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Variability and delusions of precision

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Engineering construction projects are complex undertakings both as products and as processes for their realization, operation and disposal. However, the thinking, tools and techniques which are employed remain firmly embedded in reductionist determinism. The widespread criticisms of project and project management (realization) performances are hypothesized to be significantly attributable to distortions which are endemic in and occasioned by the 'traditional' perspectives and approaches. Underpinning assumptions include people knowing what they want, articulating those requirements and constraints, and communicating them effectively. Those requirements etc. are then, essentially, fixed as the basis for the project, despite the likelihood of their being incomplete, inconsistent and relating to one, or very few, primary stakeholders only. Fragmentation of industries and project organizations lend credence to the complexities of projects and the imperative of integration of the myriad specialists. Projects as complex adaptive systems co-evolve and are self-organizing along irreversible trajectories which are sensitive to initial conditions. Thus, sensemaking and reflective practices are vital in determining effective solutions. A pervading theme is the 'fallacy of fixity', in determining requirements, producing and using databases, and forecasting. Many 'hard' techniques are available for incorporating variability but the 'soft' considerations are instrumental in determining what is done, how and with what results. Incorporating 'soft' variabilities is fraught with issues of human perceptions, cognition and decision-making. This paper examines issues of variabilities in data and information and consequences for projects and organizations. Propositions that: (a) current perspectives and techniques fail to address variabilities adequately and so, false beliefs of precision of performance prediction arise; thus, (b) a paradigm shift is required from deterministic reductionism with assumptions of certainty, fixity and control to stochastic, holism, in which emergence, flexibility and self-organizing are accommodated in the project realities of ambiguity, variability and uncertainty—are supported but further, empirical research is needed as well as implementation of knowledge into practice.

Keywords: Complexity, decisions, errors, forecasts, interdependence, sensemaking.

Introduction

Engineering construction increasingly comprises complex projects involving many, diverse stakeholders (Hobday, 1998; Miller and Lessard, 2000; Miller and Hobbs, 2002). Complexity concerns the individual and combinations of technologies that are employed to realize a project and to operate the project in use, as well as the organizations and their assembly through all stages of the project life-cycle. Project complexity comprises the categories of structure and uncertainty (Williams, 1999). The structure category comprises differentiation (the number of elements, division of tasks, etc.) and interdependency (the interrelatedness/connectivity of the elements); the category of uncertainty relates to the goals of the project (stakeholders) and the methods available/adopted for their pursuit. Not only are engineering products and their realization processes complex but so is the performance package of the project-in-use as required by the client (Caldwell *et al.*, 2009); essentially, clients buy complex performance packages rather than projects/products per se.

The constituents of engineering construction projects dictate that the input of specialisms is extensive. The design and construction (realization) processes often require major inputs from numerous, diverse engineering disciplines, financial institutions, management

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organizations and regulators (see e.g. Hong Kong International Airport Project, 2012). Many of those specializations are also required during operating (and adapting) life and during final disposal. Further, major projects secure inputs across many national borders—thereby extending the categories of cultural interactions (corporate, professional, national) and hence, the need for integration which is sensitive to accommodate those differences in order to reduce, if not, avoid, affective conflict.

Whilst it is patently obvious that engineering construction projects are complicated (comprising many, diverse inputs), the recognition that they are complex moves requisite analysis to a higher level (Winter *et al.*, 2006). Thus, the tools and techniques in widespread use to manage such projects, resultant information systems and performance expectations are likely to be significantly deficient and so, causal of problems. In accordance with the view of Chinowsky (2011), this paper argues that a paradigm shift is required to move project-oriented thinking and managerial techniques to acknowledge and reflect the realties inherent in complex projects: from linearity and determinism towards nonlinearity and stochasticism.

The argument is focused on two propositions that: (a) current perspectives and techniques fail to address variabilities adequately and so, false beliefs of precision of performance prediction arise; thus, (b) a paradigm shift is required from deterministic reductionism with assumptions of certainty, fixity and control to stochastic, holism, in which emergence, flexibility and self-organizing are accommodated in the project realities of ambiguity, variability and uncertainty.

Context and practices

Adopting the perspective that management is 'making and implementing goal-directed decisions concerning people', certain critical aspects are apparent. People are both the focus through their exercising demand—and having (perceived) need converted into demand [public sector perspective]—and the 'active' factor (resource), in many forms, through which the demands are met. Decisions must be 'forward-looking' as only the future can be influenced and goals indicate purposes, pathways and mechanisms. A major concern is the vast gamut of human (psychological) 'frailties' relating to decision-making, behaviour and interactions (Kahneman, 2011).

Winter *et al.* (2006, p. 640) articulate a chronologically based typology of models of current project practices as '… the rational, universal, deterministic model … "hard" systems'; '… organisational structure'; '… context and front end, … and managing … exogenous factors'; '… context, … experience and "contingent" capabilities'; '… projects as information-processing systems'; and '… critical management perspective'. Those models are reviewed for content and contextual application and produce a resultant, suggested research agenda comprising theory about practice, theory for practice and theory in practice. It is the theory about practice and the theory for practice categories which concern advancing theory as well as its subsequent application and so, impacts on theory in practice—i.e. process development and innovation (which involves education and training also) (Winter *et al.*, 2006, p. 641).

Lawrence and Scanlan (2007) determine eight primary causes of poor performance/failures on engineering projects: '… poor initial planning, lack of clear objectives and deliverables, lack of understanding of dependencies, inadequate resource allocation, poor risk analysis, poor change management, lack of "buy-in" from stakeholders, poor understanding of priorities' (p. 511). They assert that many of the problems result from persistent use of outdated project planning and management tools and techniques which are linear, reductionist and deterministic and so, cannot cope with iterative working practices and the complexities in realizing modern engineering projects (which involve emergent criteria, sensemaking and reflective practice). A further, generic issue is inadequate communications between project participants (see also: Higgin and Jessop, 1965), a problem exacerbated by participant diversity and by IT systems (Flyvberg, 2009)—which, often, have significant incompatibilities.

Integration: the need for holism

> The increased performance requirements and complexity of constructed facilities require additional specialists and increase the need for integration skills. Multi-skilling is rare and document-based thinking is prevalent … . Appreciation of linkages between work products in different functional areas, and the ramifications of this interdependency, is limited. (Owen *et al.*, 2010, p. 235)

That complements the observations of Baiden *et al.* (2006) that selection of project participants remains based on technical expertise and price, whilst ignoring their ability to integrate and work together. Those observations reflect the expanding complications of projects—which promote increasing specializations; however, in order to realize a project, those specializations are interdependent and so, must be integrated to overcome problems of fragmentation.

Usually, project realization and its planning is treated in a reductionist way by splitting a project into manageable components (e.g. procurement system: composed of people, processes, functional mechanisms—differentiated into project phases dominated by different 'teams' of consultants and/or specialist contractors, etc.) which are analysed individually and the results combined additively (e.g. Reugg and Marshall, 1990; Lawrence and Scanlan, 2007; RIBA, 2008). Similar concerns arise in respect of constructors' tendering by analysing drawings, bills of quantities, etc. into work breakdown structure, then method statement, programme, estimate and tender—all of which should be interactive but, perhaps due to time pressures, tend to be executed in parallel, deterministically and quite independently of each other. Thus, holistic/synergistic impacts of component combinations are omitted (Lucas, 2005) and the effects of merge events are ignored (MacCrimmon and Ryavec, 1964). In consequence, the engineering construction industry is criticized widely for (alleged) poor performance for which fragmentation is commonly asserted to be the cause (e.g. Latham, 1994; Construction Industry Review Committee, 2001), whether vertical (Egan, 1998), horizontal (Higgin and Jessop, 1965), spatial or temporal (Fellows and Liu, 2012); often, a combination.

Uncertainty: determinism in decisions

Reugg and Marshall's (1990) findings epitomize many of the behavioural issues involved when they characterize construction project price forecasts as 'best-guess', conglomerate estimates of input variables but that those forecasts are treated as certain estimates with the results presented in single-figure, deterministic terms. That is exacerbated by the common trait of readily transposing the forecasts into targets for performance which, then, become expectations and 'reference points' for evaluations of realizations (see e.g. Kahneman and Tversky, 1979; Kahneman, 2011) leading to cognitive dissonance (Festinger, 1957) of stakeholders (notably, clients).

Even within organizations (permanent, temporary; individual, multi) fragmentation of activities remains rife—'PMs [project managers] are not involved in overall planning, and are limited to implementation planning' ([ ] added; Ika and Saint-Macary, 2012)—a manifestation of narrow framing (project rather than programme) that leads to overconfidence in forecasts and decisions (Kahneman and Lovallo, 1993). That complements other findings of Kahneman and Lovallo (1993) that managers' self-image as prudent decision-takers arises, at least in part, because working practices separate decisions and consequences and so, managers are more prone to take risks because '… they do not expect that they will have to bear them' (p. 29)—i.e. the risks are passed on to others in the temporary multiorganization (TMO) who are distinctly separated, even if within the same permanent organization (e.g. estimators, tendering managers, buyers, quantity surveyors; planners, site production managers). The matter is exacerbated by the illusion of control, by lack of scaling—near proportionality (large amounts of potential loss/gain are treated very similarly to small amounts), by isolation errors (anchoring plans in prior successes), by adoption of the 'inside view', etc. (Simon, 1957; Kahneman and Lovallo, 1993; Hammond *et al.*, 2001). The consequence is a strong optimism bias which results in the 'winners curse' on the part of both evaluators and evaluatees (see e.g. Flyvberg, 2009); important effects such as baseline probabilities and regression to the mean and so, the importance of pure chance, are (almost invariably) ignored (For an authoritative and extensive exposition of mechanisms of and influences upon decision-making, see Kahneman, 2011).

The reality of many decisions is summarized by Bachmann (2001, p. 364) '… background beliefs and tacit knowledge are much more important in determining social actors' behaviour than explicit calculation over potential gains and losses associated with specific decisions'. That articulates the importance of humans' intuitive/instinctive system which reacts to external stimuli 'automatically' (denoted 'system1' by Kahneman, 2011)—as in 'knee-jerk reactions' and the 'garbage can model' of decision-making. Both the political and bounded rationality decision models involve Kahneman's 'system 2'—the cognitive, evaluative psychological processes.

Some current perspectives on projects

This section examines three important, recent theoretical developments with a view to informing theory about practice and theory for practice in the context of a cognitive paradigm shift to a stochastic, holistic perspective of engineering construction projects as complex adaptive systems to inform decision-making processes further.

Complexity

Complex adaptive systems (organizations) are characterized by four key elements: (1) agents with schemata, (2) self-organizing networks sustained by importing energy, (3) coevolution to the edge of chaos and (4) evolution based on recombination (Anderson, 1999). 'Strategic direction of complex organisations consists of establishing and modifying environments within which effective, improvised, self organised solutions can evolve' (Anderson, 1999, p. 216). A particular feature of complex systems is holism—the performance of the system is not the simple, arithmetic sum of its individual components as synergy occurs (Anderson, 1999; Bertelsen and Emmitt, 2005; Lucas, 2005).

A complex system comprises a large number of parts that have many interactions (Simon, 1996) which make up a whole that is interdependent with a larger environment (Thompson, 1967). Daft (1992) equates complexity with the number of activities or subsystems within the organization, noting that it can be measured along three dimensions. Vertical complexity is the number of levels in an organizational hierarchy, horizontal complexity is the number of job titles/departments, and spatial complexity is the number of geographical locations. Given the temporal changes in construction TMOs (participants and their agents/representatives), a dimension of temporal complexity should be included.

Because complex systems are nonlinear, their behaviour is hard to predict (Casti, 1994). Intervening to change an initial condition(s) and/or one or more parameters a small amount can affect the behaviour of the whole system significantly (Anderson, 1999)—an important consideration for project performance prediction and control endeavours. Further, 'complex systems tend to exhibit self organising behaviours: starting in a random state, they usually evolve toward order' (Anderson, 1999, p. 217), which accords with the informal system through which engineering construction projects operate (Tavistock Institute of Human Relations, 1966). Thus, attention to 'front-end' management of projects is essential (Cherns and Bryant, 1984; Morris, 2011).

Complex adaptive systems' structures and outcomes emerge through adaptations due to the efforts of individual agents who attempt to improve their own payoffs through opportunistic behaviour (Williamson, 1985); but those payoffs depend on the choices that other agents make also (as under oligopoly and game theory)—typically the case on complex engineering construction projects involving multi-stakeholders (Rooke *et al.*, 2003). Hence, agents (project participant organizations and their representatives) co-evolve with one another where local adaptations lead to the formation of continually evolving niches/coalitions (Anderson, 1999). Thus, complex systems do not operate at equilibria of globally optimal system performance—value conflicts concerning goals, processes, etc. are resolved as compromises amongst multi-stakeholders (through satisficing—Simon, 1996) so that apparent disequilibrium is actually a dynamic equilibrium (Morel and Ramanujam, 1999), analogous to Cournot equilibrium. Hence, agents shift/manoeuvre activities and behaviours to maintain equilibrium with associated co-evolving systems by balancing the needs/goals of multi-stakeholders both within and external to the project TMO. Thus, organizations can continue to exist only if they maintain a balance between flexibility and stability and so, the strategic equilibrium over time for an organization is a combination of frequent small changes made in an improvisational way (e.g. evolving use of subcontractors) that occasionally cumulate into radical strategic innovations, changing the terms of competition fundamentally (e.g. imposition/adoption of the private finance initiative) (Weick, 1979; Brown and Eisenhardt, 1998).

Adaptive entities comprise an adaptive inner environment and complex adaptive systems are nested hierarchies which contain other complex adaptive systems (Simon, 1996). Every aspect of a complex adaptive system (agents, their schemata, the nature and strength of connections between them, and their fitness functions) can change over time, i.e. new systems may appear, old systems may become extinct and existing ones may survive in a fundamentally new form. Hence, a complex engineering project is an adaptive entity containing an adaptive inner project environment with its own nested hierarchies of complex systems of participant organizations and an external project environment with complex stakeholder network systems (see e.g. Walker, 2007).

Feedback/feed-forward is vital for adaptive coevolution, self-organizing and control endeavours. Feedback is, essentially, a monitoring/reporting mechanism to inform management for control and performance improvement endeavours; feed-forward operates for predictive control. Control seeks to change the, otherwise, prevailing conditions, often on an incremental, iterative basis, in a goal-oriented direction. Negative feedback acts to return a system to its prior/initial state—stable equilibrium (yielding an ordered system)—due to their dampening the influences of variables. Positive feedbacks reinforce changes made in variables and so, small changes increase geometrically—explosive equilibrium (leading to collapse of the system; total chaos). With both positive and negative feedbacks, the system may reach a stable equilibrium (point attractor), may return to a previous state periodically (periodic stability; periodic attractor) or its behaviour can be more complex, including being completely erratic, or 'chaotic'—the system's behaviour is contained within a strangely shaped surface (strange attractor) (see Thiétart and Forgues, 1995).

The state of a system depends upon the natures and strengths of the relationships between agents and their consequent behaviour—as in the power-based perspective on behaviour of project TMO participants (Liu *et al.*, 2003). Acknowledgement of the impact of the relationships between the agents in a system contrasts with traditional paradigms of systems in which the agents are the foci in designing systems as deterministic, predictable chains of addable parts to achieve a specified 'primary task' (reductionism).

Sensemaking

People strive constantly to make sense of the continuous, complex, ambiguous and equivocal dynamics of existence (Weick *et al.*, 2005; Brockmann, 2011). That requires securing data and interpreting them through experiences and learning to make sense of them in context. Information, as interpretations of data, is employed also but as statements of meaning as determined by others and so, accepted in full, in part, or rejected; information bandwidth (amount) and fidelity (reliability of content) tend to be related inversely (Cronbach, 1990).

Forward-looking sensemaking adopts a becoming ontology (Winter *et al.*, 2006), and considers '… uncertainty as an issue of ontology rather than an issue of epistemology' (Weick, 2005, p. 63). Given human cognitive limitations (Simon, 1996), sensemaking requires simplification of the data and information through heuristics. Thus, sensemaking involves cognitive, intuitive and reactive construction of meaning and so, is likely to fall short of being completely rational; bounded rationality applies (Simon, 1996). By addressing the question 'What's the story?' (Weick *et al.*, 2005), sensemaking endeavours to avoid the stigma of a 'bad decision' (outcome) and, through fostering a narrative approach, generates a rich picture of the emerging project.

Sensemaking is a rationally driven, self-oriented activity but within the human limitations in decision-making (see, Kahneman, 2011). Weick (1995, pp. 61–62) articulates seven primary aspects of sensemaking:

Identity: who individuals think they are, and their context—shapes how persons interpret events and what they do;
Retrospective: learning from what the person said, did, etc. and perceptions of past events—experience and reflective practice;
Enactment: understanding is enhanced by the person's statements and actions;
Social: persons' statements, behaviour, etc. are determined by their socialization experiences as well as by considering the prospective audiences—professional behaviour towards society as well as the client/employer;
Ongoing: Statements and actions occur continuously in a world of statements and actions of self and of others—they may be subject to feedback and reflected on after their occurrence and reviewed against criteria which have changed—emergence of requirements, and interdependence of participants in producing performance;
Extracted cues: the focal content of a thought is a small element of the total statement, which incorporates aspects of personal dispositions and of context;
Plausibility: a person needs to know (only) sufficient to enable them to decide and act so, provided the information appears plausible to that person, its accuracy and validity are unlikely to be investigated—especially important when deciding under pressure of time, yielding satisficing solutions.

Sensemaking is important for addressing non-routine issues and problems—most appropriately using controlled thinking (system 2). As non-programmed problems involve unexpected elements, there is a tendency for people to normalize them and conflate the instant problem with something within the person's experience (memory). Especially if solving the problem requires pooled interdependence of expertise (as in designing a building), the solution-seeking process is likely to '… induce automatic, skill-based thinking which is more suited to routine [programmed] problems' ([ ] added; Weick, 2005, p. 56)—the antithesis of the reflective practice advocated for effective project realization (Schön, 1983).

Sensemaking may be regarded as what is done in practice to enable people to 'feel comfortable' with the decisions they take and the actions which ensue—that their understanding of the situation is adequate in the context of logical, social and legal norms. In agency contexts, a primary understanding relates to the requirements and constraints of the principal (such as commissioning client's performance criteria for a project). As the members of the project TMO are drawn from several disparate communities of knowledge and practice, the need to reach an appropriate and common understanding of what the project is required to achieve, both process and, especially, product, is essential. Unfortunately, the briefing process is notoriously problematic, often hurried and overly linear such that common understanding of requirements is rather rare and plausible solutions result (but see Luck, 2003, 2007) In addition, what is 'comfortable' may not always accord with the principal's and contextual needs. Ostensibly, project managers repeatedly tailor services to the client and context yet, in reality, tailor to their own 'comfort zones' (Wells and Smyth, 2011).

'When information is distributed amongst numerous parties, each with a different impression of what is happening, the cost of reconciling these disparate views is high, so discrepancies and ambiguities in outlook persist' (Weick *et al.*, 2005, p. 418). That is an apposite perspective for engineering construction projects which comprise networks of nodes of specialist expertise with relationships and interactions occurring between them. However,

> The problem with network structures is that reciprocal interdependence is most readily achieved on a local basis amongst small sets of players. As more subsets are hooked together, the interdependence drifts from reciprocal to sequential to pooled. Coincident with this drift is a shift from controlled cognition to heuristic cognition and finally to automatic cognition. (Weick, 2005, p. 57)

—thereby constraining the potential of sensemaking through enhanced reliance on experiential and 'standard' solutions.

In addressing wicked problems (Kunz and Rittel, 1972), such as the realization of an engineering construction project (Coyne, 2005), sensemaking must pay attention to every item of data and information. Less heedful approaches involve normalizing (mis-identifying new data as sufficiently approximating experience), reduced awareness of what is being omitted and discarded, and '… susceptibility to the fallacy of centrality' (Weick, 2005, p. 62).

Throughout realization, construction project realities are social constructions, each of which is an interpretation by a participant, likely to be framed as a progressively emerging narrative of what that participant would like the project to be (facilitate for that participant). Hence, project management involves capturing, understanding and communicating the essences of those emerging narratives and facilitating the development and agreeable adoption of a solution. That process is fraught with politics as the evolving project outcome constituents are contested through the constantly changing power distribution in the project TMO and the adopted solution is negotiated (Liu *et al.*, 2003; Alderman *et al.*, 2005).

Thus, sensemaking should extend beyond the 'technical' differences across boundaries to include understanding the relationships between project participants and consequences of behaviours. That should contribute not only to competitive advantage/performance through enhanced understanding of the 'technical' issues and requirements of the participants but also to enhancing interactive participation (Fellows and Liu, 2012)—if only, by recognizing potential advantages through value enhancements. Hence, project management would move beyond experienced-based, plausible solutions to incorporate the emerging requirements of stakeholders through more heedful, reflective practices.

Forecasting

As the future is, by definition, unknown, people seek means for reducing perceived ambiguity by fixing demands early, and uncertainty through forecasting (commonly, via extrapolation) in attempting to manage the risks envisaged. Producing forecasts involves data, information, techniques and decisions. The consequences of forecasts depend on comprehension of the processes and contents and how the results are understood and used in making decisions—notably, both the 'technical' and human limitations. Peoples' risk aversion fosters preference for the status quo and incremental change; also, it encourages fixing requirements and solutions early through desiring to minimize ambiguity and uncertainty. The experiential base of sensemaking encourages reliance on databases to support forecasts and, thence, decisions.

Data

No measurements are absolutely accurate—the question is whether the errors matter and, if so, their magnitude(s) and direction(s). That is an issue of consequences and so, relates to human understanding and action. As increasing accuracy is geometrically expensive, accuracy achievement is subject to marginal cost–benefit analysis. The focus here is primary data. As information comprises data which have been processed and interpreted by others—in evaluating information, and secondary data, knowledge of the processes and of the others involved in producing the information, and their purposes, is important.

Project management forecasts and targets are produced using databases—hence, two processes are operating—production of the databases, and using them to produce forecasts. (Given its global application and importance, the exemplar forecasting of 'cost planning'—forecasting the initial contract sum (accepted tender?) by the private (consultant) quantity surveyor (PQS)—is used to illustrate points of argument—for details see e.g. Seeley, 1995.)

Producing databases

In 'cost planning', the accuracy of data measurement is audited easily as the data are obtained directly from detailed project price documents (priced bills of quantities relating to initial contract sums)—hence, errors are likely to be few, transpositional between databases, and detected easily. Elsewhere, for construction activity durations or resource usage, etc. measurement error is more likely and more extensive (start, finish, allocation, etc.), however, with sufficiently large samples, the overall error should be small.

Databases are variously inaccurate and their categories, even though functionally determined, are likely to be somewhat arbitrary, historically dependent and quite generic—the wider the intended use(s) of the databases, the more generic their design. That is a particular issue concerning 'miscellaneous' categories; those are best avoided as, otherwise, through allocation difficulty and human laziness, they become the largest categories in the databases—quite meaningless of themselves and calling into question the validity of the databases.

In a study involving experienced construction cost practitioners, Fine (1975) analysed a large sample of cost allocations to cost categories in databases:

Database of 30 categories: 2% allocation error
Database of 200 categories: 50% allocation error
Database of 2000 categories: 98% allocation error

Whilst the allocation errors in a finely detailed database may not be very significant for use, the general consequence is clear—more finely divided databases are more prone to allocation error.

Using databases

Major construction databases in UK are those of the Building Cost Information Service (BCIS)—in particular, the database of elemental (standard definitions by functions) costs of buildings (costs to commissioning clients as initial contract sums analysed into elements by PQSs). Although most of that database's individual categories of building functional types contain large samples, some categories comprise very small samples. BCIS include several descriptive statistics of central tendency and of dispersion/variability (which may be consequential of important, within-category differences)—sample size, range, mean, mode, median, standard deviation—to inform users about the 'positioning' of forecasts and applicable confidence; however, anecdotal evidence is that many of those statistics are not used.

Use of databases is non-trivial. A suitable database must be selected and the relevant section determined —both require knowledge and search which are subject to bounded rationality. The database to search depends on the stage of realization of the project under evaluation. In the early stages, there are few specifics (function(s), approximate size, quality standard, location, approximate timing) and so, the database must be more generic and, in consequence, comprise data which only approximate to the project. That requires statistical awareness to interrogate and use the database and produce a helpful forecast as 'class-based forecasting' is involved—especially, for 'classes' of small samples (see e.g. Flyvberg, 2009).

Once design of the project is more advanced (to detail design), given adequate 'technical construction' skill in selecting a suitable comparator project from the database, the process involves 'adjusting' the data from that comparator to the situation of the project being forecast by evaluating quantity, quality, location and price level factors. Quantity and quality adjustments are quite subjective, often involving further comparisons with different sizes and specifications of, otherwise, similar projects and so, combine theory bases (economies of scale; quality-cost relationships) with evidential data and information, and 'expert' judgements. Location and price level adjustments employ indices (generic approximations) which, notoriously for locations, are unstable both geographically and temporally.

Fortune and Hinks (1999) confirm the widespread use of 'traditional', deterministic forecasting models by PQSs which, according to Fortune and Lees (1996), are used in design decisions regarding cost distribution within the project as well as 'control' of the project budget. Although studies (Bennett, 1982; Ashworth and Skitmore, 1983; Morrison, 1984) are consistent in quantifications of forecasting error (using coefficient of variation of the forecast against the realization—approx. 20% at early stages to 6.5% at tendering), clients are informed of the forecasts as single-figure cost predictions (Reugg and Marshall, 1990; Tan, 1999; Fellows and Liu, 2000). Despite anecdotal assurances of such forecasting being prevalent because 'that is what the client wants', it opens the door for various manipulations to ensure that project will proceed by ensuring that the forecast is unlikely to be exceeded (Flyvberg *et al.*, 2002); and operates to disenfranchise the client through implicit certainty (Fellows and Liu, 2000). In some industries (offshore petroleum exploration), such forecasts are unacceptable (personal communication from professor Peter Thompson, 17 May 1990)—there, forecasts are required to be in forms which accommodate and reflect inherent variability and forecasting risks and uncertainties (such as most likely forecast with quantified—confidence—limits, optimistic and pessimistic predictions, standard deviation, etc.).

In analysing forecasts of 258 infrastructure (public sector) projects in Europe, Flyvberg *et al.* (2002) find large and systematic discrepancies between forecasts and out-turn costs (of 20 to 45%), which are attributed to 'political' reasons to secure financial approval for the projects to proceed, and the use of 'inside view' techniques (rather than 'outside view' techniques—reference class forecasting)—i.e. the operation of the 'planning fallacy' (Kahneman and Tversky, 1979; Kahneman, 1994). Individual projects, particularly if including leading edge technology (and developments)

—e.g. Concorde, Sydney Opera House, BART, Scottish Parliament—may be subject to much larger forecast discrepancies, with out-turn costs being several multiples of the initial budget (as accepted/approved) (see e.g. Hall, 1980; Kahneman, 2011, p. 250).

Databases are used to produce forecasts which support decision-making on engineering construction projects; such decision-making occurs through various combinations of bounded rationality, political and garbage can models. The process comprises identifying that a decision is required, determining the approach (techniques), anchoring (in the data selected) and adjusting (regarding adaptations to address the instant decision situation). The decisions are required to deal with alternative courses of future actions and anticipated outcomes under conditions of risk, uncertainty and limited ignorance as well as having to embrace ambiguity (Hammond *et al.*, 2001; Kahneman, 2011).

Discussion

Although it is widely accepted that engineering construction projects operate as complex adaptive systems, many practices and techniques employed fail to accommodate the consequent requirements. Coupling complexity with the growth of individual specialisms, the requirement for integration is essential—particularly, with globalization. The chronological sequencing of project practice models (Winter *et al.*, 2006) charts the drift of interest, if not emphasis, from 'hard' deterministic linearity, via contingencies, to 'softer' approaches. The 'critical' techniques of analysing failures to extract causal lessons in prospect of indicating remedies (Lawrence and Scanlan, 2007; Flyvberg, 2009; Owen *et al.*, 2010) acknowledge the diversity of participants and hence, the importance of communications and integration (Lawrence and Lorsch, 1967) as well as the shortcomings of the management tools and techniques which are in common use on the projects (Lawrence and Scanlan, 2007).

As projects are complex, requirements and systems emerge as the projects proceed, confirming the importance of the informal system of project governance (Tavistock Institute of Human Relations, 1966) as the means by which self-organizing of projects develops. Further, complexity confirms the redundancy of deterministic, linear systems which require definitive expression of requirements, constraints, etc. at pre-determined, early stages of project evolution (e.g. RIBA, 2008). Luck *et al.* (2001) find that expert/experienced (repeating) clients may produce 'standard briefs' (for 'standard projects') but many other clients and bespoke projects 'need extensive collaboration with designers over a period of time' (p 300), due to emergence of requirements, iterative and reflective practices in design, and the need for (heedful) sense-making in discourses between people from different communities of knowledge/practice (echoed by Thomson, 2011). Thus, project 'briefing' is multi-stage (more so than suggested by Green, 1996, and previous studies) and, in reality, is likely to extend throughout design and into the construction phase (if not, beyond—on a life-cycle perspective). Likewise, value management studies commonly fix value and cost patterning of projects from limited participant perspective (s) (commissioning client) early in the realization (see e.g. Kelly *et al.*, 2004)—constituting bases for cognitive dissonance with realized performance.

Endeavours to 'fix' requirements and criteria, often, are expressed to be essential to avoid performance detriments—usually, of time and cost (see e.g. RIBA, 2008). However, contrary to such a 'fallacy of fixity', in dynamic environments of the constantly evolving power-based coalitions of project TMOs, changes are inevitable—'variations are endemic to the construction industry'! Grudging incremental changes in formal project practices (e.g. pre-pricing and sanctioning of post-contract variations) still deny the reality by addressing symptoms.

Thus, the development of what a project will comprise, as product and realization process, occurs continuously and is fostered through briefing flexibility, reflective, heedful practices and co-creation (Vargo and Lusch, 2004; Payne *et al.*, 2008). However, many processes deny the reality of continuous emergence by fixing the brief early and producing firm bills of quantities for tendering, based on, allegedly, finalized, complete design and so, with common work allocation processes (n.b., competitive bidding on price), the 'winners curse' is invoked, which, commonly, constitutes a basis for conflict.

A consideration which fosters desires for fixity and early decisions is that those have great effect through being a foundation for future decisions and actions; and people want to know the future early. Lera (1982) notes that '… the tradition persists whereby the architect prepares a sketch plan from which the other consultants work. Frequently alone, and often in a matter of hours, the architect arranges spaces in a structure using predominantly aesthetic criteria'. In accord with Kipling (2012), things seem not to have changed a great deal since Lera's finding.

Apart from project criteria, parameters and constraints that are set by the client and project environment, many other 'internal' variables—duration, programme, cost distribution, etc.—are determined by consultants and managers. Often, there is interplay, most usually assumed as a trade-off model or zero-sum game, between the variables via studies to confirm the feasibility of realizing the project as desired (e.g. cost planning). In most cases, there is considerable scope for errors and various manipulations (Flyvberg, 2009; Kahneman, 2011).

Education and training can do much to enable people to employ different, and more appropriate, systems and techniques but impacts on behavioural aspects of decision-making and, hence, forecasting are problematic (as per Kahneman, 2011). Here, initiatives to enhance awareness of decision-making 'traps' etc. (Hammond *et al.*, 2001) are helpful but likely to be of quite a limited effect, especially when situations of 'pressure' exist.

Mackinder and Marvin (1982), conclude that when architects are faced with design problems, the hierarchy of their searches for solutions is: own experience, colleagues' experience, trade literature, practice library, undertaking research. That hierarchy is likely to apply much more generally throughout realization of engineering construction projects and emphasizes the importance of the human factor in sensemaking and decision-making. Often, decisions are made via groups in actual and virtual meetings, involving various combinations of actors, interests and participations, as well as the decisions being 'built' incrementally over time, in changing contexts, and involving emerging solutions. Thus, an approach to improve decision effectiveness is to ensure that (major) decisions are scrutinized independently prior to implementation, with the data and rationale clear and justified.

A risk management perspective differentiates risks (future events, the probabilities of which can be determined 'objectively') and uncertainties (all future events other than risks, even if subjective assessments of their probabilities can be made); frequently, measures of variability are used as quantifications of risk—as in portfolio theory (Carsberg, 1975). Not only can quantifications of primary data (cost /m^2 of a building type; duration of an activity) be extracted from databases, but so can quantifications of their probability of achievement—through attention to variability statistics; otherwise, risk management requires subjective assessment of realization probabilities, or treating their occurrence as random events. The risk management approach comprises identification, quantification through analysis (assessments of outcomes, including sensitivity analyses), allocation (usually, stipulated in the contract) and response (remove, reduce, avoid, transfer, accept) and considers risk allocation as a performance motivator—allocate to contractors only those risks which they can control! Peoples' risk aversion leads to, *ceteris paribus*, endeavours to shed risks as well as to seek reward/recompense (commonly, financial) for risks which are assumed (see e.g. Fellows, 1996). Power plays an important role (Liu *et al.*, 2003).

Commonly, human factors are acknowledged to impact on data provision, use and decisions but the techniques themselves (decision trees, critical path methods, regression and extrapolation, etc.) are regarded as being 'value free'. That perspective is questionable as the techniques were developed by humans for particular purposes and the techniques to employ are selected by people; in both cases, the persons' values impact. However, a pertinent observation is by Kahneman (2011) who, variously, cites instances of people's preferences for human inputs to decisions over reliance on algorithms, and for complex approaches over simple (parsimonious) techniques; however, he presents evidence for the common superiority of simple algorithms and for algorithms over humans (see e.g. p 226).

Hammond *et al.* (2001), identify eight psychological 'traps' in decision-making—anchoring, status quo, sunk cost, confirming evidence, framing, overconfidence, prudence and recallability. Those 'traps' reinforce the human issues in decision-making discussed by Kahneman and Lovallo (1993) and Kahneman (2011)—which also include isolation errors, certainty effect, loss aversion (favouring the status quo and promoting risk avoidance), near proportionality (lack of scaling), narrow framing, optimistic bias (highly positive self-evaluation, overconfidence about personal beliefs, illusion of control, over-optimism about future plans).

A notable consequence of the operation of the psychological factors is the 'winner's curse'—'… the winning project is more likely than others to be associated with optimistic errors …' (Kahneman and Lovallo, 1993) and so, most likely to realize shortfalls against predicted performance. Supplementary analyses should be employed to determine the robustness of outcomes to incremental changes in variables—sensitivity analysis. That may be augmented by examining worst case scenarios. However, those may be only 'fairly pessimistic scenarios' instead of real 'worst cases'—politically, to minimize the effects of the 'supposed worst cases'.

A sequence of several successful decision outcomes tends to result in vigilance dissipating rapidly; however, those successes could have been caused 'more by luck than judgement' (Kahneman, 2011). Elsewhere, self-confidence in prediction and control (optimism), enhanced by some success, fosters adoption of a 'hard line' in bargaining and so, tends to increase risks of conflict. In organizational contexts, forecasts may be subject to important influences (biases) due to demands (from powerful stakeholders), commands (from higher authorities) and commitments (undertaken previously).

A particular issue concerns price forecasting in which the focus is the initial contract sum. Of course, the commissioning client actually pays the final contract sum (plus design fees, etc.). Whilst outside view analyses of initial contract sum predictions are facilitated by current BCIS databases (which include initial contract periods), no such databases are available for outturn (final) costs and durations—thereby constraining the potential for reference class forecasting of projects.

However, certain steps regarding forecasts for projects seem immediately practicable:

Ensure databases comprise sufficiently accurate data, are not too finely divided in detail (and avoid 'miscellaneous' categories) and provide appropriate descriptive statistics regarding representative measures and inherent variability.

Ensure decisions and forecasts are supported by details of data sources and techniques used and comprise 'most likely' quantifications with expressed confidence limits. Refuse to accept single-figure, deterministic forecasts.

Wherever possible, ensure that any 'inside view' forecasts are supplemented with 'outside view' forecasts (with appropriate source information etc.).

The consequent increased realism and transparency of the forecasts should also operate to reduce political manipulations and induce forecasters and other decision-makers to consider the data used and the factors impacting on judgements more carefully—i.e. to be more heedful and reflective in making decisions.

Conclusions

The (engineering) construction industry is frequently criticized for inadequate performance with causes attributed to structural and internal process factors; in turn, the industry blames governments, clients and regulation. The assertions and causes remain widely contested and debated, but the arguments presented herein contend that a significant contribution would ensue from a paradigm shift which accords with the perspective of projects as (networks of) complex adaptive systems. That perspective necessitates more comprehensive and rigorous understanding of participants' requirements and constraints as they emerge during project realization, use of more appropriate decision support techniques and express accommodation of variabilities in forecasts (due to data, techniques and human inputs).

In the critical activities of initiation and 'briefing', commissioning clients (and, occasionally, other client functionaries) interact with construction designers (and, sometimes, constructors) to determine the requirements, design and performance targets; feasibility studies determine their practical viability in the context of parameters and constraints (finance, regulations, etc.). The extensive comprehension requirements involve significant translation between communities of knowledge and practice and incorporate boundary management activities to enable groups to understand the various and emerging requirements, possibilities and outcomes and hence, abandonment of the 'fallacy of fixity'. As decisions are made under conditions of risk, uncertainty and limited ignorance, and, often, involve ambiguities, heedful sensemaking activities and reflective practices are central in determining successful outcomes.

Use of most likely estimates with confidence intervals, and via reflective realization approaches (design and construction) and sensitivity analyses, should be followed up by frequent reviews to lead to progressive repositioning of performance assessment reference points and so, result in progressive, incremental approaching of the expected project outturn, accompanied by informing and enfranchising of participants—especially, the client—and reduction of potential dissonance.

Through this review of theory and practice-oriented literature, i.e. theory about practice, theory for practice and theory in practice, both of the propositions investigated are supported. The following recommendations focus on theory in practice—to close the gap between stakeholders' desires and performance of engineering construction projects through enhanced implementation of existing knowledge and techniques.

Recommendations

Two, broad recommendations for practice implementation flow from this investigation:

(1) Through education and training, performance metrics for projects are framed using statistical methods such that inherent variabilities are quantified and published to enfranchise stakeholders, thereby enhancing the quality of assessments and decisions.

(2) Participants adopt the practice implications of the acknowledged complexity of engineering construction projects by shifting their perceptual paradigms from determinism to stochasticism—to incorporate the emergent nature of relationships and of stakeholder requirements and their accommodation through reflective, heedful practice to reflect the holistic, synergetic nature of input contributions.

Further, databases of project out-turn performance should be established to facilitate outside view/reference class forecasting of project realizations—notably cost and time performance.

Empirical research is required concerning the application of complexity theory to engineering construction projects: first to examine the consequences of the major elements of the theory (emergence, self-organization, etc.) and what coping mechanisms are adopted and appropriate. The second research area concerns project governance structures and mechanisms which accommodate the emergence of stakeholders' requirements in self-organizing networks of project participants which occur along non-reversible trajectories which are sensitive to (initial) conditions and interrelationships (feedback/feed-forward).

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