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Configuration management in complex engineering projects

Carmel Lindkvist, Angelos Stasis, Jennifer Whyte*

School of Construction Management and Engineering, University of Reading, Whiteknights, Reading, RG6 6AY, United Kingdom

* Corresponding author. Tel.: +44 (0)118 378 7172. *E-mail address:* j.whyte@reading.ac.uk

Abstract

Digital technologies are radically transforming project delivery, breaking the mould of 1960s approaches to enable more rapid and agile forms of organizing. Yet the use of large digital data-sets also requires new forms of control. This study compares the leading practices of managing change in digitally-enabled projects in Airbus, CERN and Crossrail. It focuses on configuration management, the process of maintaining system integrity while handling change to both the digital data-set and the related real-world engineering systems. The contribution is to explain: first, why configuration management has become more, rather than less, important in complex engineering in an era of 'big data'; and second, how approaches to configuration management are shaped by these industrial contexts of civil engineering, nuclear research and aerospace. The paper concludes by considering the implications for managing digitally-enabled projects.

1. Introduction

Digital technologies are radically transforming project delivery, breaking the mould of 1960s approaches to enable more rapid and agile forms of organizing [1,2]. Up-front project planning, using multiple layers of work breakdown structures, was established in the 1950s and 1960s to manage small numbers of large complex projects. New digitally-enabled approaches are emerging in industries that are dynamic and less predictable. In these, data analytics and visualization using large digital data-sets, along with rapid, informal interaction and exchanges of information, provide the basis for more responsive, flexible and real-time decision-making in project delivery.

Yet, in complex engineering projects, this increasing use of large digital data-sets, or 'big data' as this is often termed, also requires new forms of control. Configuration management is a process of maintaining system integrity while handling changes to both the data-set and real world engineering system it describes. It is a systems engineering technique that has been used since the mid twentieth century, but has renewed relevance for managing change in large digital data-sets. In this paper we compare leading practices of managing change in Airbus, CERN and Crossrail. Table 1 gives a brief overview of these organizations, all of which engage in in digitally-enabled projects.

Table 1: Background of organizations studied, and their industries

	Crossrail	CERN	Airbus
Background	Design and construction programme to develop new railway tunnel under London with 37 stations	Largest particle physics research establishment in the world with particle accelerators around the world	Aircraft manufacturer that engages in continuous production of commercial aircrafts
Industry	Civil engineering and railway infrastructure	Nuclear research infrastructure	Aerospace manufacturing

The contribution of this paper is to explain: first, why configuration management has become more, rather than less, important in complex engineering in an era of 'big data'; and second, how approaches to configuration management are shaped by these industrial contexts of civil engineering, nuclear research and aerospace.

2. Stability and Change in Project Delivery

2.1. Motivations for developing techniques to manage change

Configuration management was developed in the 1950s by the US military to control documentation in the manufacture of missiles [3-5]. It is an approach that was further developed in the 1980s in the software industry [6-8], becoming recognized as an ISO 10007 quality management process in 1995 [9]. It is used widely in safety critical systems such as nuclear and aerospace [5,8]. The drive behind configuration management is to address the problems which occur in projects due to unchecked changes in one sub-system having wider consequences for other sub-systems of a product that can come to the fore during the different phases of a product development and operation [10].

The aim is to check the consequences of a change before it is made, and to provide traceability of product data to understand where problems occur, diagnosing and contributing to recovery [11]. An authorization approach is used to control change and there are different hierarchy levels depending on the use of configuration items [12]. The processes, procedures and users of the configuration management system play an integral role in keeping data integrity throughout the life-cycle by controlling changes to a data system. If users do not follow the process, errors can occur which can cause problems to the product in production and to related information dissemination [10,13].

Research suggests that the benefits of such a controlled process of change are not always understood or realized by users. For example, in one aerospace case study, configuration management is seen by the supply chain to benefit only the client's operations and hence, while the supply chain comply in meeting clients requirements, they lose out by missing the benefit of configuration management during the project that include saving time and money [11].

2.2. Large digital data-sets

Recent research and policy has examined the role of integrated digital data-sets in the delivery of complex engineering projects [e.g. 14]. These significant repositories of data are used in decision-making in project delivery; and then re-used in the operation of the asset. In manufacturing and construction industries the approach is referred to as either product life-cycle manufacturing (PLM) and Building Information Modeling (BIM). Researchers are beginning to explore the possibilities of using techniques data-mining to analyse large digital data-sets. Yet in both of these contexts, there is an under-recognized role of configuration management in managing change to these data-sets.

Such work is particularly timely and important in an era of 'big data'. There is, for example, a strong programme of manufacturing work on predictive maintenance, using sensors embedded in assets to generate data about performance that can then be fed-back to develop next generation production processes. As new techniques are developed, new kinds of tools will become essential to address configuration management challenges associated with visualization, data integration and decision-making across epistemic communities.

2.3. Controlling change in a complex information environment

Despite the long history of configuration management, uptake has been an issue [15:37], although there are documented benefits for quality management [16] as well as avoiding and minimizing delays [11]. There has been limited changes to the established principles of configuration management on identification, planning, change control, status accounting and auditing over the years which means that it is more prepared for paper based systems than the integrated systems that have developed [11]. The upsurge in the use of information technology and flexible team-working might question current practice of configuration management [5]. While an agile approach in the context of configuration management promotes incremental development, it is difficult to implement as it requires a system to accommodate small continuous changes and there is additional complexity across dispersed teams [17]. Therefore, there are challenges within both techniques in managing change in stable and dynamic projects.

3. Methods

The aim of the empirical work was to review leading configuration management activity in through-life engineering: comparing and contrasting practices across different manufacturing settings.

3.1. Sample

Three leading organizations that use configuration management were identified and interviewed to understand why and how they seek to control rapid changes to large data-sets, and how their approaches are different. The study is informed by a tradition of research using a cross industry comparator approach, e.g. [18], and the three organizations are based in different industries, Crossrail in civil engineering, Airbus aerospace and CERN a nuclear research infrastructure located in the UK, France and Switzerland respectively.

3.2. Data collection

Data was collected through interviews, visits and a workshop. A desktop review of leading configuration management activity in through-life engineering was conducted, comparing formal processes. We conducted online or in-person scoping interviews with 1-2 personnel from the

CAD management and/or configuration management teams within Crossrail, Airbus and CERN, visiting organizations where possible. We then held a workshop in Crossrail offices, with 1-2 personnel from the CAD management and/or configuration management teams within each organization to present back preliminary findings and discuss key challenges and research questions. This day was recorded with video and notes as well as through the distribution of presentation from each organization afterwards.

Figure 1: The workshop held in Crossrail offices

3.3. Analysis

Comparison is at the heart of qualitative data analysis. In this research, a detailed table was created to compare configuration management practices in the three collaborating organizations, in relation to *Background* (overview, infrastructure type, scope of works, budgets); *Lifecycle* (typical lifecycle duration; development time) *Complexity* (physical items; digital items); *Configuration Management Motivation* (motivation, industry guidance, teams) *Approach and Systems* (lifecycle breakdown, approach, data Management, information systems and supporting tool, structure of configuration items, *Managing Change and Change Control Process* (change perspective, change control process, conformances and non-conformances); *Risks*; *Cultural and Social Issues* (language, culture) *Future* (Interest across Parties). It was used to visualize the data for discussion in the research team [19], to identify salient similarities and differences, and to check details with the collaborating firms.

4. Findings

4.1. Motivation for using configuration management

All of the organizations studied had strong motivations for the use of configuration management techniques:
- Airbus – recognizes Configuration Management as an Airbus core competency as the number of parts and combinations of solutions grow with product complexity, as do the combinations of configurations to be managed.
- CERN – has major operational constraints, such as the interval between long shutdowns (1-2 years), short technical stops (every 1-2 months), altering warm-up and cool-down period (3 plus 3 weeks), and involvement of nuclear risks, mean that ensuring well managed product datasets is an absolute must.
- Crossrail – is a large, complex and highly integrated rail system which presents many challenges and risks in terms of establishing and maintaining the integrity of the system

configuration throughout the design, build, test and commissioning and operation. It faces issues such as conformance, integrity, control, relationships, current status, auditing, prevention of corrective action, safety, quick responses and risk mitigation.

Each organization is aware of industry guidance, specifications and regulation that is important to its operating environment, and the need to be able to track configuration items to be able to revisit designs and comply with future regulation on safety-critical facilities.

Each of these organizations has to manage a vast data-set of product information. Crossrail, expects to generate 2-3 million records in asset databases, 1 million model and drawing records; and quarter of a million records in geographic information systems. In comparison with CERN and Airbus, it has comparatively little data to manage. At CERN for example, the LHC accelerator complex has approximately 100 million configurable components.

4.2. Team sizes

The organizations studied had different resources for configuration management activities. The size of the configuration management team ranges from 8000 people involved in the task of configuration management in Airbus, to globally distributed design teams with small configuration management teams in CERN and Crossrail.

4.3. Lifecycle

All of the organizations were interested in configuration management in operations as well as delivery. Airbus is involved in design and manufacturing of aircraft, but does have service contracts, which means that it retains an interest in aspects of configuration management throughout the lifecycle and has interests in managing configuration conformity. CERN is involved in the whole life cycle of its facility including design, manufacture, install, maintain, dismantle, design. Crossrail is a delivery project, but has interests in design and construction configuration items to deliver for operations, maintenance and beyond.

4.4. Approach to configuration management

- Airbus – Product identification is the backbone of the whole process, where configuration management is seen as a complexity problem. Since an aircraft is a stacking of modifications, Airbus approaches change control by managing the implementation of, and changes to, those modifications.
- CERN – continuous feedback loops throughout the different stages of the project/product lifecycle, with configuration over time – configurations of accelerators worked in parallel and managed consistently.
- Crossrail – configuration managed so that the system can be rolled back to a previous state. The level of granularity in selecting configuration items is a business decision. The classic approach: Identification, Status, Control,

Audit, is documented as a formal management process in management plans. The design phase is concerned with documents and selecting configuration items; the implementation phase is involved with configuring asset information, as well.

4.5. Risks

Identified risks relate to the challenges of getting people to take responsibility and sign off their work; and scope control to establish and maintain the integrity of the system configuration throughout the design, build, test and commissioning and operation requires a large degree of scope control.

5. Conclusions

Leading manufacturing companies, Airbus, CERN and Crossrail, see configuration management as more, rather than less, important in an era of 'big data', given the vast amounts of information that they have to manage. There is a need for control change to maintain the utility of the large data-sets that describe complex engineering assets during their delivery and operation in contexts such as aerospace, nuclear research and civil engineering.

The approaches to configuration management are not however, the same in these three contexts, but they are shaped by the industrial contexts. For example, both CERN and Crossrail have to manage data on existing infrastructures, and the interaction of new assets with existing facilities, which are often less well described in the digital data-sets. As a delivery project, Crossrail has a different relationship to the operation of the asset than CERN.

The research has implications for managing digitally-enabled projects. It highlights the importance, and challenges, of configuration management in the era of 'big data'; shows how approaches to configuration management in complex engineering projects are shaped by industry contexts and suggests some areas for further research.

6. Further research

Particular areas that warrant further attention include the inter-relationships between configuration control and data analytics and visualization using large digital data-sets. This feasibility study will be extended by detailed work examining the logs and records generated in configuration management repositories as a source of research data which can be analysed to develop new tools. The long-term ambition is to develop a generic tool, like the Design Structure Matrix that was developed at MIT in the 1980s, which can be used to guide action in next generation configuration management.

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