Part II

Chapters that Principally, but not Exclusively, Deal with Case Study Material

10

Managing Megaproject Supply Chains: Life After Heathrow Terminal 5

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10.1 Motivation for the Research

A megaproject is an extreme case of the temporariness phenomenon faced by the construction industry, where a number of firms will work together during an extended (but still limited) period of time to deliver a final one-off asset to the client (Priemus and Van Wee 2013). It is an endeavour conducted throughout several years, commonly 5 to 10 years in the construction phase, and it is not uncommon for one or two decades to elapse from initial inception to final handover. If the front-end stages of inception, planning, and approval are considered, a large proportion of projects will end up with at least one decade of life-cycle until final delivery (Artto et al. 2016).

The UK broke the paradigm and started the shift from old practices to a new approach through the Heathrow Terminal 5 breakthrough project (Potts 2009; Davies et al. 2009). The lessons learned were adapted and incorporated in the London Olympics 2012 (Davies and Mackenzie 2014; Brady and Davies 2014), and Crossrail – incorporating, what was claimed at the time to be, the world's first innovation strategy (Davies et al. 2014; Dodgson et al. 2015). In this way, the UK construction industry is 'passing the baton' and implementing best practices and innovations to subsequent megaprojects: Thames Tideway Tunnel, a 25 km sewer tunnel under the river Thames in London, and High Speed Two, a high-speed railway connecting London to the north of the UK. In this context, there is a necessity and an opportunity to analyse these five megaprojects and their ecosystems in order to understand how their supply chains were structured.

Scholars are calling for megaproject studies in a number of refereed journals: *Project Management Journal* (Söderlund et al. 2015), *International Journal of Project Management* (Flyvbjerg 2015), and *Journal of Management in Engineering* (Wang et al. 2015). The UK is consolidating an expertise and methodology to deliver megaprojects that is attracting the attention of many countries, from developed countries such as the USA and European neighbours to developing nations such as Brazil, India, and China. Therefore, this chapter will theoretically frame the megaproject phenomenon towards supply chain management literature in order to illuminate the reasons why those projects are

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critical in a global scale, the importance of their supply chains, and the opportunities for interorganisational coordination.

10.2 Construction Supply Chain Management

The construction industry historically has gathered and adapted management practices from other industries. The automobile industry, for example, influenced lean construction (Koskela 2000). Reports published by Latham (1994), Egan (1998), and the Strategic Forum for Construction (2002), which analysed the characteristics of the construction industry in the UK, have stimulated the adaption and translation of supply chain management concepts from well-developed sectors, such as retail, defence, and oil and gas, into construction. Arguably, Latham (1994) had a procurement approach for organising the supply chain, and from the perspective of Egan (1998), the construction industry needs main contractors to approach their supply chain through long-term partnerships, emphasising other factors related to performance instead of focusing on competition by the lowest price. In this context, Lambert et al. (1998) and O'Brien et al. (2008), respectively for the manufacturing and construction industries, pointed out that efficient supply chain management enables significant cost reduction through the increased integration between supply chain actors, ranging from distant 'n tier' suppliers to end users. Thus, the adoption of supply chain management practices can improve the overall performance of the construction industry, since the companies start to analyse the business holistically and make decisions through a 'systems lens', consolidating demands at an enterprise level, instead of oriented solely towards individual projects (Pryke 2009; Tommelein et al. 2009; Pryke 2017).

The fragmentation of construction supply chains generates a lot of waste and reduces productivity, since the chain is quite vertical containing several Tier 1 suppliers (Lambert et al. 1998). In terms of organisational structure, Pero and Rossi (2014) present a structure for the construction supply chain where there are four main categories of players, namely:

(i) Clients, which are ultimately owners and make their profit running operations exploiting the physical asset.
(ii) General contractors, which are organisations responsible for the delivery of the entire physical asset to clients. Usually, these are companies that rely on systems integration capabilities, through supply chain coordination (or project networks, depending of the maturity of the company, if the integration is realised at project or enterprise level).
(iii) First tier suppliers, which provide systems for the general contractors, often finished systems in the form of components ready to assemble on site.
(iv) Second tier suppliers, which provide subsystems and intermediate components for the production process of first tier suppliers.

This representation has parallels with other organisational structures present in the literature and with the understanding of the majority of construction supply chain scholars. The main variance among these representations is that some authors deconstruct the supply chain into more detail adding more levels of players, the lowest tier being responsible for the delivery of just raw materials or small components for the supplier in

the above tier. The tier number depends on the focal perspective from which the supply chain structure was designed. Pero and Rossi (2014) emphasise the role of the general contractor, and represent Tier 1 suppliers as the ones below the general contractor, while Davies and Hobday (2005) present a structure where Tier 1 contractors are the general contractors or systems integrators.

Cox and Ireland (2006) present a different conceptualisation of construction supply chains, introducing the concept of gate-keeper, which relates to the issue of fragmentation, where each tier of the supply chain can only understand and manage its immediate lower tier supplier. This logic argues that the industry lacks a player with a holistic coordination lens, which can be translated into (programme or portfolio) management. Cox and Ireland present an evolution of construction supply chain categorisation, which is segmented according to three major supply chains (materials, labour, and equipment) that are integrated by two supply chain actors in different phases of the construction project, the professional service firm and the construction engineering firm. The professional service firm, in the shape of architects and other design consultants, acts as systems integrator for information, adding value reconfiguring and transforming the available information. Conversely, the construction engineering firm is the more traditional systems integrator (as seen in high volume industries, such as manufacturing) relying on their capability of fitting all the subsystems together to form the entire physical system desired by the client (Prencipe et al. 2003; Davies 2017).

The framework proposed by Cox and Ireland (2006) is different from the average description since it divides what other authors generically call construction supply chain into supply chain categories with similar characteristics. Arguably, it is a more efficient framework considering that construction is an engineer-to-order (ETO) industry as a whole. However, there are many specialised supply chains that provide systems and subsystems for construction systems integrators, and those organisations have different production strategies, from make-to-stock (MTS) to assemble-to-order (ATO). The production strategy is important and has direct implications and effects on management once it reflects a set of decisions regarding demand and supply, inventory levels, commercialisation of the end product, and operation of the production process. It is still a very rare scenario where just companies with high maturity recognise that the construction supply chain comprises a set of diverse supply chains. This recognition is the first step in establishing an extended understanding enabling further analysis of the context and ultimately leading to creative supply chain management solutions.

Koskela and Ballard (2006) presented a discussion regarding the different perspectives and interfaces of two project management schools – economics-based and production-based. The authors argue that the economics approach conceptualises the project as an information system where organisations perform transactions amongst themselves to deliver the final product. The focus of this approach is to design and manage an organisational structure and the subsequent contracts involved in the transactions. As an optimisation mechanism, the target is to reduce uncertainty in order to have a more reliable information system (or project). On the other hand, the production approach conceptualises the project as a production system, where there is transformation, flow, and value. The focus of this approach is to design and manage the production system. As an optimisation mechanism, the target is to eliminate waste continuously in the production system to increase the value of the overall system.

This is the duality faced by the construction industry. On the one hand, the industry understands and follows the production logic, in the context of its intrinsic nature. It focuses on the physical asset being constructed and allocates resources to optimise sequencing and enable integration of systems and subsystems. On the other hand, the project-based/ETO characteristic of the industry tends to move the focus from the economics approach observed in mass production industries. The practice in construction is to establish organisational structures and production strategies on a project-by-project basis, a fact that avoids consolidation of demands at the enterprise level and the development (and improvement) of relationships (not transactions) in a long-term perspective. This discussion about conflicting economics vs production conceptualisations reflects the dilemma in managing supply chains in the construction industry.

The economics and production approaches are not mutually exclusive and do not work in silos; they are intertwined and complement each other. Before any production can start (development and delivery activities), there are activities and strategies that need to be designed at the enterprise level to support the production activities. Contracts are not production mechanisms, they are artefacts that establish and enable the rules of the game that connect the supply chain actors. Therefore, the economics approach needs to come first to design and establish an information system that will enable production to be carried out effectively later. The production-based theorists might argue that they cover the economics approach when the design of production-systems is being conducted. Once again, the problem is one of terminology; both schools are referring to different topics. The design emphasised by the production-based approach is connected to the production system (design and construction), which is connected to the project level, since the production in construction follows a logic project-by-project. The design emphasised by the economics-based approach is concerned with organisational structures, functions, and information flows of the firm, which is located at the enterprise level. There is, therefore, a need to design a macro system at the enterprise level that enables the production function at the project level.

This perspective can be expanded through the temporary–permanent lens, with projects being temporary and the enterprise permanent. The project level is associated with construction endeavours that happen at the boundaries of the firm through temporary supply chains, assembled on a project-by-project basis. The enterprise level is permanent and composed of a centralised structure that works as an enabler to all projects. Ideally, this centralised structure would be able to consolidate requirements from all projects (or at least according to a specific segmentation) and apply portfolio management techniques to achieve economies of scale and standardisation. However, the challenge of construction companies is frequency of demand, which is translated into a lack of visibility about future projects and a consequential lack of certainty over workload. Construction enterprises tend to postpone investments without confirmation of demand or at least visibility of the upcoming pipeline of projects. The visibility of future investments by public and private sectors could provide them with confidence to invest in capability building based on the expectation of successful bids. The business development department of a project-based firm is constantly mapping the market, establishing relationships, and creating opportunities for future business. When there is confidence in a specific project, the business development department informs the bidding department; there is then an interface to pass the baton and align the strategy

to secure that project, merging the current enterprise strategy and the future corporate plans (if known) with the future strategy to be deployed at the project.

Following a comprehensive research project dealing with a large dataset about major projects (Morris and Hough 1987), Morris concluded that the problems causing major disruption in the project environment are not related to the iron triangle (i.e. the pursuit of cost, time, and quality standards) during the execution, and can be tracked to the preconstruction phase – to the front-end of projects where strategic decisions are taken. Considering these findings, Morris expanded his research a few years later (Morris 1994), criticising the *status quo* of the literature and practice about the executional and operational bias of project management. Morris's research presented project management practices and perspectives and coined the term 'the management of projects'. Morris sought to distinguish between 'project management' – the executional practice with tools to optimise the production, stimulated by published bodies of knowledge and operationalised through guides and handbooks – and the 'management of projects' – a more systemic approach focused on the whole life-cycle of the project, emphasising the front-end stage where stakeholders are shaping the project and defining strategies into the various project phases. This focus on the management of projects caught the attention of the project management community who sought answers to critical questions previously neglected:

- What are the factors to be influenced in the front-end?
- What is the impact of these factors in the project life-cycle?
- Who are the stakeholders at this stage?
- To what extent should the stakeholders get involved to shape the project (Morris 2013)?

Project management or the management of projects aside, the unit of analysis, in terms of research, is still the project instead of the firm. This is in contrast to supply chain management, where the unit of analysis is a group or cluster of firms and the relationships between them, over time. The longer time scales associated with megaproject provides the opportunity to move beyond project management and the management of projects to understand how strategy is developed, needs are met, and value created through interorganisational and intraorganisational relationships within the supply chain serving the project.

10.2.1 Temporary vs Permanent Supply Chains (ETO vs MTS)

Competitive advantage is different for MTS (high-volume) and ETO (project-based) industries; the former has an emphasis on cost reduction and economies of scale, the latter has an emphasis on agile solutions and innovations, which should be available quickly to achieve the objectives in a temporary environment (Gosling et al. 2012). The construction industry is characterised as an ETO sector, which has high fragmentation, a low level of communication between the supply chain actors, one-of-a-kind projects, and temporary supply chains oriented by projects (Van der Vaart et al. 1996). Hicks et al. (2000) argued that supply chain management practices from high volume industries cannot be simply translated to project-based environments, considering that the context is not the same and there is not frequency of demand. Therefore, the context of the ETO supply chain should be carefully analysed before the application

of traditional high-volume strategies like just-in-time, supplier base reduction and long-term relationships (Souza 2015).

In the construction industry, customisation is a *qualified* factor and not a *winner* factor, as seen in aerospace and shipbuilding (Amaro et al. 1999). In a context with high levels of customisation and without 'pipeline visibility' (certainty about demand from future projects), it is not possible to forecast the demand and apply a structured strategic process for supplier relationship management. The construction industry has neither constant contact with suppliers (e.g. daily, weekly) nor an extensive buyer power like original equipment manufacturers (such as GM, Ford, Fiat, Volkswagen). The challenge for the construction industry is to establish standard processes and procedures to maintain stability in the development of nonrepetitive one-off singular facilities (Ballard and Howell 1998).

The main problem for companies running their business through MTS or ATO production strategies relates to the large volume of intermediary or final products in inventory, which obviously impacts on cash flow. On the other hand, the main constraint for companies driven by make-to-order (MTO) and ETO production strategies is the lack of order confirmation that impacts the production planning and sequencing, ultimately reflecting in barriers to the management of supply chains. In addition, for the last two strategies there is the challenge of customer engagement and retention, once the client commitment happens early in the process and the lead-time between order placement and product delivery is high (Powel et al. 2014).

ETO and project-based production strategies are fundamentally similar but supported by different literatures. ETO is more closely associated with manufacturing and management science research; project-based production is more connected to the construction industry, media projects, and IT solutions, with the literature supported by organisational science and project management. It is possible to find in the literature different terminologies for the same, or similar, concepts. Three other expressions were identified: one-of-a-kind, MTO, and built-to-order. To a large extent, built-to-order is the least related to project-based settings, while MTO and ETO are often applied to project-based contexts, with just a few studies defining clearly the boundaries and differences between them.

Considering that the level of customers' requirements and customisation has increased over the last decades and that the world is moving towards project-based production through a phenomenon called 'projectification', there is a need for new and more robust mass customisation strategies to achieve 'customer delight'. Given this worldwide necessity, Gosling et al. (2011) proposed a framework expanding the usual four production strategies (ETO, MTO, ATO, MTS) and conceptualised a stage called research-to-order (RTO), which is a production strategy even more advanced than ETO, increasing the freedom for customisation and removing any level of standardisation in the procured item. In addition, this framework provides a clear representation of the decoupling point, which is a concept widely used for production planning and control. The decoupling point is associated with the moment where production ceases to be standardised and waits for the customer order with its customisation requirements (Olhager 2003). This is the point where production stops being pushed by the manufacturers (mass production) and starts to be pulled by the customers (customised production).

Figure 10.1 summarises the contrast between ETO supply chains (project-based: temporary) and MTS supply chains (high volume industries: permanent). On the

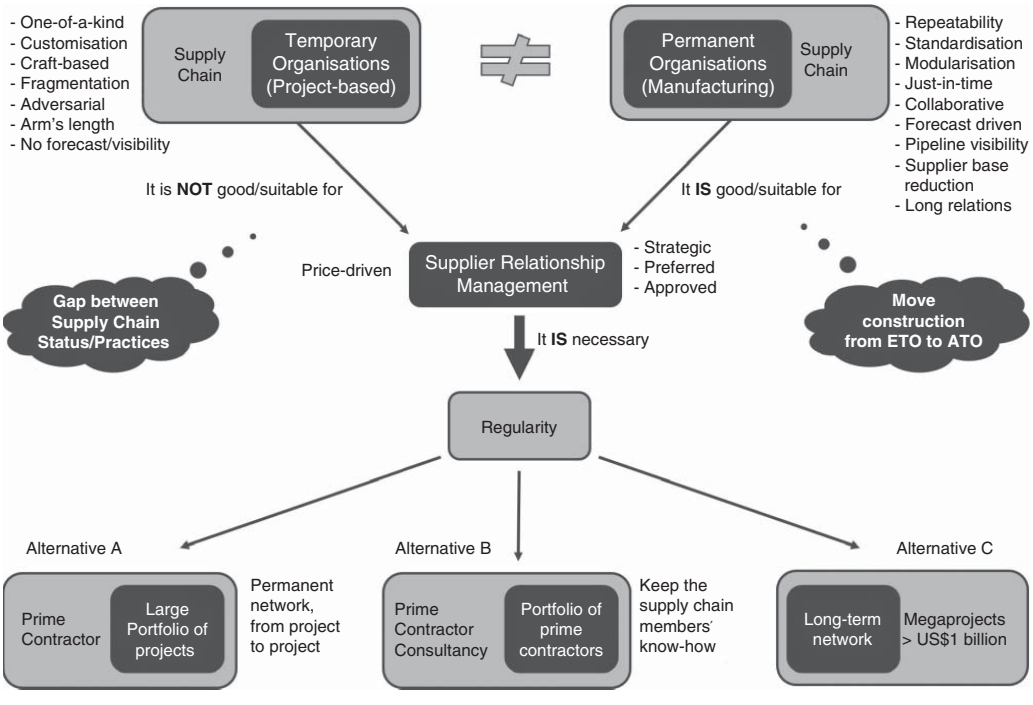

Figure 10.1 Project-based vs Manufacturing supply chains.

one hand, supply chains oriented by projects are usually reconstructed for every new project, which gives them the temporary characteristic and constrains improvements over time. Those supply chains present the following characteristics: one-of-a-kind, customisation, craft-based production, fragmentation of the supply base, adversarial relationships with business partners, arm's length as the predominant purchasing model, and high uncertainty of future projects which causes a lack of pipeline visibility constraining forecasts.

On the other hand, in contrast, manufacturing supply chains are permanent and stable, presenting the following characteristics: repeatability, standardisation, modularisation, just-in-time production, collaborative relationships with supply chain partners, pipeline visibility that allows forecast-driven demand, supplier base reduction over time, and long-term relationships with the supply chain. Arguably, these two supply chain types are in clear contrast with each other and it is possible to observe that the permanent supply chains are suitable for the establishment of long-term relationships with suppliers, while the temporary supply chain fails to achieve this goal due to the lack of regular contact between the organisations.

Frequency of demand and 'regularity' were identified as key characteristics for effective supply chain management implementation in ETO environments (Cox and Ireland 2006; Holti et al. 2000). An important critique of the previous reports which suggest the adoption of supply chain management to boost construction and foster innovations in the UK was that the context and examples provided were biased (Latham 1994; Egan 1998; Holti et al. 2000). These reports presented advice on the adoption of supply chain management in construction and building upon the consideration of the context of large clients. This generalisation is not helpful at all for the evolution of construction as an industrial sector, given that large clients are fundamentally different from the myriad of small and medium companies that comprise the supply chain. Large clients can (and should) apply supply chain management practices, capitalising on their portfolio of projects to integrate suppliers and exploit standardisation of processes and economies of scale. In other words, supply chain management is not for all organisations in construction.

Given this scenario, some questions emerged, namely:

- How to bridge the gap between the manufacturing and construction suppliers?
- How to create a business model that allows the creation of a constant supply and consequently a long-term relationship, in order to increase the productivity and competitiveness?
- How to expand towards integration with suppliers through performance measurement and supplier development?

In the light of these issues, three scenarios are proposed where it is possible to establish a proactive and effective construction supply chain management:

- Establish a prime contractor role (Holti et al. 2000) with a large portfolio of projects, each project running in a different stage, where the supplier base is replicated and reconfigured across projects, creating a permanent network.
- Utilise a prime contractor consultancy, where the focal consultancy acts to consolidate the demands from several prime contractors and maintain the supply chain know-how at a macro level.

- Explore megaprojects – large 'system of systems' projects that have an extended horizon available and power to proactively influence the supply chain.

If the client has a permanent business, running a portfolio of projects, delivering on time and budget produces financial savings. Furthermore, if there is a company/consultancy that can sell to a client the ability/assurance of delivery of a megaproject on time and budget, that company can negotiate a very attractive profit margin, considering that it will be saving a lot of money and creating value for the client, given that 98% of megaprojects tend to be delivered over budget and/or are delayed (McKinsey Global Institute 2013).

10.3 Why Are Megaprojects So Important?

Megaproject is a recent term to describe complex endeavours, with long timescales and total predicted expenditure of in excess of 1 billion US dollars. The use of the term, and its application, grew exponentially after Bent Flyvbjerg's book in 2003 (Flyvbjerg et al. 2003). Naturally, these projects always existed and are well documented in the literature under different terminologies over the last decades: major projects (Morris and Hough 1987), grand-scale projects (Shapira and Berndt 1997), large-engineering projects (Miller and Lessard 2000), mega capital projects (Rolstadås et al. 2011), large-scale projects (Merrow 2011), global projects (Scott et al. 2011) amongst others. Denicol et al. (2018a) presents a systematic literature review of the management of megaprojects drawing upon a comprehensive list of synonyms used to describe megaprojects over the years. Flyvbjerg (2014) points out that the term mega is usually associated with 1 billion projects but its correct relation would be millions, while gigaproject would be the correct term for 1 billion plus projects. However, for commercial and marketing reasons, the term gigaproject was never widely used by the market, which still utilises megaproject when referring to 1 billion projects. Galloway et al. (2012) has written one of the few books with gigaproject in the title (when comparing with titles on megaprojects). However, she proposes a complementary perspective rather than replacing one term for the other, where gigaprojects are projects with a cost in excess of 10 billion US dollars, leaving megaprojects in the classification between 1 and 10 billion US dollars. A recent classification of large-scale projects emerged when McKinsey launched the term ultra-large projects to represent projects with capital investment in excess of 5 billion US dollars (McKinsey 2017). The report suggests an analogy between marathons and ultra-marathons to support the argument that ultra-large projects are another category of projects with different characteristics from megaprojects. Analogies seem to be frequently used to convey messages about the complexity of megaprojects. Flyvbjerg (2014) presents an analogy from his colleague Patrick O'Connell advocating that project managers need to have a pilot's licence instead of regular driver's licence to deliver megaprojects.

Flyvbjerg (2014) suggests that the next frontier is teraprojects, where the cost would be above one trillion US dollars. However, to achieve this figure the author considers as a project the entire economic package launched by superpowers to incentivise their economy or the annual defence budget of a country. The scale of megaprojects is clearly increasing given the challenges faced by contemporary societies. However,

there is a necessity for clearer boundaries and a need to relate measures to projects, programmes, and portfolios. Considering the number of projects available to establish a benchmark, one would expect that megaprojects would have evolved within its delivery form over the last decades; however, we are still facing quite the opposite. Major projects are rapidly growing in complexity, specification requirements, and budget, but the learning capacity across projects seems to be very limited since the overrun pattern and practices remain almost unchanged – a phenomenon called 'Productivity Paradox' (Flyvbjerg 2017). The success of megaproject deliveries is related to how much effort the managers concentrate in the front-end of the projects, understanding the particular risks of each stage of the project and its impacts on the whole system, as well as creating strategies to minimise and overcome them (KPMG 2013).

In the USA, Boston Big Dig was originally planned to open in 1998 but was delivered in 2007, nine years late with an outturn cost of 14.6 billion US dollars, more than 500% over budget (Greiman 2013). More recently, in the UK, the Wembley Stadium project was concluded four years late and 80% over budget. This project damaged the reputation of the UK construction industry, resulting in several suppliers seeking redress through the courts for contractual disputes; in several cases Tier 2 contractors were forced into insolvency. The effects of the Wembley Stadium project were evident when the UK government began to establish contact with the industry in order to build the London 2012 Olympic Park. Diverse actions were needed to engage the industry and earn back the confidence of the supply chain. Before Heathrow Terminal 5, the predominant mindset of the industry was to transfer as much risk as possible to the supply chain, creating an assurance shield for the client with all the legal guarantees, leading to extensive legal disputes in court, one of the principal causes for failures in megaprojects (Hart 2015). The extensively adopted lump-sum contract is at the root cause of under performances and legal disputes (Stinchcombe and Heimer 1985). In addition to Wembley Stadium, another two major projects are famous for having suffered severe contractual problems with serious consequences: the Channel Tunnel and the London Underground extension of the Jubilee line (Davies et al. 2017).

A great risk for megaprojects is what Wachs (1989) and Flyvbjerg et al. (2003) call 'strategic misrepresentation' and 'optimism bias', terms that explain the behaviour of the stakeholders at early stages of the project in order to obtain the go-ahead signal. In the feasibility and conceptual stages of the project there has been a systematic pattern of under estimation of the costs and difficulties for the project in many arenas, from planning applications and associated licence approval, to availability of materials and equipment, in order to provide an attractive business case with which to convince investors and other stakeholders to support the project. This behaviour has been statistically demonstrated by Flyvbjerg et al. (2003) who argued that it is not mathematically possible that such a large proportion of megaprojects suffered from the same mistake at the same stage, project after project, ignoring not only the technical capacity of the decision makers, but also the lessons that could have been learned from previous projects. The relevance of these issues becomes even more important if we think about post-war military and NASA projects in the USA, passing through the cold war and the space race, until the last three decades and the need for new infrastructure in the developing world and upgrades in developed countries. Gil (2017) presents evidence from practitioners stating that considerable optimism is necessary for any kind of project to receive a go-ahead decision, otherwise nothing would be constructed. However, the practitioners

in this study suggested that they believed in optimism but not in falsification of documents and data to get approvals.

It can be argued that the benefits of these projects are not accurately quantifiable, especially in the very long term; this was exemplified by the Channel Tunnel and the Sydney Opera House. The latter project was highly criticised at the time of its construction and has suffered with the extensive cost and time overrun patterns. However, it is estimated that this single building contributes 775 million US dollars per annum to the Australian economy, through the boosting of tourism in Sydney (Deloitte Access Economics 2013). The measure of success of a megaproject depends when the evaluation is made. During the construction phase of the Channel Tunnel and the Sydney Opera House both were considered failures, but when the analysis is applied to the whole life of the facility, a very different picture emerges (Deloitte Access Economics 2013).

10.4 Megaproject Supply Chain Management

After the widely recognised managerial success of Heathrow Terminal 5 (Gil 2009), supply chain management practices were carried forward to the London 2012 Olympics (Mead and Gruneberg 2013), and were applied to Crossrail, the Thames Tideway Tunnel, and High Speed Two. Therefore, it is crucial to understand how these megaprojects designed their supply chain architecture.

There is a need for main contractors to outsource a large part of the production to specialist suppliers distributed throughout the supply chain tiers. This fragmentation is, arguably, a function of increasing specialisation in technically complex projects. The argument is to maintain in-house only the organisational core competencies and to maximise the outsourcing of other functions, given that specialist suppliers are likely to conduct these activities more effectively than the main contractor. The main core competence of Tier 1 contractors is the ability to oversee the entire construction process and coordinate the supply chain at project level, which is commonly called systems integration. Arguably, the innovation and value, which can be considered the hardware value, are hidden in the lower tiers of the supply chain. However, these suppliers would never be able to integrate all the pieces together due to their highly specialised business nature. Therefore, there is a large market for the software value, the systems integration capability, where companies are not producing components and products per se, but are acting as the head of the supply chain to deliver the project through integration. These companies provide the glue – the management capability to organise interdependent parts of the project. In megaprojects, this is the gap where the client can act jointly with main contractors (and/or delivery partners) in the decision-making process to design the supply chain structure and manage it over time to foster innovative solutions.

The industry is shifting its position from a risk-averse client that dumps the risk in the supply chain, towards the necessity of a more robust client organisation acting as an intelligent and strong client. The intelligent client is responsible for designing a supply chain structure to facilitate and stimulate bottom-up innovations. Suppliers of systems and subsystems are well placed to provide suggestions for problem solving and innovation. Considering the logic that suppliers will not innovate and share their best ideas without the appropriate incentives, there is a need for an organisation acting as the supply chain architect, orchestrator, manager, or systems integrator, which would be

responsible for designing contracts that are appealing to the supply chain, as well as structuring the processes to absorb the innovations that will emerge from the incentivised suppliers. From this perspective, infrastructure clients in the UK are now emphasising their own decision-making processes at the front-end of projects. This is a reflection of a market evolution which increased their maturity, where they now understand the need to have a bigger voice and bear the risk during the process of developing the strategies that will drive the subsequent phases of the megaproject. These strategic decisions need to be conducted internally or be driven by the client when developed in collaboration with development and delivery partners. The intelligent client is the controlling mind of the megaproject.

In the case of Heathrow Terminal 5, the owner and client organisation (British Airport Authority – BAA) had an organisational memory of involvement in previous capital projects throughout the years (Potts 2009). This corporate knowledge, along with other factors and worldwide benchmarking research in airports and megaprojects, informed the strategic position of the client organisation in adopting a different supply chain management approach. Instead of following the common practice of dumping the risk in the supply chain and acting as the 'law enforcer of contracts' client, BAA decided to build upon its expertise in capital projects, internalise the risk, build a client-driven supply chain, and act as the supply chain manager or systems integrator, incorporating the principles of an intelligent client (Davies et al. 2009). BAA established contracts with key supply chain players and adopted a contracting approach that guaranteed the profit margin of suppliers with the adoption of open book production costs benchmarked through an independent cost consultant. This approach removed the risk and fear from the supply chain actors of not making profits in the project, opening the path to focus on improvements in the production process that would lead to cost reduction and innovation.

Asset owners that run an operation and have market knowledge are in a strong position to take the 'make or buy' decision (Winch 2014; Winch and Leiringer 2016). These companies usually conduct small expansions and improvement programmes internally. However, megaprojects demand another level of involvement and commitment. Considering this fact, megaprojects are usually conducted through different arrangements outside the boundaries and corporate structure of the firm. In other words, clients seek to separate their operational business from new major capital projects, building upon the understanding that these endeavours need dedicated structures such as an independent leadership team and bespoke governance structure to cope with the scale and pace of expenditure (Croft et al. 2016). BAA had to make a strategic decision considering its own project management and systems integration capabilities, and it was only possible because the company had a strong team with previous experience in capital projects and knowledge about aviation sector projects (Brady and Davies 2011). However, recent interviews with senior managers revealed that, given the scale and complexity of Terminal 5 compared with previous aviation projects from BAA, it was necessary to build a different and more sophisticated suite of processes and procedures to address the project. The executives were clear that the corporate memory of previous projects had influence only until a certain point in BAA's decision of bearing all the risk, all the time. Effective supply chain management relies upon a strong, experienced client organisation (Pryke 2009) or, alternatively, the appointment of a supply chain management agent such as a contractor or consultant (Holti et al. 2000)

Denicol et al. (2018b) present a comprehensive discussion that clarifies the roles of owners, sponsors, clients, and operators in megaprojects, which usually are different entities but sometimes might combine two or more terms. This is a terminology problem originating from the management literature, where different words are used as synonyms, influenced by the necessity to use new terminologies and concepts to aid publication in high impact-factor journals. The four terms previously mentioned are used interchangeably. However, owner and operator, and sponsor and client are the most commonly used synonyms.

Building upon Heathrow Terminal 5, the evolution of the megaproject ecosystem in the UK indicates that it is necessary to establish an increased interface between the owner/sponsor and the companies appointed to deliver the megaproject on their behalf. Denicol et al. (2017) present a perspective of project-based companies that work alongside clients (shifting the mind-set of working 'for clients') helping them to deliver major programmes according to their requirements. The research analysed CH2M, a company recognised worldwide for its programme management capabilities (Engineering News Record 2015), unpacking its involvement in several megaprojects. Increasingly, owners are moving from a role solely of sponsor towards a more proactive participation in decisions during the whole life-cycle of the project, becoming an 'intelligent client'. The movement towards a close interaction by clients is connected to historic failures of large and complex projects to achieve the requirements of the owner.

In the case of the London 2012 Olympics, the temporary client organisation (the Olympic Delivery Authority) recognised that as a brand new (pop-up) client it would not have the capacity and capability to build an organisation in time to manage all the Tier 1 contractors responsible for delivering parts of the Olympic park. Hence, the Olympic Delivery Authority recruited a consortium of construction companies (CH2M, Laing O'Rourke and Mace – CLM) to perform the function of a delivery partner, with the specific remit and focus on the production dimension, coordinating all Tier 1 contractors and integrating their work packages at a programme level. Recognising the need for a stronger involvement in the project, the temporary client organisation (the Olympic Delivery Authority) was responsible not only for establishing a closer interaction with the delivery partner, but also for focusing on and managing everything external that could affect the production progress. In contrast to previous failure models, the promoters of the London 2012 Olympics had a proactive engagement throughout the project stages rather than acting as the traditional hands-off sponsor with interest only in the final asset and limited involvement in the project.

In the case of Crossrail, The Department for Transport (DfT) and Transport for London (TfL) (the sponsors) created a temporary delivery vehicle, Crossrail Limited (the client), which was empowered to deliver the project on behalf of the sponsors. Crossrail Limited also recognised that as a pop-up client organisation it was necessary to complement its capabilities by working with project-based companies. To this end, the client appointed two consortiums of three companies each to increase its capability of managing the Tier 1 contractors and delivering the £14.8 billion megaproject currently unfinished and overbudget. The two consortiums were: The Programme Partner (CH2M, AECOM, and Nichols) and the Programme Delivery Partner (Bechtel, Halcrow, and Systra). Initially, the client structure responsible to manage the Tier 1 contractors was composed of three different entities: Crossrail Limited, the Programme Delivery Partner, and the Programme Partner. After a period of tensions, lack of clarity,

and duplication of work between the three entities, Crossrail Limited senior leadership decided to remove the corporate boundaries and integrate the seven companies into one single client team. In this case client and delivery partners worked as an integrated team where everyone was recognised as a Crossrail Limited employee (even if one of the other six companies was paying the salary). Comparing Crossrail with the London 2012 Olympics, although the Olympic Delivery Authority and CLM worked very closely with clear and open communication channels, there was a much stronger separation between the two entities, with clearer distinction of roles. Regardless of the integration model, both structures were driven by the same managerial problem, where both temporary client organisations (the Olympic Delivery Authority and Crossrail Limited) recognised the necessity of a systemic approach to optimise the management of Tier 1 contractors, consolidating and exploiting the similarities at programme level.

In the case of the Thames Tideway Tunnel, Bazalgette Tunnel Limited, also known as Tideway (the client), hired CH2M to be the programme manager (Delivery Partner) to increase its client capabilities and assist in the management of the Tier 1 contractors. The contractors are organised in three joint ventures and divided in geographical areas (West, Central, and East). The West joint venture is composed of BAM Nuttall Ltd, Morgan Sindall plc, and Balfour Beatty Group Limited. The Central joint venture is formed by Ferrovial Agroman UK Ltd and Laing O'Rourke Construction. The East joint venture comprises Costain Ltd, Vinci Construction Grands Projets and Bachy Soletanche. Recognising the technical challenges of integration along the Tunnel route, Tideway awarded a systems integration contract to Amey that was to work with the joint ventures to achieve technical consistency and prepare the asset for operation. An interesting feature of this project was the alliance agreement between Tideway, Thames Water, the three joint ventures, and the systems integrator. This agreement had the objective of incentivising a horizontal collaboration between all parties, in addition to the vertical contractual incentives between the client and the organisations delivering the project. Comparing the Thames Tideway Tunnel with Crossrail, it is possible to see an evolution of the industry and a bigger appetite for risk once bigger and fewer contracts were awarded on Tideway's three geographical areas. This is a reflection and learning from Crossrail's experience, where the client divided the project into several contracts and increased its challenges to manage a large number of interfaces and integrate them all. One factor that incentivised Crossrail to divide the project into several contracts was the economic recession period in which the procurement happened, resulting in a market with reduced appetite for risks and big contracts.

High Speed Two is currently the largest infrastructure project in Europe and by far the most challenging in terms of complexity, scale, and timescales. This railway will connect London with the north of England and is divided in three phases: (i) Phase 1 – London to Birmingham; (ii) Phase 2a (Birmingham to Crewe); and (iii) Phase 2b – Crewe to Manchester and Birmingham to Leeds. The DfT is the sponsor of the £55.7 billion megaproject and has created a client organisation called High Speed Two Limited to deliver the project. High Speed Two Limited has separated the development and delivery stages and appointed a Development Partner and an Engineering Delivery Partner to increase the capacity and capability of the client organisation. Similarly to Crossrail, the partners appointed work integrated and collocated with the client (High Speed Two Limited) to procure and manage an extensive supply chain that provides services and products during development and delivery. Regarding the delivery stage of Phase 1, the client divided

the route from London to Birmingham into three geographical areas (South, Central, and North) and appointed Tier 1 contractors for each one of them. This is similar to Tideway's approach in the rationale of dividing the project geographically and also of awarding bigger contracts than Crossrail. High Speed Two Limited has awarded three contracts to deliver the enabling works, one for each geographical area, and seven contracts to deliver the main works civils (two contracts for South, three for Central and two for North). Each contract is delivered by a joint venture of two or more Tier 1 contractors, who have the freedom to design their own supply chains from Tier 2 suppliers onwards. High Speed Two Limited is responsible for managing the interfaces between contracts and to act as the ultimate systems integrator.

Recently in the UK, the involvement of the sponsor and its delivery vehicle (the client) has been particularly strong in the early stages of megaprojects, given the impact decisions taken at the front-end are likely to have on subsequent phases of the project. It is important to consider that this involvement is continuous and also encompasses the construction phase with much more emphasis on reporting and control than at the front-end, however. A particular feature of Heathrow Terminal 5 was its opening failure with massive media coverage of the baggage system problems. This example sheds light on the importance of the early engagement of the owner and operator with the development and delivery teams, to ensure consistency in the requirements throughout the project and co-create strategies to transition the asset into operation. Recently Morris has argued that the role of the owner is essential and considered it as the most influential supply chain player in the front-end of projects, shaping complex decisions such as the degree of technology to be adopted and the governance structure that would frame the functioning of complex interfaces with external stakeholders and the project supply chain (Morris 2014). Another layer of complexity relies on the permanent and temporary nature of the owner and its extent of influence in the project. If the owner is a permanent organisation with a wealth of experience in the sector, there is a constant challenge to consolidate and align the corporate and project strategies. The owner should provide guidance about complex decisions at a very early stage of the journey. Analogously, the owner can be seen as the captain of the ship – the one that has the power and whose decisions have potential to change completely the direction of the endeavour. Considering the relevance of this supply chain actor, it is surprising that so little literature deals with clients and owners (when compared with literature about main contractors) regarding interfaces with other stakeholders and the possible impacts on the project. Pryke (2012) does, however, adopt a network perspective to understand the role of four construction clients – two of which actively manage their supply chains and two of which take more passive roles as clients.

The UK megaproject clients are actively engaged in the front-end, assessing the risks and establishing strategies to impact the supply chain such as: (i) development of integrated project teams to manage the interfaces with the supply chain players; (ii) risk analyses to design the supply chain architecture; (iii) performance control and innovation management at the execution phase through a structured reporting system; (iv) creation of a more flexible organisational structure to stimulate and absorb the innovations from all supply chain actors, in advance or during construction; (v) establishment of robust change management processes, specifying the levels of responsibilities; and (vi) directives for the use of technologies such as Building Information Modelling (BIM)

and virtual reality for supplier performance control, material tracking, and just-in-time deliveries at the construction site.

10.5 Conclusion

The adversarial nature of the construction industry is well documented in the literature, mostly driven by inherent competing priorities amongst organisations, enhanced by the fragmentation of the sector. Supply chains increasingly consist of highly specialised actors. Therefore, in public megaprojects there is a need for a closer interaction between the public entity (or their representative) and the private organisations contracted to deliver the project. These entities will form a temporal and evolutionary supply chain, with organisations leaving and entering the project coalition considering the changes of scope throughout the phases of the project. It is particularly important to have an intelligent public client organisation driving the project, functioning as the controlling mind, designing the supply chain architecture and orchestrating the interfaces, relationships, and behaviours amongst the supply chain actors at different points in time.

The constant review and evaluation of the supply chain form (intra- and interorganisational structures) is an important capability for public sector clients. The capability of infrastructure clients to evaluate the dynamics of their internal processes and structures (intraorganisational relationships) is the first step of a mature organisation in the direction of the appropriate design of a megaproject supply chain. The understanding of what is happening inside the boundaries of the client organisation (sometimes the one project firm) is essential to design the interfaces of the firm with the supply chain it intends to assemble. How would you know what the complementary capability is that you need to hire without a clear understanding of what is already there? Organisations that do not have a clear understanding of what is happening inside their own boundaries are likely to be in a 'lock-in' position after unintentionally awarding nonattractive contracts to the supply chain (and to themselves). It is extremely challenging, and more expensive, to work backwards and reengineer organisational behaviours in a scenario where contracts were let without the strategic thinking of how the vertical and horizontal relationships would work. The commercial relationship is driven by the contract and all organisations will have experts analysing the contract and its propositions put forward by a client. Evidently, lower tiers of the supply chain tend to have less resources to invest in strong legal capability to analyse contracts, whereas Tier 1 contractors (systems integrators) would be in a stronger position in terms of legal advice to influence the relationship.

The vertical relationship to be designed is the one between the client, the contractor, and the wider supply chain. It is often not fully considered precontract and, in the cases where it is, there is a focus on the single interface between the client and Tier 1 contractor. The design of the relationships should go deeper and be expanded to how that contractor is planning to manage its supply chain (Tiers 2, 3, and 4) during the project, exploring topics such as prequalification, selection, performance measurement, fair payment, and others. This alignment is essential and supported by numerous industrial reports and academic publications informing that Tier 1 contractors are usually integrators of components and systems, while the innovation and value added remain at the lower tiers of the fragmented construction industry.

Considering the external environment, it is equally important for the supply chain actors to be clear as to which operations are being managed by whom and how. Naturally, there are challenges with the concept of supply chain management across a single business entity through interorganisational process integration. To start with, considering a focal company and its relationship with Tier 1 suppliers, there are differences and tensions regarding power relationships, levels of interest for the development or execution of a given task (or product), industrial and marketing core competences (and therefore secrets), and multilateral agreements with competitors, among others. Therefore, it is clear that if in a binary relationship there are challenges about processes and terminologies (the same word means different things for different people), it is even harder to achieve business process integration when amplifying the spectrum for a supply chain with several organisations involved (or affected). Metrics and indicators should be established to evaluate supply chain relationships, enabling analyses to identify the weaknesses of the system and continuous improvement through the implementation of action plans.

Arguably, the exploitation of large programmes and portfolios to implement supply chain management in construction relates to big clients with relatively constant demand and a pipeline of projects that can be forecasted in terms of utilisation of resources. For those clients, which are empowered by a favoured power relationship with the supply chain through its buyer power and supply chain knowledge, it is beneficial to develop an in-house management department to interact with supply chain partners. From the lower tier suppliers perspective there is a high level of interest in establishing a relationship with big clients, mainly supported by two facts, namely: (i) the possibility of accessing that given market, which is usually a considerable part of their current production, operations, or distribution; and (ii) the incentive of integration in a long-term relationship through a portfolio environment that might provide high visibility of current and future projects. This can be translated into certainty of demand with positive implications for production planning and control. In this scenario, suppliers are confident to invest their resources in developing productive relationships towards continuous improvement for value creation. Considering the arguments presented it is possible to state categorically that supply chain management practices for project-by-project environments are unlikely to achieve success in managing supply chains and are difficult to sustain in a long-term business perspective.

The construction industry suffers with temporary supply chains oriented towards projects and the organisational culture biased towards short-term solutions. This inhibits the implementation of supply chain management practices, depending on the context. Critically, following the concept of regularity, it is possible to establish a parallel between supply chain management in mass production and construction environments involving the necessity of a continuous flow of operations to develop the supply chain actors. Continuous improvement is closely related to regularity (or frequency) of relationships, and therefore there should be an active portfolio of projects where the buyer can integrate the supplier and improve business process considering a learning curve over time. The operations scenario from high volume and process industries can be translated to construction in the form of programmes and portfolios, where there is a management perspective relying on consolidation of demands at an enterprise level instead of project level. In summary, supply chain management relies on the establishment and development of long-term relationships; this necessarily implies a constant and close interaction between buyer and supplier.

The challenge for the construction industry is how to transfer the set of supply chain management routines successfully applied in mass production and high-volume industries to a project-based environment with production oriented towards small batches and high uncertainty in relation to future demand. Drawing upon the manufacturing experience, clients and main contractors could follow Toyota's model and embed small teams from the focal organisation managing the supply chain into the suppliers' companies to work alongside their teams. This initiative would work for short periods of time as a small project or consultancy, aiming to guarantee the focal company's requirements (clients and main contractors), as well as to provide cross-fertilisation and access to new knowledge to develop improvements and innovation through co-creation.

Drawing upon the discussion of this chapter, seven avenues for future construction supply chain management research are suggested:

1. *Enterprise and project supply chain management* – In a project-based environment, supply chain management and integration are not appropriate for all projects. It is necessary to have frequency of demand, which can be translated into programmes or a portfolio of construction projects (or sites) to manage activity of the supply chain over time, relying on a list of homologated suppliers (strategic, preferred, approved). The connection between the enterprise and project levels is yet to be improved by main contractor organisations, which could unlock business-wide value by acting holistically to integrate and exploit multiple temporary supply chains at the enterprise level.
2. *Client-driven supply chain management in construction* – The research on supply chain management has been focused on main contractors (Tier 1 systems integrators) and there is limited research available considering the perspective and involvement of the client, which is surprising and intriguing given that this is a highly influential player in the process. Property developers are clients and sometimes also the Tier 1 integrators. However, they are transient clients since they will sell the units to end customers, the ultimate owners (commercial companies or residents), immediately after the construction is finished. It would be interesting to see a comparative study of supply chain management practices between property developers and infrastructure client organisations (pop-up clients and permanent owners) (Pryke 2012).
3. *Focus on the structure not on the technology* (focus on software not hardware) – The construction industry is very resistant to change. The business model is based upon a craft industry with all the materials being brought to site and the building produced on site. How can we change or challenge this business model? How about the Chinese who are trying to manufacture their buildings in factories and just carrying out final assembly on site? First it was a hotel with 30 floors in 15 days, then another hotel with 15 floors in six days, and lastly a building with 57 floors in 19 days. The industry might reflect on a situation where construction moves from an ETO to an ATO production strategy, focusing on the maximisation of standardisation, modularisation, and off-site construction. The increasing adoption of BIM and other technologies will help and foster innovation in the near future. However, technology is not a deterministic answer or solution – the industry needs to focus on the supply chain structure, the umbrella under which technologies are included. If an efficient operation is automatised, efficiency will maximise: if an inefficient operation is automatised, however, it will be faster, but it will still be an inefficient operation.
4. *Supply chain management metrics and indicators* – Surprisingly there is little literature regarding the interface between supply chain and metrics and indicators, which

can be used to provide a diagnosis of interorganisational relationships, enabling the development of action plans for improvements and extended integration and control.

5. *The design of supply chain architectures with the focus on collaboration over time* – Clients should identify which actors are the ones likely to have long-term relationships in a megaproject and work backwards to design a favourable structure that would incentivise them to engage in collaborative initiatives with the right behaviour during the project. This strategic decision implies a shift in the mind-set of infrastructure clients in two areas:
   a) Recognising its role as the party to which the risk will return if something goes wrong during the process and therefore the necessity for an upfront proactive posture to internalise and manage risk, rather than transferring it to other supply chain actors.
   b) Moving decisions from cost-driven, arm's length, and project-by-project basis to a programme management perspective, where commonalities of multibillion programmes are consolidated at the client level and exploited.
6. *Use of data analytics to go beyond Tier 1 suppliers* – With the advancement of artificial intelligence and machine learning techniques, in the future infrastructure clients might be able to combine a range of datasets to extract business intelligence regarding the wider network of companies that might comprise the supply chain. This information could be useful to design supply chains informed by the capabilities and capacity of the players in the market. Data-driven technology will enable the necessary visibility to inform strategic decisions and avoid awarding contracts to companies likely to fail from the outset through lack of capacity.
7. *Explore and translate supply chain management practices from other project-based sectors* – The construction industry needs to try to connect practices from other industries with project-based production strategy, which have the potential to translate best practices such as offshore, shipbuilding, and aerospace. Although these industries are similar through the use of small batches and a fixed layout with dynamic production activities happening around the final product, it is important to notice that the context of each industry is very relevant and there are peculiarities that do not allow a simple observation of the practice and adoption in other industries. The process of adoption by the construction industry of management techniques from manufacturing, such as Total Quality Management and Lean Production, requires some modification or a process of translation to render these techniques effective in the construction context. This would be similar to the cultural translation conducted by Toyota when it transferred the Japanese Lean Production philosophy to manufacturing plants in the USA.

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