and 2026. It will carry passenger services which will travel at speeds up to 360 kph (225 mph). Powers for the construction, operation and maintenance of Phase 1 is being sought through the submission of a Hybrid Bill to Parliament; and
- Construction of Phase Two, approximately 186 km (116 miles) long, is expected to take place between 2023 and 2033. Phase Two will be the subject of a separate Hybrid Bill submission expected in the next parliament. (The current intention is to bring forward 'Phase 2A' [Birmingham to Crewe] with completion planned for 2017).

6.2. Characteristics of complexity related to High Speed Two

6.2.1. Financial

Overall funding: Uncertainty over overall funding to meet the cost of the programme (cost estimate has exceeded funding including contingency).

Available contingency: Uncertainty over availability of contingency in-year or overall to meet the demands of the programme.

In year funding: Uncertainty over in-year funding necessitating an application for additional funds to the DfT.

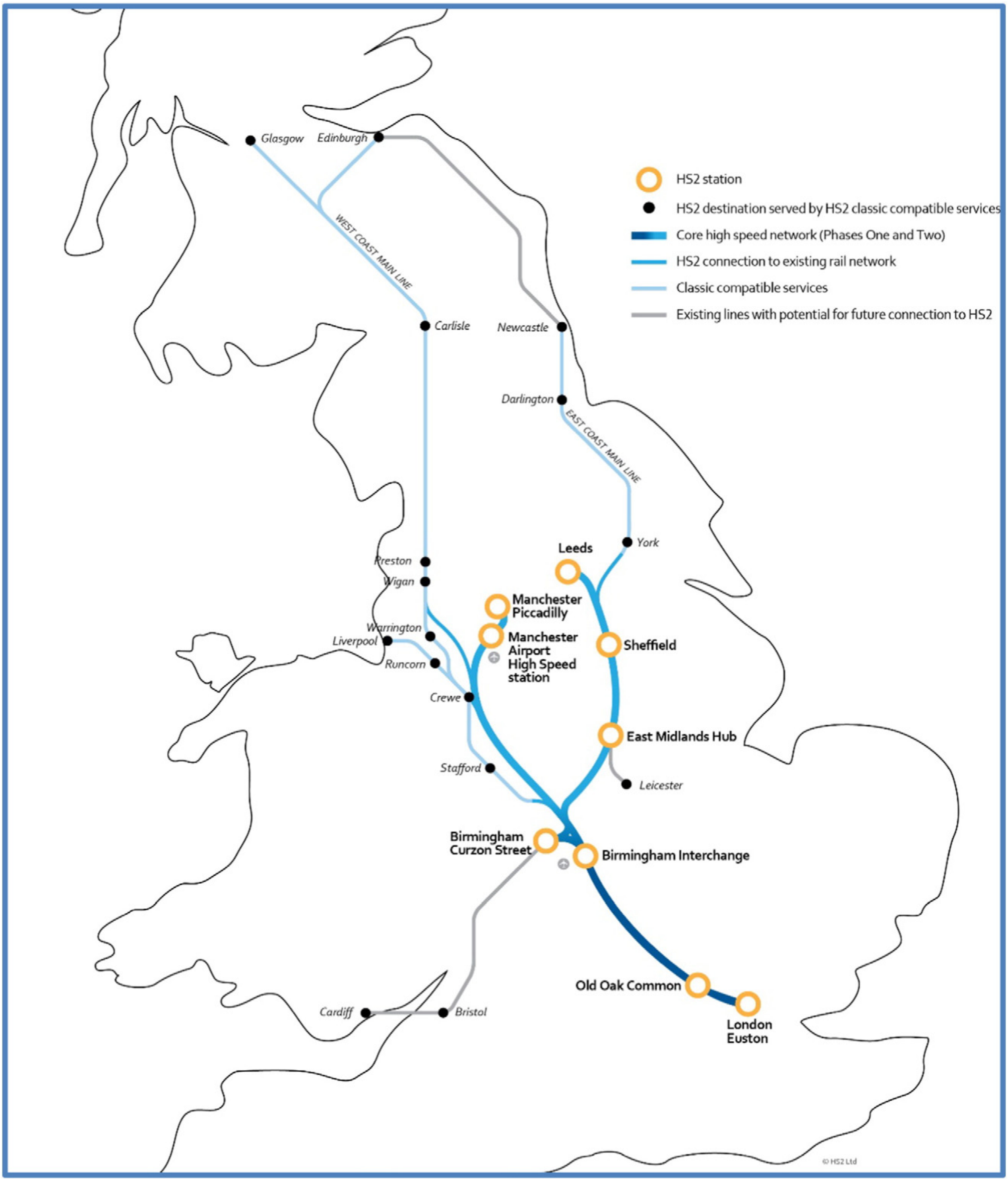

Fig. 7. Map of High Speed Two (Source DfT, Department for Transport, 2013b).

Payments to contractors: Uncertainty over timely and or accurate payments to contractors.

Financial records: Uncertainty over ability to prevent financial records being maliciously compromised through cyber-attack in terms of their integrity, availability or confidentially.

6.2.2. Context

Stakeholders: There are particular risks for the Department if it fails to effectively meet or manage stakeholders' expectations. The government's January 2012 decisions were subject to judicial review and the hybrid bill process allows dissatisfied stakeholders to petition Parliament for programme changes, which may add delay and cost. The Department faces challenges managing the concerns and aspirations of many stakeholders including members of government, local authorities, rail passengers and operators, citizens, interest groups and technical partners. HS2 Limited has a director responsible for external and parliamentary relations including stakeholder and community management, while the Department is responsible for managing relationships with other government departments.

Political support: The programme needs cross-government support and coordination, however, the Department has not always managed this effectively. For example, there was a lack of clarity between the Department and HS2 Limited over the full requirements to comply with cross-government approval processes which meant the company's original timetable for letting some contracts was unachievable. The Department has carried out some consultation with the rail industry and other stakeholders, such as the Office of Rail Regulation, but has not taken full advantage of their expertise on operating services, forecasting operating costs and revenues, and establishing regulatory frameworks and industry structures.

6.2.3. Management

Responsibilities: The two primary parties involved in the project are the Secretary of State (SoS) for Transport (acting on behalf of the UK government) and HS2 Limited. While the SoS is responsible for the policies of the UK Department of Transport (DoT), the SoS has wide ranging responsibilities for HS2 which include acting as the funder and sponsor of the project, being accountable for the delivery of the benefits of the wider HS2 programme and defining the operational model of the railway. HS2 Limited is responsible for the delivery of the railway, the execution and completion of the works, the acquisition of land, acting as the Proxy Operator and the performance of the Operations. In summary HS2 Limited is the delivery agent for the project and is wholly owned by the SoS. The primary agreement between the two parties is the Development Agreement established in December 2014.

Organisation: Within its Delivery Strategy HS2 Limited state designing an organisation to address the complex requirements and challenges of HS2 was a complex challenge in itself. *While the scale, duration and individual components of complexity may have equivalents elsewhere, the combination within the HS2* [*project*] *is believed to be unique. Its stakeholders rely on HS2 Limited to not simply deliver a railway but to deliver an integrated, high performing, sustainable new HS2 business, supporting a range of benefits.* […] *HS2 is the first new Railway and Railway business to be launched* [*in the UK*] *in 115 years.* The strategy advises that the organisational structure will be assured as being 'fit for purpose' through periodic senior level review.

PM Team: HS2 Limited has recognised that it is critically important for the efficient delivery of the project that it acquires and develops the required people and capabilities in sufficient time to deliver the project to schedule. Achieving the required headcount represents a number of challenges in terms of estimating the required headcount, the availability of the skills in the market place and the ability to attract and retain high calibre personnel.

Governance: The programme has a complicated governance structure. This is because the DoT aims to preserve some independence for its development body, HS2 Limited, while also maintaining effective governance. The effectiveness of the governance structure depends on a clear understanding by those involved of their respective roles and responsibilities. The HS2 Delivery Strategy states that HS2 Ltd. will progressively implement governance arrangements tailored to the objectives, complexity, phases and wider context of the programme and ensure compliance with both statutory regulations and the public sector controls appropriate to an Executive Non Departmental Public Body.

Assurance: HS2 Ltd.'s Assurance Model adopts the 'Three Lines of Defence' approach as recommended by HMT guidance on 'Assurance Frameworks' (HMT, HM Treasury, 2012) and the APM's Guide to Integrated Assurance (APM, Association for Project Management, 2014). The first line of assurance is conducted by the programme delivery units themselves, the second line is delivered by the programme assurance function (independent of the first line) to provide oversight and challenge and the third line is conducted by internal and external auditors, regulators and when considered appropriate external consultants.

Sub-strategies: HS2 Ltd. has developed 19 discreet sub-strategies under the overarching Delivery Strategy which have been grouped under the headings of: 'understanding HS's stakeholders and ensuring value is delivered to them' (example: benefits realisation strategy), 'delivering the right things' (example: design strategy), 'delivering the right way' (example: procurement strategy), 'controlling delivery' (example: risk management strategy) and 'managing knowledge and information' (example: BIM strategy). The number of strategies creates a significant coordination burden to avoid duplications or contradictions.

6.2.4. Site

Site conditions: Given the length of the work sites, there is the potential for the discovery of unanticipated archaeological finds together with possible unrecorded: geotechnical and geophysical characteristics, live services, redundant services, ground contamination, buried structures, old industrial workings, protected flora and fauna, water courses and protected species. Geotechnical conditions will be particularly critical given the extent of the planned cuttings, embankments, tunnels and under-bridges.

6.2.5. Task

The design, construction and operation of the railway will be very challenging. For instance:

Train speed: Designing a railway infrastructure for trains to travel at 225 mph (and safely pass each other when travelling in opposite directions) which has not yet been accomplished in the UK.

Rolling stock: Testing and commissioning rolling stock for operation at 225 mph has not yet been accomplished in the UK. Providing the rolling stock with suspension that can actively shift modes when it is running at high speed or on what is termed the classic network (existing track).

Systems: Uncertainty over establishing systems which can manage up to 1100 people entering (or exiting) a station, platform and train every 3 min.

Track: Uncertainty over contractor's ability to consistently lay track so that there is no more than 6 mm deviation between the rails-through tunnels, up gradients, across viaducts and through cuttings.

Headway: Controlling and running 18 trains per hour in each direction.

6.2.6. Delivery

Construction interfaces: Uncertainty over the management of civil-to-civil contractor interfaces and civil-to-railway system contractors where contractor interfaces may lead to delays, disputes and conflict. Phase 1 will be divided into five delivery areas, with 3 to 5 contractors working in any delivery area supported by 2 to 4 'secondary' contractors.

Contractors: Uncertainty over the performance of single contractors or newly formed joint ventures which will not be eradicated through tender processes.

Concurrent working: There will be considerable concurrent working of contractors which will introduce uncertainty over logistics management, movement and storage of materials together with movement of excavated material and plant and the management of security.

Equipment: Uncertainty over the productivity rates of track equipment until the equipment is in use and production can be monitored.

6.3. Classifying High Speed Two as a complex project

A way of summarising the complexity issues facing High Speed Two is to make a comparative analysis with a simple rail project involving an extension to the existing Classic Rail Network. The same *dimensions* of complexity illustrated in the framework are adopted for the comparative analysis.

Table 9
Classification of HS2 as a complex project

Element of complexity	Simple rail project	Complex rail project /HS2 (summary only)
Finance	• Funding included in 5 year plan without the need for dedicated application for government funding.	• Government funding (overall provision and annularity) • Contingency definition and drawdown. • Application for additional funding. • Cost base and management of inflation.
Context	• Known external stakeholders with predictable behaviours and requirements. Localised planning authority processes without the need for a Hybrid Bill.	• Number of external stakeholders and communication requirements. • Potential for legal challenge • Programme duration and the number of general elections during the life of the project. • Requirement for Hybrid Bill for both Phase 1 and Phase 2. • Need to engage Ministers and local political and economic leaders along the route.
Management	• Existing Network Rail governance structure and decision making processes. Established project management team, methodology and processes.	• Delineation of the responsibilities of the Dept. of Transport and HS2 for cross-government support. • Number of committees and attendees at each. • Implementation of a matrix organisational structure • Size of the project management team • Roll-out of the selected project management methodology • Assurance process and the 3 Lines of Defence • The role of the Project Representative to provide assurance processes. • Definition of the benefits and measures to determine that they have been realised.
Site	• Small area of land take and purchase of a small number of businesses and dwellings.	• Number of compulsory purchase orders. • Number of buildings to be managed prior to demolition. • Number of buildings to be demolished • Varying geotechnical, geophysical and topographical conditions. • Number of environmental impact assessment contracts.
Task	• 5 km extension to existing Classic Rail Network over location of former railway track to accommodate existing rolling stock at current operating speeds using existing signalling system	• First new railway business to be launched in the UK in 115 years • First high speed railway in UK operating at 225 mph • Production of rolling stock to meet travel speeds • Headway (18 trains per hour in each direction) • Phase 1: 225 km in length (Crossrail is 21 km in length) • ERTMS signalling system to accommodate 225 mph trains
Delivery	• Tender documents issued to contractors previously engaged on the network. • Single civil contractor. • Railway System contractors familiar with local area of the network. • Minor road closures of a temporary nature.	• Number of concurrent civil contracts • Number of civil-to-civil contractor interfaces • Number of railway system to civil contractor interfaces • Number of contractor to local authority interfaces • Number and duration of road closures and community interfaces • Number of tender and contract documents • Number of contractor compounds and temporary land take • Managing adverse impacts of construction • Interfaces between railway systems and viaducts, tunnels, embankments, cuttings, bridges and drainage systems.

7. Discussion

In summary the complexity framework proposed in this paper places greater emphasis on: all aspects of the project life cycle including finance and context; the *characteristics* of complexity relating to rail projects; and the aspects of complexity within and outside of the control of a project. In addition the framework suggests that the degree of complexity changes over time due to aspects of initiation, the evolving maturity of project management, the intrusiveness of assurance processes together with decision making and governance processes effected by senior management. The implications for the project management profession are very significant in terms of project performance overall and the achievement of objectives, specifically achieving the cost plan and schedule. Complexity must be considered across the whole project life cycle. While the frameworks examined had extensive coverage (in terms of the high number of complexity *characteristics* identified) they all had major omissions when compared against the life cycle. It could be concluded that the original pre-occupation with technological and organisational complexity during early research in the late 1990s has coloured contemporary thinking and as a consequence complexity has not been considered for all project stages. The project management function must seek to understand and respond to complexity from initiation to handover. For those aspects of a project which are under the management team's direct control, the decisions the project management function make can introduce complexity *over and beyond* the complexity it has to accept and absorb to achieve the project's objectives and the benefits it seeks to realise, unnecessarily exacerbating its management burden. This specifically relates to governance, organisational structure, adoption of novel technology, selection of procurement route, the packaging strategy and schedule duration. For rail projects they have the added dimension of the impact of complexity on passenger safety during both trials and operation. For those aspects outside of a project's direct control project management must be attuned to the sources of uncertainty and ambiguity. Given that risk management explicitly addresses uncertainty, tailored but mature risk management practices should be adopted. Project risk management is internationally recognised as a vehicle to predict, examine and take proactive action to remove or reduce the threats to a project's objectives. Research has shown that effective risk management is positively correlated with improved project performance, (Irimia-Diéguez et al., 2014; Junior and Monteiro de Carvalho, 2013; Raz et al., 2002; Zwikael and Ahn, 2011). When responding to imposed complexity from the environment, (see Table 8) effective decision making is paramount. However effective analysis of alternative courses of action will only occur when there is an understanding of the threats and opportunities associated with each. As a consequence risk management must be at the heart of decision making (Flyvbjerg et al., 2003a). In addition, while there is broad recognition that projects are dynamic in their nature, the project management function must recognise that a project's degree of complexity changes over its life. As aspects of a project's governance, organisational structure, scope definition, assurance processes and project management practices mature, the degree of complexity will fluctuate over time. Project management practices in particular mature over time especially on megaprojects and hence will contribute to complexity to varying degrees during the life of a project.

8. Conclusions

The contribution this paper makes is the presentation of a complexity framework which goes beyond existing frameworks in that it considers the dynamic nature of projects. It considers for instance the evolving maturity of project management practices, the application of assurance processes and the adaptation of project governance to suit the needs of a project overtime. In addition emphasis is placed on those aspects of complexity under the control of the project and those emanating from its environment. The framework is unique in that it focuses on rail projects and examines complexity *characteristics* relating to this industry. Possible avenues of further research are to use the framework on a large number of live rail megaprojects so that the appropriateness of the *dimensions* and *characteristics* of complexity and the drivers of the dynamic nature of complexity can be more rigorously assessed with the goal of determining a universally applicable framework. Risk management practices which use frameworks to support risk identification and assessment would then be able to place greater reliance on such inputs to the overall risk management process.

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